A Laboratory-Based Course in Process Quality Engineering

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Abstract

Beginning with the 1992-1993 academic year, ABET criteria require the undergraduate engineering curriculum to include the application of statistics to engineering problems. The Department of Industrial and Management Systems Engineering at Penn State, in consultation with several other engineering departments, has developed a new course to meet this requirement. It provides an extensive curriculum that includes exploratory data analysis, probability models and confidence intervals, statistical process control, regression models and the design of experiments (DOE). These topics are placed in the framework of the TQM environment present in many U.S. firms today. Lecture concepts are reinforced by a laboratory experience that includes data generation, metrology, and computerized statistical analysis.

Introduction

During the past fifteen years we have witnessed a quality revolution in industry. The creation of the Malcolm Baldridge award in 1987 and the continuing development of ISO 9000 standards are two indicators of this development. There is an increased focus on customer satisfaction, quality, and product and process improvement that calls for a reshaping of engineering education.[8] The new ABET criteria require that "students must demonstrate knowledge of the application of statistics to engineering problems." The increasing role of statistics in engineering education was discussed by Nelson and Wallenius at the ASEE Centennial Conference, who suggested an integration of statistical thinking and methodology throughout all engineering departments, in particular, in laboratory exercises throughout the undergraduate engineering curriculum.[9] In this spirit, the Department of Industrial and Management Systems Engineering at Penn State has developed a new laboratory-based service course to provide undergraduate engineers with a strong background in industrial statistics. Laboratory exercises provide an important opportunity to link statistical concepts with engineering activities, particularly in the area of the design of experiments (DOE), an area which is receiving great attention in industry.[3,4]

Course Goals

The new course is entitled "Process Quality Engineering" and is intended to meet ABET requirements for probability and statistics for all undergraduate engineering disciplines. The goal was to develop a course that reflects the extensive use of statistical methods in industry, and that provides an exposure to the most commonly used tools and techniques. A further goal of the course was to provide a hands-on data generation and analysis experience for students, with a focus on engineering design and manufacturing examples. The laboratory provides important evidence of the practicality of the mathematical techniques described in lecture, and an opportunity to become proficient with powerful PC-based data acquisition and statistical analysis software.

Course Topics and Text

The course focuses on the following themes.

- The place of statistical methods in the industrial TQM culture.
- Statistical inference from population samples.
- Statistical process control.
- DOE, analysis of variance (ANOVA), and regression analysis.
- Product and process optimization and robust design.

These are described in more detail in the syllabus below. The text is by Mark Kiemele and Stephen Schmidt.[6] It combines TQM concepts including Quality Function Deployment with exploratory data analysis, elementary statistics, statistical process control, multivariate regression, and DOE. Each chapter includes case studies that show the application of statistical methods in industrial quality improvement studies.

While this text provides an excellent fit to an ambitious curriculum, no text is ever perfect for every course. The Kiemele and Schmidt has two major shortcomings for our use: i) at times the material level is below a junior/senior level of difficulty, and ii) there is an incomplete coverage of graphical methods for data analysis. The latter weakness has been addressed by supplementary readings in the book by Chambers, Cleveland, Kleiner and Tukey.[1] These readings and lab exercises cover box plots, quantile-quantile plots, and glyph plots for multivariate data. We use MINITAB Version 9 for Windows in place of the limited-capability MYSTAT software that accompanies the text.

Quality and Precision Measurements Laboratory

Key concepts in statistical analysis and the design of experiments are understood and retained more thoroughly through hands-on exercises. The Process Quality Engineering curriculum is structured around two lectures and one lab per week. The laboratory exercises are

designed to emphasize the relevance of statistics in a manufacturing setting, to illustrate key issues in metrology, and to provide the students with an opportunity to use state of the art data collection and statistical analysis software. Most laboratory sessions take place in the Quality and Precision Measurements Laboratory. The laboratory will be completely equipped in 1995. At present, it includes eight work areas equipped with IBM Value Point PCs for collection and statistical analysis of measurement data. A surface plate provides the work center with dual use, for manual measurement and data entry activities. In addition there are specialized work centers for precision measurement activities, each of which is equipped with specialized automated measurement equipment. Some activities, such as tensile strength testing and resistor measurements, have used other laboratory facilities in the College of Engineering.

TQM in the Classroom

In developing this course, we have attempted to follow the tenets of total quality management in several regards. First, we talked to our customers, in this case the department heads of all engineering departments at Penn State, undergraduate students, and their potential employers in industry. In addition, extended face to face discussions were held separately with faculty and department heads from Engineering Science and Mechanics, Mechanical Engineering, Electrical Engineering, and Statistics, to describe the course content and to identify the needs of the individual departments. The course plans were presented and discussed at the Fall 1993 Leonhard Center Advisory Board meeting, with over twenty advisors from industry and academia.

Second, we follow the suggestions of our ASEE colleagues in bringing TQM into the classroom.[10,11] We have a CQI team of six students and a facilitator (Eileen Christman) to provide feedback on the laboratory exercises, and to develop and implement instruments to capture student evaluations of our performance in lectures, assignments, tests, and quizzes.

Spring 1994 Offering

The Spring 1994 offering of Process Quality Engineering has an enrollment of 52 students. Electrical Engineering, Mechanical Engineering, and Engineering Science and Mechanics have the largest contingents, with a few students from Nuclear, Chemical, and Aerospace Engineering. There is a reduced set of six laboratory activities for this offering, which will be expanded next year on completion of the Quality and Precision Measurements Laboratory. These are listed in the curriculum description above. As of this writing, the first lab, using exploratory data analysis techniques to compare two resistor manufacturing technologies, has been completed. It was rated highly by the students. Feedback from the CQI team members participating in the Monday lab session led to revisions in the Wednesday and Friday sessions.

Plans

With a new laboratory facility expected to be in place in late 1994, we will offer a full set of 10-12 laboratory sessions in 1995. We expect to purchase additional measurement equipment, including multimeters and precision scales for SPC experiments. In addition, we hope to purchase a small injection molding machine for DOE studies. We expect to instrument our machining fixture and the injection molding machine to allow us to use Labview software to control and monitor manufacturing and measurement experiments.[2,5]

Until enrollment grows substantially, Process Quality Engineering will be offered only one semester each year. The College of Engineering at Penn State has over 1000 engineering undergraduates in each class. If our efforts are successful, we can expect to serve a substantial fraction of this number each year. Our laboratory facilities are planned to accommodate approximately fifty students per laboratory, or 250 students per semester. We will rely on market forces to determine our class size. We are planning for growth.

Conclusion

Historically undergraduate engineering students outside the field of industrial engineering have received inadequate exposure to the key concepts and tools of industrial statistics. Process Quality Engineering is an innovative course in engineering statistics. To our knowledge, the collection of topics, combined with a hands-on laboratory experience, is unique in the university engineering community. We look forward to continuing development and improvement, and to increasing enrollments.

Acknowledgments

Many individuals in industry, government, and academia have provided substantial assistance toward the development of this course. We would first like to acknowledge Professors M. Jeya Chandra, Laura Raiman, and Allen Soyster who were involved in the conceptual development of the course, particularly Dr. Laura Raiman, who developed a lecture version of this course and was instrumental in securing funding for the laboratory. Part of the course development and much of the laboratory equipment and software has been supported through the IBM Total Quality Management grant to the Pennsylvania State University. Additional support has been provided by the State of Pennsylvania, and by the undergraduates themselves, through funds received from the tuition surcharge program and through their efforts on the CQI team. The Department of Electrical and Computer

Engineering has provided laboratory support, facilities, and materials for the resistor laboratory. Larry Burton, Department Head, and faculty members Derald Cummings and Eileen Christman made extra efforts to insure the success of the lab. The Leonhard Center for Excellence and Innovation in Engineering Education provided support in several ways. Eileen Christman, Leonhard Center Faculty Fellow, served as a research assistant in support of laboratory development, and organized the CQI team. Dr. Jack Matson, Director of the Leonhard Center, and the Leonhard Center Envisioneers have taken responsibility for preparing new laboratory activities for the 1995 offering of Process Quality Engineering.

References

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12. Wickman, J.L., "A Manufacturing Engineering Technology Capstone Course Emphasizing Design of Experiments (DOE)," *1993 ASEE Annual Conference Proceedings*, 168-170.

Process Quality Engineering Course Syllabus

1/10-1/14 **K&S Chapters 1, 2.1-2.5, 11**. The TQM culture. QFD. The 'seven tools' and EDA. Data properties: location and spread: sample mean, robustness, median, interquartile range.

1/17-1/21 **K&S 2.6-2.9 and CCKT: Graphical Methods for Data Analysis**. Ogive/ecdf, quantile plots, multi-sample plots (box, paired stem&leaf, paired ecdf, quantile-quantile. Multivariate plots (scatter, symbol), misleading R^2, star, Chernoff face. Lab: characterization of carbon composition vs. carbon film resistors.

1/24-1/28 **K&S 3.1-3.5, 3.8**. Probability definition and computation. Conditional distribution and independence. Applications of Bayes rule.

1/31-2/4 **K&S 3.6, 3.7, 4.1-4.5, 4.8**. Expectation and variance. Common probability distributions and their properties: binomial, hypergeometric, Poisson, pmf, cdf.

2/7-2/11 **K&S 4.6, 4.7, 5.1-5.3**. Normal, lognormal, and exponential, expectation and variance.

2/14-2/18 **K&S 5.4-5.6**. Sampling distributions and the Central Limit Theorem. Estimates and confidence intervals. Lab: law of large numbers and central limit theorem, and MINITAB introduction.

2/21-2/25 **K&S 5.7, 6.1, 6.2**. Comparing two data sets: hypothesis tests and confidence intervals. Determining sufficient sample size.

3/2-3/4 **K&S 6.3-6.5, 6.8**. Tests for equality of populations. Lab: normal plots and confidence intervals for resistors, sample size for mean nail diameters.

3/14-3/18 **K&S 9.1-9.10**. Manufacturing process variations, fishbone diagrams and probability models. Statistical Process Control (SPC).

3/21-3/25 **K&S 9.11, 9.13, 9.14**. Attribute control charts. Metrology. Lab: SPC for nail data.

3/28 **K&S 9.12**. Multivari charts.

4/4-4/8 **K&S 7.1, 7.2**. Regression: models, estimation, ANOVA table and confidence intervals.

4/11/-4/15 **K&S 7.3 & Handout**. Regression: multivariate, GLM, and incorporating qualitative variables. Lab: tensile strength data collection and regression.

4/18-4/22 **K&S 8.1, 8.3, 8.4**. Designed experiments: factorial and fractional factorial designs. Lab: DOE for spot welding.

4/25-4/29 **K&S 8.2, 8.5, 8.7, 8.8, 8.10**. Designed experiments: EVOP, RSM, Taguchi models and designs.

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Russell Barton joined academia after ten years in industry (RCA) and consulting. From 1987-1990 he was a Visiting Associate Professor at Cornell University. He joined Penn State in 1990 as an Associate Professor of Industrial Engineering. His research and consulting activities are in optimization and statistics, particularly the design of experiments. He received the IIE Student Chapter Outstanding Faculty Award in 1991 and the Penn State Engineering Society Outstanding Teaching Award in 1994. He is a fellow and an executive board member of the Leonhard Center for Excellence in Engineering Education at Penn State, and a member of IEEE, IIE, Sigma Xi, the Society for Industrial and Applied Mathematics, and The Institute of Management Sciences (TIMS). He is also active in the TIMS College on Simulation.