
AC 2011-508: USING DESIGN FOR SIX SIGMA PRACTICES TO DEVELOP A "ROSE" BELT COURSE

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Using Design for Six Sigma Practices to Develop a “Rose” Belt Course

Abstract

Due to the well-documented benefits of Six Sigma methodologies in many successful and competitive organizations, the adoption of Six Sigma continues to expand within and outside of traditional manufacturing and service organizations. As such, the Engineering department of Rose-Hulman Institute of Technology set out to develop a 10-week Rose Belt course to provide students with fundamental knowledge, quality tools, and practical experience using the DMAIC (Define-Measure-Analyze-Improve-Control) process. The intent of the course is not to supplant other forms of certification (white, yellow, green, or black belt). Rather, the goal is to use a project-based approach so that students gain valuable insight into the organizational (operational) improvement process, as well as experience using Six Sigma tools (qualitative and quantitative). It is the author’s belief that these experiences will reduce the amount of time required by students/graduates to begin engaging in “live” Six Sigma projects upon completion of the course. In the absence of a universally accepted or practiced Six Sigma body of knowledge, the DMADV (Define-Measure-Analyze-Design-Verify) methodology was used to design the course. Previous uses of similar industry-focused quality management tools, such as Quality Function Deployment (QFD), have been used to redesign engineering education curriculum with notable success. The objective was to correctly identify and assess the technical concepts and non-technical skills industrial practitioners most frequently utilized when leading or participating in successful Six Sigma projects. This information will serve as the critical-to-quality (CTQ) components of the curricula.

Introduction

Six Sigma projects have made a profound contribution in helping successful leaders achieve great improvements in their operational activities and customer satisfaction. As such, the need for Six Sigma belt certification and training has increased significantly in recent decades. Gygi et al.¹ indicated, “In certain corporations, Six Sigma proficiency on your résumé is now a prerequisite to moving into a management position.” This movement has led many undergraduate and graduate engineering students with management aspirations to seek out Six Sigma training during their formal studies. Unfortunately, acquiring Six Sigma training through popular means (professional quality organizations or private consultants) is costly, geographically challenging, and oftentimes the timing is incongruent with academic schedules. Given these common constraints, students have begun to investigate alternative means of training and found high levels of variability in both in cost and quality of Six Sigma training opportunities. Combining the students’ struggles to acquire credible training and recalling the personal effort required for the author to acquire Six Sigma Black Belt certification, the idea of internalizing the training opportunity to Rose-Hulman began to materialize.

Attempting to balance the needs of students and their potential employers has been an ongoing concern in higher education. Many administrators and faculty say that maintaining high levels of customer satisfaction is both a priority and a challenge to institutions of higher education. Cloutier and Richards² communicated that measuring customer satisfaction at an educational establishment might be regarded as one of the greatest challenges. Therefore, it is vital to

maintain a curriculum that is both rigorous and relevant. In the field of Engineering Management, as well as many other STEM (Science, Technology, Engineering, and Mathematics) disciplines, discussions about the need for Six Sigma training, projects, and certification have reached a fevered pitch. While recognizing that educational institutions have an obligation to prepare our students for the workforce, we realize we cannot respond to every request presented by our students or the organizations that hire them. In the case of Six Sigma, a response was deemed warranted given the unrelenting number of requests from students, past and present, over the last couple of years as well as the number of employment opportunities preferring candidates with Six Sigma experience.

To begin addressing this need, informal discussions were undertaken with internal and external constituents to understand their needs prior to developing our Six Sigma course, which would take the form of a cross-listed undergraduate/graduate-level course. The overall consensus was to provide students with the fundamental knowledge of the DMAIC process and its relevant tools. Facilitating a specific credential or belt certification was not found to be critical, but the inclusion of mini-projects (those suitable to an academic environment) was determined to be rather vital to ensuring the credibility and authenticity of student proficiency. The balance of this article will outline how the author used DMADV methodology to shape the development of the Six Sigma course at Rose-Hulman Institute of Technology.

Literature Review

Continuous improvement is the life-blood of maintaining a competitive edge in most, if not all, successful organizations. As such, many forward-thinking academic institutions have begun to incorporate various quality assurance systems, methodologies, and tools to ensure they are providing a quality academic experience for their customers, the students. One of the more popular approaches used in engineering education has been Quality Function Deployment (QFD). In 1991, Donald Ermer used QFD to assess and respond to the needs of the Mechanical Engineering faculty of the University of Wisconsin – Madison³. More recently, in 2010 Wang Qiulian presented his work utilizing QFD theory to improve the responsiveness of undergraduate Industrial Engineering education at Nanchang University in China⁴. Faculty at Rose-Hulman Institute of Technology are continuing on the path of using proven quality assurance systems to improve programs and courses. This paper will discuss how the methodologies and tools of the Six Sigma DMADV approach were utilized to develop a graduate-level Lean Six Sigma course.

Developed at Motorola during the 1980s, Six Sigma is a process improvement methodology that focuses on the overall quality of an organization, to include product or service quality to external customers as well as operational quality of internal processes⁵. The DMAIC approach uses a five-step sequential structure to produce actions toward improving customer satisfaction or product/service quality. Defining the problem and outlining the scope, goals, and timeframe are typical activities achieved during the *Define* phase. One of the vital outcomes of the define stage is the establishment of project boundaries. Scope creep can undermine and dilute the effects of a concentrated effort by the involved parties. Once the deliverables are identified and agreed upon, the project will move into the *Measure* phase. During the second step team members using process and value stream mapping identify the parameters thought to be most influential and thus are considered to be critical-to-quality (CTQ). The *Analyze* phase is the third step of the methodology where the goal is to understand what improvements are necessary to achieve the desired level of performance or quality. During this phase, all attention is given to determining

the root causes of poor performance or system failures that lead to internal or external customer dissatisfaction. The use of both quantitative and qualitative tools is suggested during the analysis. Using one without the other can lead to an incomplete diagnosis or less than optimal project outcomes. With a thorough analysis completed, the *Improve* phase provides the forum where team members can identify and suggest solutions that directly address the shortcomings identified in the previous step. Care should be taken to ensure that solutions truly eradicate issues directly related to customer dissatisfaction or poor performance. Implementing “Band-Aid” solutions minimizes the profundity and credibility of the DMAIC process. The *Control* phase is the last of the five steps. The activities of this phase should lead to the development of new standard operating procedures and managerial systems to ensure compliance with the newly developed operations. In essence, the activities that result from this last step should prohibit digressions toward old and less effective means of “doing business.”

While Six Sigma is an excellent approach to fine tuning and improving existing products and processes, Design for Six Sigma (DFSS) provides a platform to proactively design systems to incorporate customer expectations and elements critical-to-quality. This forward-thinking approach allows practitioners to design quality into the products and processes before deploying them full-scale. When DFSS and traditional Six Sigma practices are used in datum, the results are outstanding. One way to visualize how DFSS and traditional Six Sigma approaches complement one another is to understand their application during a product’s lifecycle. Generally speaking, DFSS practices focus on the preproduction stages (Research, Design, and Development) while Six Sigma focuses on the production/execution stages (Manufacturing and Delivery). To achieve the goals of this project the DMADV methodology of DFSS was utilized. The details of each stage are presented in the ensuing paragraph.

Similar to the DMAIC process, the DMADV methodology is well suited to facilitate innovative solutions to meet the needs of systems or products not producing the desired results. While both DMAIC and DMADV techniques incorporate a structured five-step approach, the two methodologies diverge during the final two steps. Once the analysis of data has been conducted in the DMADV process, practitioners move to the *Design* stage in efforts to develop a new product or process that meets customer requirements. For many, the activities are focused on developing redesigns based upon their current engineering change processes. However, some organizations take the opportunity to develop new products and processes that ensure increased customer satisfaction. The last stage of the DMADV approach is *Verification/Validation*. Depending on the source of information to which you subscribe, the term verify or validate will be utilized. Nevertheless, for all practical purposes, the goal of the final stage is to ensure that the design output meets or exceeds the design requirements and specifications set forth in the Define stage⁶.

In academic settings, we parallel this approach with our evaluation of academic course offerings and the delivery methods of such courses. In addition to implementing robust systemic changes that improve productivity, it is the author’s belief that we must also employ Lean thinking to remove wasteful elements and improve efficiency. Although both methodologies, Six Sigma and Lean, originated in manufacturing environments, they have gained great purchase and success in non-manufacturing arenas. Today quality practitioners have begun to synergistically use both methodologies under the moniker of Lean Six Sigma (LSS). Integrating Lean concepts into the traditional Six Sigma DMAIC process expands the power of each phase. Moreover, LSS is

viewed as a fact-based, data-driven philosophy of improvement that drives customer satisfaction and bottom-line results by systematically removing non-value added waste, promoting strategic changes, and thereby creating competitive advantage for organizations⁷.

Advocates see great value in the integrated and balanced combination of the speed and variation reduction power of both Six Sigma and Lean to achieve productivity never previously accomplished. Although these methodologies and practices are used primarily in manufacturing industries, the author has chosen to use them in the design of a graduate level Six Sigma course. The principle interest is to show the power and the versatility of using the DMADV principles and methodologies to create the most effective course delivered in the most efficient manner. As Kukreja et al.⁸ stated “the application of Six Sigma methodologies in higher education has been limited...[and they had] not found any articles in the literature that employ Six Sigma practice to address curriculum development or improvement.” However, this article will attempt to contribute to the Six Sigma body of knowledge relating to the field of engineering education and curriculum development.

Methodology

To understand the elements, concepts, and tools of Six Sigma most relevant to today’s successful organizations, a mixed-methodology research approach was utilized. Integrating qualitative and quantitative research approaches to acquire data to study a single phenomenon provides a more complete understanding and leverages both approaches to develop new constructs and demonstrates plausibility of new relationships^{9,10}.

In the first phase of data collection, the author set out to understand how Six Sigma practices are used in the organizations being examined through a series of face-to-face interviews. The interviews were conducted with seven senior officials representing organizations that have successful Six Sigma programs and hire a significant number of Rose-Hulman graduates. Additionally, discussions focused on specific skill sets interviewees felt were critical for successful project implementation. To complement the qualitative data obtained from the interviews, the second phase of data collection surveyed Six Sigma practitioners to capture their experiences using the various tools associated with Six Sigma. A total of 400 potential participants were identified for the study.

The survey was developed based on a review of literature, full-scale Six Sigma project reports, potential textbooks, and information obtained during face-to-face interviews. The final instrument contained seven items. Item One asked participants to select the five most important Quantitative Tools they felt would be essential to students taking a Six Sigma course. Similarly, in Item Two respondents were asked to identify the top five Qualitative Tools. In addition to identifying the five most important quantitative and qualitative tools, respondents were asked to indicate the frequency of usage for each of the tools presented. There were 19 quantitative and 20 qualitative tools presented. Item Three sought to determine which software applications would be most valuable for students’ use while taking a Six Sigma course. Four popular titles were suggested along with an option to indicate others. Item Four inquired whether curriculum from a traditional Quality Control course should be a prerequisite, co-requisite, or integrated into the Six Sigma course. The final three items collected demographic information. Items Five and Six asked respondents to indicate their highest level of certification (belt) and the percentage of

their overall workload dedicated to participating in or leading Six Sigma projects. Finally, Item Seven ascertained the means by which they acquired their certification.

Prior to deploying the instrument to the target population, it was pilot tested with academics, practitioners, industrial trainers, and consultants. Pilot testing is one of the most important stages in the development of a new survey instrument to ensure the usefulness, reliability and validity of data collected¹¹. Their feedback focused on four primary areas: format, presentation, item clarity, and ease of use. Based on their recommendations, appropriate revisions were made to the instrument. The most significant change recommended was the addition of operational definitions for each tool to ensure a common understanding. With the survey finalized, the author moved on to address the deployment activities.

Qualifications to participate in the study required any level of Six Sigma certifications (belt) as well as active engagement in projects. Individuals were identified for the survey by working with Career Services and the Alumni Offices' databases. Additionally, Six Sigma agents who were not captured using the Institutional databases received a personal communication from the author.

With the target population identified, each potential participant received an email invitation requesting their participation in the study. If the email recipient was not an active Six Sigma practitioner, they were asked to forward the email to the appropriate person(s) within their organization. It was the author's hope that this request would yield a higher return rate of valid responses. Participants were given approximately three weeks to respond to the electronic survey. The results of both the qualitative and quantitative data collection are discussed in the next section.

Results

Qualitative Findings

The seven participants in the first stage of data collection represented the automotive, pharmaceutical, medical device, aerospace, healthcare, and logistics industries. In this forum, the interviewees served as an informal industrial advisory board. Each offered insight on business trends, provided suggestions on the Six Sigma curriculum, and indicated ways in which Performance University could fulfill current business needs. They provided high-level insight on how Six Sigma is used in their industries and organizations. Early on in the conversations, a general theme emerged that focused on the best practices of Six Sigma. All participants indicated that Six Sigma activities were integral to their success and that they will continue to use DMAIC practices for process improvement in the near future. When the conversations moved toward the discussion of human capital needs, all but one of the participants indicated they would be hiring a significant number of engineers over the next few years, both experienced and entry-level. As such, they were then asked what level of Six Sigma certification would be ideal for entry-level new hires recruited directly from an academic institution. Interviewee responses to this item helped to shape the Define stage of the DMADV process.

Overall, the participants indicated that entry-level hires from post-secondary institutions did not need to possess a specific level of certification. Instead, they preferred that graduates have a fundamental understanding of the DMAIC process and, whenever possible, practical experience

using the appropriate quality tools. Furthermore, they stated that most new hires would be required to undergo company-sponsored Six Sigma training to introduce them to their internal quality processes and techniques specific to each organization. This information was encouraging as it highlighted an opportunity for Rose-Hulman to provide its students with not only a highly marketable engineering degree, but also additional academic training that directly responds to the Six Sigma needs of potential employers.

Quantitative Findings

The survey instrument was administered electronically by Performance University's Office of Institutional Research, Planning, and Assessment (IRPA). Email invitations were sent to approximately 350 alumni and associates of the Institution. A total of 38 valid responses were received resulting in an overall response rate of 10.9%. When investigating the low response rate, the author uncovered several reasons that ran parallel to related literature regarding response rates for electronic surveys. The three most prominent reasons were invalid or inactive email addresses, increased spam filtration, and issue salience. Although the response rate of this study is somewhat disheartening, the data it produced was impactful.

The sample of respondents represented all levels of certification (belt): Master Black Belt (8), Black Belt (15), Green Belt (14), and White/Yellow Belt (1). The majority of the respondents (24) identified company-sponsored training as the means by which they acquired their certification. The balance of respondents indicated professional organizations (7), consulting firms (4), academic institutions (2), and a supplier (1) as the avenues taken to obtain certification. Furthermore, respondents indicated their percentage of workload dedicated to participating in or leading Six Sigma projects ran the full spectrum. The minimum percentage was 1% and the maximum was 100%. The median percentage of time dedicated to Six Sigma activities was 30% while the mean was 45%. The responses of this cross-sectional group served to fulfill the Measure stage of the DMADV framework. Participants' responses to survey Items One, Two, and Three were critical in determining what topics, concepts, and tools will be integrated into the pilot Six Sigma course.

Survey Items One and Two asked respondents to perform two tasks. The first task was to select the top five important tools in each category they felt were essential to students taking a Six Sigma course. Additionally, they were asked to indicate the frequency of usage for all of the tools presented in the quantitative and qualitative sections. A five-point Likert scale with endpoints of "Never" and "Always" was utilized to capture how frequently they used the tools while working on or leading Six Sigma projects. To ensure a common understanding of each tool, a brief description and context was provided using a "hover over" function.

The results from the quantitative category identified the most important tool as the Failure Modes & Effects Analysis (FMEA). Cost/Benefit and Process Capability Analysis were selected as second most important. Analysis of Variance (ANOVA) ranked as the fourth most important, while Design of Experiments (DOE) and Measurement System Analysis (MSA) tied for fifth most important. Topics not selected as one of the top five most important were analyzed based upon their frequency of use ratings. The results showed Hypothesis Testing, Regression Analysis, and Critical Path Methods (CPM) as other tools that should be considered in the design of the course. The top five qualitative tools were: 1) Value Stream Analysis, 2) Brainstorming and Voice of Customer Gathering Techniques, 4) Cause-and-Effect Prioritization, and 5) SIPOC

Diagramming and 5S. Again, analyzing the frequency of use showed Stakeholder Analysis, Benchmarking, and Risk Mitigation Planning as other valuable topics for inclusion.

When asked which software applications would be most valuable for students to utilize while taking a Six Sigma course, Microsoft Excel was noted most often (36%). Respondents suggested both Minitab and JMP 22% of the time and Microsoft Visio 20%. Additionally, Microsoft Project and PowerPoint were noted several times as additional valuable software titles.

The last item related to building the content of the Six Sigma course focused on the topic of Quality Control (QC). Typically, Quality Control is taught as a standalone course. However, the theory and practices of Quality Control are interlaced throughout most, if not all, Six Sigma projects. As such, respondents were asked if they felt the learning outcomes of a traditional Quality Control course should be a prerequisite, co-requisite, or directly integrated into the Six Sigma course. The largest number of respondents (18) suggested Quality Control practices be integrated into the course. The next largest contingency of respondents felt it should be a prerequisite (14) and the smallest number of respondents (6) suggested it be a co-requisite.

Given the findings presented here, the author felt comfortable that a solid starting point had been established to develop a Six Sigma pilot course. The findings highlighted the topics, concepts, tools, and software necessary to provide students a solid foundation to begin mastering the process improvement power of Six Sigma.

Discussion

The aim of this research project is to identify the tools, concepts, topics and software titles necessary to design a value-added Lean Six Sigma course at Rose-Hulman Institute of Technology. Using the information gathered from interviews and data collected from the electronic survey instrument the author made significant progress toward the creation of the course. Once these findings were placed in the framework of the DMADV process, the author was able to complete the Define and Measure phases.

Define

The Define phase of Six Sigma projects is paramount to obtaining a positive outcome, provided sound execution of the subsequent steps. Using the remarks and information gleaned from interviewees, the author began to construct the project scope. Once the initial scope was established, the researcher began to investigate the feasibility of designing a 10-week course that addressed all the concerns communicated by the interviewees. After having discussions with campus stakeholders and other interested faculty members, a new scope was established to optimize the course design while operating within the current resource constraints. Additionally, two major concerns were explicitly expressed: 1) Create a course that maintains the academic excellence and rigor reflected in other Rose-Hulman STEM (Science, Technology, Engineering, and Mathematics) courses and 2) Integrate experiences to help students build the leadership skills required of successful project leaders. Given these criteria and the original interview findings, the final scope read as follows:

Design a 10-week, project-based Lean Six Sigma course that provides students a fundamental understanding of the DMAIC process using both quantitative and qualitative

tools. Additionally, provide students the opportunity to learn appropriate facilitation (soft) skills necessary to lead productive Six Sigma projects.

With the project scope in place, the researcher moved to the second phase of the DMADV process, the Measure phase.

Measure

During this phase, the goal is to measure and quantify the customers’ needs and expectations. More specifically, in this study, the author set out to identify the tools, both quantitative and qualitative, as well as software applications deemed critical-to-quality of a Six Sigma course. This task was accomplished using an electronic survey instrument. The following table shows the top five most important quantitative and qualitative tools identified by survey respondents. The percentages presented in Table 1. indicate how often the tool was selected as being a member of the top five important quantitative or qualitative tools practitioners felt were essential for students taking a Six Sigma course. However, six are presented due to an equal number of responses for some of the tools.

Table 1. Most Important Quantitative and Qualitative Tools

Quantitative Tools	Qualitative Tools
Failure Modes & Effects Analysis (FMEA) – 74%	Value Stream Analysis – 58%
Cost/Benefit Analysis – 53%	Brainstorming Techniques – 53%
Process Capability Analysis – 53%	Voice of Customer Gathering Techniques – 53%
Analysis of Variance (ANOVA) – 40%	Cause-and-Effect Prioritization – 40%
Design of Experiments (DOE) – 37%	SIPOC Diagramming – 34%
Measurement System Analysis (MSA) – 37%	5S Concepts – 34%

Upon review of the tabularized data, it is interesting to note that there seems to be a casual trend showing quantitative tools are mostly associated with traditional Six Sigma activities while the qualitative tools are more aligned with Lean Six Sigma activities. This information will also be useful when allocating time to each of the items throughout the 10-week course.

Microsoft Excel was selected most often as the software application of choice for the Six Sigma course. Furthermore, several of the comments indicated that the use of predesigned templates to perform common statistical calculations and non-statistical analysis would be beneficial. These templates would be most useful if students are provided the opportunity to customize them to suit the needs of a specific project.

Having defined the scope of the project and gathered data to measure the needs of our industrial clients (potential employers and Six Sigma practitioners) the next natural step would be to start the Analyze Phase. However, since this article is documenting a work-in-progress the next three sections (Analyze, Design, and Verify) will provide the theoretical basis for the activities the author plans to complete over the next 12 months.

Analyze

In the analysis phase, the author will determine the best approach for integrating the maximum number of suggested topics into the 10-week course. Given the amount of material required, it

will be vital to choose resources capable of augmenting in-class discussions and activities. Chief to this point, will be the selection of a textbook. Preliminary discussions have been held with textbook representatives to determine which publisher has the flexibility to customize a textbook to provide maximum alignment with the course objectives. Presently, Prentice Hall is the provider whose electronic examples show the greatest promise. However, the initial textbook criteria may need to be re-evaluated due to the results of the analysis activities. Another large component of this phase will be investigating the use of other subject matter experts in the course. Given the amount of on-campus expertise, the author will investigate avenues to incorporate the experience and talent of faculty from the Mathematics and Mechanical Engineering Departments. In general, the goal will be to select the most salient concepts/topics that best meet the charge outlined in the Define phase while operating within the budget and resources of the campus. To this end, the author will attempt to develop the most instructional effective combination of elements to provide a valuable Lean Six Sigma course to the students and all other stakeholders.

Design

Using the findings from the Analyze Phase the author will begin to develop both a strategic as well as a tactical-level design of the course. The strategic-level design will be satisfied with a syllabus that provides a course overview, description, objectives, and required resources. Conversely, the tactical-level design will highlight the 10-week structure of the course complete with an outline of lectures, in-class activities, specific homework assignments, exams, digital media, and potential case studies to be used. Once the course components are finalized and the structure is set, the author will move to the Verification stage in the fall quarter of 2011.

Verify

The verification phase will be bifurcated. After running the pilot course, student evaluations will serve as the first component of verification. The goal will be to assess whether or not students were provided the required academic experience to build a solid understanding of Six Sigma's DMAIC process. Furthermore, they will be asked to rate their ability to apply the technical and non-technical skills presented during the course to solve business concerns. The second component of verification will be obtained from active Six Sigma practitioners, both industrial and academic. They will be asked to review student projects and provide their opinions on the thoroughness and feasibility of the solutions presented. Using the feedback from these two populations the course will be revised to incorporate lessons learned and all other relevant improvements. At this point, the revised course will be presented to the Curriculum Committee for adoption and inclusion in the Institution's Academic Bulletin as a permanent course.

Conclusion

As the author continues to plan and design this Lean Six Sigma pilot course it will be critical to ensure the course provides an academic experience that truly reflects the structure, flow, and lifecycle of actual Six Sigma activities. Given the opportunity of providing students with a fundamental understanding of the DMAIC process and its tools, the course will not focus solely on Six Sigma tools and spreadsheets. The course will offer students a unique balance of technical and managerial concepts that help them develop leadership skills essential to deploying Six Sigma initiatives. A measure of success will be achieved when students are able to identify

the right problem, analyze the data using the right tool, provide the right communication (content and delivery), at the right time, to the right people to eradicate problems and drive measurable results.

The activities associated with the Analyze, Design, and Verify phases will be vital to the overall success of the Lean Six Sigma course. Working with the Mathematics and Mechanical Engineering Departments will help to ensure the course minimizes unnecessary redundancy while maximizing the educational experience. Additionally, the author will continue to involve our industrial partners to shape the curricular activities. Given that it is impossible to design a course that satisfies every permutation of business needs, this course will focus on building a solid foundation of Six Sigma problem-solving skills applicable to any organization. The DMAIC process is a roadmap; this “Rose” Belt course will produce skilled drivers capable of using Six Sigma concepts and tools to successfully navigate the landscape of today’s complex and competitive business environments.

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