A Successful Masters Curriculum in Quality Engineering

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INTRODUCTION

Quality engineering as a job title in industry existed well before any 4-year degree or masters programs were created in U.S. universities. By 1985, there were eight colleges that provided a 4-year degree program in quality[1] . However, universities have continued to be reluctant to establish new 4-year degree programs in specialized areas such as quality engineering. This is not the case with a master's degree in quality engineering, many of which are now offered as a major (or concentration) in industrial and manufacturing engineering departments. The reason is that industrial engineering and/or manufacturing engineering programs "provide an excellent background for quality engineers because of the emphasis on cost, schedule, and quality parameters...courses in statistical methods are required, and some schools require courses in quality control[1] ."

In 1988, the author established a major in quality engineering within the Master of Science in Industrial Engineering (MSIE) degree program at The University of Alabama. The objectives of the major in quality engineering were to:

- Provide a comprehensive education in the philosophy of Total Quality, the preventive process-oriented methodologies of Quality Engineering, and the planning, control, and improvement techniques--both classical (statistical process control--SPC, acceptance sampling, statistical design of experiments--DOE, regression, reliability and maintainability) and modern (Taguchi Methods, Quality Function Deployment, failure modes and effects analysis--FMEA, Total Productive Maintenance, etc.).

- Prepare individuals for early and mid-career transition into quality program leadership positions in their organizations.

- Prepare B.S.-level engineers, regardless of undergraduate majors, for entry-level jobs as quality engineers.

Prerequisites were established to enable non-BSIEs to enter the program and, within a semester, be prepared to tackle seven required quality engineering courses. The prerequisites are:

- Calculus, through differential equations (offered every semester, including summer)

- A two-semester undergraduate-level course in probability and statistics, or enroll in GES 500 Engineering Statistics (survey) during first semester in program (every semester).

- A two-semester undergraduate-level survey of Operations Research techniques, or enroll in GES 501 Operations Research (survey) during first semester in program (Fall only).

- A two-semester course in work methods and ergonomics design, or enroll in IE 502 Work Design and Human Performance (survey) during first semester in program (Fall only).

- A course in engineering economy, cost analysis, or similar applied economics (IE 203 offered every semester).

A decade later, we have reduced the core courses to six in number by rearranging, adding, or deleting material. An average of two graduates per year have been produced 1990-97, and these students have obtained quality engineering positions at top corporations such as 3M, BellSouth, Johnson and Johnson, Carrier Corporation, Texas Instruments, and Andersen Consulting. Some are now quality or production managers.

The objectives of this paper are to define quality engineering, explain the motivation behind the original curriculum, compare the original curriculum with what we require today along with the rationale we followed, and discuss potential future curriculum changes.

DEFINITIONS OF QUALITY ENGINEERING

There are at least three definitions of what it means to be a quality engineer: 1) The American Society for Quality's (ASQ's) Body of Knowledge for the Certified Quality Engineer (CQE) Exam; 2) The use of the approach to designing quality into products and processes, referred to as Parameter and Tolerance Design, advocated by the Japanese engineer Genichi Taguchi; 3) The use of the term to refer to an engineering specialty practiced in large companies as part of the quality assurance function, especially when participating in the development of new products, processes, or systems.

ASQ's Body of Knowledge for the CQE exam[2] uses the following first and second-level groupings:

1. General Knowledge, Conduct, and Ethics

2. Quality Practices and Applications
   A. Human Resource Management
   B. Quality Planning
   C. Quality Systems
   D. Supplier Management
   E. Quality Audit
   F. Cost of Quality
   G. Continuous Improvement Tools

3. Statistical Principles and Applications
   A. Terms and Concepts
   B. Distributions
   C. Statistical Inference
   D. Correlation and Regression Analysis

E. Experimental Design
F. Acceptance Sampling

4. Product, Process, and Materials Control
   A. Work Instructions
   B. Classification of Characteristics and Defects
   C. Identification of Materials and Status
   D. Lot Traceability
   E. Materials Segregation Practices
   F. Materials Review Board Criteria and Procedures
   G. Sample Integrity and Control
   H. Statistical Process Control

5. Measurement Systems
   A. Terms and Definitions
   B. Metrology
   C. Repeatability and Reproducibility Studies
   D. Destructive and Nondestructive Testing

6. Safety and Reliability
   A. Terms and Definitions
   B. Reliability Systems
   C. Reliability Life Characteristic Concepts
   D. Risk Assessment Tools and Risk Prevention
   E. Product Traceability Systems and Recall Procedures

Taguchi has defined high quality to be low (or minimum) loss to society in producing and using a product. The minimization of the sum of manufacturing cost (supplier's cost prior to sale) and quality loss (unnecessary cost to customer after the sale) is the approach advocated by Taguchi. Phadke[3] has defined quality engineering to be "concerned with reducing both these costs and, thus, is an interdisciplinary science involving engineering design, manufacturing operations, and economics." Taguchi views the design process as consisting of three steps:

- System design,
- Parameter (robust) design, and
- Tolerance design,

regardless of whether a product or a process is the subject of the design. In parameter design, one determines the best settings for the control factors to make performance insensitive to noise in the operating environment, minimizing quality loss. In tolerance design, a trade-off is made between reduction in quality loss due to performance variation and an increase in manufacturing cost due to tightened tolerances on processes, components, and materials. Taguchi has a large set of tools to accomplish parameter and tolerance design, and several U.S. authors have generated excellent textbooks to guide in their use in quality engineering:

- Parameter design[3,4]

- Tolerance design[5,6].

Finally, a definition of quality engineering as one of the engineering specialties that contribute to systems engineering was given by Feigenbaum in his famous text Total Quality Control[7]:

> The body of engineering knowledge for formulating policy and for analyzing and planning product quality in order to implement and support that quality system which will yield full customer satisfaction at minimum cost...Quality engineering relates the particular requirements of the plant and company to the available quality technology--including both hardware equipments and planning and control actions--to put in place much of the ongoing operating detail of the quality systems framework of the firm.

The curriculum we offer overlaps significantly the ASQ Certified Quality Engineer Body of Knowledge. It also has a course that is predominately Taguchi Parameter Design, though the curriculum as a whole is much broader than Taguchi's view of QE. A systems orientation is evident in the courses on operations research, simulation, and safety.

MOTIVATION FOR ORIGINAL CURRICULUM

Why did we choose to offer a masters-level curriculum in quality engineering? First, we were receiving requests from employers of our graduate students that we were unable to fulfill. I remember all too well sending a graduate-student on a summer internship to help a local steel mill with "quality problems" knowing the student had not yet had my course in statistical quality control. Second, we saw openings for quality engineers developing nationwide in all industries and wanted to give our MSIE students the option to fill them. Students were contacting us to see if they could "major in quality" within our program. Finally, I had a personal interest in seeing the concentration in quality succeed based on my growing participation in ASQC (now ASQ) and my extensive readings of "the quality masters," including W.E. Deming, J.M. Juran, A.V. Feigenbaum, P.B. Crosby, K. Ishikawa, and others.

The content of the original curriculum was motivated by:

- The body of knowledge for the ASQ Certified Quality Engineer and Certified Reliability Engineer Exam;

- The body of knowledge for the State of California Professional Engineering (PE) Exam in Quality Engineering;

- Two reports on quality education for engineers in Japan:

    1. "Quality Practices in Japan"[8], a 1988 report on a study mission to Japan by a team of researchers from AT&T Bell Laboratories and the University of Wisconsin.

    2. "Total Quality Control Education in Japan"[9], a 1989 report by the GOAL/QPC Sustaining Members' Research Committee.

These last two reports each contained sample curricula in quality topics for all engineers, created and taught by members of the Japanese Union of Scientists and Engineers (JUSE)--the organization responsible for inviting Deming to Japan after WWII--and other quality control associations. I had read more than enough to know what needed to be done. Luckily, I worked for a department head and within a "course approval system" that permitted us to begin offering the quality engineering major in Fall 1989, with the first graduates in 1990.

ORIGINAL CURRICULUM

The original curriculum consisted of the prerequisite courses listed in the introduction (a student entering with a BSIE would have had all these already), and the seven courses in Table 1. IE 522, and IE 591 were completely new; the other courses existed, but required some modification by me (IE 521 and 525) or my colleagues (IE 526, 554, and 561).

Notably absent are: explanations of total quality management, especially Deming's 14 Points and Juran's Quality Trilogy (planning, improvement, and control); the seven visual quality improvement tools. IE 521 and IE 554 both covered safety engineering, though in IE 521 we went into fault tree analysis (FTA). IE 522 and IE 526 both had sections on multiple regression analysis, though IE 526 teaches mostly proper diagnosis of model adequacy (not optimization), whereas in IE 522 students needed to understand the least-square, multi-factor regression model only as a tool to construct first- and second-order response surfaces as intermediate steps in the RSM process to find optimal "set points."

These problems were remedied in the revision of the quality curriculum that became effective around 1992.

TODAY'S CURRICULUM

Today's curriculum is somewhat like the original, but content has been fine-tuned and one less course is required; see Table 2. Another change that helps the student is the decision by the IE faculty to permit all students requiring IE 502, Work Design and Human Performance, to count these 3 hours toward the MSIE. Any student can now make it through the program in 12 months (if a BSIE) or 15 months as shown in Table 3, so long as they have external support. If the student holds a graduate assistantship, most find it necessary to spend 21-24 months in the program in order to complete their degree. However, a highly motivated student could hold an 0.5 FTE graduate assistantship (20 hours/week of duties) and still carry as many as three 3-hour courses needed to finish in the 15-month program shown in Table 3. Note that a thesis is now required by the IE faculty of all students holding university support (assistantships or fellowships). Others are required to finish a non-thesis report while enrolled in IE 598 non-thesis research, and complete at least 33 total hours of graduate credit.

Some examples of quality engineering theses and non-thesis research reports are given below:

C. J. Yoo:	Synergism Among TQC, JIT, and TPM, 12/90
M. Reddy:	Simulation of Time and Temperature Variation in Delivering Metal to a Pipe Shop, 8/92

K.C. Chiu:	Parameter Design Experiments in Electrical Resistance Welding, 5/93
S. Gholston:	Taguchi Methods in Metrology, 8/93
P. Mueller:	Enhancement of Selected SPC Tools via Dynamic Computer Graphics, 5/94
J. Schumacher:	Quality Metrics for BellSouth Information Systems used in Customer Support, 5/94
B. Chen:	Team-based Approach to Supplier Quality Improvement, 12/94
D. Datta:	Guidelines for ISO 9000 Implementation in the Foundry Industry, 5/95
R. Sudheer:	Expert Advisory System for ISO 9000 Clause 4.20, Statistical Methods, 5/96
K. Chan:	Updating Total Productive Maintenance, 12/96
C. Turner:	A Methodology for Forecasting Transaction Volumes in Large Service Organizations, 5/97
B. Fowler:	An Explanation of how Equipment Preventive Maintenance helps assure Product Quality, 5/98

TOMORROW'S CURRICULUM

Topics that dominate our thinking in how the quality engineering curriculum at the University of Alabama should evolve are these:

A. A metrology lab experience

B. More material on tolerance design, allocation, analysis, etc.

C. More knowledge of automatic process control (APC), contrast of APC with SPC, use of SPC to improve performance of APC, how to use Taguchi Methods to derive/update set points, etc.

D. Multivariate control, both automatic and via advanced control charts

E. ISO 9000 depth training

F. Knowledge of Malcolm Baldrige criteria.

The easiest solution is to create three new courses:

1. Tolerance design and measurements (A, B)

2. Advanced process control (C, D)

3. Quality standards (E, F).

Today, we are well on our way in addressing item A with the creation of a joint metrology lab shared by our industrial engineering and mechanical engineering departments, thanks to a Brown and Sharpe equipment grant; as for item B, we have identified an outstanding tolerance design handbook by Creveling[6]. Therefore, course number 1 will likely be the next addition to the curriculum. If it replaces anything in the current curriculum, it will probably be IE 554 Safety Engineering. QE students will probably then take safety as an elective.

CONCLUSIONS

We have traced the decade-long history of a successful masters-level curriculum in quality engineering. Although the national excitement over Total Quality Management (TQM) has waned[10], quality engineering masters graduates remain in high demand and quality engineering enrollments remain strong. The reason for this resilience is that this curriculum, and others similar to it around the U.S., is based on solid scientific and engineering principles. The philosophical underpinnings found in the writings of such engineering giants as Juran, Feigenbaum, and Ishikawa have stood decades of testings, and are proven. Even in the potential topics to be added to the existing curriculum, one finds primarily engineering terms: tolerances, controls, standards, and so on. Quality engineering has found its proper position in engineering education, that of preparing degreed engineers to become quality specialists and leaders in their organizations. There are active Ph.D.-level research programs in quality engineering at schools such as Arizona State, Pennsylvania State, Rutgers, Lehigh, Wisconsin, and others. But that's another story.

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BIOSKETCH OF AUTHOR

ROBERT G. BATSON is Professor and Head of the Department of Industrial Engineering at The University of Alabama, where he teaches and performs research in statistical quality control, risk analysis, and reliability. Since 1984, he has held research contracts and grants worth over $950,000 and has published over 100 articles, chapters in textbooks, and technical reports. He is also a consultant to the foundry and aerospace industries in the application of the Deming and Juran quality management principles, SPC, and Taguchi Methods. In particular, he served as Acting Quality Improvement Coordinator at American Cast Iron Pipe Company during his 1990-91 sabbatical. From 1979-84, he was a senior operations research analyst with Lockheed Corporation. He received a Ph.D. in Mathematics and an M.S.I.E. from Alabama in 1979, and an M.S. in Mathematics from Florida State in 1974. He is Past-Chairman of the Birmingham Section of the American Society for Quality, an ASQ Certified Quality Engineer, an ASQ Certified Reliability Engineer and a fellow of ASQ. Bob is a register P.E. in California. He is a senior member of the Institute of Industrial Engineers and is current President of the Birmingham Chapter. He received the IIE Aerospace Division Award in 1989. He is also active in the American Society for Engineering Education, and is past-President of the Southeastern Section.

Table 1: Original (1988) Quality Engineering Curriculum*

Major Course	Title and Timing	Subjects
IE 521	Design for Operational Feasibility (every summer)	Reliability, Maintainability, Systems Safety; and Life-Cycle Cost.
IE 522	Industrial Process Optimization (every fall)	Taguchi's Loss Function, Parameter Design, and Tolerance Design; Response Surface Methodology.
IE 525	Statistical Quality Control (every spring)	Quality Costs, Statistical Control Charts, Capability Analysis, Acceptance Sampling Plans.
IE 526	Design and Analysis of Experiments (every spring)	Factorial Designs, Special Designs, ANOVA, Multiple Regression, Analysis of Covariance.
IE 554	Safety Engineering (every spring)	Industrial and occupational safety engineering, including surveys, audits, hazard analysis.
IE 561	Systems Simulation	Discrete-event simulation using SIMAN; modeling of production and service processes with probabilistic elements.
IE 591	Quality Planning	Juran's quality planning roadmap; Quality function deployment; Seven visual management tools.

*Students who had simulation as an undergraduate have one additional elective. All students take elective courses so that total hours beyond the prerequisite courses are at least 30 (thesis option) or 33 (non-thesis option). Those choosing non-thesis options must still conduct non-thesis research for at least six hours and produce a final report of length and quality similar to a thesis, but typically more applied.

Table 2. Today's (1998) Quality Engineering Curriculum*

Major Courses	Title and Timing	Subjects
IE 521	Reliability, Maintainability, and TPM (every summer)	Reliability, FMEA, Maintainability, and Total Productive Maintenance (TPM)
IE 525	Statistical Quality Control (every fall)	Control Charts, Capability Analysis, Acceptance Sampling Plans, Measurement Systems, Tolerances, Deming, Juran, Ishikawa, ISO 9000, 7 Visual Tools
IE 526	Design and Analysis of Experiments (every spring)	Factorial Designs, Special Designs, ANOVA, Multiple Regression, Response Surface Methodology
IE 554	Safety Engineering (every spring and summer)	Systems Safety, Hazards Analysis, Fault Trees, Safety Management
IE 561	Systems Simulation (every spring)	Discrete-event simulation using ARENA; modeling of production and service processes with probabilistic elements.
IE 622	Quality Engineering (every fall)	Taguchi Loss Function Parameter Design, Tolerance Design, Quality Function Deployment (QFD), Relation between Parameter Design and QFD, 7 Management Tools

*Students who had simulation as an undergraduate have one additional elective. All students take elective courses so that total hours beyond the prerequisite courses are at least 30 (thesis option) or 33 (non-thesis option). Those choosing non-thesis options must still conduct non-thesis research for at least six hours and produce a final report of length and quality similar to a thesis, but typically more applied.

Table 3. Plan of Study Samples*

Semester	12-Month Program*		15-Month Program	
Fall	IE 502	Work Design and Human Performance	GES 500	Engineering Statistics
	IE 622	Quality Engineering	GES 501	Operations Research
		Minor Elective No. 1		
	IE 525	Statistical Quality Control	IE 502	Work Design and Human Performance
Spring	IE 561	Systems Simulation	IE 561	Systems Simulation
	IE 526	Design and Analysis of Experiments	IE 526	Design and Analysis of Experiments
	IE 554	Safety Engineering	IE 554	Safety Engineering
	IE 599	Thesis Research (3 hrs)		Minor Elective No. 1
Summer	IE 521	Reliability, Maintainability, & TPM	IE 521	Reliability, Maintainability, & TPM
		Minor Elective No. 2		Minor Elective No. 2
	IE 599	Thesis Research (3 hrs)	IE 599	Thesis Research (3 hrs)
Fall			IE 525	Statistical Quality Control
			IE 622	Quality Engineering
			IE 599	Thesis Research (3 hrs)

*The 12-month option assumes the student meets prerequisite requirements in statistics and operations research.