THE CONTRIBUTIONS OF SIX SIGMA TO THE DEVELOPMENT OF STATISTICAL THINKING IN THE WORKPLACE

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Arizona State University's Ira A. Fulton Schools of Engineering offers a Master Black Belt certification program that enables Six Sigma Black Belt managers, directors, engineers and others to achieve the highest level of technical and organizational Six Sigma proficiency. Black Belt and Green Belt certifications are also offered through a variety of educational platforms. These programs have been running for a number of years. This presentation will review the range of people that participate in these programs, the projects they have undertaken and the program's impact on the development of statistical thinking in the workplace.

INTRODUCTION

Statistical techniques along with other problem-solving tools are the technical basis for modern quality control and improvement. To be used most effectively, these techniques must be implemented within and be part of a management system that is focused on quality improvement. The management system of an organization must be organized to properly direct the overall quality improvement philosophy and ensure its deployment in all aspects of the business. Effective quality management involves successful execution of three activities: quality planning and design, quality assurance, and quality control and improvement. I think these are the essential components of any quality management system.

Quality planning and design is a strategic activity, and it is just as vital to an organization’s long-term business success as the product development plan, the financial plan, the marketing plan, and plans for the utilization of human resources. Without a strategic quality plan, many resources of time, money and effort will be wasted by the organization dealing with faulty designs, manufacturing defects, field failures, and customer complaints. Quality planning and design involves identifying customers, both external and those that operate internal to the business, and identifying their needs (this is sometimes called listening to the voice of the customer). Then products or services that meet or exceed customer expectations must be designed and developed. The organization must determine how these products and services will be realized. Planning for quality improvement on a specific, systematic basis and having a structured quality-oriented approach to design is an integral part of this process.

Quality assurance is the set of activities that ensures the quality levels of products and services are properly maintained and that supplier and customer quality issues are properly resolved. Documentation of the quality system is an important component. Quality system documentation involves four components: policy, procedures, work instructions and specifications, and records. Policy generally deals with what is to be done and why, while procedures focus on the methods and personnel that will implement policy. Work instructions and specifications are usually product-, department-, tool-, or machine-oriented. Records are a way of documenting the policies, procedures, and work instructions that have been followed. Records are also used to track specific units or batches of product, so that it can be determined exactly how they were produced. Records are often vital in providing data for dealing with customer complaints, corrective actions, and, if necessary, product recalls. Development, maintenance, and control of documentation are important quality assurance functions. One example of document control is ensuring that specifications and work instructions developed for operating personnel reflect the latest design and engineering changes. In short, a major component of quality assurance is to document what you say you are going to do and maintain records so that you can verify that you have done what you said you are going to do.

Quality control and improvement involve the set of activities used to ensure that the products and services meet requirements and are improved on a continuous basis. Since variability

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is often a major source of poor quality, statistical techniques, including SPC and designed experiments, are the major tools of quality control and improvement.

Quality improvement is often done on a project-by-project basis and involves teams led by personnel with specialized knowledge of statistical methods and experience in applying them. Projects should be selected so that they have significant business impact and are linked with the overall business goals for quality identified during the planning process. Montgomery (2013) and Snee and Rodebaugh (2002) discuss some important aspects of project selection.

Since the 1980s various management systems have emerged as frameworks in which to implement quality improvement. Key among them is total quality management (TQM), which flourished briefly in the mid to late 1980s, and Six Sigma, which began in the late 1980s. TQM has largely disappeared as a framework for quality improvement, while Six Sigma has flourished. This is largely due to the emphasis Six Sigma places on delivering bottom-line business results in addition to quality improvements. Motorola developed the Six Sigma program in the late 1980s as a response to the demand for their products, which contained many components, and achieving very low levels of defectivity is critical to product function. See Montgomery and Woodall (2008) for the evolution of Six Sigma.

The focus of Six Sigma is reducing variability in key product quality characteristics to the level at which failure or defects are extremely unlikely. The model of a Six Sigma process that is typically adopted assumes that if the process is centered at the target and the nearest specification limit is six standard deviations from the mean, the process will operate at the 3.4 million parts per million (ppm) defective level. Montgomery and Woodall (2008) point out that many advocates of the Deming philosophy reject Six Sigma because they feel that the 3.4 ppm metric is a "goal" or "target" and that this conflicts with one of Deming's 14 points. However, Montgomery and Woodall (2008) argue that the assumptions that lead to the 3.4 ppm metric are based on a process model that is probably wrong (as are all models) but one that is inherently useful because it focuses the organization on the critical concepts of continuous improvement and variability reduction.

Companies deploying Six Sigma employ specially trained individuals, called green belts (GBs), black belts (BBs), and master black belts (MBBs). A project-based team approach is used in Six Sigma deployment (this is directly adapted from Juran's philosophy). Teams used a structured problem solving approach with five steps: define, measure, analyze, improve and control (DMAIC). See Montgomery (2013) and Montgomery and Woodall (2008) for a discussion of the DMAIC problem-solving process. DMAIC is a direct outgrowth of the Shewhart cycle, advocated by Deming as an ideal framework for implementing continuous improvement.

Design for Six Sigma (DFSS) is an extension of operational Six Sigma that takes the variability reduction and process improvement philosophy upstream from manufacturing or production into the product design process. DFSS is a structured approach efficiently commercializing technology that results in new products, services, or processes. DFSS spans the entire development process from the identification of customer needs to the final launch of the new product or service. Customer input is obtained through a voice of the customer process designed to determine what the customer really wants, to set priorities based on actual customer wants, and to determine if the business can meet those needs at a competitive price that will enable it to make a profit. Voice of the customer data is obtained in various ways, such as through customer interviews, by a direct interaction with and observation of the customer, through focus groups, by surveys, analysis of customer satisfaction data and through discrete choice experiments. The purpose is to develop a set of critical to quality requirements for the product or service. Perry and Bacon (2007) is a good introduction to DFSS.

Lean systems are designed to eliminate waste. By waste, we mean unnecessarily long cycle times, or waiting times between value-added work activities. Waste can also include rework, scrap, and excess inventory. Rework and scrap are often the result of excess variability, so there is an obvious connection between Six Sigma and Lean. Important metrics in Lean are the process cycle efficiency, process cycle time, work-in-process, and throughput rate. Lean also makes use of many tools of industrial engineering and operations research. One of the most important of these is discrete-event simulation. Properly constructed and validated simulation models are often very good predictors of the performance of a new or redesigned system. Both manufacturing and service organizations can greatly benefit by using simulation models to study the performance of their processes. Lean improvement projects can be managed using DMAIC.

LEAN AND SIX SIGMA AT ASU

The Lean Six Sigma education programs at Arizona State University started about 10 years ago as a cooperative effort of the members of the interdisciplinary committee on statistics, which at the time administered the MS degree in statistics and a graduate certificate in statistics. Leadership of the program was in the Department of Industrial Engineering, which has become part of the School of Computing, Informatics and Decision Systems Engineering, one of the five schools of the Ira A. Fulton Schools of Engineering. The initial effort was to start a Black Belt certification program that could be delivered by faculty to currently enrolled graduate students as part of their degree program requirements. Any student may earn the certificate if they have graduate standing and have completed a previous calculus-based course in statistics.

Some universities that offer Six Sigma certifications have out-sourced the program to third parties. These third parties are often consulting organizations and in our view the programs they offer are often of very questionable quality The ASU certificate requires completion of four regular graduate courses plus an applied Black Belt project. The required courses along with a brief description follow.

- *IEE 570 Statistical Quality Control*. An overview of quality management principles including cost of quality and quality improvement strategies. Shewhart control charts, cumulative sum and EWMA control charts, multivariate control charts and monitoring methods. Specialized control chart topics such as group control charts, risk-adjusted control charts, and control charts for autocorrelated data. Overview of feedback control and process and measurement systems capability analysis. Acceptance sampling plans.
- *IEE 578 Regression Analysis*. Simple and multiple linear regression, including least squares model fitting and inference. Variable selection methods. Common problems in the application of regression, including use of transformations, multicollinearity, weighted least squares and regression model validation. Nonlinear regression, logistic and Poisson regression.
- *IEE 572 Design of Experiments*. Strategy of experimentation, analysis methods for experimental data, randomization, replication and blocking. Factorial and fractional factorial designs, response surface methods and designs, computer experiments, experiments with random factors, split-plot experiments, experiments with nested factors.
- *IEE 581 Six Sigma Methods*. The DMAIC problem-solving approach, how the six sigma tools are deployed in each step of DMAIC, tollgates, project selection, project management techniques, team leadership and facilitation, introduction to design for six sigma, applications of Lean and Six Sigma in various business and industry settings.
- *IEE 585 Six Sigma Capstone*. This is the project course. Students identify and complete a suitable Six Sigma Black Belt project. This project is almost always done in collaboration with local industry, although some students defer this until after graduation and complete the project with their permanent employer. Many projects are the traditional defect reduction, waste elimination projects associated with Lean and Six Sigma, but many projects have been performed with local nonprofits to help them improve their business systems, and with various health care providers.

A few remarks about IEE 581 are appropriate here. This course is intended to deal with a common shortcoming in statistical education; methods-oriented courses such as IEE 570, IEE 572, and IEE 578 do not often show how the specific course techniques are integrated into an overall problem-solving framework, or how one goes about selecting the best technique with which to approach problems. By using the DMAIC framework as a guide, this course provides in-depth guidance on how to do this. This course is administered by ASU faculty but it relies heavily on a highly-qualified guest lecturer core consisting of individuals with Master Black Belt credentials and extensive experience from local industry. Most of these individuals hold doctoral degrees from ASU. Their industrial experience spans the financial services, electronics/semiconductor, medical device, health care, and government/military systems industries, so they bring a wide range of experience to the students about how Lean and Six Sigma is deployed in their industries.

Students are able to link the Black Belt certificate to the Graduate Certificate in Statistics, so that both certifications can be acquired with one set of courses and one applied project. Student projects cover a wide range of application environments. Many are traditional campus students and others are distance students enrolled in the online Master of Engineering degree programs offered by ASU. We also offer this certificate program as a stand-alone program to non-matriculating students.

ASU has a partnership with the University de Los Andes in Columbia to offer a joint black belt certificate. The University de Los Andes students take two ASU courses (IEE 572 and IEE 581) through the Ira A. Fulton Schools of Engineering online distance education system, two courses at the University de Los Andes, and complete their Black Belt project working with University de Los Andes faculty. The students completing the program obtain a joint certification from both institutions.

THE GREEN BELT PROGRAM

In response to requests from several organizations, ASU launched a Green Belt Program several years ago. This program is entire online and is run through the Global Outreach and Extension Education (GOEE) organization that is part of the Ira A. Fulton Schools of Engineering. Several cohorts complete this program each year and a typical cohort size is 25 students. The online lecture material is adapted from the graduate courses that comprise the Black Belt program described above. Students complete online exams after each block of material. There is a course moderator that is available for questions and assistance. The moderator has typically been a PhD student from industrial engineering. This has worked very well. Recently we have been providing webinars for these cohorts, and one faculty member has mostly supported this effort. This faculty member has also led a number of online meetings with student groups as needed by the course participants. Student satisfaction with this program has been excellent.

For the last three years we have offered a Lean Six Sigma Green Belt certification to our undergraduate industrial engineering students. We developed an undergraduate version of IEE 581 (IEE 381) that is offered once each year. If students complete this course along with the undergraduate courses in engineering statistics and statistical quality control and complete their required senior design project using the DMAIC approach, they are awarded a Green Belt certificate. We also offer this course online to industrial engineering students at Tec de Monterrey in Monterrey, Mexico. It is taught live in one of our television studios and delivered simultaneously to the Tec de Monterrey students via the internet. They distribute the program to a large number of their 27 campuses. It is part of the Green Belt certification at Tec de Monterrey and students completing the program there obtain a joint certification from both institutions. During the spring of 2013 over 100 Tec de Monterey students and 40 ASU students participated in this program.

THE MASTER BLACK BELT PROGRAM

The success of our Black Belt and Green Belt programs led us to initiate a Master Black Belt (MBB) certification program four years ago. Our philosophy is that the MBB should be both a high-level technical resource within the organization and a resource for senior management that can provide guidance on issues such as strategic project selection, education and training, and overall business improvement methodology and its implementation. Our MBB program is designed with those objectives in mind.

The ASU MBB program is offered twice each year. The class size is held to under 20 so that the opportunity for personal interaction with the instructional staff can be maximized. There are two phases of the program. The first phase is an intensive on-campus one-week session that focuses on strategic planning and management issues and helps to develop the participants' understanding of the role of the MBB within their organization. Participants are also given an overview of the technical skills component that will follow the on-campus session. The instructional staff consists of both ASU faculty and MBBs from organizations that have experienced successful Lean Six Sigma deployments.

The second phase of the MBB program is aimed at further developing the participants' technical capabilities in both industrial statistics and Lean. They are asked to select three online courses and complete them over an approximately three-month period. The courses that they can currently select from include:

- IEE 572 Design of Experiments
- IEE 578 Regression Analysis
- IEE 531 Production Systems
- IEE 582 Response Surfaces and Process Optimization
- IEE 573 Reliability
- IEE 579 Forecasting and Time Series Analysis
- IEE 520 Data Mining and Knowledge Discovery

These are regular ASU graduate courses available in an online streaming video format. The variety of offerings enables participants to gain expertise in areas of immediate applicability to their organizations.

We do not require a project for MBB certification. The final deliverable is a White Paper describing how Lean Six Sigma has been implemented in their organization, and a critical analysis of the level of success that has been achieved. Gaps and opportunities are identified, and a strategy for building upon the current level of success should be presented. The role of the MBB in this process should be clearly developed.

CONCLUDING REMARKS

ASU offers a broad range of educational opportunities in Lean Six Sigma, with certifications available at the Green Belt, Black Belt, and Master Black Belt levels. The programs are tailored both for undergraduate and graduate students and professional practitioners. We strongly believe that organizational success in many dimensions depends on increasing the capability of the workforce in statistical thinking. Universities should play a leading role and Lean Six Sigma programs can be an effective way to do this.

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