Integrating Design for Six-Sigma into Project-Based Learning

Abstract

Design for Six-Sigma (DFSS) has been a Best Practice staple for many years in industry and has proven valuable in providing quality products. Companies such as Johnson & Johnson and Xerox have teams that are specifically tasked with training, certifying, and implementing DFSS into their work force. It has been estimated that it costs between $5,000 to $8,000 in industry to train and certify an employee for a Green Belt in Six-Sigma. The companies that have adopted DFSS have stated that there is an advantage of new hires having experience in Six-Sigma. This tends to give an edge during an interview process to the student with this knowledge.

In Academics, traditional training of Six-Sigma techniques have been from specifically designed courses that describe the hierarchy of the process and work down into the tools used in each phase of the process. This certainly is an effective technique to introduce the concepts of DFSS but suffers from a disconnect between academic and direct applications.

The Mechanical Engineering Technology program has implemented a Design for Six-Sigma approach directly into two core courses of the MET program. The focus is upon the course content and solution of the problem while implementing the set of DFSS tools and its process to aid in the solution of the problem. Both of these courses are heavy project-based with the team project counting to upwards of 25% of the final course grade. Both courses have been identified as providing an integrating experience for ABET evaluations.

This report discusses the implementation process, along with its concerns and benefits, of integrating the DMAIC (Define, Measure, Analyze, Improve, and Control) and the DMADV2 into the MET Failure Mechanics and Machine Design courses. This report presents some initial results experienced by the students and industry as it relates to Co-op and new hires. It will also discuss the impact experienced on the course projects and the faculty overseeing them.

Introduction

The Mechanical Engineering Technology (MET) program has many project-based courses that span the entire quarter and is heavy with team based activity. Some of these projects are intense enough that they parallel specific testing procedures and small projects as seen in industry. The MET program has strived to implement best practices into their course work in order to better prepare the student to meet industrial needs. As the projects grew larger, there was a need for improved management. In discussing this with our Industrial Advisory Board (IAB) it was suggested that we use the DMAIC process to better organize the projects. This turned into an idea where the project actually was controlled by the DMAIC process and used as milestones in the Stepped-gates & Phases process which requires a Gantt style project planner. This method quickly morphed into the idea of providing a Green Belt certificate that is commensurate with ANSI accreditation under ASTM E2569-09. This is now being offered in the Failure Mechanics course and the MET Machine Design course. Several undergraduate courses are now using the Define phase in their lab reports and mini-projects. This provides an excellent pre-exposure to the start of this process.

Perceptions

Design for Six-Sigma (DFSS) seems to have a perception by many to have an exclusive connection to the manufacturing community. However, this is far from the case. Certainly, Six-Sigma has a solid foundation in manufacturing but it has evolved into a platform for several different methodologies spanning many disciplines such as health care and business management. Two methodologies of particular interest in the Mechanical Engineering Technology field are:

- Define, Measure, Analyze, Improve, Control – DMAIC
- Define, Measure, Analyze, Design, Verify and Validate – DMADV2

The DMAIC process, which strives to improve and control a defined problem is well suited for the MET Failure Mechanics course where a project investigates the fatigue properties of a specific material and compares that actual value to published. The DMADV2 process is one that focuses on a design of a product (or even a process but the concentration here is design) and the validation of that design which favors the MET Machine Design course.

Connection to Industry.

Industries such as Johnson & Johnson Ortho-Clinical Diagnostics use DMAIC and $DMADV^2$ in their engineering departments that is responsible for the design of new products, testing problem products, and improving existing products. They have a well-established training program in these areas with management holding them responsible for not only the successful implementation but also for showing value from those methodologies to the company bottom line. J&J is a major contributor to the MET Industrial Advisory Board.

Quality of Process

Of greatest concern is how to maintain the quality level of the Six-Sigma methodologies within the program. This has been resolved by setting up a specific industrial advisory council within the current Industrial Advisory Board specifically chartered to develop and maintain the quality level to industrial standards. This was accomplished by selecting master black belts of DFSS to chair the council. The council has required at least two specific tools for each phase of the DMAIC process. For example, the student must show competency in the Define phase by demonstrating proficiency in developing a project charter and a project plan using a Gantt chart. For the improve phase the team must demonstrate the use of statistics to defend the quality of their data results from their testing of the material in the fatigue project. They must show a ninety five percent confidence interval of their results along with standard deviation. Another tool that must be used is a two-sample t test to validate improvement during the anneal process while an ANOVA is used to compare data between teams (usually there are about 8 to 12 teams per quarter). Typically three or more tools are used for each phase.

Once the course has been completed and the project finished the students then have an option to defend their knowledge in front of a panel of master black and black belts. If they can successfully defend their knowledge of the material and their application of tools to the completion of the project, then they are awarded an MET Green Belt in the DMAIC process.

Course project

The Failure Mechanics course requires a group project to investigate the fatigue characteristics of AISI 1018 CRS samples given and to compare them to published values. This requires the team to first run a fatigue test on the material given and if the values are different than the published values then they are to explain the cause of the difference and what is required to bring that material to within acceptable published values.

This is a live experiment in that the outcome is not known and the results of the tests drive decisions and actions on the part of the team. Hypotheses are developed and experiments are selected to validate their suspicions. A test is not allowed to be run unless it can be shown to add value to the decision-making process and must be cost defined prior to running. The tools primarily used are statistical graphics such as box plots along with analytical statistics such as two-sample t tests and ANOVA evaluations. Process flowcharts are used to define experimental steps along with fishbone diagrams identifying possible causes of error.

The students are responsible for defending all of their actions via engineering principles and statistical data. Once an unacceptable variance has been identified, the students must devise a plan for improvement and effectively execute that plan showing results. They also need to show that their process is in control and is repeatable.

The report is a sizeable percentage of their grade and is presented to faculty in the form of a poster session along with other courses, such as machine design, at the end of the quarter.

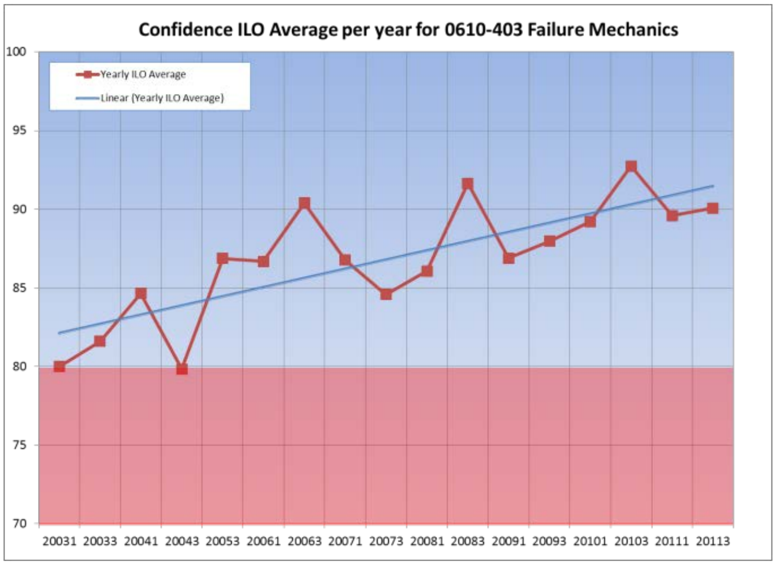
Implementation issues

It is imperative that the curriculum content not be compromised while incorporating the DMAIC industrial process. Introducing additional lectures to cover the DMAIC was a concern but actually was found to enforce the content by demonstrating the application of the material into the process.

This does require an open mind to a different methodology to teaching the course with much less lecture and greater amounts of activities and team meetings. This can be uncomfortable to faculty that is lecture-based. It is observed that faculty with a great deal of industrial experience favors experiential project-based learning. It is those faculty that seem to have little problem implementing the DFSS processes in their courses.

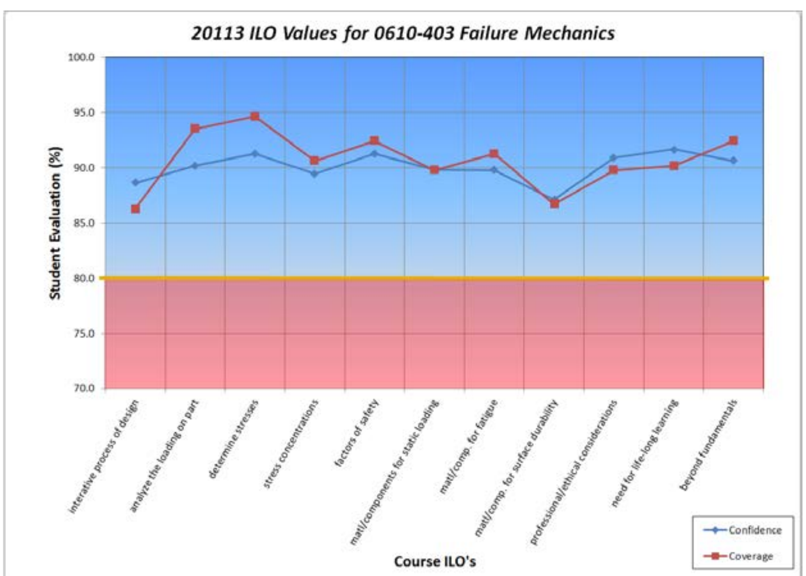
Results

Each course in the program is evaluated every time it is run by subjective student input for the coverage that the instructor has provided and their confidence level of the subject material. The MET Curriculum Committee has set a standard of 80% for both categories. The DMAIC process was introduced two years ago in the failure mechanics class and it can be seen from the graph below that



including the DMAIC process into the course has either contributed to the class improvement or at least has not affected the course outcome to any appreciable amount.

It can also be seen from the next graph below that the specific intended learning objectives (ILO's) required from the course has been met by the student evaluations. This was of greatest worry because of the perception by the faculty that the addition of the DMAIC teaching moments would diminish the quality level of the course along with pushing out some specific content deemed necessary for generating student success.



It is to be noted that the course intended learning objectives, text book used, or the faculty teaching the course has not changed during that time. An interesting observation can be made that there is a spike of improvement usually during the spring (20033, 20063, 20083, and 20103) quarter. It is hypothesized that most of the enrollment of those classes are seniors. This is the only difference noted between the courses at this time.

Another result observed is the improved organization and time management of the project. The inclusion of the industry best practice of stepped-gates-and-phases allows a personalized touch through team design reviews focused on completing the tools used DMAIC process. Each team is periodically scrutinized for their progress and activities during the design review resulting in a better time managed project. The DMAIC process itself easily breaks into five logical phases and identifies specific task completion before moving onto the next phase.

Enough testimonials from graduated students and seniors on Co-op have shown the impact and value of this process. (RIT requires students to complete five 10 week industrial employment segments in order to graduate.) Many students have stated that they have observed a distinct advantage during the interview process while others have stated that they have actually used the DMAIC process while on Co-op.

Here is a portion of one such testimonial:

> ***"… This year I had the failure report as well as other reports I completed and documents such as the Six Sigma Green Belt certification with me to show the recruiters, which I didn't have the previous year. The failure report turned out to be extremely helpful when talking to a major company I was interested in. During my time talking with the recruiter I was asked all the routine questions that every recruiter asks when they briefly scan over resumes until he seen that I took a class in failure mechanics which intrigued him. He asked me what the class was about in which I briefly explained to him what was covered and that we had a large project associated with it. I then showed him the failure mechanics report and he was very impressed when flipping through it. He was shocked at the quality of the report and the subject matter covered. Next, the recruiter seen that I had my Six Sigma Green Belt and began to ask question about it, in which I handed him the certificate and discussed briefly some information about it. The recruiter asked what I did for a project for the green belt and I told him that it was incorporated into the failure mechanics report. When he heard that he just could not believe it. He then scanned through my resume again and seen my graduation date and asked me if there was any way I could graduate early because I have all the skills they are looking for in an employee for some of their positions. It was after this discussion with the recruiter that I realized that the failure project was more than worth the effort. …" (Unsolicited testimonial from an MET student.)***

This has interested other faculty in how to incorporate at least portions of the DMAIC process and an effort is being made to incorporate a similar process in the Packaging Science Program at RIT.

Case Example

An additional measure of the success of the Green Belt program can be seen in the work of the matriculated students. While not a quantitative aspect of the implementation of the Green Belt program; specific cases do demonstrate a positive response from the students. One such case is that of a student who completed the Green belt training introduced through the failure mechanics program, and continued to a graduate degree. While in a robust design course the student was presented with a project that required the selection of a process for which an L16 design of experiments would be ran. The student approached the project with the intent of applying their knowledge of Green Belt practices in an attempt to generate a process improvement project.

The student elected to examine the variation in the annealing process used in the failure mechanics program. The design of experiments project would integrate a Taguchi method in the DMAIC process in order to both reduce variation and bring the results of the annealing process on to target. The student began by defining the problem and generating a project charter to determine the scope of the project and the stakeholders involved. The annealing process was known to produce high variation in the ultimate tensile strength(UTS) of the samples. In addition the historical data indicated an average UTS higher than the desired target value. A team of three students was then formed, and a champion from the parent department was then selected to be a resource for the project.

Having obtained the background on the project, and determined the project charter, the student team set out to use the the available Green Belt tools to define the possible areas for the variation in the process. After completing a process flowchart, and fishbone diagram, it was determine that the four possible sources of variability were; entrance temperature, exit temperature, gas flow rate, and position in the oven. At this time the student group moved to the measure phase where a series of four anneals were performed with the settings dictated by the orthogonal array. From theses samples a series of ultimate tensile strengths were developed and the team elected to moved to the analyze phase of the project.

The analyze phase toolset was expanded to include the use of the Taguchi methodology. In place of an anova or two sample t test that is typically found in the analyze phase an investigation of the signal to noise ratio of the samples was performed. The resultant analysis indicated the best possible combination of factors to produce the desired output. In keeping with the DMAIC philosophy an improvement over the current system was purposed and executed by the student team. The final result of the improvement yielded a product that had reduced variation, and average values that were on target as specified by their project charter. As part of the control phase a continuos record of the parts produced by the improved process are being kept to determine the longterm effects of the improvements on the process.

This project demonstrates that the student(s) were able not only to implement the knowledge gained in the Green Belt program, but adapt that knowledge to include an outside toolset not typically associated with the DMAIC process.

This case helps to confirm the hypothesis that the students are indeed able to be practitioners of the Green Belt tools put forward in the DMAIC process. Furthermore this case demonstrates that the initial knowledge, and tool set, presented to the students was done so in manner that assisted in additional learning and adoption of previously unknown tools. This learning skill is critical in that the students will be exposed to additional and expanded DMAIC tools while in industry.

In addition to the evidence of student success, this project also illustrates the flexibility of the DMAIC process. In the case the students were able to move, add, and drop tools as needed to complete the project. The ability of the DMAIC process to loosely couple these tools to a fairly rigid steped-gates & phases approach generates a unique method of problem solving. This highlights the ability of the DMAIC process to be flexible enough to be adapted to a multitude of different projects and environments. The students understanding of this flexibility coupled with the ability to properly implement the approach of the DMAIC process provides the students a unique skill set when entering into industry.

Benefits

As can be seen by the above results, there have been benefits not only within the courses but also increases the resume value a job-interview process of graduating students. Even companies that do not incorporate DFSS seem to be impressed with the project report's logic and organizational structure.

It seemed that, in the past, the course project always was pressed for time at the end of the quarter. It now is observed that most of the projects are completed on time. This can be contributed to better management, consistent methodology, and improved project planning through the use of the DMAIC.

Previously, the students were focused on testing the samples and running experiments. Now, that effort has been converted to focus on the customer requirements resulting on more effective testing selections. If the test cannot be proven to support the decisions leading to customer satisfaction, then it is not done.

The project emphasis is on direct and real applications from information generated by tools used such as statistics, controlled experiments, and cost analysis. Again, the tools applied must support the customer requirements. Each experiment is driven by an hypothesis from a previous experiment. Critical thinking is encouraged at each step of the DMAIC process.

Concerns

Of greatest concern is the sustainability of these methodologies in the courses and the program in general. Many academic professors have not been exposed to these methodologies enough to champion them into their programs. There must be a defined set of activities and evaluation rubrics to support a new instructor. Specific activities need to be documented along with lectures specific with the tools used in each phase of the process.

In order to maintain industrial credibility an industrial advisory board must be held responsible for the oversight of the tools used and the methodology used. It is necessary to form a council of local/regional industrial representatives to not only give greater credibility to the process via oversight but also to balance the workload of the defense process.

Specific documentation of all of the students who successfully defended needs to be securely kept as a registry of completion. This requires a record keeping procedure along with a backup process to assure the credibility of the student documentation.

Future

At this time, the DMAIC is in its second year in Failure Mechanics and is well established in the course project. Further work needs to be done to develop an Instructor's manual with activities and grading rubrics. This is part of the sustainability effort so that all instructors familiar with the course content can feel comfortable using this process.

The Machine Design course is now out of the prototype phase of the $DMADV^2$ process and has run its first course with this methodology. It is early to declare any success but the instructors teaching the course seem to sense the same benefits occurring as in the Failure Mechanics course. Again, further work and documentation needs to be completed for future instructors to assure sustainability.

As the testimonials increase and word is spread about the benefits of DFSS it is optimistic to think that this effort of course integration rather than separate course offering of DFSS will spread.