# AC 2008-2680: TEACHING CONCEPTS OF LEAN MANUFACTURING THROUGH A HANDS-ON LABORATORY COURSE

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# Teaching Concepts of Lean Manufacturing through a Hands-on Laboratory Course


## Abstract

The use of lean manufacturing principles has grown significantly in recent years. Although these principles make use of many Industrial Engineering methods, there is still limited coverage of lean manufacturing in many Industrial Engineering programs. This may be due to reluctance to add additional courses to existing degree requirements, or a difficulty in bringing together lean concepts that are often scattered among existing courses in the curriculum.

To integrate lean principles into the Industrial and Systems Engineering curriculum at Ohio University, a laboratory course was developed. The course integrated methods taught in other ISE courses and demonstrated how these methods related the concept of a lean system. The laboratory approach was taken to enable students to gain hands-on experience in lean principles. The laboratory course met one day a week, which also made fitting the course into their schedules easier for the students.

This paper provides an overview of the activities that were conducted in the laboratory sessions to demonstrate lean principles. The paper also discusses the supporting materials, including introductory lectures and out-of-class work. Observations from the instructor of the course and the students participating in it are also included.


## Introduction

Interest in the topic of Lean Manufacturing (or, more generally, Lean Systems) has increased significantly in the past several years. Although many of the methods used in Lean have been used by industrial engineers for many years, their organization into a single methodology called “lean” has raised the profile of the methods in industry.

The motivation to teach the topic of lean at Ohio University was encouraged by feedback (directly and indirectly) from employers. Several employers of co-op students indicated on the evaluations that were completed at the end of a student’s term that one area in which students could improve is in their knowledge of lean principles. In addition, some graduating students reported that in job interviews, they were asked about their experience with lean.

However, while there appeared to be a demand for covering lean within the curriculum, the difficulty lay with finding a place for it.

One option would have been to incorporate lean into an existing class. However, since the related topics are covered in multiple required and elective courses, there wasn’t an apparent existing course that would be a good fit for adding the material on lean. In addition, incorporating the lean material into an existing course would have required dropping material that was already being covered, which would have been difficult to justify.

Another option would have been to create a new course devoted solely to lean topics, but this would have also had disadvantages. Creating such a course would have placed a burden on faculty to staff the course and a burden on students as well, to fit another three or four credit course into their schedule.

The creation of a 1-credit lab-based course served as a compromise in allowing a course on lean to be offered without adding a significant burden to the faculty or students. The lab-based structure of the course also served the content well, since it provided students with the opportunity to see the application of the principles and not just read or hear about them.

The course was designed to be taken by seniors, as it relied on the fact that students had already taken courses on topics like Work Design, so that less coverage of these topics needed to be done in the workshop.

One additional aspect of the course is that it was designed for a ten-week schedule because Ohio University uses a quarter-based calendar. However, for schools on a semester schedule, additional material on lean topics could be incorporated to expand the course to fill the remaining weeks.

**Background Information**

The term 'Lean Production' was coined by Womack et al. in 1991[1]. The basic premise was 'doing more with less'. Womack et al. outlined a set of 5 principles towards implementing and sustaining a lean production environment. They are

- Identify value of the product or service as perceived by the customer
- Investigate the stream of activities involved in the design-to-market cycle of the product to separate value-adding activities from non-value-adding activities (wastes)
- Ensure continuous flow of value-adding activities
- Ensure a pull system where the customer drives production
- Strive for perfection through continuous improvement

. Each of these principles can be implemented using various techniques. Value-Stream Mapping (VSM) facilitates clear understanding of the sequence of activities involved in creating the product which enables easy identification of wastes in the process. A continuous flow of parts, in contrast to batch production, reduces inventory, and improves response times. A successful implementation of *kanban* system ensures that production is triggered by actual customer orders thus avoiding excess production. *Kaizen* activities are aimed towards continuously improving existing systems and processes by eliminating wastes.

In today's world of global competition and shrinking markets, it is vital for companies to reduce operating costs in order to remain profitable. Lean principles are a means towards this end. Thus, equipping themselves with the knowledge and understanding of these aforementioned techniques is imperative for industrial engineers. Some of these techniques are already included in the Industrial Engineering curricula under different courses. However, seeing how these individual techniques can be combined together effectively to reap remarkable rewards for the company is important.

The course titled 'Lean Manufacturing Workshop' was designed and developed in the Industrial and Systems Engineering Department at Ohio University with this objective in mind. Since a hands-on learning experience better illustrates the practical implications of the various techniques, the course was structured to include a substantial amount of hands-on activities using LEGO-Models apart from the regular in-class presentations.

**Course Outline**

The objective of the course titled 'Lean Manufacturing Workshop' offered at Ohio University in the spring quarter of 2006-07 was to familiarize senior-level students with various lean manufacturing concepts through hands-on LEGO Model-based simulation exercises and in-class presentations. During the course of their undergraduate program in Industrial and Systems Engineering at Ohio University, students are exposed to various industrial engineering methods and tools. This course demonstrated the application of these methods and tools in a lean environment to achieve lean objectives.

Since no single book covered all the aforementioned topics in sufficient detail (in the authors' opinion), no particular book was assigned for this course. The other option was to prescribe multiple textbooks which would have put undue stress on the students' budget. In lieu of this, lecture notes were handed out each week. These lecture notes were prepared based on multiple sources which included books, news articles, journal papers, and websites. Each package had a list of references related to the topic at the end for the more inquisitive students. The slides for the in-class presentations were also made available to the students in advance. At the end of the course, a comprehensive bibliography arranged topic-wise was handed out to the students. Another hand-out describing the various terms commonly used in lean literature was also handed out for easy reference. Sample copies of the various forms used during the course were also distributed to the students.

The course was designed for 10 weeks with the class meeting once a week for 2 hours. The following was course plan adopted:

- **Week 1** – Introduction to Lean Manufacturing and Toyota Production System – This included a detailed study of the Toyota Production system and its elements followed by a brief discussion on the origins of Lean Manufacturing.
- **Week 2** – Value-Stream Mapping (VSM) and Waste Identification – The 7 types of waste were studied and the importance of value-stream mapping in identifying wastes in the process was discussed.
- **Week 3** – Continuous Flow – A comparison between batch-production and continuous-flow production with their respective merits and demerits were discussed.
- **Week 4** – Work Leveling / Line Balancing / SMED – The concepts of line balancing were introduced followed by a brief overview of the Single Minute Exchange of Dies (SMED) concept and the importance of reducing set-up times.
- **Week 5** – Pull Systems / *kanban* – Different kinds of push and pull systems with their advantages and disadvantages were studied.

- **Week 6** – Continuous Improvement / *kaizen* – The importance of continuously improving the process and the system in order to reduce costs and eliminate wastes through *kaizen* activities was studied.
- **Week 7** – Standardized Work / *poka-yoke* – Techniques to eliminate mistakes and reduce scrap/rework through mistake-proofing devices and standardized work procedures were examined in detail.
- **Week 8** – Total Preventive Maintenance (TPM) / Performance Measurements – Concepts and techniques to implement TPM were dealt with followed by a brief look at how to evaluate the implementation of various lean concepts through performance measurements.
- **Week 9** – Workplace Organization / *5S* – Techniques to maintain order both at the office and the factory were elaborated upon using concepts of 5S.
- **Week 10** – Lean and 6-Sigma / Lean Applications – The complementary behaviors of Lean and 6-Sigma were touched upon followed by applications of Lean Concepts in other areas like Supply Chain, Warehousing, Software Development and Financial Accounting were discussed.

The general format adopted during each class was a 45-60 minute in-class presentation followed by an activity designed to illustrate the concept discussed during the lecture. Depending upon the nature of the activity, the students were expected to perform the activity either individually or in groups of 2-3. Upon completion of the activity, a quiz was conducted in order to evaluate the students on the concepts covered during the presentation and the activity.

At the end of each class session, the students were also asked to fill out a feedback form. This was designed in order to gauge the effectiveness of the different learning techniques employed in the session and how these could be improved upon. The results of the student feedback are discussed later.

In order to provide a hands-on experience for students, a series of activities were designed to illustrate the various lean concepts. Most of these activities utilized LEGO Models. A LEGO Model with sufficient complexity in terms of number of individual parts and method of assembly was selected. The selected LEGO-Model could be used to assemble multiple types of motorcycles (see Figure 1) out of the same set of parts. This was particularly useful when using *kanban* cards to incorporate product variety.

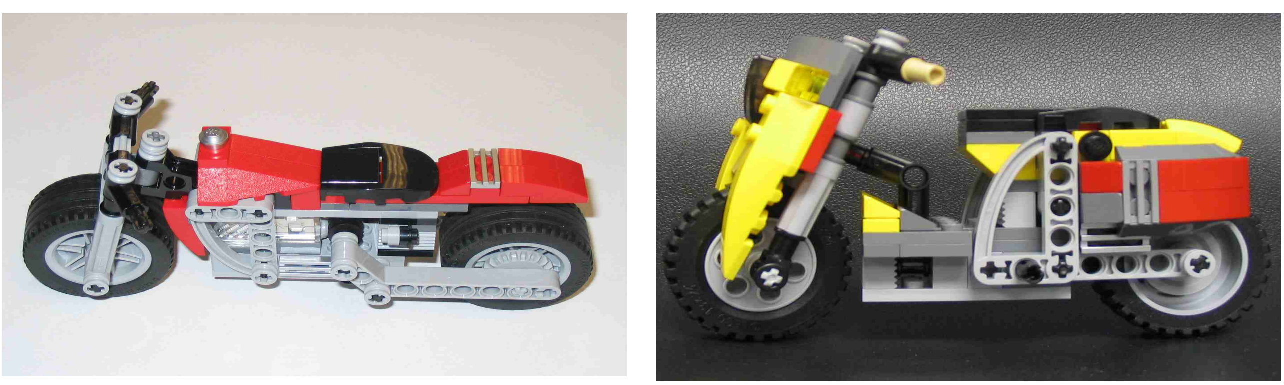

**Figure 1 Examples of Motorcycle Models**

The assembly of the motorcycles was divided into different numbers of stages depending on the number of groups being used for an activity. The assembly instructions that came from the manufacturer with the models were used with instructions on the steps to be followed at each stage. The stages were designed such that the entire motorcycle was assembled by the last station and hence, the students could see what their role was in the final product.

The activities were carried out in a room where the tables could be re-arranged according to the needs of the activity. Posters (See Figure 2) depicting various lean concepts were also displayed in order to create the required ambience.


**Figure 2 Posters in the Activity Room**

**Weekly Activities**

A brief description of the various activities designed is given below.

- **Value-Stream Mapping –** The students were divided into groups of four and each group was given a different case-study. Each group was provided with a blank sheet of paper, post-it notes and marker pens and the group was expected to develop the current-state map (See Figure 3) for the case given using the standard value-stream icons discussed in class. As a take-home assignment, each group was also required to turn in the future-state map with the improvements to eliminate wastes and reduce lead-times and inventories.

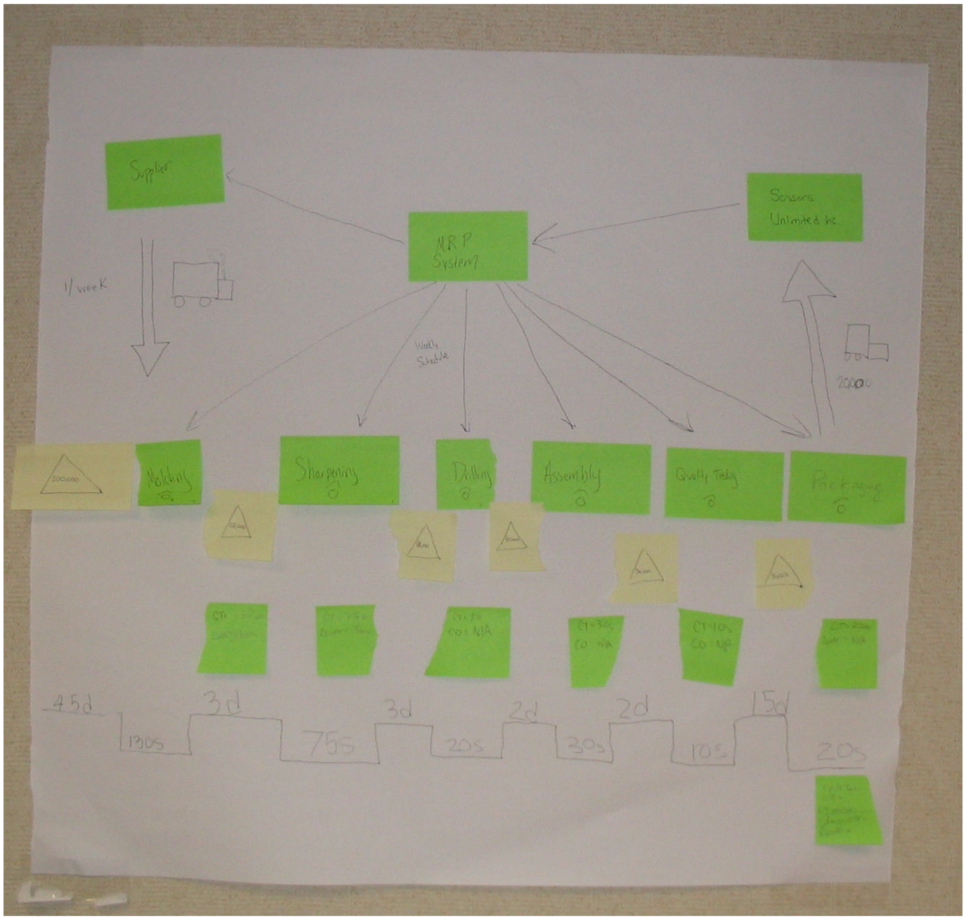


**Figure 3 Value-Stream Mapping Exercise**

- **Continuous Flow** – In order to better illustrate the importance and usefulness of continuous flow, the students were first required to assemble a LEGO-Model in the batch-production mode (See Figure 4). Each workstation (See Figure 5) was well-organized with the required steps of assembly clearly indicated and a sample of the partially assembled product exhibited at each stage. This exercise was designed to give the students a feel of batch production and the issues associated with it. In the second part of the activity, the layout was changed to a U-Layout and the students assembled the LEGO-Model in a continuous flow mode (See Figure 6).


**Figure 4 Production Line Set up for Batch Production**

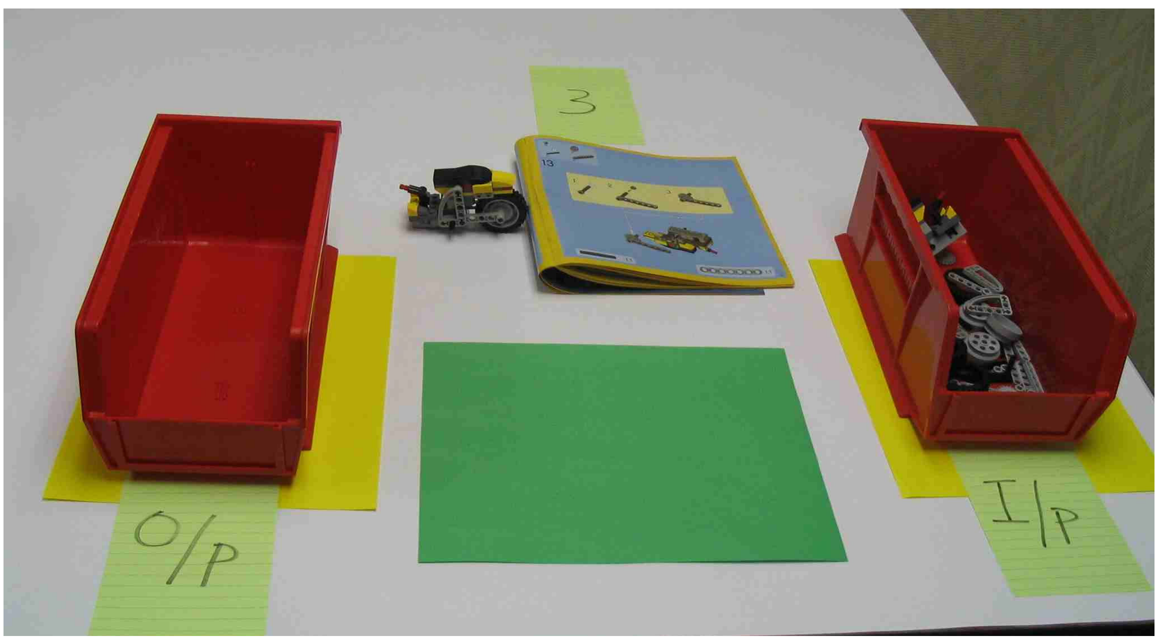


**Figure 5 Typical Workstation on the Production Line**


**Figure 6 Production Line Set up for Continuous Flow**

- **Work Leveling –** Toyota's Goal Chasing algorithm was used to illustrate the work leveling concept. Students were divided into groups of two and were each assigned a case where they were expected to use the Goal Chasing algorithm to balance the production.

- **Pull Systems –** The students were divided into groups of two and were first engaged in assembling a LEGO-Model with each step in the assembly process pushing the sub-assemblies to the next stage. Following this exercise, the production line was converted to a pull system (See Figure 7). The students used *kanban* cards (See Figure 8) so that they assembled only what was needed to replace the parts that had been taken from their station by the preceding station.

**Figure 7 Layout of Production Line for Pull System**

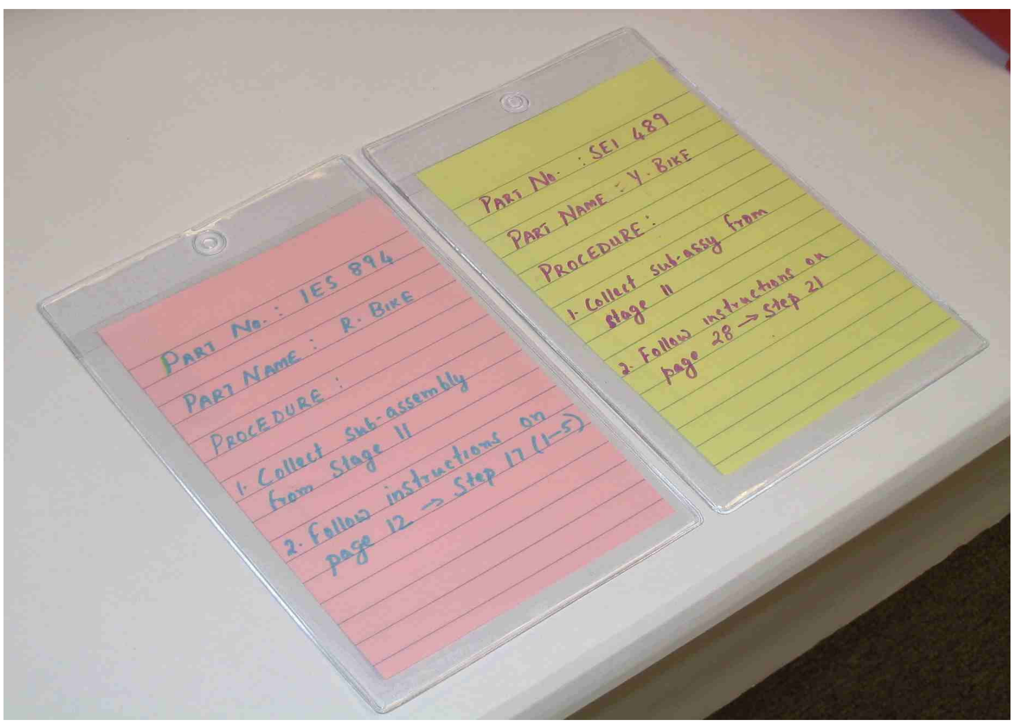


**Figure 8 Pull System Activity - Kanban Cards**

- **Setup Time Reduction** – Using the Walking Route diagram and Setup Combination Worksheet[3], the students were expected to work in groups of two on a case to reduce the setup times by charting the before-improvement and after-improvement operations.

- **Continuous Improvement / *kaizen*** – Using the various forms[4] for identifying, implementing and recording improvement like Suggestion Form, Event Area Selection, Event Feedback, Event Preparation Checklist, Materials and Equipment Checklist, Team Leader Checklist, and Waste Categories, the process of implementing continuous improvement on the shop-floor was illustrated with an example.

- **Standardized Work / *poka-yoke*** – The procedures used to develop standardized work and methods were illustrated with the help of examples using the various forms like Job Element Sheet[1], Motion Diagram[3], Production Capacity Chart[1], Standard Operations Pointers Chart[11], Standard Work Combination Sheet[1], Standard Work Sheet[1] and Work Methods Chart[11].

- **Total Preventive Maintenance** – The methodology to implement and sustain TPM activities on the shop-floor was illustrated through examples using sample forms like Equipment Operations Analysis Chart[4], Equipment Problem-Solving Plan[4], Hourly Production Record[4], Malfunction Cause and Treatment Chart[4], Minor Stoppage Cause Sheet[4], P-M Analysis[7], Pre-Shift Check Sheet[4], TPM Survey[4], and TPM Team Meeting Evaluation[4]. Videos[8] of actual implementations of TPM were also shown to the class. The students were also asked to solve in groups a case-study dealing with Overall Equipment Efficiency (OEE).

- **Workplace Organization** – In order to experience a highly disorganized workplace, students were asked to assemble the LEGO-Model without any instructions and with many evident signs of disarray as shown in Figure 9.

**Figure 9 Workplace Organization Activity - Disorganized Workspace**

Following this, students experienced a highly organized workplace replete with visual indicators (See Figure 10) and clear instructions (See Figure 11). This enabled the students to appreciate the importance of having an organized workplace.


**Figure 10 Workplace Organization Activity - Sample Visual Indicators**


**Figure 11 Workplace Organization Activity - Organized Workspace**

Techniques and tools used to organize the workplace were also illustrated with the help of examples using forms like 30-Day 5S Action Log[3], 5S Evaluation Review[3], 5S Map[3], 5S Sustainment Schedule[3], Clipboard Checklist[4], Meeting Worksheet[4], Opportunity Watch Card[4], Recognition Watch Card[4], Red Tag[3], and Wall Chart Checklist[4]. Example were also shown on applying 5S concepts in the office area with the help of 5S Office Evaluation Review[3], Autonomous Maintenance Calendar[5], Blue Tag[5], Blue Tag Register[5], Blue Tag Schedule[5], Filing Cabinet Index[5], Master Index of Documents[5], Meeting Worksheet[5], Moving File Label[5], Needs and Want Matrix[5], Ownership Matrix[5], and Permanent File Label[5].

- **Lean Concepts in Supply Chain Management –** The popular Beer Game[8] was used to illustrate the bull-whip effect in a supply chain environment. Flash cards were used in place of pennies.

**Student Feedback**

Since the course was being offered for the first time at_________________, feedback was collected from students after each session in order to improve their learning experience in the following sessions. Some of the comments from the students are given below

> "I liked the idea of using Lego's to demonstrate the flow process"
> "Activity was really fun and seemed purposeful"
> "The activities strengthened my understanding"
> "I liked the video. The problems helped me grasp the material"
> "I liked the Beer game. It did help me look at the whole supply chain"
> "(I would have preferred) shorter case studies"
> "(Use) a more up-to-date video"
> "(Include more) in-class physical examples of *poka-yoke*"

Apart from open-ended comments-type questions, the students were also asked to provide feedback on the teaching approach. Some of the questions on the feedback form were

1. The presentation was effective in improving your knowledge of Value Stream Mapping.
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree
2. Which of the following best describes your opinion on the duration of the presentation?
   A. Too long B. Just about right C. Too short D. No comment
3. Tell us what you think about the activity that was done in class today.
   A. Enjoyed a lot B. Enjoyed a bit C. Didn't really care D. A bit boring
   E. Wanted to get out of the class! F. Not applicable
4. The activity was effective in illustrating Value Stream Mapping.
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree
   F. Not applicable
5. Which of the following best describes your opinion on the duration of the activity?
   A. Too long B. Just about right C. Too short D. No comment
6. The activity performed complements the in-class presentation
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree
   F. Not applicable

The responses to the above questions were compiled and are presented below. The options were assigned weights and the average scores were computed for each question. In the feedback questionnaire, the term 'activity' referred to something that the students did as opposed to demonstrations by the instructor.

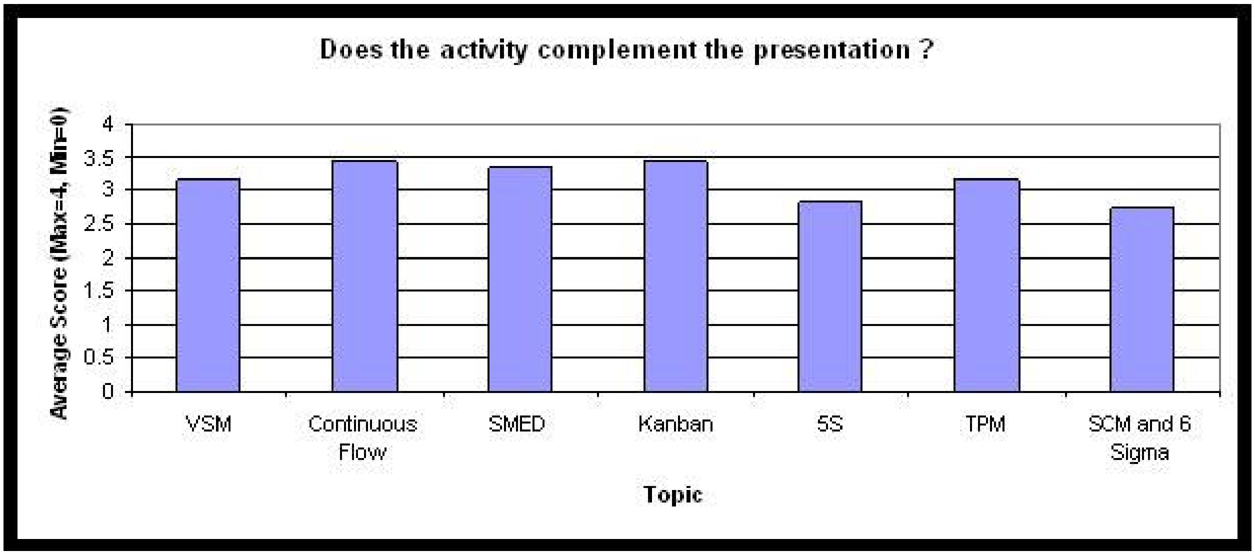


**Figure 12 Student Feedback on "Does the activity complement the presentation"**

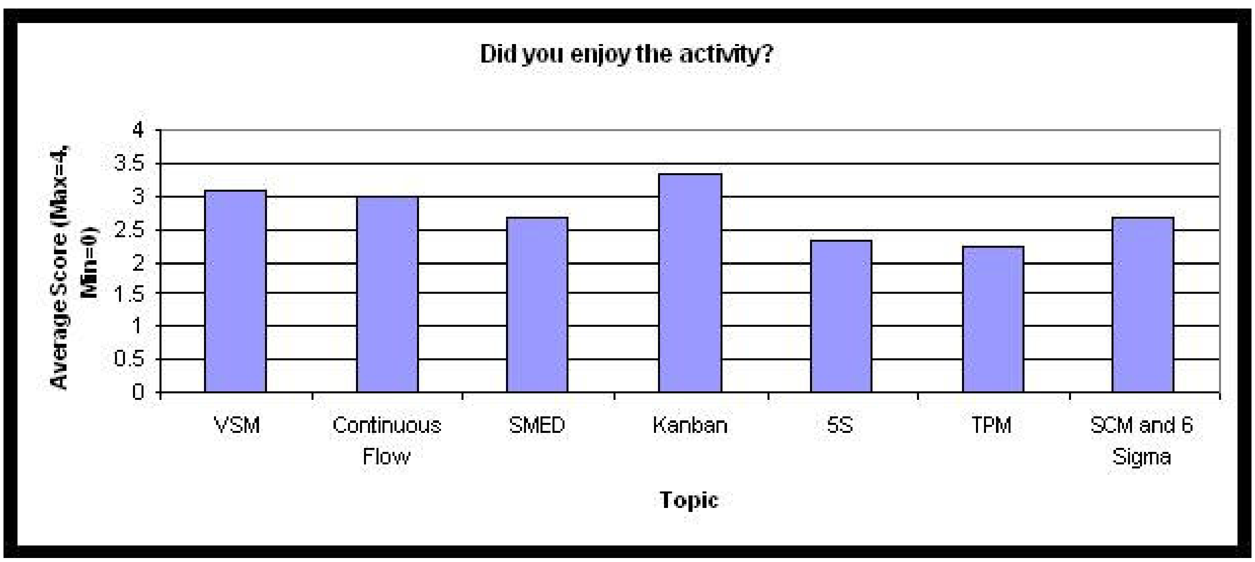


**Figure 13 Student Feedback on the activity**

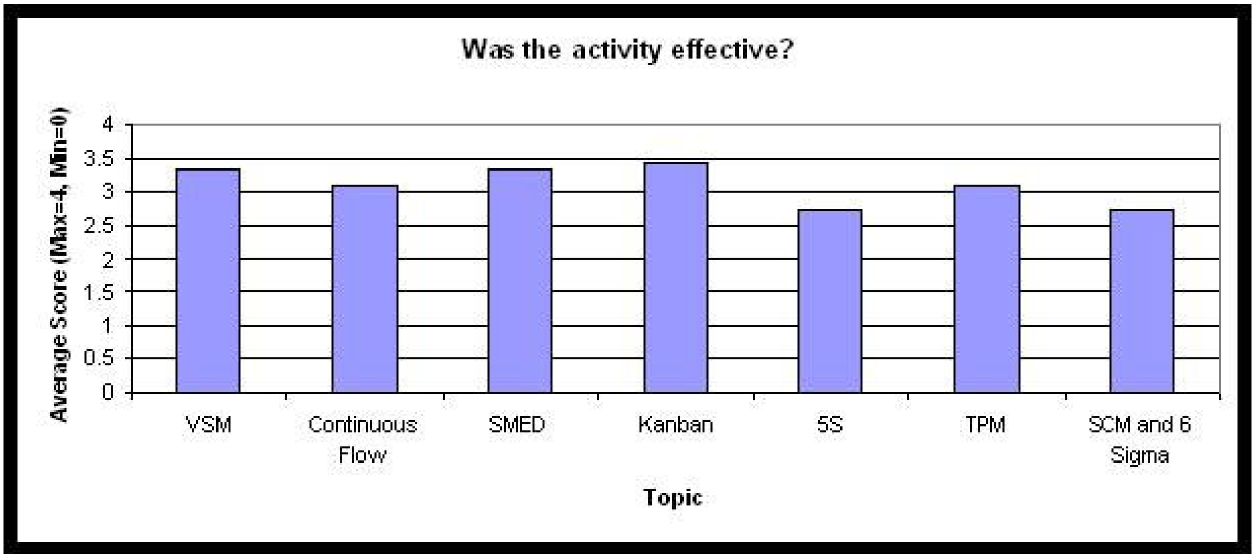


**Figure 14 Student Feedback on the effectiveness of the activity**

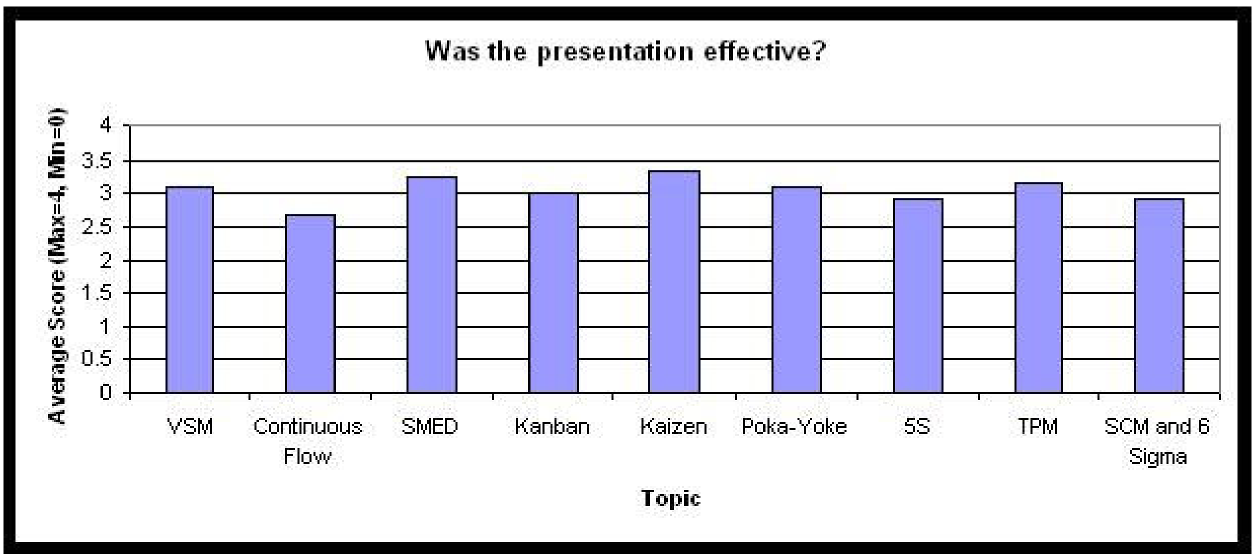


**Figure 15 Student Feedback on the effectiveness of the presentation**

## Instructor Assessment

Videos were used in a couple of lectures and based on feedback from the students, they really enjoyed seeing the implementations of various lean concepts in real world. Hence, we would like to include additional videos (where available) showing other real-world implementations of lean principles. This could be done at the end of the lab activities, once students had completed the assignment and more clearly understood the principles being covered, so that they understood what they were seeing.

To extend the course to cover a semester schedule, some of the topics like *kanban*, VSM and continuous flow could have been split into multiple lectures to be covered in more detail, which would allow the course to be extended to. Also, a few examples of mistake-proofing were included in the presentations, but some specific real-world examples/demonstrations also could have been included.

## Conclusions

The course described in this paper provided an opportunity for students in industrial and systems engineering to learn about lean principles. The workshop format allowed for the students to have a hands-on experience and built upon material that they had learned in previous classes.

The students who enrolled in the first offering of the course had positive feedback about their experience. In general, they felt that the experience in the course complemented the material that they had learned in previous classes and provided them with a better understanding of lean principles.

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