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Introduction of Lean Six Sigma Principles intoAeronautical Engineering Technology Courses

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Abstract

Faculty members in the aeronautical engineering technology program are redesigning courses in the curriculum to give students a solid background in the Lean Six Sigma (LSS) methodology and techniques. This knowledge will help graduates land their dream jobs in many industries, including aviation, because LSS methodology is widely used in many areas to achieve drastic performance improvements. Aviation companies want graduates to possess more problem-solving skills as a requirement for both employment and success. Most of the aeronautical engineering technology graduates will apply for jobs at major aircraft manufacturers, where the challenge is to fill the gap between the production floor and the engineering department. In addition to manufacturing liaison positions, these graduates are hired for positions in scheduling, tooling, design, and even purchasing. To better prepare students for these careers, new courses are designed to not just teach the students to follow instructions, but to give them a set of tools to truly understand the design and improvement of processes. Specifically, the courses address two major Lean Six Sigma methodologies: DMAIC and DMEDI. DMAIC is a methodology for process or product improvement with five phases: define, measure, analyze, improve, and control. DMEDI is a methodology for process or product design with five phases: define, measure, explore, develop, and implement. This paper discusses these methodologies, their significance, their implementations in the courses, and the results.

Introduction

The Aeronautical Engineering Technology (AET) program has a long history at Purdue University, starting with a focus on aviation maintenance technology. Recognizing the realities that most graduates were starting their careers in positions beyond the typical vocational graduate, the faculty recently redesigned the curriculum. The program was renamed Aeronautical Engineering Technology in 2008 to better identify the nature of the curriculum and reflect the mission of the program

The AET baccalaureate level program has identified ABET Technology Accreditation Commission (ABET TAC) accreditation as a key goal to further set Purdue graduates apart and to provide additional and more advanced career opportunities. One part of the ABET TAC requirements is that graduates are able to apply technical skills and knowledge “to the analysis, development, implementation, or oversight of aeronautical/aerospace systems and processes" [1]. Three senior level courses were developed and are addressing this requirement through the incorporation of Lean Six Sigma methodologies. This paper introduces Lean Six Sigma methodologies, the courses developed, the course implementation, and examples of projects.

Lean Six Sigma Methodologies

The "lean" approach to reducing waste and adding value was brought to western manufacturers through *The Machine that Changed the World* [2]. Six Sigma was developed at Motorola to provide a structured approach to reduce variation in product output in the 1990s [3]. At first, these two methodologies for dramatic improvement were seen as competitors, but in the late 1990s, a Lean Six Sigma approach was developed that combined the strengths of each [4]. This discussion presents Six Sigma, lean, and Lean Six Sigma.

Six Sigma is implemented through projects that are selected based on relevance to key business issues and the potential financial impact on the company [3]. Each Six Sigma project has five phases, with each phase requiring a review, sometimes referred to as a tollgate review. The tollgate review may result in one of three outcomes: continue to next phase, stop project, or continue study in current phase. Within each phase, data is collected and analyzed statistically to aid decision-making. Six Sigma may be thought of as a data-driven approach that uses tollgate reviews at the end of each phase [4]. These five phases are: define, measure, analyze, improve, and control (DMAIC). This DMAIC methodology is designed specifically for improvement of existing processes. There is also a similar Six Sigma methodology that addresses design of new products, components, or processes. The phases of the methodology are slightly different: define, measure, explore, develop, and implement (DMEDI). Some authors use design, measure, analyze, develop, and verify (DMADV) for the design approach, but they are essentially the same. Both methodologies use specialized tools for designing or improving manufactured products [4] and services [5].

Lean is often understood to be a waste reduction method [3]. In this view of lean, processes are examined for seven specific wastes and the wastes are permanently removed from the process [3]. Lean is sometimes understood to be the Toyota Production System [8] described by Taiichi Ohno [6]. The Toyota lean principles as presented by Womack and Jones reveal a more holistic picture of lean that extends beyond elimination of waste [2]. In these principles, value is defined from the customer's perspective. The enterprise provides what the customer wants at the moment the customer wants it, value streams are mapped, steps are flowed and waste is eliminated, and the enterprise constantly pursues perfection [2].

Lean techniques have been adopted in aerospace companies for many years. In 1993, the Lean Aircraft Initiative (LAI) at the Massachusetts Institute of Technology began to formalize and study the effects of lean throughout the aerospace industry [7]. LAI has kept the same acronym, but has changed what it stands for two times: first, to Lean Aerospace Initiative and second, to Lean Advancement Initiative. There are 13 aerospace companies listed as current members [10]. The original focus of LAI was on lean aircraft processes that later expanded to all aerospace applications and, most recently, other industries. Since that time, lean has been implemented in manufacturing, design, and business processes in aerospace companies and other industries.

The Lean Six Sigma approach combines the data-driven tollgate project methodology and variation reduction focus of Six Sigma with the reduction of cycle time and waste by using lean principles and techniques [4]. The overlap between lean and Six Sigma is significant because they both have the goal of improving performance. As an example of the overlap between lean and Six Sigma, consider just-in-time manufacturing (JIT). While JIT is considered a way to reduce cycle time, there are many processes that cannot cope with the reduced batch sizes or inconsistent parts and processes and must undergo a variability reduction effort before implementing JIT. Before Toyota implemented the JIT system, they reduced variability in demand, manufacturing, and suppliers [8].

Lean Six Sigma is used in aerospace companies, in addition to many other types of industries and governmental agencies [5, 9]. Lean Six Sigma is being applied to business, design, manufacturing, and supply chain processes. For example, in 1999, Lockheed Martin developed an approach called LM21 which stands for Lockheed Martin in the 21st century. The ultimate goal was to provide the best system for achieving excellence to customers, shareholders, and employees. To achieve this goal, Lean Six Sigma was adopted as a management philosophy. The idea of process improvement has migrated to to every business function such as finance, operations, cash management, etc. [15]. Another example is a problem Boeing addressed with its 777 program when recirculating air fans were rejected during testing on the production line [16]. Replacement was costly and required additional testing. Professionals from many departments were on the team that found the root cause to be foreign object debris. In this particular case, items designed to prevent debris in the first place such as ductwork caps and plastic sheeting, became debris themselves. The process was changed and the problem was solved [16].

Implementation in AET Courses

In the AET curriculum, there are courses in design and analysis of systems, but there are no courses dedicated solely to lean and/or Six Sigma. In fall 2007, three new senior level courses were developed to expose students to DMAIC and DMEDI in team project environments where students must use skills and knowledge acquired throughout their education to complete a project. The three senior level courses are AT496 Applied Research Proposal, AT497 Applied Research Project, and AT408 Advanced Manufacturing Processes, shown in Figure 1.

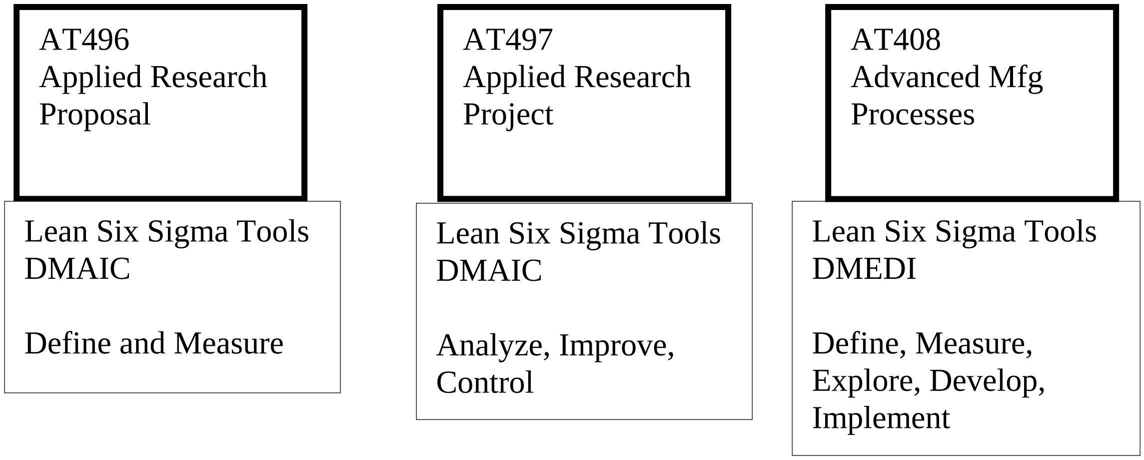

Figure 1: Three Aeronautical Engineering Technology Courses with Lean Six Sigma

The DMAIC methodology was selected for use in the AT496 and AT497 courses. These two courses are a two-semester proposal and project implementation pair. The DMAIC methodology was selected because the projects in these courses focus on improving existing processes or products. The projects for these courses are mostly real-life problems, similar to those found in industry, that need to be solved to improve the bottom line of an organization. The projects should be scoped such that they can be completed in approximately three months; have measurable impact; are of an appropriate level of difficulty to incorporate skills and knowledge from previous courses; and are interesting to both the student team and the affected process owner. The methodology consists of *defining* business opportunities, *measuring* performance, *analyzing* opportunity, *improving* performance, and *controlling* performance [11]. The AT496 course addresses define and measure. During the AT497 course, the student teams analyze and improve the performance of processes, then develop and implement controls to sustain the gains in process performance.

This DMAIC methodology was selected for the AT496 and AT497 courses because of the process improvement nature of the projects, and because the DMAIC methodology is used in many aerospace companies as a preferred method for process improvement. It is very important to note that the AT 496 and AT497 courses are not courses in DMAIC, lean, or Six Sigma. These two courses are project proposal and project implementation courses, with those two objectives being the primary objectives. The DMAIC methodology is being used as a vehicle to proceed through the proposal, implementation, and hand-off stages in the project. The DMAIC methodology helps students tackle a process improvement project in a structured manner. The first year these two courses were offered was 2007–2008.

The DMEDI methodology was selected for the AT408 course due to the new product design nature of the projects. The DMEDI methodology is specifically indicated for projects that create a new product, service, or process [12]. DMEDI shares the same first two steps with DMAIC, with the first two phases being *define* business opportunities and *measure* inputs and outcomes. The next three phases are different in DMEDI: *explore* options; *develop* new product, process, or service; and *implement* the best solution. The AT408 course gives students an opportunity to go through all five phases of the DMEDI methodology as a vehicle to structure the course while the students learn about new product creation, design, and advanced manufacturing processes.

The DMEDI methodology is widely used in many industries, including aerospace. DMEDI is used to reduce waste in designing new products and to speed up the creation process from concept to full production. Knowledge of this methodology is preferred by many employers in the aerospace industry. The graduates should be comfortable working in teams, as well as communicating effectively with each other, with a customer, and with upper management. New hires have to demonstrate problem-solving skills to be successful. The students learn to use tools, such as brainstorming, 6-3-5 method, and Decision (Pugh) Matrix.

DMAIC Implementation

AT496 and AT497 are two new senior level courses added in the 2007-2008 academic year. In the fall semester, the AT496 students had to find and propose a project for completion during the spring semester AT497 course. Students are exposed to the DMAIC methodology and find a project that interests them. The students then form teams and prepare a proposal for the faculty. To successfully propose the project, the team must solicit both cooperation and advice from the persons responsible for the operation of their target process. The students may select processes not under the direct control of the instructor. For instance, the students may want to propose and complete a project in a laboratory that is not the AT496/AT497 course instructor's lab. The team members learn new skills in problem-solving such as project selection, team dynamics, and presentations, in addition to learning how to prepare a proposal. After the project is proposed and accepted, the team implements the project in the spring semester. In the AT497 course, the team must use technical knowledge, project management, and conflict resolution skills to successfully complete the project. Throughout the AT496/AT497 courses, the student teams meet regularly with the course instructor and the supporting faculty members (who are the process owners affected by the projects). In these meetings, the student teams review progress, ask questions, and are mentored by the faculty.

In the first offering, the six projects developed by the students were all concerned with redesigning processes within the laboratories in the aviation technology (AT) department. For example, "perform 100-hour power plant inspection," "control magneto testing equipment inventory," and "stage and de-stage turbine engine," were three of the six processes identified for redesign by student teams. In the proposal, the teams were required to identify the problem, its significance, a goal that addresses the problem, and a plan to address the goal. For these proposals, the student teams were instructed not to focus on the solution, but rather focus on identifying the problem, defining the problem in terms of performance parameters and the "as-is" performance levels, identifying the goal or "to-be" level of these parameters, and developing a plan to achieve the "to-be." None of the six projects were in laboratory areas controlled by the AT496/AT497 instructor. The teams had to acquire cooperation from other faculty members who controlled those laboratories. The AT department assisted this process by offering a 10 percent assignment in the faculty workload.

In the second semester, the teams each revised their project plans and used Gantt charts to self-manage the projects. Similar to a Master Black Belt [4, 5], the instructor's role was facilitator, mentor, and technical instruction and guidance on the use of tools. The student teams scheduled their time and meetings with professors; monitored their performance; provided weekly Gantt chart updates; and presented impromptu short updates in class on the challenges they faced, how they overcame it, and asked for class member inputs on alternate solutions or approaches. As an added difficulty for this project, the team members not only had to agree among themselves but also had to convince the faculty of the affected laboratory that the project was worthwhile, that the solutions were appropriate, that the control methods implemented would contribute to sustaining the gains in performance, and that the quantified benefits would be believed. For example, the teams used common Lean Six Sigma tools, such as 5S, process mapping, SIPOC, experiment design, work sampling, data collection and analysis, spaghetti diagrams, statistical tests of significance, and voice of the customer [3, 4, 5, 11], to reduce the number of process steps, reduce cycle time, and improve accuracy. During the program industrial advisory board meeting held in April, the aerospace industry board members agreed that the projects were the types of project experiences valued in newly hired graduates of aviation technology.

DMEDI Implementation

The AT408, Advanced Manufacturing Processes course, was developed and implemented in fall 2007. The course exposes students to both "worlds": the hands-on world of manufacturing and the other world of component design processes. Prerequisite coursework prepares the students for the challenges of AT408. Up to this point the students have learned in the curriculum how to follow instructions, document their progress, and how to work in teams. The AT408 course introduces the students to the design process, and requires them to create working instructions, process sheets, and drawings, then manufacture components, assemble them, and perform testing and final adjustments.

In AT408, the students are asked to use the DMEDI methodology to create a product starting with a defined need and ending with a physical assembly. The course instructor begins the DMEDI process for the student teams by completing the define phase. The student teams then complete the other four phases with guidance and mentoring from the instructor. In the first offering of the course, the students were given a task to design and produce specific missing components for a Pratt Whitney PW4000 turbine engine in the AET Turbine Laboratory. In the future, it might be possible to ask the students to come up with their own ideas for an interesting product. The biggest obstacle to starting the process with the students generating an idea is the limited amount of time available in the one semester allocated for the course. The students in the projects establish deadlines, design the parts, and produce 3D computer aided design models, drawings, process sheets, and a cost analysis. In addition, the students manufacture the parts in the materials and manufacturing laboratory and build the final assembly.

Conclusions and Future Work

The Aeronautical Engineering Technology program has implemented two Lean Six Sigma methodologies into three senior level courses. These three courses are project based. The students learn by going through the phases of design creation or process improvement. The instructors of the senior level courses agree that the students should be exposed to common elements throughout the curriculum with regard to report content, presentation content, and team evaluation. With more common elements in upper level courses, there would be greater student understanding with repeated use, and this would allow more time for in-depth questions for instructors.

The work on common course elements has begun, but there is still more to do. Initial steps to create and use a common team evaluation form took place in spring 2008. A common team evaluation form was developed and used in upper-level courses [13]. The instructors are also working together to establish common guidelines for writing a proposal, creating presentations, and reporting content. A difficult part that remains is to design a common set of rubrics that could be applied throughout the senior level courses and adapted for lower level courses.

The work accomplished this far has provided a solid foundation for future course improvements and has demonstrated the use of Lean Six Sigma methodologies. To strengthen the courses, the instructors are planning to incorporate more project based learning techniques beyond the instructor acting as a facilitator and the development of problem solving skills in a team environment. Similar to Beringer's findings [14], the instructors in the AT496, AT497, and AT408 courses observed that the projects were not structured sufficiently for some students who only focused on the technical aspects and not the entire collaborative design experience. In addition, the instructors are meeting informally with the instructors of the lower-level courses to incorporate introductions of specific tools into these earlier courses.

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Biography

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