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DISCRETE EVENT SIMULATION CLASS FOR ENGINEERING GRADUATE STUDENTS

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ABSTRACT

To graduate students accustomed to working with the numerical solution of partial differential equations using finite difference, finite elements, spectral methods, etc. where time generally progresses in evenly-spaced small intervals, switching paradigms to a discrete-event simulation environment is not only counterintuitive but is also difficult. The SimCenter at the University of Tennessee Chattanooga recently introduced a class in discrete event simulation with the goal of providing sufficient coverage of the topic to enable any of the SimCenter's students completing the course to work effectively in a typical industry- or government-supported simulation modeling group. The course is structured around a diverse set of engineering problems rather than traditional industrial engineering-type simulations in order to present the material in a more palatable fashion for students who come primarily from other disciplines. This paper discusses the organization of the class and serves as a good outline for another professor attempting a similar introduction.

1 INTRODUCTION

Most recent Winter Simulation Conferences contain a session on discrete event simulation education. For example Garcia and Centeno 2009, Tag and Krahl 2007, and Standridge et al. 2007 are educational papers. These papers describe ways to improve discrete event education in industry, they describe new discrete event classes in academia, or they discuss generally applicable discrete event simulation education topics. This paper describes the contents of a graduate-level discrete event simulation class currently offered in the SimCenter at the University of Tennessee Chattanooga that has the intended purpose of helping non-discrete-event savvy engineering graduate students to become competent in the theory and practice of discrete event simulation. In addition, with this class being an elective, a secondary goal was to present a very diverse set of topics to increase the engineering background of the students since many come for mathematics and pure science backgrounds.

2 APPROACH

2.1 Class Structure

First and foremost is the selection of a strong text book. For this class, Averill M. Law's classic text on simulation modeling (Law 2007) was the logical choice specifically for his thorough coverage of simulation in general and because of the book's in-depth treatment of statistics including model output analysis.

These topics are essential to a practicing simulation modeler and typical engineering graduate students are weak in these areas. Second, is the selection of a software package. We selected ExtendSim (Imagine That, Inc. 2010). This choice was driven by the professor's familiarity with the software, the availability of a low-cost version for student use that has full capability, and the user friendliness of ExtendSim. Figure 1 presents an outline of the class organization .

Discrete Event (DE) Class Outline (Chapters are from Law 2007)

1. Introduction
    1.1. What is DE simulation
    1.2. DE versus continuous
    1.3. Ch. 1 Basic Simulation Modeling
2. Introduction to DE Software
    2.1. DE software and how it works
    2.2. Building a model
    2.3. Three activities with random variation
    2.4. Use of numbers in DE modeling
    2.5. Ch. 3 Simulation Software
3. More Advanced Models
    3.1. Multi-server Queue
    3.2. Attributes and Resources
    3.3. Supply Chain
    3.4. 2^{nd}-order Ordinary Differential Equation
    3.5. Production Lines
    3.6. Matching and Batching
    3.7. Routing
    3.8. Job Shop
    3.9. Ch. 2 Modeling Complex Systems
4. Model Analysis
    4.1. Power screw
    4.2. Probability of being operational
    4.3. Equations and mathematics
    4.4. Rate and chemical models
    4.5. Statistical fitting
    4.6. Ch. 4 Review of Basic Probability and Statistics
    4.7. Ch. 6 Selecting Input Probability Distributions
5. Advanced Concepts
    5.1. Agent-based Modeling
    5.2. Transportation and Conveyors
    5.3. Optimization
    5.4. Sensitization
    5.5. Shifts and Schedules
    5.6. Design of Experiments
    5.7. Verification and Validation
    5.8. Ch. 5 Building Valid, Credible, and Appropriately Detailed Simulation Models

Figure 1: Outline of discrete-event class.

2.2 Detailed Class Topics

The class is divided into a series of segments designed to build upon one another so that by the end of the semester the successful student would be able to "hold his or her own" in any simulation modeling team. It was critical that the class time be shared between theory and application so that the student would exit with practical as well as analytical capabilities. In addition, some topics were primarily focused on simulation modeling theory, techniques, and applications; whereas, other topics were intended to reinforce the engineering background of the students since the SimCenter's students come from a diverse background including engineering, physics, mathematics, and other sciences. Three of the primarily engineering models (the thermal model, the power screw, and the design of experiments) will be presented in more detail to make them more useful to future teachers.

2.2.1 Primarily Simulation Modeling Topics

- **Bank Model Demo from Imagine That Inc.**

  This model is one of the demonstration models included with the ExtendSim software. It is a multi-server, single-queue model with capability to easily vary the number of operating servers.

- **"Generic" Model – Single Server Queue**

  This is a general single-server, single-queue model. It is used as the basis for many example models in the textbook and in the classroom.

- **Three Activities in a Row**

  This model has three activities arranged serially. It is used to illustrate the impact that the inclusion of random numbers has on the results of a discrete event model.

- **Simple Integration**

  This is a "numbers only" model showing how ExtendSim can be used to model non-discrete event systems as well as discrete event systems.

- **Supply Chain Model**

  This model illustrates a very advanced application of discrete event modeling. The supply chain approach and custom-developed software provide an excellent lesson in the versatility of discrete event modeling theory. The supply chain model also enabled the introduction of supply chain concepts and definitions.

- **Simple Generic Model with Resources**

  This model is the basic single-server, single-queue model with resources added. It is used to teach several ways resources can be applied in the ExtendSim software. It also illustrates how constraining resources can impact model throughput.

- **Matching Example**

  This model illustrates the use of matching and batching as a way to model assembly and packaging. This is often a critical piece of logic in many discrete event models.

- **Machine Model**

  This model is used to illustrate how mean time to failure and mean time to repair can be implemented either directly in ExtendSim or indirectly through mathematical calculations and logic.

- **Equation Block Example**

  This model is used to teach the ubiquitous ExtendSim equation block. This block is essential to understand for any advanced logic models.

- **Throw and Catch Example**

  This simple model is used to teach throw and catch blocks; an essential routing construct in the ExtendSim software.

- **Shift**

  This very simple model builds off of the generic single-server, single-queue model to illustrate the application of shifts and shut downs to an ExtendSim discrete event model.

- **Sensitization**

  This very simple model builds off of the generic single-server, single-queue model to illustrate the application of parameter sensitization to an ExtendSim discrete event model.

- **UPS Facility**

  This is a model of a truck loading facility. Its purpose is to illustrate the use of ExtendSim's conveyor blocks and various item generation techniques.

2.2.2 Primarily Engineering Topics

- **Thermal Model – Immersion in Constant Temperature Fluid**

  This model covers the temperature of a thermometer immersed in a fluid of a higher temperature. Temperature versus time is the result. Its goal is to contrast discrete event simulation and continuous time simulation. This is intended to "set the stage" for the class. The mathematics of the model is the following. Consider an object (e.g., a thermometer) inserted in to a fluid of a higher temperature. The temperature versus time may be modeled by the following differential equation:

  $$mc_p \, dT/dt = hA(T_\infty - T), \tag{1}$$

  which balances storage of thermal energy with convective heat transfer into the object. In equation (1), the following definitions apply:

m	= mass (kg);
c_p	= specific heat (J/kg-^{o}C);
dT/dt	= time derivative of temperature (^{o}C);
T_∞	= fluid temperature (^{o}C);
h	= convective heat transfer coefficient (J/m^2-^{o}C);
A	= area (m^2); and
T	= object temperature (^{o}C).

  In the classroom presentation, use a simple Euler method to illustrate how a modeler might solve this problem in a continuous solution. Use this to contrast continuous modeling and discrete-event modeling.

- **2^{nd}-Order Ordinary Differential Equation**

  This model is another application of a “numbers only” technique; however, it is used to illustrate engineering principles. The second-order differential equation that is used in the example is taken from vibration theory, specifically, it is a spring-mass-damper system.

- **Able-Baker Car Hop**

  This model is a classic industrial engineering application of a two-server, single-queue system. It is used to example rule-based selection of alternative servers.

- **Cookie Production Line**

  This model is a simulation of a robotic line assembling cookies. It integrates discrete event modeling and manufacturing applications as well as robotics. The cookie production line model is shown in figure 2.

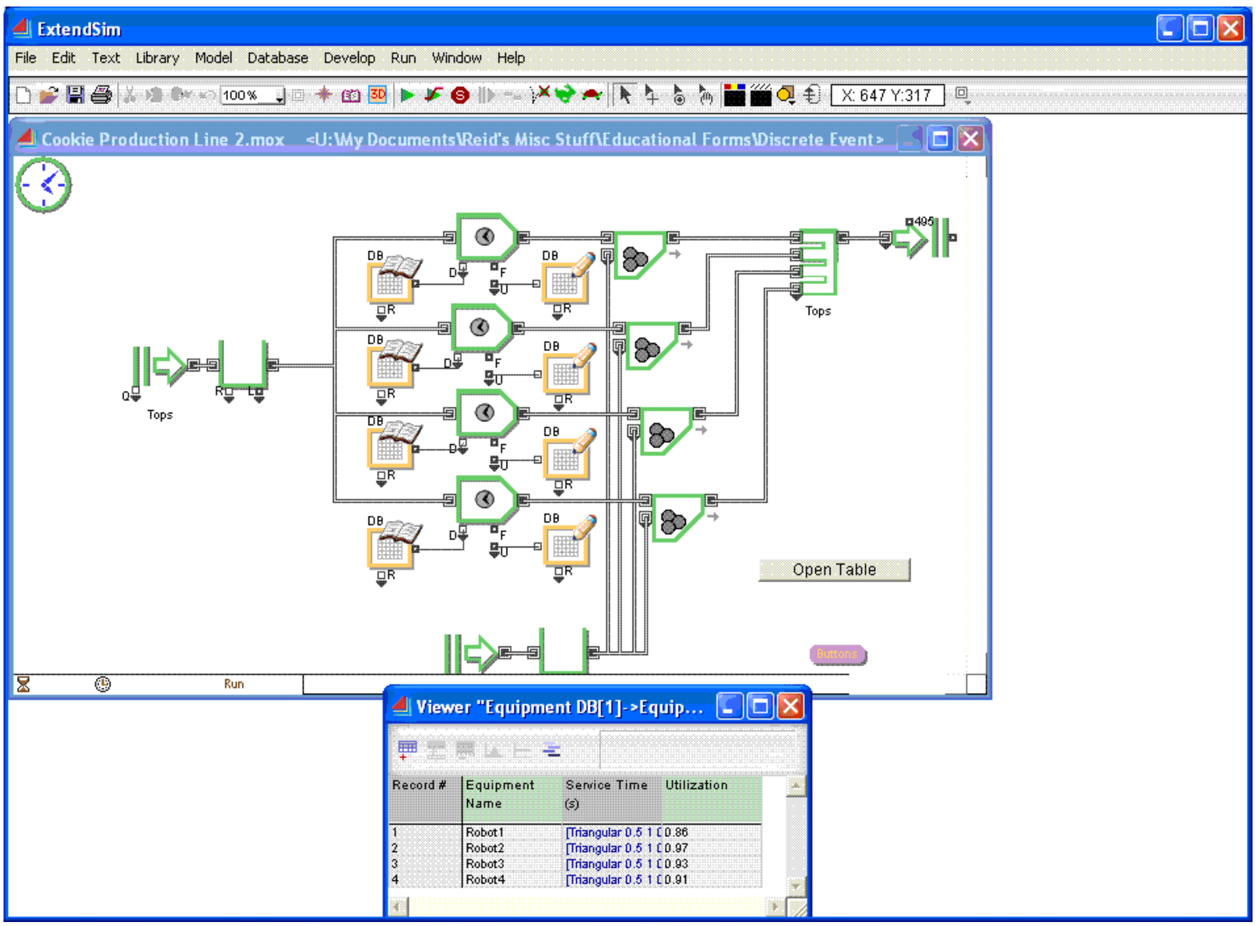


Figure 2: Cookie production line model.

- **Power Screw (Deutschman, Michels, and Wilson 1975)**

  This is a rather sophisticated model used to illustrate the use of a database and specifically ExtendSim’s database capabilities. Its secondary purpose is to teach several mechanical engineering principles including power screw design, torque calculation, friction, and motor velocity profile. This model uses the relationship between speed, torque, poser, etc. in a screw drive mechanism but introduces randomness through the coefficient of friction in the drive screw. The equation relating torque to power screw design is the following (from Deutschman, Michels, and Wilson 1975):

$$T_R = \frac{d_m W}{2}\left[\frac{\mu_s + \cos\theta \tan\alpha}{\cos\theta - \mu_s \tan\alpha}\right] + \frac{d_{mc}\mu_c W}{2}, \tag{2}$$

where

T_R = power screw torque (N-m);

d_m = thread center diameter (m);

W = weight (or virtual weight if accelerating) of load (N) ;

μ_s = coefficient of friction between nut and screw (-);

μ_c = coefficient of friction between screw and thread (-);

θ = thread angle (rad);

α = helix angle (rad); and

d_{mc} = diameter at which wrench of drive torque is applied (m).

A velocity profile can be assumed to relate toque to speed and then to required power. Discrete simulation can be brought into the model by assuming that at random times during the velocity profile one or both of the coefficients of friction change randomly as a result of changes in the physical system (heats up, becomes dirty). Discrete event simulation can be used to determine the maximum required power over many runs.

- **Mixing Tanks**

  This model is used to teach the rate (formerly flow) library of ExtendSim. Its secondary purpose is to teach a very basic chemical engineering example of flows and mixing of flows of different concentrations in a tank.

- **Boids**

  This is one of the demonstration models that come with the ExtendSim software. It is used in ExtendSim to illustrate 3D simulation capability. It is modified in this course in order to facilitate teaching agent-based modeling, programming in ExtendSim with the simulation language ModL, and to illustrate basic 3D modeling.

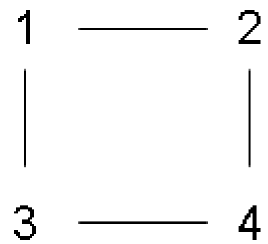
- **Optimization**

  This is a multi-server, single-queue model used to demonstrate the use of ExtendSim's built-in optimizer routine. This model has a secondary objective of teaching optimization.

- **Design of Experiments (DOE)**

  This model is used to illustrate how a simulation modeler can do a design of experiments approach within the ExtendSim software. It also illustrates different methods to interface an ExtendSim model with text files or Excel spreadsheets. It uses the travelling salesman problem to illustrate design of experiments; therefore, it also introduces this classic optimization problem to the students. The objective is to find the shortest possible tour between cities visiting each only once. For a simple DOE example use the set up illustrated in figure 3. Solve the problem by "brute force" (simple for this size problem) and by using DOE within the simulation modeling software.

Cities arranged in square



Distances between cities

	1	2	3	4
1	0	1	$\sqrt{2}$	1
2	1	0	1	$\sqrt{2}$
3	$\sqrt{2}$	1	0	1
4	1	$\sqrt{2}$	1	0

Figure 3: Simple travelling salesman problem for Design of Experiments (DOE) example.

2.2.3 Justification of Topics and Relationship to Course Outline

Table 1 provides a justification for each of the topics discussed in section 2.2.1 and 2.2.2 and also relates them to the outline of section 2.1.

Table 1: Justification of Topics

Topic	Outline	Justification
Bank Model Demo from Imagine That Inc.	1.1	Shows first DE simulation
"Generic" Model – Single Server Queue	2.2	First model to build
Three Activities in a Row	2.3	Importance of random processes
Simple Integration	2.4	Numbers and math in DE modeling
Supply Chain Model	3.3	New form of modeling, supply chain concepts
Simple Generic Model with Resources	3.2	Labor constraints
Matching Example	3.6	Manufacturing
Machine Model	3.7 & 8	Job shop, route tables, bill of materials
Equation Block Example	3	Sophisticated math in a model
Throw and Catch Example	3	Complex routing
Shift	3	On- and off-shift, failure, mean time to repair
Sensitization	5.4	Parameterization of models
UPS Facility	5.2	Transportation, conveyors, rates
Thermal Model – Immersion in Constant Temperature Fluid	1.2	Introduces thermodynamics concepts
2nd-Order Ordinary Differential Equation	3.4	Vibrations
Able-Baker Car Hop	3.1	Sharing resources, "classic" industrial engineering planning
Cookie Production Line	3.5	Robotics and manufacturing
Power Screw	4.1	Screw design, automation, velocity profiles
Mixing Tanks	4.4	Chemical engineering models, concentrations, mixing
Boids	5.1	Agent-based modeling
Optimization	5.3	Optimization
Design of Experiments (DOE)	5.6	Classic travelling salesman problem

2.3 Fictional Bicycle Plant as a Project

Students were also assigned an end of the semester project to model a fictional bicycle plant. The plant is illustrated in figure 4.

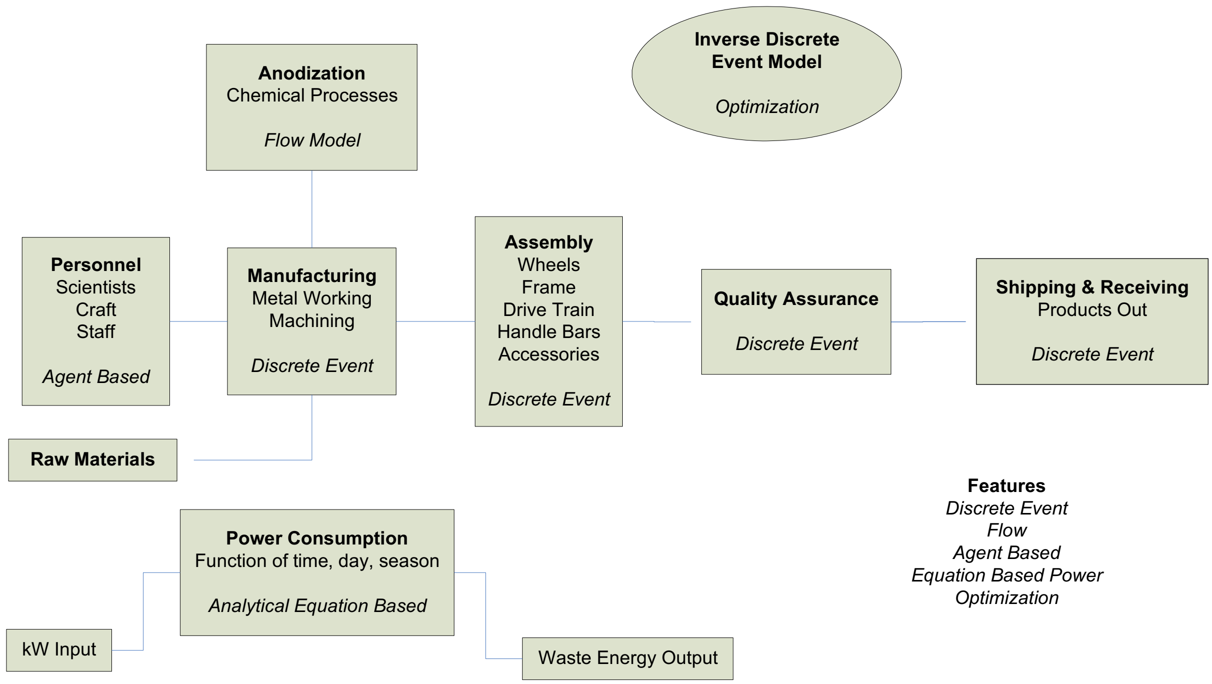


Figure 4: Fictional bicycle factory block diagram. Italicized words indicate particular model features associated with the block.

This model contains many of the advanced topics taught in class including but not limited to: discrete event, flow, agent based, equation blocks, optimization, database, and routing. The students were asked to do a specific part of the model and to integrate their respective models into a single model. This allowed us to introduce working in a modeling team, development of requirements, documentation of model development, verification and validation, output analysis, and team presentation of results.

3 RESULTS

Teaching discrete event simulation in this manner produced many desirable results. Several are listed below.

1. Students from diverse engineering discipline learn a new skill that is often restricted to a limited set of majors.
2. Students learn simulation modeling theory and application.
3. Students learn specific discrete event simulation software.
4. Students learn engineering topics as well as discrete event topics.

For the first semester, the class was very small, consisting of the three co-authors. The primary comment summarizing the class: this is the type of class we need to be teaching and the format and examples were very practical.

4 CONCLUSIONS

Every engineering graduate student aspiring to be a well-rounded computational engineer should take this course! Besides being interesting, it adds a new tool to their toolbox! Most certainly the course helps the students' resume, broadening their portfolio and opening doors that would have previously been closed, but it also serves to broaden their thinking so that concepts like discrete progression of time and systems subjected to event-based interruptions are not so foreign.

The organization presented herein was effective and flowed well throughout the semester. Certainly the choice of text and software significantly enhanced the learning experience. Splitting the class time between theory and application was essential to achieving the overall objective of producing competent, ready-to-go simulation modelers.

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