ME 6105: Modeling and Simulation in Design

Course Number:	ME 6105
Instructor:	Chris Paredis
Room:	Love 184
Time:	Tue – Thu 1:35 – 2:55PM
Credit Hours:	3-0-3
Prerequisites:	Graduate standing in engineering or related discipline; Undergraduate seniors with permission of the instructor.
Catalog Description:	Modeling and simulation concepts, algorithms, and methods; Modeling and simulation concepts, algorithms, and methods; modeling of energy-based and discrete-event systems; modeling of design decisions; information modeling and knowledge representation; Project.
Text Book:	No textbook will be used. Specific chapters or overview articles will be provided on-line.
References:	Making Hard Decisions: An Introduction to Decision Analysis, R. T. Clemen. Duxbury Press, 1997. Principles of Object-Oriented Modeling and Simulation with Modelica 2.1, P. Fritzson, Wiley, 2004. Simulation with Arena (third edition), W.D. Kelton, R.P. Sadowski, D.T. Sturrock. McGrawHill, 2004.

Goals:

To provide a theoretical foundation for the development and use of models in system design. The models include both decision models and analysis models.

Upon completion of this course, the student should be able to:

- frame design decisions: objectives, alternatives, outcomes, preferences.
- evaluate the performance of design alternatives by conducting simulation studies
- select the appropriate modeling paradigm to support a design decision
- select a solution algorithm that matches the characteristics of an analysis model
- critically evaluate analysis results in the pressence of uncertainty
- model designer preferences – risk averseness and multi-attribute utilities
- describe general modeling concepts including idealizations and associativity

Prerequisites by topics:

The students are expected to be familiar with the following topics at an *undergraduate* level:

- Statistics
- Differential equations
- Design topics: specifications, functional requirements, conceptual design,

embodiment and detailed design.

- The behavior of physical systems: thermal systems, electrical systems, dynamics of mechanical systems, hydraulics (to complete their projects, the students will need familiarity with at least a subset of these topics).
- Computer-aided design and engineering (CAD/CAE)

Topics:

1) Context
   - What is modeling? Simulation? A taxonomy of models
   - Systems design: an overview
   - Information and knowledge in the context of simulation-based design
   - Framing design problems: objectives, alternatives, outcomes, preferences.
2) Modeling of Energy-based systems
   - Modeling approaches and history: CSSL, Bond graphs, Object-oriented modeling
   - Object-Oriented Modeling: equation-based v. procedural modeling; across and through variables, energy conservation, and causality
   - Modelica and the Dymola simulation software
   - Modeling lumped-parameter, multi-disciplinary systems
   - Solving ordinary differential and differential algebraic equations
3) Discrete event simulations
   - Definitions, models, simulation approaches
   - Discrete event modeling in Arena
   - Input distributions
   - Output data analysis
4) Uncertainty in Models
   - Sources of uncertainty
   - Representation of uncertainty
   - Validation and verification: can models be validated?
   - Solving models with uncertainty: Monte Carlo simulation
5) Decision-making under uncertainty
   - Modeling preferences
   - Preferences under uncertainty: Utility theory
   - Multi-attribute utility theory
   - Sequential decision-making in design
   - The role of optimization in design
6) Information and knowledge management in design
   - Value of information; information economics
   - Modeling at different levels of abstraction; trade-offs between accuracy and cost

of models

- information and knowledge modeling
- ER-diagrams; information schema; ontologies
- Reusability of models: encoding, storing, retrieving, appplying, and maintaining models

Delivery Mode (%):

Lecture 100%

Grading Scheme (%):

Homework 60%

Homework Assignment 0: Planning your simulation-based design study (0%)
Homework Assignment 1: Energy-based modeling with Modelica (15%)
Homework Assignment 2: Discrete-Event modeling with Arena (15%)
Homework Assignment 3: Uncertainty in models and simulations (15%)
Homework Assignment 4: Decision-making under uncertainty (15%)

Project 40%

Additional information:

Motivation: Modeling and Simulation (M&S) have become important tools for analyzing and designing complex systems. Since mechanical engineers often serve as system integrators, it is important for them to be familiar with both the practical and theoretical foundations of modeling and simulation for systems design. This course addresses this need in an application independent fashion so that it appeals to ME students working in a broad range of domains.

Modeling of an entire Design Problem. In this course, we will expand the traditional focus of M&S courses by framing M&S in the context of decision-based design. In engineering design, the goal is not to develop models that describe a system as accurately as possible (as in traditional sciences), but models that are as inexpensive as possible while still being adequate to support the design decisions. In this course, the students learn about modeling and simulation in this unique context so that they can make appropriate modeling decisions based on economic cost and benefit considerations.

Projects. Through course projects, the students will gain practical experience applying the theory of modeling and simulation in the context of design of complex, multi-disciplinary systems. The students will perform an entire simulation study of a multi-disciplinary system, from requirements definition and modeling, through simulation and analysis of the results. This project is an important component of the course and will allow students to customize the course contents to their individual interests. This will make the course attractive to students working in a broad range of disciplines including design, manufacturing, controls, and thermal systems.

Enrollment: In the first offering (Spring 2004), 11 students were enrolled with an additional 3 students auditing the course. For Spring 2005, 12 students were registered and 1 student audited. Next year (2006), the enrollment is expected to grow even further with the addition of a distance learning section. The goal is to reach a stable enrollment of 20-25 students. I think that this is feasible given the broad appeal of the course and its relevance to non-thesis students.

I would also like to open the course up to undergraduate seniors. Seniors with a GPA of at least 3.2 can take graduate courses to fulfill their electives.

Relation to other Courses: This course is well integrated with the ME 610x graduate level courses in CAE/Design that cover all the important aspects of the engineering design process, i.e., converting functional requirements into form specifications:

- ME6101 (Engineering Design) covers the foundations of engineering design focusing on design concepts, processes, and methodologies.
- ME6102 (Designing Open Engineering Systems) covers the design of open, evolving systems, focusing on the modeling of design processes, methods, and tools.
- ME6103 (Optimization in Engineering Design) covers the optimization tools to support decision making.
- ME6104 (Computer-Aided Design) focuses on the representation of product geometry for design and manufacturing.

The aspect that is missing in this design curriculum is an in-depth treatment of computational models for design. M&S is used to convert a description of the system (relation to ME6104) into a prediction of the performance characteristics on which design decisions are based (relation to ME6101-3), and finally into an expression of the designer's preferences for the design alternatives.

The focus in the proposed course will be on the Modeling and Simulation of *systems.* In this sense, the course complements ME6124 (Finite-Element Method: Theory and Practice), which focuses on detailed modeling and simulation of individual components through finite element analysis.

The course is also complementary to ME6754 (Engineering Database Management Systems; cross-listed as CS6754 and COA8676). In ME6754 the focus is primarily on information modeling of geometry and low-level management of this information in database systems. *ME 6105: Modeling and Simulation in Design* will expand this in the directions of knowledge modeling and simulation modeling (discrete event models, continuous time differential algebraic equation models, and preference models).

In addition to students in the CAE/Design area, the course is likely to be of interest to students in manufacturing, automation and mechatronics, and thermal sciences. These disciplines all use modeling and simulation for the analysis and design of complex systems, each with their own specific application focus. The proposed course is not limited to one specific application domain, but covers M&S issues that are common to the design of systems in general. Students in these different areas can customize the course by defining an application domain for the homework assignments and project that fits their interests.

The course also complements the material covered in ISyE 6644 and ISyE 6831. These ISyE courses focus exclusively on discrete event simulation with a strong emphasis on statistical topics, including input analysis, random number generation, output analysis and variance reduction techniques. The proposed course will go over discrete event simulation only at a basic level and focus primarily on its use within systems design and its relation to DAE modeling of energy-based systems.

Concluding Comments. The proposed course will be complementary to several existing courses and will appeal to a broad range of ME students (and possibly students in ISyE and AE).