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Lean Manufacturing
A unique approach to educating students

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Abstract

This paper presents a recently developed method of teaching Lean Manufacturing. The Lean Manufacturing course is structured as both a lecture and an open discussion class. The class is presented as a 400 level course, which qualifies as a technical elective for all undergraduate engineering major, and as an elective for the masters level. Normal teaching methods were altered to allow for an easy exchange of experience from class members who have industrial experiences. These arrangements increase the level of involvement and participation among the students.

The early portion of the course is primarily lectures and simulations, designed to cover the basic components that make up Lean Manufacturing. The later portion of the course involves group participation and investigation of actual industrial applications of lean practices. Each group consists of a leader (called a Champion) and three to four members. Each leader of a group has had significant industrial experience and is currently working in an industrial setting locally. The groups, once formed, go to the Champion's industrial location for a tour to discuss opportunities for improvement through lean practices. The groups follow the guidelines of Value Stream Mapping[1] to "map" the processes with the plant. The team then chooses one lean practice within the plant to concentrate on, and analyzes the best methods for initiating changes. At the end of the course, each group presents their findings and turns in a written report covering the entire project. The "Champion" then has the opportunity to present the project paper to their management for review and possible implementation.

Penn State Erie - The Behrend College is currently in the second year of teaching this course. Lean Manufacturing is offered only in the fall semester, in the evening. There were 18 students in the first year's class, which resulted in five teams being formed. The successful review by the first year's students resulted in the second year's class attendance of 30 students (originally limited to 25 students).

Basis

Why is it important for engineering students to learn Lean Manufacturing? Many companies, both domestic and worldwide, are implementing the practices of lean manufacturing. Most of these companies rely on obtaining this knowledge through seminars and consultants. Students that have obtained the basic knowledge of lean manufacturing and the methods of implementation are more desirable than those without. Most undergraduate students do not have much industrial experience, so any additional exposure in the industrial arena is an added bonus for job applicants.

In an industrial setting, Lean Manufacturing is typically taught on-site by a consultant. Such seminars, typically lasting two to five days, are designed to give a detailed explanation of only one or two of the many lean manufacturing processes. For a company planning to train many employees, a seminar given by a consultant is a good method, although very expensive.

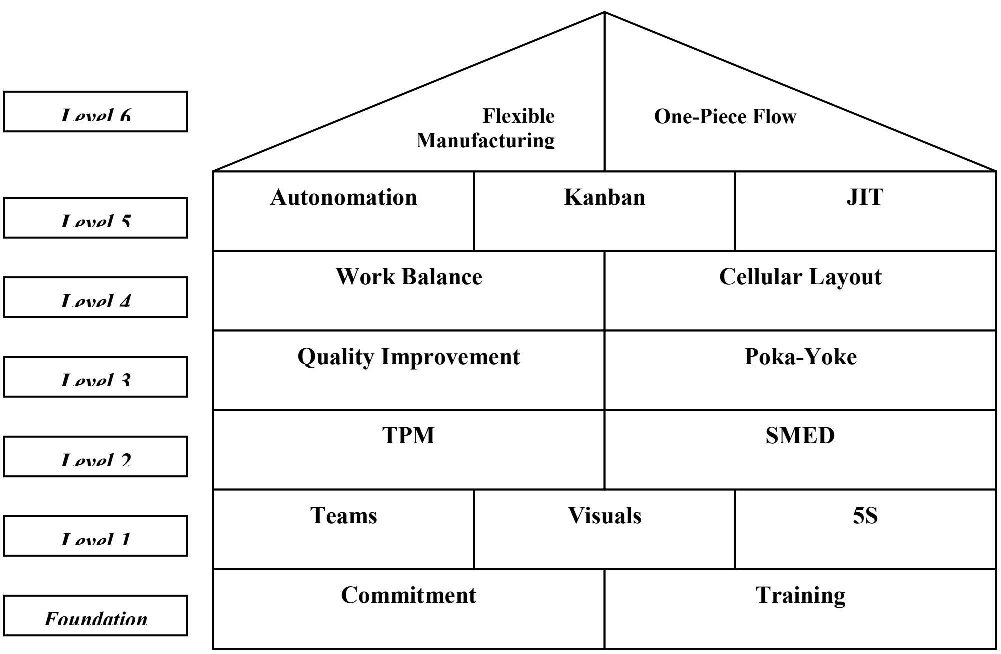
Lecturing is the common method of teaching Lean Manufacturing in an educational environment, followed by exams; or lean manufacturing is incorporated within another general course. These methods are easier to administer; however, the students will lack a true grasp of the advantages of lean manufacturing, and how to use lean manufacturing in an industrial setting.

A unique way of teaching lean manufacturing has been developed at Penn State Erie - The Behrend College, and has been taught for the past two years. The course is offered in the fall semester to seniors and graduates students. In order to increase the level of involvement with the student base, the class is presented as a 400 level course which qualifies it as a technical elective for all undergraduate engineering major and as an elective for the masters level. In order to promote and encourage open participation within the class, the normal teaching methods had to be altered to allow for an easy exchange of experience from class members with industrial experiences, typically graduate level, to undergraduates with little or no industrial experience. By providing an environment where open discussion of the different topics is encouraged, it is believed that the students have a better understanding of the concepts and uses of lean manufacturing in industry.

The class is structured with lectures (presentation of foundation and visuals), open discussions, exams, simulations, a guest speaker, a plant tour, projects, and presentations. Each of the lecture topics is designed to take approximately 1 hour, including class discussions of each topic. The class semester begins with an overview of lean manufacturing starting with the Toyota Production System (TPS), including the importance of Lean Manufacturing in the industry. The roles that each individual within a corporation plays from the CEO to the hourly workers is also discussed and explored. Since Lean Manufacturing can be considered a mixture of many techniques and methods, it is important to display to the students how the lean system may be structured such that the information presented in class will follow a logical path.

In order to accomplish this, a "House of Lean" was developed by the author which depicts the required foundation and the levels, or stories that reside in each topic. Many authors use very similar depictions of the levels that can be obtained through lean manufacturing, so the term "house of lean" has become a very generic analogy. Each increasing level is considered more difficult to implement in a manufacturing environment. It is important for the students to understand, at this early stage, that in order for a company to use lean practices, it does not have to incorporate all of the methods. Rather, each company will tailor their lean manufacturing program to fit the company's manufacturing needs. Some companies are satisfied with simply doing one or two the methods, such as 5S (Simplify, Straighten, Shine, Stabilize, Sustain), or Poka-Yoke (Error Proofing). Other companies see a need to incorporate more methods. The students need to understand that companies can choose the methods that will best fit their needs, much like choosing from a buffet. It is also very important for the student to grasp the knowledge that without a firm foundation (Commitment and Training), the rest of the methods will only be short term attempts at Lean Manufacturing.

The illustration below shows the six levels of Lean Manufacturing also called a "House of Lean".



The "House of Lean"

Components of Approach to Teaching Lean Manufacturing

There are seven components to this class, several of which make this approach to teaching Lean Manufacturing unique in the academic arena: Foundation, Visuals, Reading ("The Goal"), Simulations, Guest Speaker, Projects, and Final Presentations.

Foundation: Commitment and Training

The foundation (taught mostly by lecture) is one of the most important aspects of Lean manufacturing. Lean cannot be a viable method without a firm base on which to establish, or build, the other Lean methods. Within this foundation are the ideas of Commitment and the method of Training. Commitment must come from all levels of the corporation, from the CEO down to each hourly worker. Without a commitment for time and resources, lean manufacturing is only a dream. A break in this chain of commitment will cause a failure in the lean system. Once a company is committed to embrace the lean methods, the training of employees is extremely important. It is very difficult for any person to stay focused and committed to any cause if that person is not well informed on the importance of the cause. Training not only includes the reasons for lean manufacturing, but also on the methods for starting, monitoring, and improving on each topic.

Once the commitment and training has been established among teams, any of the remaining lean manufacturing practices can be initiated at any level. However, without teams being properly established, the responsibility to initiate any practice would fall on an individual. Therefore it is very important to form the proper teams to conceptualize, formalize, initiate, and improve on any of the topics. Most companies have many teams established to perform a variety of lean practices, rather than having only a few to do the work.

Visuals

During the course, visuals are discussed at length. Visuals are the public relations portion of any Lean Manufacturing project, and are the key to displaying information and accomplishments from the team to the rest of the work force. Visuals cover a wide array of types including shadow boards, metric boards, project boards, lighting systems for work flow, as well as many others. The topic of 5S (Simplify, Straighten, Shine, Stabilize, Sustain) is covered using analogies to spring cleaning or work shop/garage organization.

The remaining topics are lectured and discussed for approximately an hour on each topic.

- TPM: Total Productive Maintenance
- SMED: Single Minute Exchange of Die
- Process and Quality Improvements
- Poka-Yoke – Error Proofing

Work Balancing
Cellular Layout
Kanban
Autonomation
JIT: Just In Time
Flexible Manufacturing
One Piece Work Flow
Continuous Improvement

During the class Value Stream mapping was taught and used as a vehicle with which to determine which of the many lean manufacturing methods should be used for any particular situation. The book chosen for this was *Value Stream Management*[1], by Tapping. This particular book presents the material in a very clear and formatted method. Each step is detailed in order to allow the reader to systematically complete the mapping sequence easily. Value stream mapping is a method of depicting (graphically) the progression of the processes through the various operational steps. Each step is broken down to determine value added portions and non-value added portions which includes any idle times. Each non-value added portion can be considered a waste contributor and warrants further investigation. The goal of lean manufacturing is to eliminate all waste contributors and value stream mapping is a good method of identifying areas for improvements.

Reading

As part of each session, the class discusses the reading requirement from the book "The Goal", by Eliyahu Goldratt[2]. For each class, the students are required to read four chapters from the book and be prepared to discuss the chapters, and the relationship of the chapters to real world experiences. The book is written as a novel, rather than as a technical book. The characters have personalities and personal issues that are interjected into the technical portions of the book. Students state that the book is easy reading, has a good story line, and depicts the actual situations in industry.

Simulations

After all of the topics have been discussed, the group does a simulation of manufacturing - building Lego airplanes. The simulation has four portions, and all of the students participate. Two simulations are performed using the standard industrial method of production in batches (push system). The remaining two simulations are performed using the Kanban method (pull system). A six-piece Kanban flow is set up, followed by a one-piece Kanban flow. During the final one-piece simulation, the students are encouraged to initiate any of the lean manufacturing practices learned in class to optimize the system. For each of the four simulations, specific metrics are measured and compared, such as: units produced, % scrap, work in process, unit cost, units per person, time per unit. Each simulation is an improvement on the previous one, and the students learn to appreciate what the changes mean to the production system.

Guest Speaker

An arrangement has been made to have a guest speaker talk about actual lean manufacturing experiences in an industrial environment. The speaker is allowed to use the entire class time, 160 minutes for this course, including questions. The speaker is selected based on knowledge of the material and direct involvement in implementing lean manufacturing within a facility. The speaker presents real life scenarios where Lean Manufacturing has been implemented. These scenarios include both the successes and failures. This allows the students to obtain a broader view, and often, a different spin on the material.

Projects

It is very important for students, especially those with little or no manufacturing background, to be able to see lean manufacturing actually being implemented and used. To that end, the group attends a plant tour in the local area. The production facility is selected based on their lean manufacturing involvement, ability to give a pre-tour overview on the company's ease or difficulty in initiating lean manufacturing, and their willingness to participate. The plant tour gives the students the ability to see first hand, why and how lean manufacturing is used and the benefits derived from it. They are given the opportunity to ask questions that may not have been fully explored during class.

Up to this point, the course has generally followed a normal college level lean manufacturing class. What differentiates this class is the direct involvement of graduate students in the course work. The graduate students are able to give additional insights to the implementation of lean manufacturing. At the beginning of the course each student is asked to discuss their individual background in manufacturing. Usually the graduate students have much more experience in an industrial setting than an undergraduate, and typically the graduate is also currently employed at a local industrial facility. After introductions and backgrounds have been discussed, the class openly discusses ideas for projects. These project ideas come from the graduate students and depict a current opportunity for improvement the graduate's facility. Depending on the number of graduates and the class size, a finite number of projects are selected from the list.

The class is divided into project groups of four to five students with the graduate student as the "Champion" or team leader. For each team, during the semester, the project requirements are: to take a plant tour of the facility, select a product or production system to review, and then perform an initial assessment of the system using Value Stream Management (Mapping). By mapping the current situation, the group can select an opportunity for improvement by using any one of the lean practices discussed in class.

The team's goal is to analyze the current situation, select an appropriate improvement opportunity, determine the improvements necessary, and determine the benefits of the improvements to the system. Since the team is working in a host environment (the graduate student's facility), actual implementation of the improvements is not a requirement for the project. However, the team is required to determine potential project costs, cost benefits, and payback time for the costs. The team works on the project the entire semester in lieu of excessive homework, other than reading assignments, and several classes are allotted for project time. As a final exam at the end of the semester, each team presents to the class on their project and submits a formal written report typically 10-20 pages.

Many of the companies involved in the lean manufacturing projects indicate that their company would prefer not to have exact details published. Therefore, the company names will be omitted and detailed descriptions of the product that was analyzed has also been kept vague in this report. During the two semesters that the course has been taught, there have been a total of 11 project teams formed and 11 projects successfully investigated. Not all companies are willing make large investments even when the payback justification well exceeds the initial costs. Many of these companies are implementing the changes in phases over several years. An example of several of the final projects are as follows:

- A set-up reduction effort at a local large plastics manufacturing company indicated an annual savings of $1,000,000. This savings would be realized by an increase in machine utilization, reduced labor costs, reduced inventories, improved lead times, and improved quality and safety. The implementation cost for the project was estimated as $260,000 and could be divided into 4 phases.
- A set-up reduction effort at a local metal stamping plant indicated an annual savings of $70,000. This savings would be realized by an implementing SMED and directly reducing the time associated with setting up stamping dies in presses. The implementation cost for the project was estimated as $16,000.
- At a local juice manufacturing facility, a team used the lessons of value stream mapping to introduce Just In Time manufacturing (JIT) along with error proofing (POKA-YOKE) and visual boards for metrics. The team justified an annual savings of $30,000. This savings would be realized by an implementing by rearranging some equipment, installing several error proofing systems, and installing an electronic marquee as a visual board. The implementation cost for the project was estimated as $9,100.
- A team, comprised mainly of engineers at a local metal manufacturing company, investigated if a critical processing turnaround time could be reduced to a single day as opposed to the several day currently needed. The team's efforts indicated that the process could be improved by improving each of the operational cycle time, thus obtaining a larger overall reduction in turnaround time. This was done through a reduction in the individual setup times and changes to each process operation. There was no cost associated with the improvement other than the team's time. Although the team could not reduce the turnaround to only a single day, they did dramatically reduce the

time. A future Kaizen activity is planned, by the company, to determine if additional improvements can be made.
- At a local metal manufacturing plant, a team used value stream mapping to indicate potential areas of improvement. The area of improvement was a manufacturing area within the plant. The team was able to reduce the lead time of the products made in this area by 13% and reduced the total cycle time by 72%. This was accomplished by using cellular manufacturing concepts and rearranging the machines in a pattern that would most optimize the production. The cost of the implementation would only be the internal costs of a maintenance team to rearrange the equipment and involved no material costs.

Benefits

The benefits to the students are substantial. The undergraduates are introduced to actual industrial environments and work on a team led by a knowledgeable industrial sponsor (graduate) who also happens to be a fellow class mate. This method strengthens the tie between the lecture portion of the class and actual application of the material. The graduates not only obtain the same benefit as the undergraduates, but also are given the opportunity to lead a lean manufacturing team and find actual benefits for their respective companies in the area of manufacturing improvements. The companies involved benefit by have a team of knowledgeable individuals analyze a production area and determine justifications for improvements in that area. The choice to implement the improvements at the company's discretion, based on willingness and financial needs.

Although the program heavily relies on the graduate students to represent the company sponsor, this style of course would still be viable without a graduate program present. The requirement to have a company sponsor could be fulfilled by using local companies that are willing to have an employee register for the class and become the team's "Champion". The sponsor companies would benefit by being introduced to lean manufacturing and having a team project basically free of charge.

In the balance of nature, there is seldom a strength without a weakness. The strength of this course is primarily the use of graduate level students leading a team of undergraduates in the pursuit of determining an improvement to a process. In this situation, the graduate student is able to lead a team and obtain leadership qualities and the undergraduate students are able to utilize the industrial knowledge that the leader possesses. Unfortunately, not all individuals have the aptitude for leadership and can actually be a detriment to the team's efforts. It would be the instructor's responsibility to closely monitor the team's progress and be available to lend assistance, as a facilitator, whenever needed in order to keep the team on a viable path. There may the rare case in which an instructor is forced to replace the team's leader if the leader is not of the caliber necessary to motivate and help the team accomplish its goal.

At the end of each semester, students are given an opportunity to express their views on the course material as well as the course instructor. Overall, the students express the opinion that when the course material is delivered via different methods, the knowledge is reinforced more readily. This course is designed to inter-mingle lectures, open discussions, team involvement, simulations, and hands-on applications (projects) in order to strengthen the probability that the knowledge obtained is not a short term event. We believe that the student's education can be improved by using techniques similar to the ones describe for this course, even if the material is not lean manufacturing.

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