Course Development in Maintenance and Reliability Engineering

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Abstract

A comprehensive university program to support America's massive industrial maintenance and reliability activity has been established at The University of Tennessee in the form of The Maintenance and Reliability Center. A certification program, which operates in parallel with engineering degree programs, provides the educational component of the Center's activity. Seven new maintenance and reliability engineering courses have been or are being developed (six with NSF funding), and a teaching laboratory is being developed with NSF funding. The courses are being formulated for traditional in-class delivery and for distance education delivery. Distance education is now provided through a cooperative program between Monash University and The University of Tennessee.

Introduction

In 1996, The Maintenance and Reliability Center was formed by The College of Engineering at The University of Tennessee. The motivation for this step was the tremendous maintenance and reliability effort in industry (at least $300 billion per year) that lacked coordinated support from universities in providing personnel, technology and information. This Center is industry-supported with a current membership of thirty companies from throughout The United States. The Center is headquartered at The University of Tennessee, but it also involves the following partner institutions: The University of Alabama, Pellissippi State Community College, Oak Ridge National Laboratory and Pacific Northwest National Laboratory. The Center's mission includes education, research, outreach (mainly conferences and short courses) and business methodology development. The education component is the focus of this paper.

Maintenance and Reliability Engineering Defined

Maintenance, in an industrial sense, is preserving or restoring the operability and function of systems through service or repair. Maintenance Engineering refers to the design and implementation of activities required to accomplish maintenance. Maintenance engineering includes the following:

1. **Design for Maintenance**
   This activity includes selection of materials and configurations that provide required operating lifetimes and ergonomic features which facilitate condition monitoring, servicing and repairs.
2. **Condition Monitoring, Analysis and Interpretation**
   This activity includes selection of status information on components, systems or processes from on-line instrumentation, human observation and/or sampling and offline analysis. Analysis involves determination of signatures which indicate whether the system is "healthy" or "unhealthy." An unhealthy system is one that is approaching unacceptable performance, as well as one which is already performing unsatisfactorily. System instrumentation, signal processing and analysis methods play important roles in this activity.
3. **Maintenance Management**
   This activity includes the economic and ergonomic aspects of servicing and repairing systems. This includes financial analysis, inventory control, procedures development and work management.

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Reliability, in an industrial sense, is preserving the operation and function of systems through design activities which identify and eliminate failure-prone components. This process is oriented particularly towards components whose failure is likely to cause premature failure of the total system. Reliability engineering deals with probabilistic methods which identify the likelihood of faults in components and the consequences of those faults on total system performance.

Maintenance and Reliability Engineering Academic Program

Since it was neither desirable nor feasible to establish a new degree program in maintenance and reliability engineering, the education commitment of the Center was satisfied by establishing a certification program that operates in all of the degree programs in the College of Engineering at the University of Tennessee (none of the partner institutions have yet established academic programs). The certification is available at the B.S., M.S. and Ph.D. levels. At each of these academic levels, students undertake activities in parallel with their traditional degree programs, permitting receipt of their maintenance and reliability engineering certificate at the same time that their degrees are conferred. By employing electives and summer activities, no time is added to that necessary to earn a degree.

Undergraduate students are normally admitted to the Maintenance and Reliability Engineering (MRE) program after the sophomore year though a few select freshmen are sometimes admitted. Candidates must have a GPA of at least 3.0, they must prepare an essay demonstrating some knowledge of the maintenance and reliability field and their ability to communicate, and they must sit for an interview. Selected students begin their involvement in the program in the summer after their admission. The first activity is participation in the MARCON (Maintenance And Reliability CONference) that is hosted by The Maintenance and Reliability Center every May. The students attend sessions and serve as conference workers. The following week, the students attend a weeklong intensive course (eight hours per day) designed to familiarize them with important topics in practical maintenance and reliability engineering. Then the students leave for twelve-week summer internships with Center member companies where they work on pre-arranged maintenance and reliability topics. Host companies pay the stipends and travel expenses for the interns. Students submit reports on their internship activities when they return to campus in the fall. Students are required to complete at least two of these summer programs (MARCON, short course, and internship).

Undergraduate students must also complete at least two specified maintenance and reliability engineering courses and maintain a GPA of at least 3.0. The courses must include “Introduction to Maintenance Engineering” and “Introduction to Reliability Engineering”. Other courses in addition to these are encouraged, but since the degree requirements in programs in The College of Engineering have few technical electives, students can do this only if they are willing to take overload courses.

M.S. students must take at least two additional approved courses beyond those required of the undergraduates. Instead of requiring internships for M.S. students, they are required to complete thesis research or a non-thesis project on an approved maintenance and reliability engineering topic. The research is usually related to a project sponsored by the Center members.

Ph.D. requirements for MRE certification consist of passing an MRE component of the Ph.D. qualifying examination, completing at least two additional approved courses beyond those required for M.S. students and completing a dissertation on research on an approved MRE topic.

Course Development

Course Needs

Courses available in The College of Engineering when the academic program started contained some of the material needed, but a major effort was needed to construct a new group of courses with appropriate content and organization.

1997 NSF Grant

A proposal was prepared for submission to the NSF Combined Research Curriculum Development (CRCD) program and a grant was awarded in 1997. The grant supports the development of four new courses and a new teaching laboratory. The courses are as follows:

1. Introduction to Maintenance Engineering, Dr. Belle Upadhyaya, course developer (See http://web.utk.edu/~bru/ for details.)
2. Managing Maintenance and Reliability, Dr. Ken Kirby, course developer
3. Advanced Condition Monitoring and Diagnosis, Dr. Wes Hines, course developer (See Http://web.utk.edu/~hines/hines.html for details.)
4. Reliability and Life Prediction Technology, Dr. Les Frair (University of Alabama), course developer (See http://www.ie.eng.ua.edu/current_courses/ges591/course_home.htm for details.)

Drs. Upadhyaya and Hines are developing the teaching laboratory. The project staff also includes a project manager (Dr. Tom Kerlin) and a professional assessment and evaluation specialist (Dr. Russ French).

The course development followed the following steps:

1. Collection of course-related information including new research results
2. Development of course syllabi
3. Preparation of teaching resources (notes, slides, problems, etc.)
4. Group critique of syllabi and teaching resources
5. Initial in-class presentation of the courses
6. Assessment of course effectiveness and revisions as necessary
7. Revision of course resource materials for use in distance education
8. Presentation of the distance education versions of the courses
9. Final assessment
10. Preparation of resource packages for sharing with other interested engineering educators.

The laboratory development followed the following steps:

1. Identification of laboratory experience needed to augment the class work
2. Identification of equipment needed for the laboratory
3. Obtaining equipment by purchase ($60,000 to date) or solicited donations ($86,000 to date)
4. Preparation of procedures for laboratory exercises
5. Testing the exercises
6. Assessment of the effectiveness of the exercises and revision as necessary
7. Preparation of information packages for use by other interested engineering educators.

The project is now in its third and final year. The course development activities are now mainly focused on further in-class course presentations, distance education course development and presentation, assessment, dissemination of information about the courses and preparation of information for other engineering educators.

Condensed syllabi for the courses follow:

1. Introduction to Maintenance Engineering
   - Overview of maintenance engineering
   - Digital Signal Processing and Information Extraction from Machinery Measurements
   - Vibration Analysis and Rotating Machinery Monitoring
   - Robotics in Remote Handling and Maintenance
   - Lubrication Oil Analysis
   - Nondestructive Examination Methods and Applications
   - Failure Models and Lifetime Prediction
   - Maintenance Planning and Management
   - Monitoring and Maintenance of Process Instruments
   - Electrical Signature Analysis for Machinery Condition Monitoring

2. Managing Maintenance and Reliability
   - Introduction to The Management of Maintenance/Reliability
   - Customers of Maintenance/Reliability
   - Evolution of Maintenance
   - Controlling Maintenance (Human Resources and Materials)
   - Maintenance Effectiveness (Planning and Scheduling)
   - Maintenance Integration

3. Advanced Condition Monitoring and Diagnosis
   - Introduction
   - Statistics in Machinery Monitoring and Diagnosis
   - Non-Parametric Methods in Machinery Monitoring and Diagnosis
   - Neural Networks in Machinery Monitoring and Diagnosis
   - Fuzzy Logic in Machinery Monitoring and Diagnosis

4. Reliability and Life Prediction Technology
   - Introduction
   - Statistical Trending and Life Estimation Using Machinery Data
   - Structural, Mechanical and Electrical Failure Modes
   - Advanced Methods for Reliability Testing and Life Prediction
   - New Methods in Design for Reliability

The laboratory exercises developed are as follows:
- Vibration Monitoring and Analysis
- Induction Motor Testing
- Motor Current Monitoring and Analysis
- Variable Speed Machinery Monitoring
- Eddy Current Testing
- Ultrasonic Testing and Analysis
- Lubrication Oil Analysis

1999 NSF Supplemental Grant: The International Component

In 1999, a proposal was submitted to NSF for a supplemental grant to expand the educational project by cooperation with French engineering educators. This grant was awarded in August 1999. The supplemental project has the following three main components:

1. Assisting the French in adapting course material from the CRCD project

2. Adapting course resources developed by Dr. Gilles Zwingelstein, a highly respected maintenance and reliability expert and educator in France. One course deals with Reliability Centered Maintenance and the other with Asset Management in Maintenance. Dr. Greg Kawiecki of the University of Tennessee is handling the translation and adaptation of the courses for American use.
3. Developing and implementing a new approach to international student collaboration called "cyber-linked student projects" in which French and American students work together on assigned MRE projects via the internet. Dr. Belle Upadhyaya is managing the cyber-linked student projects.

Internal Course Development

As work on the academic program evolved, it became clear that a senior-level course in reliability engineering was needed. The Dean of Engineering provided funds for this effort. Dr. Peter Groer has developed and presented this course following essentially the same development scheme as was followed in the CRCD development effort.

Distance Education

Strategy

Many engineers throughout the U.S. need formal education in maintenance and reliability for professional development and career enhancement. Delivery of this education to widely dispersed individuals is best accomplished via modern distance education delivery techniques. The Center is providing distance education opportunities by forging an alliance with an existing program in Australia and subsequently augmenting that program with new distance education capability resulting from work supported by the NSF grants at The University of Tennessee.

Cooperation with Monash University

Monash University in Australia has been offering distance education in maintenance engineering since 1985. This program has served many engineers throughout Southeast Asia. The Monash program provides opportunities to earn a certificate (approximately one year), a diploma (approximately two years) or a Master's degree (approximately three years). Students must also attend weeklong residence schools on campus. The University of Tennessee now manages the North American delivery of the Monash program and operates the residence schools for North American students.

Incorporation of New Courses

The Monash distance education program is well developed and mature, but can benefit from incorporation of new internet-based delivery technologies that have appeared in recent years. The distance education versions of the courses being developed under NSF sponsorship include internet-based delivery schemes. These will be folded into the Monash/Tennessee program when they are completed.

Conclusions

Significant new educational opportunities for engineers who wish to pursue careers in maintenance and reliability engineering now exist. A curriculum that leads to Maintenance and Reliability Engineering Certification is in place. The curriculum is supported by development of seven new courses:

1. Introduction to Maintenance Engineering

2. Managing Maintenance and Reliability
3. Advanced Condition Monitoring and Diagnosis
4. Reliability and Life Prediction Technology
5. Introduction to Reliability Engineering
6. Reliability Centered Maintenance
7. Asset Management in Maintenance

A teaching laboratory has also been designed and outfitted. A new distance education program in maintenance and reliability engineering is in operation and will be upgraded with new formulations of the new courses for modern delivery.