Journal of
INDUSTRIAL TECHNOLOGY

Volume 19, Number 4 - August 2003 to October 2003

Teaching Lean Manufacturing Concepts through Project-Based Learning and Simulation

By Dr. Kenneth W. Stier

KEYWORD SEARCH

Curriculum
Management
Manufacturing
Teaching Methods

Peer-Refereed Article

The Official Electronic Publication of the National Association of Industrial Technology • www.nait.org

Dr. Kenneth Stier is a professor and Certified Manufacturing Engineer (CMfgE) in the Department of Technology at Illinois State University (ISU). He is the sequence coordinator for the Integrated Manufacturing Systems Sequence and teaches materials technology, manufacturing processes, and manufacturing organization and management.

Teaching Lean Manufacturing Concepts through Project-Based Learning and Simulation

By Dr. Kenneth W. Stier

Introduction

New technologies such as computer-aided design (CAD), rapid prototyping (RP), computer numerical control (CNC) systems, or robotic systems, drive changes in the industrial technology curriculum. Now technology departments need to consider more than just the technologies that need to be infused into the curriculum. Manufacturing management practices have become equally important in helping companies become more productive and profitable. Lean manufacturing is one management practice that is sweeping the industry. (Green, 2002; Waurzyniak, 2003; & Rakowski, 2003).

As change is introduced into companies through lean manufacturing practices, universities should consider changing their curriculum with this movement. There is a high likelihood that students will encounter and participate in some aspects of lean manufacturing as they begin internships or full-time employment in the manufacturing industry. It is important that universities provide appropriate learning experiences in the curriculum to prepare students prior to them entering the lean manufacturing environment.

Selecting an appropriate delivery system to teach lean manufacturing concepts may seem like a formidable task because it isn't some form of technology that can be purchased and infused into laboratory activities. Alternatively, lecturing on the subject does not adequately convey the concepts and allow the students to fully understand how this management practice works. One instructional approach that seems to be a widely accepted method of improving student learning in today's educational environment is to actively engage them in activities that simulate theories, concepts and principles that are being presented. This article will present one approach to teaching lean manufacturing principles through laboratory activities and simulation that reinforce these concepts.

Definition of Lean Manufacturing

Robert Green (2002), Quality Digest's editor, points out in his article that this is not a new management practice or concept. Henry Ford actually practiced lean manufacturing in his company. Levison (2002) cites two of Henry Ford's books, *My Life and Work* (1922) and *Moving Forward* (1930) as references which describe lean manufacturing techniques. These references are a strong indication that lean manufacturing actually began in the United States decades ago (Green, 2002). Today, lean manufacturing has been resurrected in the United States as companies are struggling to survive in a globally competitive market. It is one of the fastest-growing movements in the quality field, according to Paton (2002).

While lean manufacturing may have been around for decades, it still remains somewhat of a mystery to many involved in this initiative. According to Green (2002), there are as many practitioners and consultants as there are definitions of this term. For the purposes of this article, lean manufacturing will be defined as a systematic approach to identifying and eliminating waste (nonvalue-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection (Manufacturing Extension Partnership, 2000).

Consultants can be hired to assist in the implementation of lean manufacturing and provide workshops to train employees as they begin this initiative (Productivity, 2003). Simulations are used in order to help employees grasp the changes between traditional mass production practices and lean manufacturing. Sometimes these simulations can be applied in an educational setting as well.

Purpose

Introducing students to lean manufacturing also means exposing them to advanced manufacturing concepts such as cellular manufacturing, pull systems and small batch production. Several approaches can be used to introduce the students to these concepts. In the author's case, students receive an introduction to lean manufacturing in a management course that is part of their core curriculum. Lecture and reading assignments are used to introduce the students to lean manufacturing content. The students are also required to research the topic and write a short paper. This assignment is then used to promote discussion in class among the students. This is a very brief, but important, encounter with the content. It helps prepare manufacturing students for more in-depth coverage of lean manufacturing in their capstone experience.

The manufacturing capstone course is expected to be a culminating experience for students in the sequence. Students need the opportunity to apply their knowledge and gain experience in a similar fashion to what they will encounter when they are employed. It helps reduce the anxiety and confusion sometimes experienced by graduates when they begin their career in the manufacturing industry.

While traditional field experiences are beneficial to students, there are other equally valuable alternatives (Miller, 1994). One such alternative is to use a laboratory project and professional workshop to involve students in hands-on experiences of an industry situation. This is what the author has done in the capstone course for the Manufacturing Sequence at his university.

Methodology

Students in the manufacturing sequence take technical and management coursework at the author's university, in a building block fashion during their first three years. Even though the content continuously builds on concepts they learn, the courses they take are still stand alone type courses for the most part. The capstone course is intended to be a culminating experience that helps students apply the technical knowledge and management concepts that they learned in previous classes.

Three years ago the Department of Technology at the author's university began to revise its curriculum to respond to changes that were suggested by its alumni and advisory boards. As part of that revision, the four sequences within the department (construction management, industrial computer systems, integrated manufacturing systems, and printing management) revised their capstone courses and made them a requirement for students. To provide consistency among the capstone courses in the four sequences, the faculty developed a suggested outline for faculty to follow in developing their capstone course.

The outline consisted of 3 major components: primary goals, primary themes, and instructional parameters. The consensus of the faculty was that there were 3 primary goals they would like all capstone courses to accomplish in the Department's curriculum. The three primary goals were to apply the fundamentals of management (planning, organizing, leading and controlling), analyze and implement a project, and place emphasis on synthesizing content. The faculty also decided on instructional parameters for the capstone courses. The capstone courses were to be project-based, team-based, activity-oriented, student-driven, and industry-connected.

This helped lay the groundwork for the revisions in the manufacturing sequence capstone course to include lean manufacturing concepts and principles. It was important to select a project-based approach that provided the means for students to experience managing a project and apply lean manufacturing concepts in an educational environment. It was also important to have a project-based approach that encouraged students to work in teams and problem solve production-related issues.

The author chose a production project with input and assistance from colleagues and an advisory board to expose the students to lean manufacturing while meeting the goals and instructional parameters for capstone courses that were decided upon by the faculty. The project is student driven from the standpoint that the students have to generate the ideas for what they want to produce. This provides a potential for approximately 20 new ideas each semester since that is the usual enrollment for the class. The standards and expectations for good project ideas are set in the beginning of the course by reviewing some of the successful projects from past semesters. This provides the students with a reference point for successful completion of the class. The students are then split up into groups and asked to brainstorm and develop a list of potential sources for seeking ideas for their projects. The list is then used by the students to identify a project idea for the next class period.

The author has taken different approaches with the class over the semesters with selecting the best ideas for projects. One way was to have each student stand up and present their project idea to the class. Another way was to have the students divide up into groups and then discuss their ideas within the group. Each of the groups is then assigned to identifying their top four choices for a project. The groups explain their project ideas to the rest of the class and the project ideas are listed on the whiteboard. Once all the ideas are presented, the class votes on their top choices. Table one shows a form the instructor has used occasionally to help the students rate their project ideas. The weight per consideration column in table one places weighted values on considerations one through six. It's a good way to help the students make decisions with regard to ranking the project ideas because it forces them to think about some of the factors that will play the biggest role in the success or failure of their project selection. The table also provides them with some data which helps them to visualize their decisions. The products column can be expanded or reduced based on the number of groups that there are in the class. The purpose is to identify as many top choices as there will be groups in the class for the semester. In the author's case the class has always been divided into four groups.

Students are then assigned to the groups based on the way they rated the projects that were chosen. Most of the time the student will be able to work on a project that was their first or second choice. The projects then become a means to actively engage the students in technical work and management principles such as lean manufacturing.

In most cases, this is the first time that the students have had to consider how to go from an idea to a finished product. It is also the first time that they have to think about how to produce a product in quantity. Normally the students are used to stand alone courses that required them to deal with designing or making one part. Having to produce an entire product in quantity causes them to draw from all their past experiences and expand their thinking.

Often times the students are overwhelmed with the idea of having to move from the idea of project to the production of their product in quantity because of their lack of experience with this type of assignment. The author has used Klein's (1999) unpublished operations manual as the framework to help guide the students through the process. Providing an operations manual gives the students a reference with regard to the criteria they will need to meet, the evaluation system that will be used, and the sequence in which assignments need to be completed. In essence, it becomes the main guide for much of the course.

During the semester the students are held to academic rigor with each of their projects through five evaluations that are identified in their operations manual. They are also required to evaluate their group members at each evaluation point. A peer evaluation form is provided by the author which identifies specific evaluation criteria and a point system that the students need to use. The peer evaluation criteria used includes such things as the amount of work contributed, completion of assigned work within schedule, attendance at group meetings, quality of individual meeting participation, and quality of assigned work.

The first five weeks of the semester are devoted to the design phase of the project. During this time lectures and case studies are also used to orientate the students to the approach that will be used with the main project throughout the semester. At the due date for the first evaluation each group submits a binder with their engineering logs, initial drawings, and initial bill of materials. They also submit their peer evaluations and prototypes. Time is set aside for each group to present their prototype to the rest of the class. The students are given an opportunity to provide other groups with their input and feedback at this point since they will be the customer who will eventually receive these projects at the end of the semester.

The second evaluation of each group's project takes place at the eighth week or the midpoint of the semester. Each group submits their project binder again with revised drawings in an archived section and new documentation that was developed during this phase of the project. The students submit five main plans (design, materials, tooling, production, quality, and safety) which become sections in the project binder. Each student submits a peer evaluation again privately to the instructor as part of this evaluation.

The third evaluation is completed around the eleventh week of the semester. A prototype of each tool the group will use for their production is also submitted as part of this evaluation. This evaluation focuses on a pilot run of each group's project. Each group has to produce a minimum of two complete products utilizing the tooling they designed and prototyped for their production run. The tooling and completed products are submitted by each group for this evaluation.

Table 1. Project rating form.

Considerations	Weight per consideration	Products #1 Average Rating	#1 Avg Weighted Factor	#2 Average Rating	#2 Avg Weighted Factor	#3 Average Rating	#3 Avg Weighted Factor	#4 Average Rating	#4 Avg Weighted Factor
1. Fabrication Techniques (equip-facilities)	3								
2. Design & marketability (appealing competition)	4								
3. Time (tooling-production)	6								
4. Material (cost-availability)	2								
5. Profitable ($- experience)	1								
6. Functionality	5								
Totals:									

The remaining four weeks of the semester are devoted to making the needed changes for the production run and running the production of each group's product. When a group is scheduled to run the production of their product they become the managers and the rest of the students in the class become the workers. During the production run the management group cannot do any of the physical work. They are expected to utilize lean manufacturing methods and to manage the production run so that it yields a specified number of products within a given timeframe.

The first time the class was offered under the latest curriculum revision, the author had each group produce 22 of their completed products within two lab periods. Through lean manufacturing techniques and other modifications to the class each group is required to produce 12 of their products in one lab period. This allows them to randomly select one of their own products and one from another group at the end of the semester.

Choices with Regard to Lean Manufacturing Simulations

In order to prepare the students for using lean production techniques in their production run, it seemed appropriate to provide them with an opportunity to experience lean manufacturing through a simulated activity beforehand. The author considered two different lean manufacturing simulations for use with the students in class. Both simulations focus on assembly operations and call for assigning people to specific jobs in the simulation.

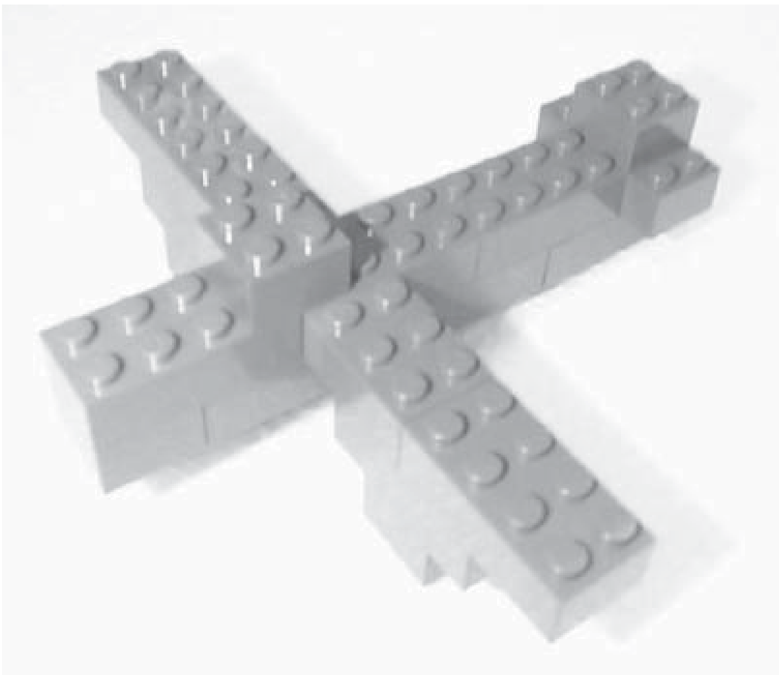
One of the simulations can be completed in a one-hour timeframe with the participants producing airplanes with plastic interlocking blocks (see figure 1). It involves 6 participants (four workers, one inspector, and one teardown person) under the direction of a facilitator. More kits would be needed to involve more people at one time.

The second simulation the author considered was developed by the National Institute of Standards (Manufacturing Extension Partnership, 2000) and is completed in about an 8-hour period. It uses two different circuit board assemblies (see figure 2) to simulate two different lines of product that the participants are required to produce. This simulation works well with approximately 20 people and has many roles to assign participants.

Both simulations run the participants through four rounds of timed production. The airplane simulation is designed to allow around 6 minutes for each round of production while the circuit board assemblies are set up to run in specific 20 minute timeframes. The first round in these simulations is an example of traditional mass production and plant layout with a lot of problems and chaos. At the end of each round of production a facilitator gives the participants feedback on how well they did with respect to such things as producing good product, rework, scrap, work-in-process, etc. Each round of simulation introduces change in the way the production is run until lean manufacturing and a pull system with a batch size of one is achieved. Both simulations are designed to help the participants grasp the advanced concepts of lean manufacturing and how change from traditional production methods can produce positive results. This is done through hands-on activities and feedback sessions which compares the results of each round of production. The author elected to use the circuit board simulation during the tenth week of class as students began working on their pilot run. Two technical specialists who conduct this lean manufacturing simulation for companies on a regular basis donate their time to offer it to the students in the author's class just as they do for their clients. In the end of the workshop the students are given a certificate of completion and encouraged to list this professional workshop on their resume. This helps the capstone course to be industry-connected as specified in one of the department's instructional parameters.

Students assess the simulation and the instructors at the end of the experience. They are also asked to respond to questions concerning the lean manufacturing concepts that they were exposed to such as takt time and work-in-process. Their responses are used for the focus of a follow-up discussion in the next class period.

Figure 1. Airplane with plastic interlocking blocks.



Summary

The author has run the manufacturing capstone class three times in this manner. Anecdotal evidence through comments on the simulation evaluations and the capstone class evaluations indicate that the students learned a great deal through the capstone project and the lean manufacturing simulation. The timing and active involvement of the lean manufacturing simulation helps the students make the connection between the new concepts they are expected to apply in their own production run and previous knowledge they have about manufacturing. The simulation helps build their confidence to apply lean manufacturing techniques as they assume the role of a manager in their production run for the class.

A project-based approach, along with a professional workshop that contains a simulation used to re-train professionals in the manufacturing industry, can be a powerful means of motivating students and improving learning. The students can practice their skills before being thrust into a real-life situation on the job, much like doctors practice to prepare for their profession. The students can also include the professional workshop as part of their portfolio when they interview for a job. Even more importantly, these new graduates should have the potential to become change agents in the companies that hire them and can help the company to advance within its industry.

References

Ford, H. (1922). My life and work, Garden City Publishing Company.

Ford, H. (1930). Moving forward. Garden City, New York: Doubleday, Doran & Company.

Green, R. (2002). Bare bones production. Lean: What it is, where it started and where it might be going. Quality Digest, 22(2), 23-27.

Levinson, W. A. (2002). Lean manufacturing: Made in the USA. Quality Digest, 22(2), 64.

Manufacturing Extension Partnership (2000). Principles of lean manufacturing with live simulation. National Institute of Standards. Gaithersburg, MD.

Miller, R. L. (1994). A model curriculum for a capstone course in multidisciplinary engineering design. Journal of Engineering Education, 83(4), 311-316.

Klein, P. (1999, Spring). Operations Manual. Unpublished manual. Athens, OH.

Paton, S. M. (2002). Thin is in. Quality Digest, 22(2), 4.

Productivity, Inc. Homepage. (2003, Spring). http://www.productivityinc.com/home.html

Rakowski, L. (2003). Moving to lean manufacturing. Modern Machine Shop, 75(9), 88-89.

Waurzyniak, P. (2003). Going lean at Baxter. Manufacturing Engineering, 130(5), 89-94.

Figure 2. Blue avenger (left side) and red devil (right side) circuit board assemblies.