Partnering With Students to Continuously Improve the Systems Engineering & Engineering Management Program

Dr. Jonathan Philip Mayhorn, Univerisity of North Carolina, Charlotte

Dr. Jonathan Mayhorn currently works for AT&T as a Lean Six Sigma Master Black Belt where he coaches those who lead projects to improve processes in the Construction and Engineering Department. He recently became a certified Project Management Professional. Jonathan also serves as an Adjunct where he teaches four classes in the Systems Engineering & Engineering Management Department at the University of North Carolina at Charlotte (UNCC) that focus on process improvement, project management, and leadership. His educational background includes a Bachelors in Mechanical Engineering and a Masters in Engineering Management both from UNCC. He also holds a Doctor of Strategic Leadership degree from Regent University and is currently working on a revised edition of a manuscript called ”Life Leaders” which teaches how everyone can be a successful leader.

Dr. Ertunga C Ozelkan, University of North Carolina, Charlotte

Dr. Ertunga C. Ozelkan, Ph.D., is director and associate professor of Systems Engineering & Engineering Management, and the associate director of the Center for Lean Logistics and Engineered Systems at the University of North Carolina at Charlotte. Before joining academia, Dr. Ozelkan worked for i2 Technologies, a leading supply chain software vendor and for Tefen USA, a systems design and industrial engineering consulting firm. Dr. Ozelkan holds a Ph.D. degree in Systems and Industrial Engineering from the University of Arizona. He teaches courses on supply chain management, lean systems, decision analysis, designed experimentation, and systems design and optimization. His current research interests include on the education side, development of simulations and cases for active learning, and on the modeling side, supply chains and logistics management, and production systems planning and optimization, and applications in different industries.

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Continuous improvement philosophy is a fundamental principle for creating a sustainable system and education is no exception. Engineering departments have been implementing continuous improvement processes as part of ABET accreditation requirements for many years. One of the main challenges, especially for small programs is to identify resources to carry on these continuous improvement initiatives along with the ongoing teaching and research activities. In this paper we present an innovative approach in which systems engineering students are involved in the improvement of the Systems Engineering & Engineering Management (SEEM) Program at the University of North Carolina at Charlotte (UNCC). The initiative has been carried under the junior level Systems Design and Deployment course where project teams of systems engineering students were given the task of analyzing the processes of the program as a consultant would do.

During the semester a streamlined version of the five phased six-sigma methodologies known as DMAIC (Define, Measure, Analyze, Improve, and Control) and DMADV (Define, Measure, Analyze, Design, and Verify) were taught and key deliverables of each phase were completed. The storyboards were presented to the key stakeholders within the SEEM program for approval to implement.

The output of two projects resulted in redesigned websites, one for the undergraduate Systems Engineering program and the other for the Engineering Masters program. A third project team created process flow maps along with the methods and procedures to facilitate a supply chain game for the department's students. The fourth project developed flow charts for seven of the department's key processes and improved two of these by eliminating non value added steps. As a result of this approach the students were passionate about improving a program they care about while learning valuable Systems Engineering design and deployment skills. At the same time faculty and staff within the department were grateful to have four projects completed to improve the program. Our experience shows that both students and teachers can benefit from partnering together in their semester projects to design and deploy systems that improve their department. This approach to utilizing students to improve systems within the department could be replicated to other classrooms and universities in order to achieve similar results.

Introduction

Continuous improvement is an important part of engineering education in US universities. This process has been formally driven by the Accreditation Board for Engineering and Technology (ABET). ABET continuous improvement processes are primarily related to educational objectives and student learning outcomes, which ultimately helps improve related courses over

time. In this paper, we look at continuous improvement from a related but slightly different perspective: specifically program office processes.

UNCC's Systems Engineering and Engineering Management (SEEM) Program is a relatively small but fast growing program (Figure 1). The program offers two degrees: BS in Systems Engineering which was introduced in 2008 and MS in Engineering Management which was introduced in 2000. The program's enrollment is 119 students as of fall of 2012 with 85 of them being undergraduate students. There are four full-time tenured faculty and four part-time faculty along with one faculty jointly appointed with the Electrical and Computer Engineering Department. The BS in Systems Engineering was ABET accredited in 2012. Both the undergraduate and graduate programs are also accredited by SACS (Southern Association of Colleges and Schools). In addition, the online program is certified by the USDLA (United States Distance Learning Association). The program has been growing by about 15-20 students per year mainly due to growth in the undergraduate program since 2008 and due to the introduction of the online MS in Engineering Management in 2009. To support this growth the program is recruiting two tenure-tracks and several part-time faculty at the time of this writing. SEEM has a director who chairs both undergraduate and graduate degree programs. There is one administrative support associate, who provides student and financial services for the program.

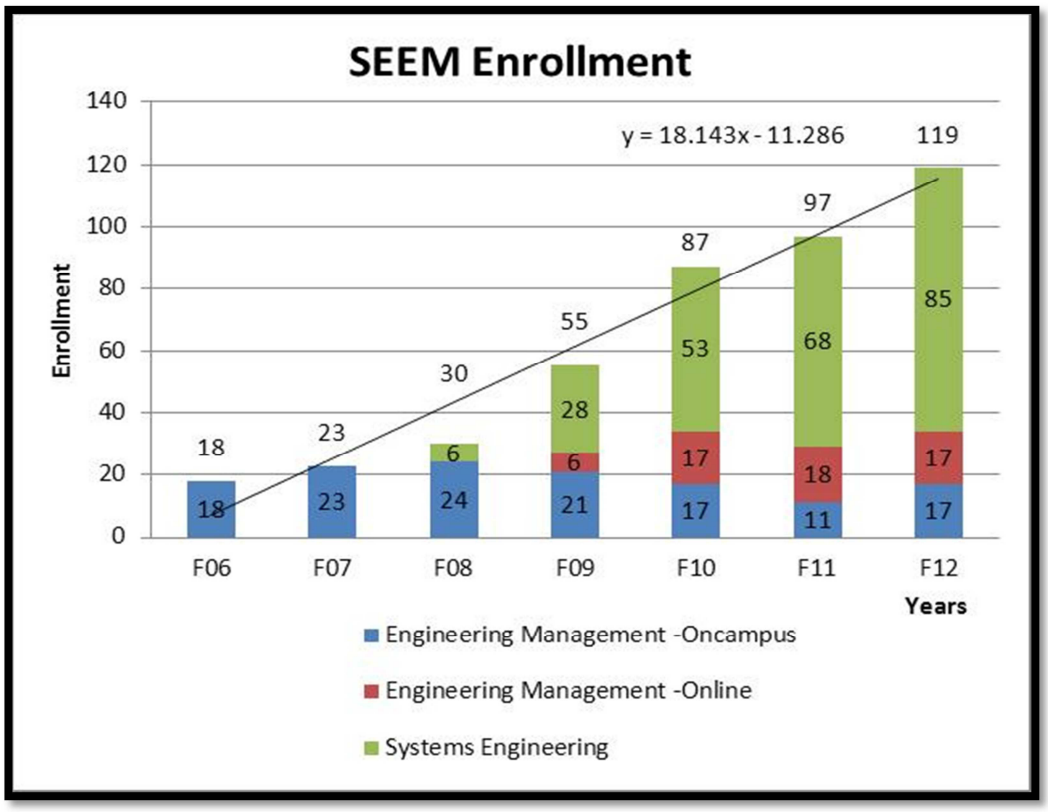


Figure 1: UNCC, SEEM Program Growth

Recently, the SEEM program had a change of both the director and the administrative support positions coincidently around the same time. During the transition of the new director and the new administrative support associate, it was observed that quite a few processes were only known to the departing staff. The lack of documentation of processes made the transition more difficult than it should have been. Having new eyes at the administrative positions also brought up the question of whether improvements to the existing processes could be made and then documented.

With the new direction to the program a student survey was conducted to understand what the students liked the most and least about the program and what areas they wanted to see improvements. The survey revealed multiple important things, two of which are related to the study presented here: 1) that more activities could be done to increase the "family" feel in the program and to promote a "belonging" feeling, 2) more hands on projects are needed for students to appreciate the systems engineering concepts.

The SEEM Program offers a course SEGR 3101 System Design and Deployment which was handed over to a part-time instructor who works full-time in the industry as a Lean Six-Sigma Master Black Belt. As the new instructor came on-board, there were questions about the content of this course and type of system design and deployment projects that the students could work on. Based on the above stated motivations, the program director and the instructor had decided to pilot a novel approach to program continuous improvement: letting the systems engineering students design and continuously improve the SEEM processes. Given that the program is relatively small, this would be a win-win by avoiding additional service work on the limited number of faculty. The students worked on four projects during the fall 2012 semester and this paper aims to present the process, results and lessons learned from these projects.

The rest of the paper is organized as follows: after a brief literature review, we cover basics of the six-sigma methodology that has been used as the underlying framework for the continuous improvement projects. The paper then proceeds with the description of the student projects and their findings. The last section is a summary of major conclusions.

Literature Review

As indicated in the literature, instructors are often challenged to provide realistic hands-on engineering design experiences during their courses [1]. Since real projects may not be easily available, instructors often place emphasis on computer-based simulators [2]. In order to mimic real life engineering projects, and to fulfill ABET requirements for multidisciplinary teams, course related projects are often targeted for collaborative teams. It is shown in several studies that collaboration can improve student learning while also producing significantly better projects [3]. Lean six-sigma has been taught in systems and industrial engineering curriculum and has been applied in student projects [4, 5]. It is also recognized that lean six-sigma can help improve

the quality of the engineering education [6, 7, 8]. Based on the literature, leveraging students for academic program improvement is not a common practice, but it has been done before utilizing graduate students in conjunction with their thesis work [6]. Here, we describe a six-sigma based teaching approach to provide hands-on system design and deployment experience to undergraduate systems engineering students.

Six-Sigma Methodology

Six-sigma was originally developed by Motorola as a business management strategy that reduces defects from processes, increases profit and empowers employees [9]. It is a data driven approach to process improvement based primarily on statistics. The term sigma is a statistical term measuring how far a process is from perfection. There are six standard deviations between the process mean and the nearest customer specification limit. The lower the deviation the better the sigma level which also means the fewer number of defects found in the process.

The key that makes six-sigma more sustainable than other traditional quality programs is its focus on training everyone in the organization on the methodologies with a goal of achieving a verifiable return. This approach requires quality to become everyone's job instead of just the quality department. Six-sigma programs also place emphasis on the following: passion, management, leadership, and support of the project teams. The methodology starts with the needs of the customer and ends with reliable processes that achieve sustainable results. If these benefits can be utilized by organizations in industry than why not try them in an academic setting? It was with this thought that the SEEM program decided to run a pilot with the junior students in SEGR 3101 System Design and Deployment.

The first decision to be made was determining which type of lean six-sigma methodologies would be taught. There are two main methodologies that are widely taught and used within industry today. The first enables a project manager to improve existing processes using a five phased approach called DMAIC (Define, Measure, Analyze, Improve, and Control). The second enables a project manager to design new processes using a five phased approach called DMADV (Define, Measure, Analyze, Design, and Verify). These two methodologies were taught to twenty-two junior students during the first 10 weeks of the course SEGR 3101 Systems Design and Deployment. After each phase of the six-sigma methodologies were taught, the students were then given an assignment to complete their phase deliverables in an MS Power Point template file.

The objectives of the DMAIC methodology are to reduce defects, cost, and variation within an existing process. The DMADV methodology is used to design or redesign a new process, product, or service to meet the customer's needs. Figure 2 below illustrates the cyclic nature of the five phases used in the DMAIC and DMADV methodologies along with the main objective of each phase.

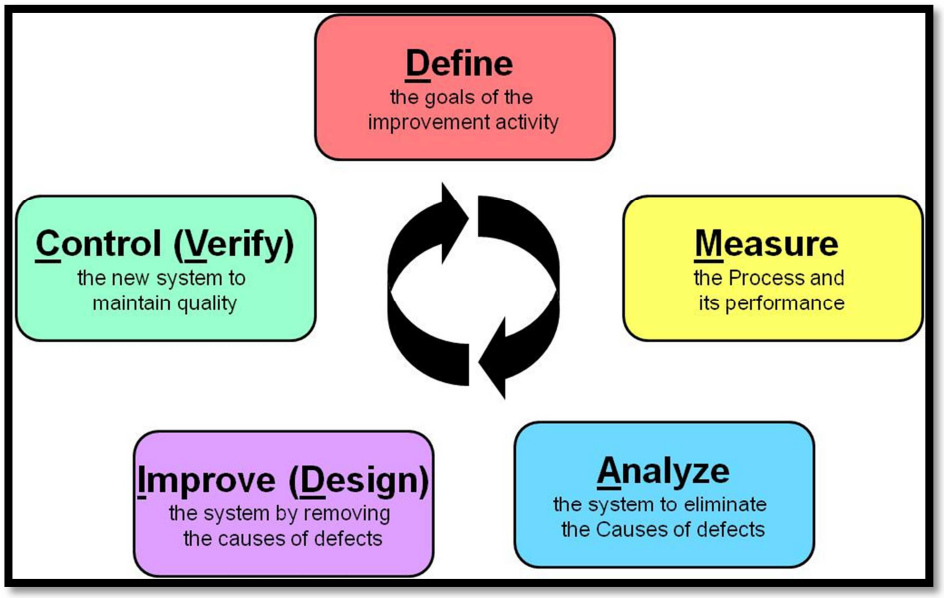


Figure 2: Six-Sigma DMAIC (and DMADV) Cycles

It is important to teach the differences between DMAIC and DMADV methodologies because it is useful when it comes time to pick the right methodology for a student project (Table 1).

DMAIC	DMADV
Detecting problems	Preventing problems
Improving existing processes	Designing new process
Transactional processes	Developing and marketing a transformational product or process
Incremental improvement is needed	Breakthrough improvement is needed
Needs to be finished in 6 to 9 months	Could take up to 12 months
Rooted in manufacturing	Rooted in systems engineering
Detective point of view (investigating)	Anthropologists point of view (proactive)

Table 1: Methodology Selection DMAIC vs. DMADV [9]

Our students quickly learned that three projects would use the DMADV methodology since they were designing new websites or processes. The fact that DMADV is rooted in systems engineering worked out well for these projects because the students were able to utilize the tools that come with this methodology to design and deploy their project solutions. The fourth project

used the DMAIC methodology because it required tools that could help the students get to the root causes of the SEEM program office processes being so inefficient. Teaching students the differences between DMADV and DMAIC allowed them to select the right methodology for their project. At first glance one would think the first three phases of both methodologies is identical. There are however, a few slight differences between the first three phases known as Define, Measure, and Analyze as outlined in the table below (Table 2).

Phase	DMAIC	DMADV
Define	Project charter includes a goal statement that identifies an improvement target to reduce a problem in the existing process	Project charter includes an opportunity statement to capitalize on a potential opportunity
Measure	Focus is to baseline the existing process; collect data to aid in detection of root causes of problem	Benchmark against organizations that do well with similar services/products/processes
Analyze	Focus is to look for root causes	Focus is on seeking to understand the environment and critical factors that will impact your design. Teams start to put metrics (Y's) behind their new process

Table 2: Define, Measure, Analyze Differences

Teaching Six-Sigma

Define

The first phase that was taught is Define, which seeks to establish the cause and boundaries of the problem under study as well as the goals of the improvement activity. The first major deliverable for a streamlined semester project is a charter, which is the contract with the Systems Engineering department as to what the project team was to accomplish. The second deliverable was a project plan and was placed in a Gantt chart form (using Microsoft Project 2010 software). The last deliverable of the Define phase which is to document lessons learned should also be completed at the end of the other four phases in the DMAIC or DMADV methodology. This forces students to stop and learn from the phase they just completed in order to improve their project management skills for the next phase. The class deliverables for the Define phase, which are summarized in Table 3, were due during the third week of the class.

Deliverable	Description
Project Charter	Problem/Goal/Scope statements
	Team member and resource names
	Communication plan

	Business case/financial benefits
	Assumptions/Constraints
Project Plan-Gantt Chart	Name of project deliverables along with their due dates
	Team member responsible for each task or deliverable
	Key milestones to close each phase of the project
As is process flow map	Existing process flow steps in Visio/PowerPoint
Lessons Learned	What worked well?
	What could have been done differently or improved?

Table 3: Summary of Define deliverables

Students completed the Define phase by presenting their deliverables in front of the class in the form of a project storyboard (using MS PowerPoint). This gave the instructor who served as the Project Champion a chance to formally approve the phase closure and offer feedback for improvement.

Measure

The second phase in the DMAIC or DMADV methodology is measure, which seeks to establish baseline performance for the current process and develop measures that will enable improvement of the process. Key deliverables that were due included a Critical To Quality (CTQ) matrix, which captured the voice of the customers and translated them into needs which could be measured. Students then prioritized their customer needs into three categories using a Kano Model. The three levels based on customer priority are: 1) must haves 2) more is better 3) and delighters. Students were instructed to meet the "must have" needs of their customers first followed by priority two and three needs if development time was still available near the end of the semester. The next deliverable that was assigned was to walk the current process and document these steps in the form of a flow map. Students then completed the phase by documenting lessons learned and presenting their storyboard in front of the class. The class deliverables for the Measure phase, which are summarized in Table 4 was due during the fifth week of the class.

Deliverable	**Description**
CTQ Matrix	Define the customers
	Capture the voice of the customers
	Translate the voice(s) to the customer need(s)
Kano Model	Rank the customers' needs based on level of priority
	Must haves
	More is better and delighters
As is process flow map	Existing process flow steps in Visio/PowerPoint

Lessons Learned	What worked well?
	What could have been done differently or improved?

Table 4: Summary of Measure deliverables

Analyze

The third phase in the DMAIC methodology is Analyze, which seeks to eliminate the gap between current process performance and the expected process performance or goal of the project. There are two methods used in analyze; process and data analysis. Process analysis helps the team focus on problems that cause waste or inefficiency using the detailed as is process map and a tool called Failure Mode and Effects Analysis (FMEA). The FMEA forces the students to brainstorm potential failures that could prevent a solution from solving the problem and improving the process. The second method taught in this phase is data analysis, which uses statistical software to produce charts and graphs that help the team prove or disprove that the narrowed root causes of the problem have an impact on the main primary metric. Students were taught how to plot histograms, Pareto charts, and control charts using a software package called Minitab. This enabled students to narrow down the root causes of the problem that had the greatest impact on their primary metric. Students then completed the phase by documenting lessons learned and presenting their storyboard in front of the class. The class deliverables for the Analyze phase, which are summarized in Table 5 was due during the seventh week of the class.

Deliverable	**Description**
FMEA	Failure Mode and Effects Analysis
Charts/Graphs	Showing the main root causes of the problem
	Using Minitab software
Lessons Learned	What worked well?
	What could have been done differently or improved?

Table 5: Summary of Analyze deliverables

Improve/Design

The fourth phase in a DMAIC project is Improve, which seeks to select, develop, test, and implement solutions using the list of vital few root causes developed in the analyze phase. Similarly, the fourth phase in a DMADV project is Design, which seeks to develop a high level and detailed design and then test its components while preparing for the pilot and full scale deployment. Both methodologies used similar deliverables to brainstorm the potential design elements that will meet the customers' needs. Students then developed mockups of their design followed by prototypes to be tested and approved by their customers. Finally, they documented the future state process and any methods and procedures as to how the users will follow the new process. The phase was completed after documenting lessons learned and with a presentation in

front of the class. The class deliverables for the Improve/Design phase, which are summarized in Table 6 was due during the eleventh week of the class.

Deliverable	Description
Detailed Design Elements	Types of solutions to be created by the team
	Design features
Customer Acceptance Checklist	Importance rating
	Whether customer accepts deliverables
Mockups	How new design should look
Future state process flow map	Flow of improved/designed process
Methods and Procedures documents	How users will follow improved/new process
Lessons Learned	What worked well?
	What could have been done differently or improved?

Table 6: Summary of Improve/ Design deliverables

Control/Verify

The fifth and final phase in the DMAIC methodology is Control, which seeks to hold the gains realized by the implementation of the improvement solution before closing out the project. The project team should think about the type of controls to put in place to make sure everyone is using the solutions for years to come. The final phase in the DMADV methodology is Verify and seeks to pilot and test the prototype, implement the final design, and close out the project. Both phases use similar deliverables to come up with a plan to implement the final solutions. Students are taught to build controls into their designs so that they can sustain the gains of the new process long after the team has closed the project. They were required to document who the process owners were and how these stakeholders could maintain the gains of the new processes. To close the final phase the students had to present their storyboards for thirty minutes, detailing how they used the six-sigma methodologies to complete their projects. The audiences during the final presentations were their fellow classmates as well as the program director and instructor. All SEEM faculty and staff was invited to see how the deliverables of these projects would improve the department. The class deliverables for the Control/Verify phase, which are summarized in Table 7 was due during the thirteenth week of the class.

Deliverable	Description
Implementation Plan	How and when deliverables were put in place
	Who is responsible for implementing each deliverable
Control Plan	How gains will be maintained for each solution

	Who is responsible for measuring use and success of each solution
Lessons Learned	What worked well?
	What could have been done differently or improved?

Table 7: Summary of Control/ Verify deliverables

Class Projects

There were twenty-two students in this SEGR 3101 Systems Design and Deployment course that had to complete their final project which was worth 35% of the overall semester grade. Students worked in teams of five or six to design, develop, test, and implement a system that would improve the SEEM program. Students had to complete their deliverables for each class project using the DMADV or DMAIC methodology they had been taught in class.
The following four projects were completed during Fall 2012

1. Re-design the B.S. in Systems Engineering Website
2. Re-design the M.S. in Engineering Management Website
3. Design, Document, and Deploy the Time Wise Supply Chain Game
4. Design, Document, and Deploy Processes for the SEEM Program

At the end of each of the first four phases, the four project teams presented for ten minutes or less to the class the corresponding deliverables of that phase. The groups were given deliverable templates (MS Power Point Files) already created to guide them through the standard DMAIC or DMADV methodology. Having this presentation structure in place allowed the students to build the storyboard during each phase of the project while getting timely feedback from the instructor and their peers at key approval points. A brief description of the four student projects is given below.

Project 1: Re-design the B.S. in Systems Engineering Website

This team of six students reviewed the existing undergraduate website and worked to re-design it to meet customers' needs. This involved sending out customer surveys, interviewing customers, and meeting with key stakeholders. The Systems Engineering program faculty and staff were the stakeholders for this project. Students followed standard university templates for website mockup development and worked with a programmer to finalize the requirements before launching the new website. This team also had the additional requirement of working with the Engineering Management Project website team to make sure all their design elements were implemented under the umbrella of the final program website.

Through surveys sent to SEEM undergraduates this team found that students were not happy with certain sections of the current website. From the surveys it was apparent that students needed an easier way to navigate and the solution was to design an effective site map. Another

section that needed to be added was to have more examples of engineering careers to aid students with future job prospects. The other key takeaways from the survey were to clearly define the mission statement, improve website functionality, and add a calendar of events section to the website. This team worked on a step by step mockup for the programmers to follow when implementing the website requirements. Two of the mockups are shown in Figures 3 and 4 below.

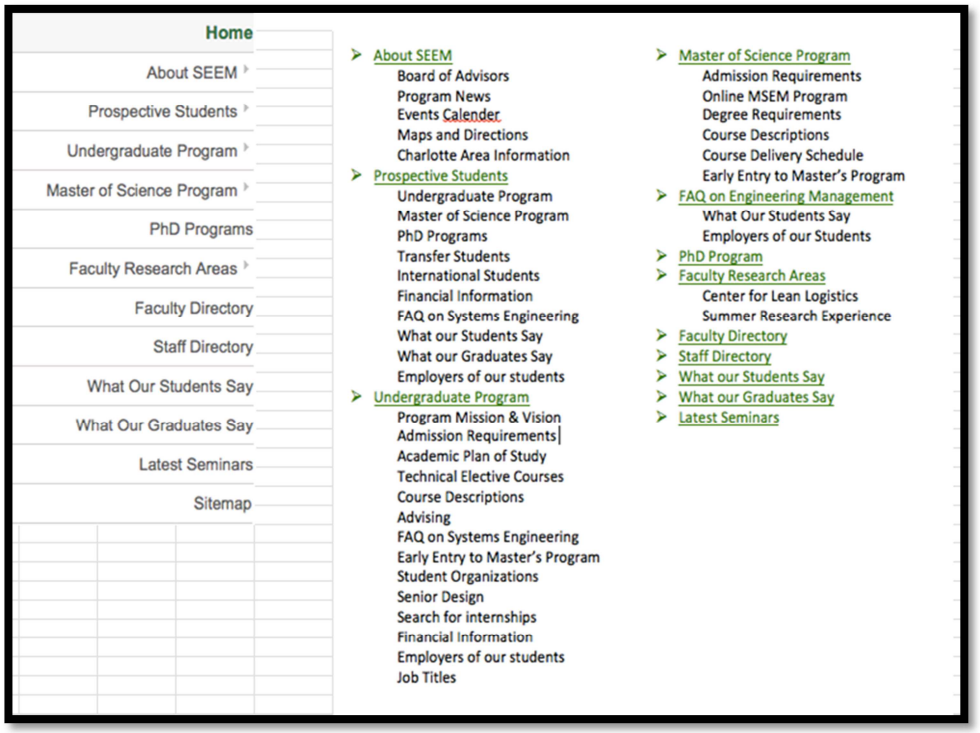


Figure 3: Mockup of Future "Site Map" Tab

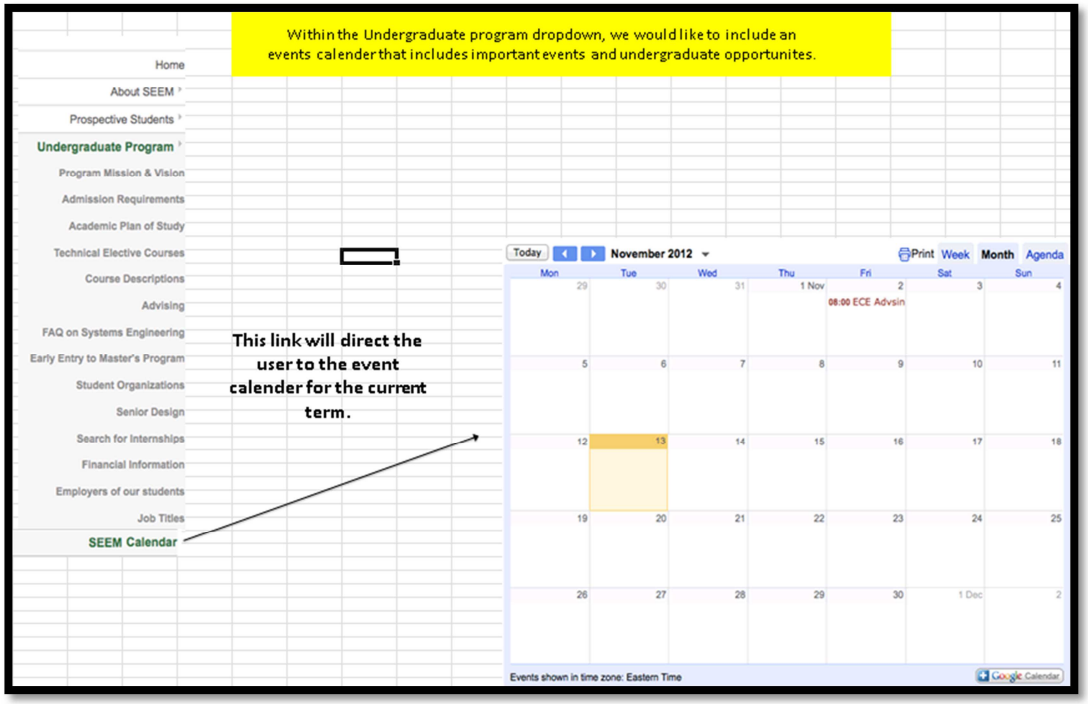


Figure 4: Mockup of Calendar of Events Tab

This project was win/win for the SEEM program, current undergraduate students, and future prospective students as well. The SEEM faculty and staff benefited from having a website re-designed based on their customers' needs. The current students will benefit from an easier to navigate website that meets their everyday needs. Finally, prospective students and their parents benefit from having a website that answers their questions about the SEEM program before they make a major decision to enroll.

Project 2: Re-design the M.S. in Engineering Management Website

This team of five students reviewed the existing graduate website and worked to re-design it to meet customers' needs. This involved sending out customer surveys as well as interviewing customers and stakeholders. Again, the SEEM faculty and staff were the key stakeholders for this project while the Engineering Management students were the customers. As in project 1, students followed standard university templates for website mockup development and worked with a programmer to finalize the requirements before launching the new website. This team also had the additional requirement of working with the Project 1 team to make sure all their design elements were implemented under the umbrella of the final program website.

This project team sent out electronic surveys to all of the MS Engineering Management students that currently reside in the program. They also met with the graduate students in a face-to-face session to ask follow up questions to find out what they would like in a re-designed website. Some of the key takeaways from the customers are shown in the Kano model in Figure 5. These

would include more information on the early entry to the masters program, a calendar, and testimonials from current students.

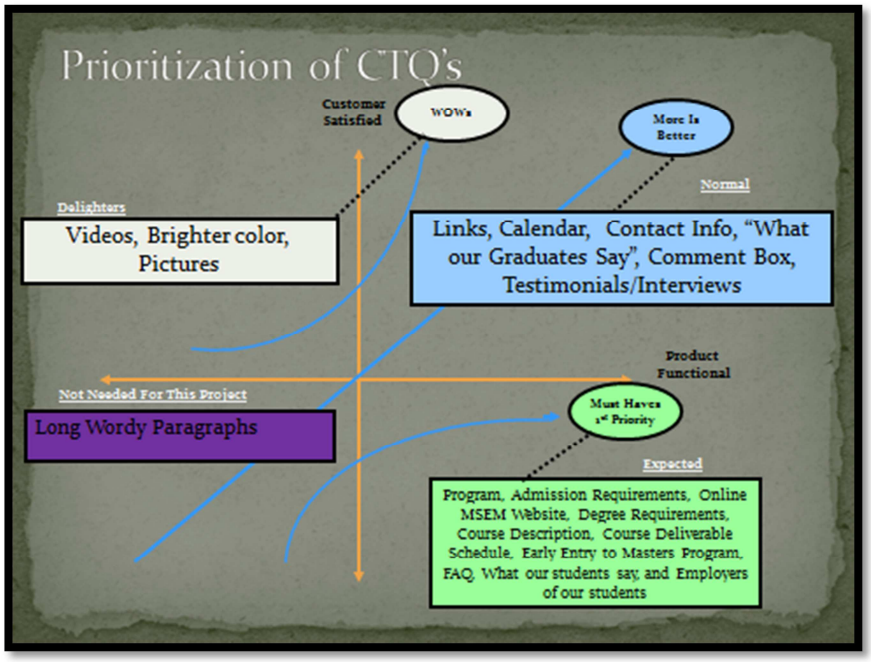


Figure 5: Prioritization of Customers Needs Using Kano Model for Project 2

Students took these customer needs and developed a mockup that programmers could use to re-design the graduate website. A sample mockup is shown below (Figure 6).

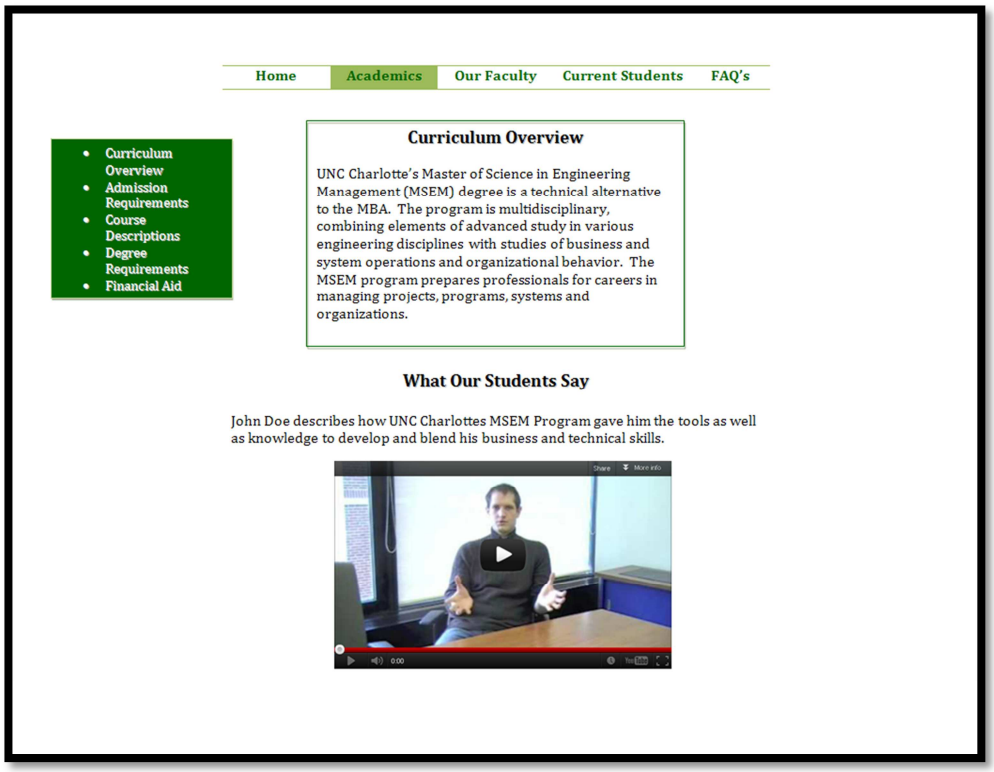


Figure 6: Future Academics Tab

Similar to the first project, the second project was also win/win for all stake holders. Since many of the current graduate students are busy balancing jobs and school, they will benefit from an easier to navigate website that meets their time management needs. Finally, prospective graduate students will benefit from having a website that answers their questions about the MS Engineering Management degree program before they make a major decision to enroll.

Project 3: Design, Document, and Deploy the Time Wise Supply Chain Game

This team of six students examined an existing supply chain game that had resided in two large blue suitcases in the program office but had not been used for several years. This game was developed by Time Wise Management Systems to analyze the complexities in supply chain networks, and to illustrate how lean supply chain techniques can help improve the overall supply performance [10]. The team was required to design large flowcharts to demonstrate how three different strategies could be used to build alarm clocks. This team was also required to document methods and procedures so that future students could follow these different strategies in the form of playing three rounds of the game. These deliverables would be placed in the Systems Engineering Design Lab to enable future students to know how to play the Time Wise Supply Chain game. The first round was called, “make to plan”, which is a traditional production strategy used by businesses to match production with consumer demand forecasts. The make to plan method forecasts demand to determine how much stock should be produced. If demand for the alarm clock product can be accurately forecasted then this make to plan strategy could be an efficient choice. The process flow that the students designed is shown in Figure 7 along with a picture of SEGR 3101 students playing round one in Figure 8.

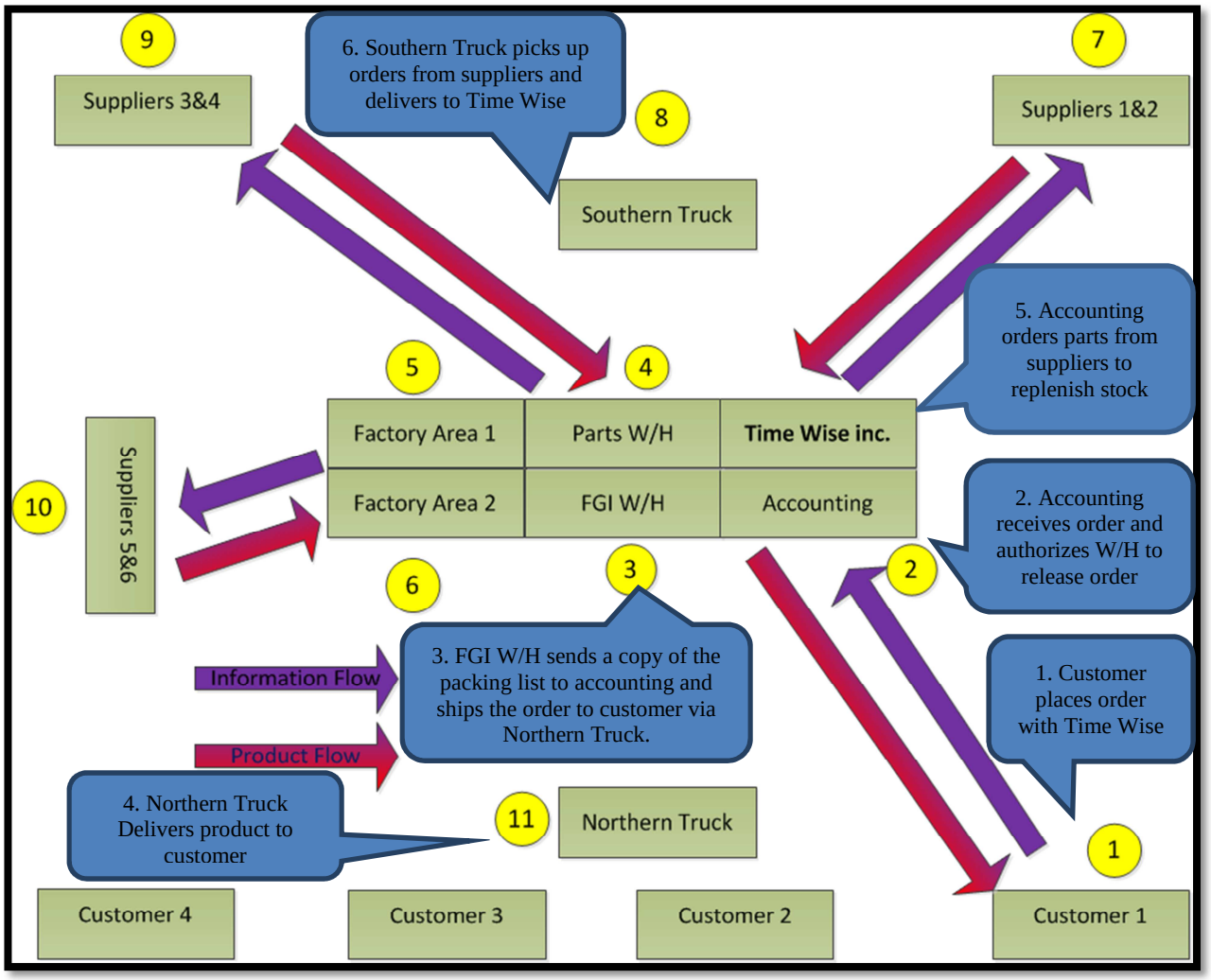


Figure 7: Make to Plan Process Flow for Round 1

Figure 8: Implementing Make to Plan Process for Round 1

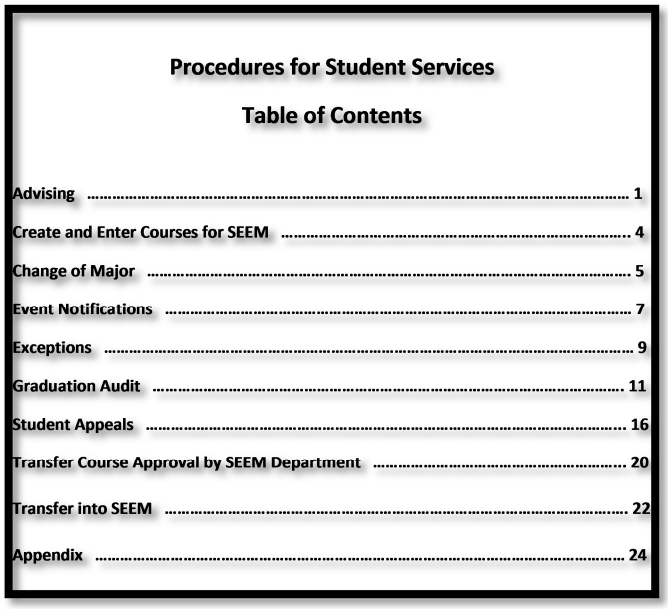
Next students within this group designed the second round based on a strategy called, “replenish to order”. This business production strategy typically allows consumers to purchase products that are customized to their specifications. By manufacturing the alarm clock product after the customer places the order an additional wait time for the consumer to receive the product was created. The advantage of this strategy is that it allows for more flexible customization of the alarm clocks compared to purchasing the product from retailers’ shelves.

Finally students designed the third round based on a strategy called, “build to demand”. This is a production strategy used to meet the seasonal customer requirements. In order to achieve this, the supply base must be able to handle the demands placed on them. Students put together a plan and procedures to determine the appropriate production and inventory schedule that would be required from each supplier based on their current production capacity and manufacturing cycle time.

This project was beneficial to both students and the SEEM faculty for several reasons. It taught the entire class of students how to follow flow maps of three different supply chain strategies in order to produce real life alarm clocks. It also served as a great teaching tool for the project team to learn how to design those three different supply chain systems that could actually be deployed. The faculty benefited by having methods and procedures to play the game with future students. Last but not least, future visiting prospective students and their parents will benefit from demonstrations of the game to teach them Systems Engineering principles since the program director has set up a permanent room for the game to be show cased.

Project 4: Design, Document, and Deploy Processes for the SEEM Program

This team of five students met with their stakeholders who included the SEEM faculty and staff in order to determine which of the programs' processes needed to be documented and improved. The requirements for this project were to document and improve the flow charts, procedures, and to create new electronic forms for seven key processes that the program office performs everyday to aid students coming into the program. These deliverables were to be stored in a central location in the program office so that SEEM faculty and staff could access them when needed. The final output was a twenty-four page spiral bound manual outlining methods and procedures for seven different processes that the department uses regularly. These processes are listed in the table of contents in Figure 9. Within the manual the following questions were answered; who, what, when, and where for each of the processes as shown in the example in Table 8. Where appropriate a flow chart of the process was developed and placed into the manual as well.



Procedures for Student Services

Table of Contents

Figure 9: Table of Contents for Spiral Bound Process Manual

What	Who	When	Where
Justification is made for an exception	Appropriate College Dean, Athletic, Vice Chancellor	Pre-Registration	Registrar's Office keeps records of all programs granted special permission
Claim approved	Registrar's Office	Pre-Registration	Registrar's Office responsible for implementing
Holds removed	SEEM Advisor	Pre-Registration	SEEM Office
Registration	Student	Registration	Click Self Service to register

Table 8: Example Process, "Exceptions due to Programs Causing Schedule Restrictions"

This project has several advantages for both the students and the SEEM program. For the program the advantages were to have seven of the most often used processes clearly documented in a bound and laminated notebook. This will allow new and existing employees to quickly figure out how to implement major administrative processes. It also taught students how to document processes and even make them more efficient. Future students will benefit from the new electronic forms as well as the documented methods and procedures which will be placed on the SEEM website. The students also enjoyed impacting the bottom line of the program which made them feel part of the SEEM family.

Summary and Conclusions

The improvements to the program websites, better documentation of the Time Wise simulation game facilitation, and improvements in the administrative processes helped the SEEM program's continuous improvement mission. At the same time the students have learned how to design and deploy real systems that impact an organization. The knowledge and skills gained in project management, leadership, and six-sigma will hopefully benefit the students in their future academic and professional careers in years to come. The students now have a methodology to design new processes in DMADV. They also have a methodology to improve existing processes in DMAIC. More importantly, they know when and how to use all of the tools and templates that comes with these two methodologies.

The lean six sigma framework that has been used to continuously improve processes manufacturing or service based industries, has also helped the SEEM Program and its students. It was observed that students gained more confidence when they interviewed for internships with prospective employers. Due to the small size of the SEEM program, the faculty has benefited from the additional resources in the form of students who are willing to design and deploy solutions to improve the program. Last but not least the program has benefited from embracing this new teaching/learning style to help fulfill the vision of bringing the SEEM faculty, staff, and students together as one family to grow the program. In the future, the SEEM program will look for more ways to partner with students to continually improve the program as a result of the successful pilot that was conducted in the Fall of 2012 in SEGR 3101 System Design and Deployment. Based on the pilot teaching experience, it is our recommendation for other universities to use the lean six-sigma methodology to partner with their students for continuous improvement of their programs through semester projects. This approach should especially be beneficial to small programs with fewer faculty or in programs where there is a shortage of real hands-on projects.

References

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