AC 2007-516: INTEGRATING LEAN SYSTEMS EDUCATION INTO MANUFACTURING COURSE CURRICULUM VIA INTERDISCIPLINARY COLLABORATION

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Integrating Lean Systems Education into Manufacturing Course Curriculum via Interdisciplinary Collaboration

Abstract

Lean systems have proven to be an effective strategy to increase productivity and cost competitiveness for many companies in the U.S. Lean systems are fundamentally the Toyota management model that utilizes significantly fewer resources to produce a larger variety of products at higher levels of product quality and service. Toyota's success is renowned and is most often attributed to its management, engineering, and workforce being well-educated and highly-efficient in lean systems.

In this paper, we report our recent effort that focuses on integrating lean systems education into a manufacturing course curriculum at our university. At present, most lean manufacturing courses are taught either by engineering faculty alone or by business faculty alone. We take a more effective approach by forming an interdisciplinary faculty team to develop and co-teach a new Lean course at our university. Our team consists of faculty from both engineering and business and takes advantage of the expertise of each faculty member. The interdisciplinary nature of the course is beneficial to the students because they begin to see the necessity of coordinating the world of design (process design and product design) and process problem solving.

Our Lean course attracts student enrollment from five departments in the College of Engineering and the College of Business. Through interdisciplinary collaboration, we have designed and implemented two pedagogical approaches: a Lean Lego Simulation (LLS) and student-company team projects via close collaboration with the local companies. This paper introduces in detail how the two pedagogical approaches are performed and their impact on student learning with diversified background. The paper also describes the general framework and contents of our course. Both the experiences we have gained and the lessons we have learned are shared with the educational community in order to support continuous improvement to the Lean curriculum.

Background Introduction

The U.S. manufacturing industry has suffered in the recent economic recession. In 2001-2004, 2.7 million manufacturing jobs have left the U.S. to Mexico, Taiwan, China, Thailand, Malaysia, Eastern Europe, and South America [1]. As an increasing number of U.S. companies are outsourcing manufacturing operations to foreign countries that have cheaper labor markets, the issues of keeping manufacturing jobs in America and increasing the competitiveness of the U.S. manufacturing industry have become critical to the long-term sustainable prosperity of the U.S. economy and its technological progress.

Lean systems (or lean manufacturing systems) have proven to be an effective strategy to increase productivity and cost competitiveness for many companies in the United States [2]. Distinguished from traditional mass production systems, lean systems are fundamentally the Toyota management model that utilizes significantly fewer resources to produce a larger variety of products at higher levels of product quality and service [3,4]. Toyota has achieved its renowned success through a completely aligned set of management systems, which rely on the complete engagement of managers and engineers in these systems. In addition, factory and office workers are trained in problem solving and encouraged to participate in the rapid improvement process.

Over the last 15 years, lean systems has gained interest and application in a variety of industries, going far beyond its initial beginnings in the automotive manufacturing sector to the aerospace, defense, communication and medical equipment-manufacturing sectors. The Lean systems strategy has been employed not only at the shop-floor of large and medium sized manufacturing enterprises, but also at small manufacturing companies [5,6]. Manufacturing companies who have applied lean systems have typically seen cost and space reductions of over 30%, inventory and throughput time reductions of well over 50%, and reduction in quality defects of 50% or more. For example, Autoliv Inc., a Swedish automotive safety company with plants in Utah, has reported that applying LM principles has resulted in a 52 percent reduction in scrap costs, a 32 percent drop in defects per million, and productivity improvements of 36 percent [7].

Lean systems also help create manufacturing jobs that are more meaningful, challenging, and rewarding for all employees. Lean systems focus on giving employees more responsibility for designing and improving their own work. This requires significant additional training and skills. In the end these jobs are harder to move offshore as long as they support sales within North America.

Today, companies are demanding engineering and business students who have a background in lean system principles and techniques, in addition to the traditional technical preparation. This demand is particularly evident from the Manufacturing Education Plan (MEP) of the Society of Manufacturing Engineers Education Foundation. SME is making an aggressive push with North American industry and universities and colleges to ensure that new graduates acquire the appropriate knowledge and skills to become effective contributors in the manufacturing workforce and more importantly, to "hit the ground running" once they leave school. Working with numerous manufacturing practitioners, the MEP has identified 15 competency gaps that need to be closed between industry's manufacturing workforce requirements and current educational programs [8]. Lean systems aim to manufacture products with 1) low cost, 2) high quality, 3) short delivery time, 4) high safety, and 5) high morale. All five dimensions require the training in three skills: technical, professional, and business. The absence of any one of these three skills has a negative effect on all five dimensions. Lean systems education directly addresses at least five high priority competency gaps that the Society of Manufacturing Engineers has identified: 1) business knowledge/skills, 2) supply chain management, 3) project management, 4) communication skills, and 5) teamwork.

In this paper, we report the results of our recent efforts on integrating lean systems education (particularly lean thinking) into manufacturing course curriculum at our university. We have developed and co-taught a new Lean course through close interdisciplinary collaboration between engineering and business faculty. The paper starts from a brief introduction to the course objectives and features. Because there is no formal textbook available to address our particular course objectives, we have designed and developed our own course materials. A detailed description of the course syllabus and contents is then provided in this paper. A particular focus is given to the introduction of two pedagogical approaches that we have designed for and implemented in our Lean course. One approach is a "Lean Lego Simulation (LLS)," and the other approach is "Student-Company Team Projects." It is described in detail how the two pedagogical approaches are performed and their impact on student learning with diversified background. Both the experience we have gained and the lessons we have learned are shared with the educational community in order to provide a continuous improvement to the Lean curriculum.

Course Objectives and Features

Since lean systems and lean thinking were introduced in the United States in the early 80s, there have been many different descriptions of the concept [9-12]. For the purposes of our course, lean thinking is a comprehensive management framework that encompasses the entire organization, and focuses on creating value or the converse, i.e., the identification and elimination of waste.

Bearing this mind, we have defined the overall goal of our course — educate students with lean systems principles, which shape lean thinking, and associated techniques, so students can have competitive advantages in the job marketplace in 21st century. The three specific course objectives are as follows:

1) Develop an understanding of basic fundamental principles of lean systems that can be used to eliminate waste in modern manufacturing environment.
2) Master essential lean system techniques through hands-on project training.
3) Improve communication skills for students and promote interdisciplinary collaboration in team work environment.

The course combines three important features as follows:

1) Close interdisciplinary collaboration among engineering and business: At present, most lean courses are taught either by engineering faculty alone or by business faculty alone. We take a more effective approach by forming an interdisciplinary faculty team to develop and co-teach the Lean course. Our team consists of faculty members from both engineering and business and takes advantage of the expertise of each faculty member. The interdisciplinary nature of the course is beneficial to the students because they begin to see the necessity of coordination, the world of design (process design and product design), and problem solving [13-15].

2) Direct involvement of lean industry in student education: In addition to plant tours and guest lectures, students directly work with industrial professionals on real-world lean projects. Knowledge gained through hands-on real projects is invaluable in helping students better understand engineering and business principles and applications. This will be introduced in detail later in this paper.

3) Unique learning experiences through Lean Lego Simulation (LLS): Hands on simulations have been widely used in teaching a variety of engineering courses [16]. Sometimes, these simulations are done with legos, using ten to twenty pieces and taking about an hour. However, our lego car uses 45 pieces and takes about 6 hours, which we divide between

two sessions. Our purpose is to show students, through hands-on Lego experiences, a variety of benefits from lean production. In addition, because of the complexity of the assembly, the students also learn to improve the process using lean tools. Our unique LLS approach will also be described in detail later in this paper.

Course Framework and Contents

The course was designed to be a balance between reading and discussion of the body of knowledge at an introductory level, and experiential learning through the simulation and real company projects. We structured the course to fit the basic principles from the "House of Toyota" [17, 18]. The House of Toyota has become the most common way to show the framework and also supports the definition of a body of knowledge rubric. We designed the core framework topics of the course in the same order as would be dictated by the scientific method, which is fundamental to the "House of Toyota" approach [17, 18], which includes 1) understanding the operation and establish stability and standardization, and 2) the pillars of the house that support continuous improvement, such as making material flow according to customer demand, Jidoka (make no defect), and the power of employee involvement and respect for humanity.

Because there is no textbook available that sufficiently meets our course objectives and covers the learning topics designed in our course syllabus, we have developed our own course materials. Realizing that one single course cannot cover all aspects of lean system, we have selected the most fundamental and important lean concepts and theories to teach. Table 1 shows a shortened version of the course syllabus (contents).

Table 1. Course contents

Week	Contents	Week	Contents
1	Introduction to Lean Manufacturing and The "People" Side of Lean	9	University Spring Break
2	Defining Value and Value Stream Mapping	10	Quality and Problem Solving and Plant Tour (II)
3	Waste Identification and Elimination	11	Lean Supply Chain Management and Plant Tour (III)
4	Stability and Standardization	12	Business Results and Lean Lego Simulation (II)
5	Just-In-Time (I)	13	Student-Company Team Projects
6	Just-In-Time (II) and Pant Tour (I)	14	Student-Company Team Projects
7	Lean Lego Simulation I and SMED	15	Student-Company Team Projects
8	Lean Product Design		

The course began with a discussion of the "thinking" differences between lean and traditional manufacturing frameworks, and a view of the people side of manufacturing. This section was especially beneficial to the engineering students who have little exposure to these concepts. Since there was a clear connection made between manufacturing and the need to create value for customers and society, through safety, quality, cost, delivery, and protecting the environment, we particularly highlighted the importance of the "people" and "customer" side of manufacturing.

Topics such as identifying the exact needs of customers, cost of product development, break-even analysis, etc., were discussed in the class.

Two weeks were devoted to learn fundamental and critical lean concepts. Particular emphasis was given to value stream mapping, which teaches students to see the whole picture of how products flow throughout the value stream, that is from raw material to delivery to the customer (for the production area) and from concept to launch of a new product (for the design area). Value stream mapping also provides students an effective tool to achieve continuous improvement and enhanced value in a company. In classroom lectures, we started from the introduction of the concept of a value stream and the different levels of value stream mapping (from mapping a single process to mapping across multiple companies). We introduced different icons for mapping the material and information flow, and explained when they were used. Then, an example of mapping a current value stream within one company was explained in detail. Students were engaged in a discussion to identify the benefits of value stream mapping to a company. A "roadmap" for drawing a value stream was provided for the students. To practice the concept, students drew a current state map for a case study taken from a reference book [19]. The concept of the future state map and how to achieve it were also explained.

Three weeks were devoted to the demonstration of the importance of system stability and standardization as well as an important lean technique of Just-In-Time manufacturing. Our engineering instructor brought real-world examples to illustrate how to conduct lean product design and analyze manufacturing costs of different designs. Product built-in quality, the concept of supply chain management, and business results were dealt with to a level of depth and breadth that is appropriate to the background of the students.

During the course, we arranged three plant tours for students to visit two local lean plants and one not-lean-yet plant for comparison purposes. The Lean Lego Simulation was conducted twice (Phases I and II) in the class, one in the middle and the other near the end of the course. The last three weeks of the course were allocated for students to work "full-time" on their company team projects. There were no classroom lectures during the last three weeks, but the instructors worked with the students to go through the entire problem solving process following the scientific method, and coordinated with local plants that provided real-world projects to our students. The course ended with students giving oral presentations to a group of plant managers and front-line workers at the respective companies about their recommendations and what they learned from the projects.

Pedagogical Approach #1: Lean Lego Simulation (LLS)

The purpose of Lean Lego Simulation (LLS) is to show students a variety of benefits from lean production and to provide an opportunity to improve a process through hands-on experiences. Lean principles demonstrated in the LLS include reduced inventory through pull systems, better throughput by designing flexible work cells, improved communication and worker motivation through visible systems, the importance of teams and appropriate teamwork processes, and the scientific method for problem solving and learning.

Students were grouped into teams, which competed to create the most profitable production line for Lego cars over two extended class periods (Phases I and II) of three hours each. In Phase I, students became familiar with the Lego cars and the production process, and established the baselines for productivity, inventory, labor, space, and output. Then they were encouraged to apply concepts from the class to improve the assembly operation. We required students to come up with the basic improvements by transforming from batch flow production to lean single piece flow, and students experienced the human benefits of participation and empowerment.

Each team was given several weeks to study and plan for the final Phase II session, which resulted in additional improvements. The simulation in Phase II further helped students appreciate the power of the simple concepts of waste elimination, standard work and flow to significantly improve upon even single piece flow. In the end, both student teams had significant increases in output, attributable to the process design changes. All students found the simulation fun, challenging, and the competitive nature of the simulation made it more realistic.

In this section, we introduce how our LLS works. To start the simulation, we established a batch flow process for assembling a Lego car with 45 components (see those assembled cars in Figure 1) and five work stations. We purchased 150 car kits and divided the class into two teams with 7-8 students on each team. Students in each team were assigned different roles (supervisor, line worker, material handler, or timekeeper/observer). Role statements are shown in Table 2.

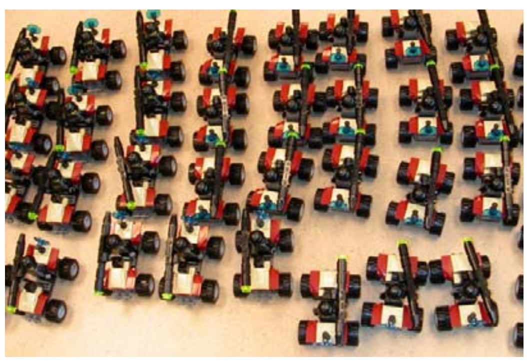

Figure 1. Lego's cars that students built for lean simulation

All materials were placed on a table in the back of the room, and material handlers were required to bring parts from the "stockroom" (back table) to the "work stations," in small batches defined by how much could fit in the fictional cart. Clearly a person could not move more than four tires at one time in a manual cart.

Both Phase I and Phase II of our LLS comprised three rounds. Take Phase I as an example. In round one, the line workers were allowed to practice building cars at their stations, and material handlers were able to get to know the components and how many were needed at each station. Then each team was allowed to run their process for 15 minutes. A shorter amount of time would not allow the processes to stabilize or for process problems to occur. Based upon pre-timed station cycle times, the process should have produced a batch of three cars every three minutes. However, neither team was able to get past 10 cars in the 15 minutes. Each team had several places in the line with more than double the planned work-in-process inventory. Even

Table 2. Role statement employed in Lean Lego Simulation

Role	Role statement
Supervisor	You are responsible for quantity and quality of output. However, you are not trained as a worker in this process, so you cannot do the work. Workers see you as not knowing what they do, so should be careful not to tell them how to do their work. You can encourage, motivate and reprimand workers in order to maximize the quantity and quality of their work.
Line worker	You are a skilled line worker who is paid by the hour, but your bonus and job performance evaluation are heavily weighted on your output quantity and quality. Your job is defined and you cannot change it. You work in batches of three, assigned to one of the work stations below: 1. Assemble bazooka and soldier 2. Chassis Assembly steps 1-3 3. Body Assembly steps 4-6 4. Accessories Assembly steps 7-9 5. Mount tires on wheels and mount wheels on jeep You can only do one of the tasks, and you are not cross trained on any other station. A material handler will bring you the parts you need, but it is your job to sort and inspect the parts after they arrive.
Material handler	You are responsible for getting materials to the line. Central inventories are kept in the back of the room. You may transport the equivalent of four units of materials in one trip, except for wheels and tires. Because of the sheer size of the tires, you must make two additional trips with 8 tires and 8 rims per trip. You have a forklift (a large Ziploc Tray) in which to transport material to your line. When you deliver parts to the line, you must give each station the right parts, but you are not required to organize or even separate the parts.
Timekeeper /observer	Your role is to observe the entire process in order to provide feedback to the team after the process. You should measure the total throughput at least once in the middle of the production period. You should also measure the cycle time per unit at each station.

still, each line had other stations in the line starved for components on many occasions. Detailed production and inventory records were recorded after round one.

In round two, the teams were encouraged to redefine their roles and to switch to single piece flow. Teams were allowed 30 minutes to conduct a rapid improvement event to define the new process and role statements. Both teams made significant changes in the material handler processes, and added material handlers to assure that material shortages were eliminated. Supervisors were converted to team leaders who could help throughout the process where needed. The assembly process was not changed, other than to eliminate batches. Then, the students were allowed to run their processes for 15 minutes. This time, inventories were less, but some stations still had excess inventory. The teams had not focused on pull, but rather had only eliminated batching. However, output jumped to over 20 cars in 15 minutes.

Finally in round three, the teams were encouraged to apply the key principles of pull and flow, and eliminating obvious wastes. Another 30 minutes were allowed for a rapid improvement event. As would be expected, additional improvement was achieved. However, the improvement was startling. Each team surpassed 40 units in 15 minutes, and the inventory was limited to one active unit in each station. Teams created work cells that supported much better cooperation and cross training between cells. They also enhanced cooperation between material handlers and line workers, establishing better methods of communicating and delivery.

Pedagogical Approach #2: Student-Company Team Projects

Through close collaboration with local companies, we organized three tours for students to visit one "net-yet-lean" plant and two lean plants for comparison purposes. For example, students visited a leading manufacturer of automotive safety airbags and a leading manufacturer of furniture. Through these two plant tours, students were impressed with the successful applications of lean principles in industry.

All these hands-on experiences (Lean Lego Simulation and plant tours) are finally enhanced by students working on real-world lean projects (as their final course projects) provided by a national brand bakery plant that makes famous cookies and frozen bread, and a local electronics assembly company.

Students formed three project teams with both business and engineering students on each team. One project was in the truck loading area (manually stacking boxes in the truck), another in the assortment packaging area (packaging boxes that contain not only one but an assortment of different cookies), and the final team worked in a board coating area. Working closely with a manager, engineers and front line workers at the plants, students created a current-state value stream map, identified the problem, determined the scope and the focus of the projects, collected detailed information on both material and information flow, and offered possible solutions for improvements. Each project team made at least six visits to the plant. In the end, each team made an oral presentation about their data analysis and improvement suggestions to a group of plant managers, which included top managers, engineers, and some employees in the area they worked on.

Take the truck-loading project as an example. The plant sends daily trailers to their distribution centers in the Midwest and the East coast. The current technique of loading these trailers was "floor loading," meaning boxes are manually stacked on the truck floor to the maximal high possible. Floor loading is labor intensive because all boxes have to be first manually stacked in the truck at the manufacturing facility and then stacked onto pallets at the distribution center. On the other hand, the "floor loading" practice maximizes the use of trailers. Thus, the question is if floor loading is the most economical solution.

The "truck-loading" student team first observed the floor loading process and came with different ideas for improvements. To apply the lean problem-solving approach, we required students to provide quantitative data to support their improvement ideas. Working with the plant Lean coordinator and front line workers, the team collected data about quantities and the cost of the current shipping method. Based on the collected data, the team came up with alternative, optimized shipping methods. The team suggested two alternative methods: 1) pallet loading the truck with a single layer of pallets, and 2) two pallets stacked one over the other. They further developed stacking patterns for the different box sizes on the pallets, analyzed the overall pros and cons of each alternative method, and made a cost comparison for the three products that were shipped the most.

Student Evaluation

Our Lean course attracted student enrollment from five departments in the Colleges of Engineering and Business. Internal course evaluation was completed at the end of the semester. Students were asked to evaluate the project results in two broad categories: "overall quality of the course" and "effective of the instructor." Each category has more than 10 Likert-type questions. Students' comments on the course were overwhelming positive. They liked having three professors from differing departments, especially the mix of engineering and business. This gave them different perspectives and teaching styles, which added to the enthusiasm the students felt from the faculty. Students appreciated the variety of assessment methods, which included short essay exams, a competition with the Lego simulation, presentations from team activities, and the project write-up. They unanimously felt the plant tours were great. They would have liked to do more. Some of the students' comments are provided here: "It was great to finally have a class that combines engineering and business," "Plant tours ere extremely helpful to see actual implementation of Lean," "The class simulation of building cars was excellent."

At the time of writing this paper, the data for formative and summative evaluation is being collected by an external evaluator of the course. The purpose is to measure how well the course is working in terms of faculty collaboration and student achievements.

Experiences Gained and Lessons Learned

The students liked the Lean Lego Simulation, which was the most popular classroom activity. An interesting observation made in LLS was the importance of the people side of Lean. During round one, there was significant confusion and poor communication among students, which resulted in a noisy environment with students yelling to and at each other. Round two was quieter. Round three was almost peaceful, with workers proceeding at a relaxed pace with confidence and focus.

Another phenomenon we observed in LLS is the team frustration with a supervisor who had no knowledge of the process and no interest in helping. The teams had a strong sense of their own teamwork or lack of it. One team definitely clicked more than the other. The poor team was unanimously envious of the other teams' culture.

As to the overall facilitation of LLS, we strongly felt that we need to create a more clear definition of the costs of inventory (for example some costs per component and space requirements) and to introduce some design change in the product that would display the cost of converting or scrapping all the inventory. Of course, the component costs will have to be kept relative to the labor costs. This is what we will work on the next summer. We also need to develop more precise discussion questions, which will provide better lessons learned for the students. One thing in particular we learned was that the students were able to improve their systems so much that we didn't have enough cars to run the simulation for over ten minutes in the last round.

The students also liked real company projects, which provided them an excellent opportunity to apply what they have learned from the class to solve real-world problems. However, we delayed the start of the company projects with the intention to allow the students to learn more of the basic concepts before starting the projects. This put a heavy burden on the students during the last month of classes, just prior to final exams. Students were rushed and didn't have sufficient time to do everything that they wanted on the projects.

Therefore, we will schedule a plant tour earlier in the next class to get students excited about their projects. Then we will get the teams started on the project within the first month of the semester. Even though they will not be able to completely understand the problems or be able to solve them, these real life examples will be beneficial as examples for classroom discussions. Starting early will allow students to make more visits to the companies sponsoring their projects, and especially to finish the project early.

The final experience we have gained from our teaching the Lean course is on our re-thinking of how one can teach a class about lean systems that focus on continuous improvement and creating value. Traditional lean books, courses, and consultants spend a significant amount of time showing experienced managers the errors in their current way of thinking. We found that we do not need to cover this in a class of college students. Before taking the class, engineering and business students have not developed all of the incorrect principles and practices, and they find lean systems quite intuitive. Traditional models and thinking are so counterintuitive to students that discussing them in detail only confuses students. Therefore, in our future classes, we plan to remove all discussion of the traditional views except for the initial introduction of the history of automobile manufacturing. In short, one does not have to teach students the wrong way in order to then teach them the right way.

Concluding Remarks

As an increasingly growing number of U.S. companies outsource manufacturing operations to foreign countries that have cheaper labor markets, there is a growing need to keep manufacturing in the U.S. and maintain long-term sustainable prosperity of the U.S. economy and its technological progress. Lean systems have proven to be an effective approach to increase productivity and cost competitiveness of the U.S. companies.

We have reported in this paper how we integrated lean systems education into manufacturing course curriculum via interdisciplinary collaboration between business and engineering. Our Lean course is a balance between reading and discussion of the body of knowledge at an introductory level, and experiential learning through a Lean Lego Simulation and real company projects. We have described in detail the framework of the course, its major contents, and the step-by-step demonstration of how the Lean Lego Simulation—a new instructional pedagogy we designed for and implemented in the course—can be performed.

We believe our experiences gained and lessons learned from the teaching of the lean course can serve as an important basis for future continuous improvement in the Lean curriculum; thus, the experiences and lessons reported in this paper are valuable to our educational community.

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