Certificate in Engineering Risk, Uncertainty, and Decision Analysis

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Educational Objectives and Goals

The design and analysis of engineering systems are becoming much more dependent on the ability of the engineer to analyze the system in the context of uncertainties in system performance, evaluate the reliability of normal operation and the risk of off-normal operation, and then make appropriate decisions to maintain reliability with optimal performance. As a result, many industries (e.g., manufacturing, chemical, nuclear) are looking for engineering graduates with appropriate understanding and knowledge in these areas. The Certificate in Engineering Risk, Uncertainty and Decision Analysis includes courses in statistics and probability, modern uncertainty analysis, decision analysis, and probabilistic reliability and risk assessment. The primary goal of this program is to significantly increase the number of engineers with a fundamental understanding of uncertainty, reliability and risk-based decision-making.

Certificate Description

Introduction

Engineering systems design and analysis are becoming much more dependent on the ability of the engineer to analyze the system in the context of uncertainties in system performance, evaluate the reliability of normal operation and the risk of off-normal operation, and then make appropriate decisions to maintain reliability and optimal performance. As a result, many industries (e.g., chemical, construction, nuclear transportation) are looking for graduates with appropriate understanding and knowledge in these areas. Hence, we propose to enhance our engineering curricula in these areas by developing one new course and packaging it with several existing courses into a new Certificate in Engineering Risk, Uncertainty and Decision Analysis. The Certificate will be available to both undergraduate and graduate students and would be unique among Engineering Colleges in the United States.

In order to properly prepare our students to be productively engaged in risk-based decision-making in industry, we must provide them with instruction in several areas, specifically including:

- Statistics and probability
- Modern uncertainty analysis
- Decision analysis
- Probabilistic reliability and risk assessment (PRA)
- A practicum with realistic examples, projects and seminars

UW has active courses in statistics, probability, and PRA, and we propose to revive an existing decision analysis course (which has not been taught for several years) and create a new course in uncertainty analysis. These courses will be supplemented by a practicum course that will bring in outside speakers to discuss contemporary issues along with realistic projects. These will be the key elements of our new certificate program to encourage engineering students from all majors to gain an understanding of risk-based decision-making.

Goals and Outcomes

The primary goal of this program is to significantly increase the number of engineers with an understanding of uncertainty, risk, and risk-based decision-making. Many of our industries (e.g., Midwestern utilities such as Exelon and Dominion – see letters of support) have identified a need in this area and cannot meet the need with current graduates. Hence, they are forced to do their own training. Such training programs, while important to emphasize plant specific issues, can more efficiently provide the fundamentals to engineering students as part of their academic training at engineering schools and colleges. The nuclear industry can also benefit from this program by providing the key educational background that their new hires need on fundamental issues as they are integrated into their engineering curriculum.

Certificate Program Concept:

The concept of a Certificate in Engineering Risk, Uncertainty and Decision Analysis (RUDA) originated from the growing need for engineers from all disciplines to be able to analyze system performance and reliability under normal and off-normal operation and to be able to formulate decisions based on a keen knowledge of the system uncertainty, reliability and risk; e.g., power plant operations and associated hazard analyses, fire protection, transportation systems, construction projects, and manufacturing operations. The basis of the certificate lies in requiring the student to take a grouping of 13 credits of formal course work and a two-credit practicum and seminar in Engineering Systems RUDA applications.

The certificate requirements would be the following:

- Calculus-based Statistics (4 credits): Statistics-311 or equivalent statistics course;
- Modern Uncertainty Analysis (3 cr): will be developed as part of this effort;
- Probabilistic Risk Analysis (3 cr): NE-574 (also ISyE-574 offered jointly http://www.engr.wisc.edu/ep/neep/courses/neep574.html) this is already taught and will be updated and transformed to be taught at a distance via the web);
- Decision Analysis (3 cr): IE-516 (http://www.engr.wisc.edu/ie/courses/ie516.html/) or CEE-494 already offered and will be updated as part of this certificate program;
- Team-Based RUDA Professional Development Seminar and Practicum (2 cr): will be developed and will consist of guest speakers and realistic RUDA projects.

Frequency of Course Offerings

We anticipate offering these courses at a frequency sufficient to allow students to complete their certificate requirements without undue complication. The statistics courses are offered each semester. We anticipate that the uncertainty, PRA, and decision analysis courses will be offered on an annual basis. The seminar/practicum will be taught each semester, with responsibility for the course rotating between the ISyE, CEE, and EP departments.

Course in Modern Uncertainty Analysis

There are currently no courses in our engineering college devoted to uncertainty analysis. The closest is a course in Civil and Environmental Engineering (CEE), taught by Professor Adams, which spends about 1/3 of the semester on related topics. We intend to create a new course, expanding relevant portions of the existing course to a full semester, adding depth and case studies related to several disciplines outside of CEE, including nuclear and mechanical engineering.

The course will begin with an introduction to the need for incorporation of risk-based methodologies into decision making for engineers, followed by a brief review of the statistics principles to be used over the course of the semester. This will lead us into a discussion of the various probability distributions one might employ in uncertainty analysis and the practical aspects of the important decisions regarding choosing among them.

The next module of the course will discuss the sources of uncertainty encountered by engineers and common ways to represent the uncertainty in forms that are useful for decision making. This will include an introduction to Bayes's Theorem and its implications for decision analysis. This prepares the students for a lengthy discussion of methods for studying uncertainty, including analytic and numerical methods. We will survey these methods in detail, providing students with the fundamental tools needed to be productive in a variety of work environments. Topics covered here will include moment-based methods, discrete distributions, Monte Carlo sampling, and response surfaces. The last general topic covered will be two-dimensional (second order) Monte Carlo methods, which separates uncertainty from randomness. This is a topic that was introduced relatively recently and will likely require introduction of some research papers to supplement the chosen textbook.

At this point we will introduce commonly used software, such as @RISK or Crystal Ball to allow the consideration of realistic problems in a fashion typical in many industries. This will permit us to discuss the issues students will face with respect to the consideration of large, complex models and the value of gathering high-quality data on the uncertainties in key model inputs. Students will carry out a project on a contemporary engineering topic to get additional practical experience with incorporating uncertainty into technical decision making.

We will complete the semester with a series of case studies relevant to various engineering disciplines, including issues related to nuclear safety, waste transportation, and the treatment of hazardous wastes. After brief introductions to these case studies, students will choose a topic of interest, develop some quantitative models as a capstone project, and present the results in oral presentations the final week of class.

Textbooks we will consider for this course include Probabilistic Techniques in Exposure Assessment : A Handbook for Dealing with Variability and Uncertainty in Models and Inputs by Cullen, and Frey, Statistical Models in Engineering by Hahn (Author) and Shapiro, and Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis by Morgan and Henrion.

Probabilistic Risk Analysis Course

The current course on probabilistic risk analysis (PRA, NE574) begins with an introduction on why PRA is needed, and an overview of the PRA process. It includes a brief review of probability theory, since people often come to the course with varying backgrounds.

The first module of the course deals with methods for systems analysis. Those include fault-tree analysis and common-cause failure analysis. This module also discusses how to adapt systems-analysis models to address issues like maintenance unavailability, human error, and differing boundary conditions—for example, if some support systems (such as electric power) are unavailable. This module of the course also includes an opportunity for students to use standard software such as SAPHIRE.

Next, the course moves on to discuss event-tree analysis. This module begins with the basics of how to construct an event tree, and then moves on to illustrate event-tree construction for systems of realistic scale and complexity, including for support systems such as AC and DC electrical power components and systems.

Brief modules present the state of the art with respect to both human reliability, and the analysis of external events (such as earthquakes, hurricanes, tornadoes, floods, and fires). The discussion of human reliability draws heavily from the book on human error by Reason (Human Error, Cambridge University Press, 1990), but also discusses several practical methods for human-reliability analysis that are used in industry, such as the EPRI calculator and the NRC SPAR-H methods, as well as the results of the ATHEANA project sponsored by the Nuclear Regulatory Commission.

A detailed module on data analysis is also included. This module includes both the mechanics of data collection and interpretation, and also the use of Bayesian statistics. The treatment of Bayesian statistics again involves software demonstrations.

The module on data analysis naturally feeds into a subsequent module on uncertainty propagation. This module focuses on the use of Monte Carlo simulation, as the most widely used method of uncertainty propagation at present, but also discusses the method of discrete probability distributions and the method of moments, as options when a rough estimate of uncertainties is needed and simulation software is not readily available.

Finally, the last technical module of the course deals with level 2 and level 3 PRA analysis, including containment analysis and offsite dispersion analysis of the accident source term. This module will first involve a discussion of the historical approach for level 2 and level 3 PRA analyses first used in the Reactor Safety Study (WASH-1400) and later in the application of containment loads and accident consequences in NUREG-1150 activities and the associated Individual Plant Examination efforts. Finally, we would work with the students in developing simple models for containment loads and consequence calculations and then use these simplified approaches to compare to MELCOR and MACCS for particular severe accident simulations and associated source term dose-consequence analyses.

The course concludes with a module on the uses of PRA results. This module discusses the interpretation of PRA results and their use for diagnostic purposes (identification of the dominant contributors to risk). It also presents a number of successful examples of effective (and cost-effective) risk management using PRA. One of the key topics that will be discussed in this phase of the course will be the recent efforts to develop a risk-informed approach to safety analysis as well as the recent implications on the safety regulations. We expect case-studies on fire protection, loss-of-coolant accidents, waste transportation, and other topics will provide an excellent motivation for the students to appreciate the importance of PRA in nuclear safety issues as well as the broader applications in other engineering systems.

Numerous textbooks exist that are useful for the purposes of this course. At present, we plan to use a new book by Bedford and Cooke (Probabilistic Risk Analysis: Foundations and Methods, Cambridge University Press, 2001), which appears to be the most modern and rigorous of the available options. However, we are also familiar with numerous other options, including Dhillon and Singh (Engineering Reliability: New Techniques and Applications, Wiley, 1981), Fullwood and Hall (Probabilistic Risk Assessment in the Nuclear Power Industry: Fundamentals and Applications, Pergamon Press, 1988), Kumamoto and Henley (Probabilistic Risk Assessment and Management for Engineers and Scientists, IEEE Press, 1996), McCormick

(Reliability and Risk Analysis: Methods and Nuclear Power Applications, Academic Press, 1981), and Modarres (What Every Engineer Should Know about Reliability and Risk Analysis, Dekker, 1993).

Decision Analysis Course

This course presents an overview of modeling techniques and methods used in decision analysis, including multi-attribute utility models, decision trees, and Bayesian models. Psychological components of decision-making are also discussed. Elicitation techniques for model building are emphasized via lectures and problems. Practical applications through real world model building are also conducted.

The ability to make good decisions is a fundamental skill for engineers and managers in any organization. This course will teach the skills and concepts that you need to make better decisions. The ideas will be applicable in your personal life as well as your professional life. We will learn quantitative techniques for identifying good decisions in complex situations, but also general concepts that can help you even if you don't use those quantitative techniques. These ideas can help you deal with many of the things that can make decision-making difficult, such as uncertainty about future outcomes, tradeoffs between competing objectives ("comparing apples and oranges"), and nonlinearity of preferences (e.g., the fact that twice as much of something may not be twice as good).

After successfully completing this course, the student will be able to:

- Recognize the types of problems that decision analysis can and can't address.
- Identifying the values, objectives, attributes, decisions, uncertainties, consequences, and trade-offs in a real decision problem.
- Apply the concepts learned in this class (expected value, value of information, risk aversion, and tradeoffs between attributes) to identify good decisions and strategies.
- Represent a decision problem graphically and/or mathematically.
- Determine the optimal decision mathematically.
- Identify which parameters have the most impact on the results of an analysis.
- Explain the results of a decision analysis to managers and other non-specialists.

Seminar/Practicum Course

An important aspect of the certificate is the creation of a course, which is designed to give students exposure to contemporary topics in RUDA from real-life practitioners as well as real-life projects. We will have a weekly seminar series consisting of a mix of speakers from our campus, other partner campuses, and industry partners. These speakers will address RUDA in a practical, industrial context, as well as future directions in RUDA. These seminars will also be offered via the same distance learning tools used to offer the distance courses (as described in the next section). Since this will be the capstone course of the certificate we also plan to pair up the students into teams to address a semester project on reliability and risk.

Key Faculty:

- **Mike Corradini**, Chair and Wisconsin Distinguished Professor of Nuclear Engineering and Engineering Physics, has been at UW since 1981 and is a Fellow of the ANS and a member of the National Academy of Engineering. He is well known for his research in nuclear reactor safety. He will help to update the PRA course and its delivery via the web as well as help develop the uncertainty course, primarily through the development of nuclear-specific modules.

- **Vicki Bier**, a Professor of Industrial and Systems Engineering and Director of the Center for Human Performance and Risk Analysis, has been at UW-Madison since 1990. She is well known for her research in risk and decision analysis, applied primarily to nuclear systems and, more recently, homeland security. She will have primary responsibility for upgrading the existing PRA course and with the assistance of Prof. Blanchard offering it online to our CIC and HBCU partners.

- **James Blanchard**, a Professor of Nuclear Engineering and Engineering Physics, has been at UW since 1988 and is best known for his research in computational science and structural mechanics as applied to fission and fusion systems design and radioisotope power sources for MEMS. He will help to develop the new uncertainty course and will have primary responsibility for creation and administration of the Certificate program. He also will help lead the development of the online/internet delivery of the PRA course.

- **Teresa Adams**, a Professor of Civil and Environmental Engineering, Director of the Wisconsin Transportation Center, has been at the UW since 1989. She is well known for her research in, among other things, decision support for managing transportation infrastructure assets, including maintenance quality assurance. In 2002, she established a campus-wide certificate program in Transportation Management and Policy that has been very successful in attracting and developing students. She teaches decision tools to civil engineering students will assume the lead responsibility for developing the new uncertainty course.

Sponsoring Unit for Certificate Program:

Engineering Physics Department will be responsible for administering the certificate program. This will include student records, DARS and other functions related to student support.