Teaching Lean Manufacturing Principles in a Capstone Course with a Simulation Workshop

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Introduction

Traditionally, improvements in manufacturing costs have been achieved by capital investments in new equipment intended to the lower manufactured costs per unit. Often, the new equipment was designed to achieve the lower costs through faster production speeds, more automation, etc. Typical focus was on pieces per minute and often gave inadequate consideration to size of production runs, changeover times and inventory carrying costs. Many times, the new automated, higher speed equipment required lengthy changeovers before a different product could be run, resulting in management believing the most cost-effective practice was long production runs (large batch sizes).

In today's manufacturing climate, firms are re-thinking many of the traditional ways of achieving improvements, and exploring new methods. One in particular, lean manufacturing is a practice that is receiving quite a bit of attention today[1,2,3,4]. Manufacturers have embraced lean manufacturing during the slow down in the economy as one method of remaining profitable[5].

Having students experience lean manufacturing concepts in the laboratory can have a positive effect on the experiences offered to the students prior to them entering the industrial setting. It is important that faculty provide students with the experiences that develop a strong conceptual framework of how this management practice will benefit the industry in which they work.

Many of our students learn best when they are actively engaged in activities that emphasize the concepts that we are trying to teach. This paper will focus on a National Institute of Standards (NIST) developed Lean Manufacturing Workshop and a project-based manufacturing capstone course. It will explain how concepts are learned through simulation and applied through project work within the university context.

Nationwide Network and Its Services

The Illinois Manufacturing Extension Center (IMEC) originated in the 1990's as a result of a funded NIST project. IMEC is staffed by an experienced group of professionals, averaging more than 18 years of manufacturing experience. These specialists assist Illinois manufacturers by drawing upon expertise in an integrated network of manufacturing extension centers located in all 50 states, including more than 2,000 field engineers nationwide. Along with Illinois-based private sector firms and affiliated organizations, IMEC has a range of resources to help manufacturers implement improvements that will lead to greater productivity, increased profits, and enhanced competitiveness[6].

Funding for IMEC is provided by the NIST - Manufacturing Extension Partnership, the Illinois Department of Commerce and Community Affairs, and the Illinois Board of Higher Education. In 2002 IMEC worked with 500 small and mid-sized manufacturing companies and delivered in-depth project services to 250 companies[7]. These companies consider IMEC an extension of their own operations and routinely call on the specialists to help them: meet the quality registration demands of their larger customers, contain operating costs and increase profits, improve production output and time to market, integrate advanced manufacturing technologies and business practices, solve specific problems, reverse negative business situations such as sales decreases, loss of market share, and cost increases, and diversify their customer base[8].

Services that IMEC offers include Lean Manufacturing training and implementation assistance. The training and implementation assistance helps to minimize waste in both the material and information flows, allowing customer orders to more quickly and efficiently turn into profits[9]. An example of where lean manufacturing training improved a company's performance was with a tier-one supplier to the automotive industry in Rockford, Illinois. The company is faced with continuing demands to reduce prices and operate more efficiently. The company produces idler arm and pitman arm brackets (used in vehicle steering systems) which require two heat treating processes. Multiple checkpoints to monitor the integrity of those processes were costing the company labor, time, scrapped parts, and money[10].

Value Stream Mapping conducted by a lean manufacturing team helped to eliminate the need to send the brackets to the metallurgical lab after the first heat treating operation. Instead, operator test results are used after the first operation. The parts are sent to the Met Lab for testing following the second heat treating operation. This maintains the integrity of the product while speeding the production process and freeing the time of the Met Lab[11]. Other lean improvement projects were also undertaken to reduce set ups and increase capacity utilization.

IMEC offices are strategically located within one hour of every manufacturer in Illinois. IMEC partners with some of the major universities in Illinois and has established a good working relationship with the university involved in this paper.

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The Lean Manufacturing Workshop

In recent years the authors of this paper have collaborated with regard to a professional Lean Manufacturing Workshop developed by the National Institute of Standards to help small to medium-sized manufacturers introduce lean manufacturing practices in their production facilities[12]. This is a one-day workshop that simulates 4 different improvements in manufacturing, with the final example being lean manufacturing using a pull system incorporating Kanban signals and a controlled Takt Time to define a targeted rate of production.

It begins promptly at 8:00am and runs until approximately 4:30pm with breaks and a 30 minute lunch period during the day. The workshop is conducted by professional project managers and technical specialists, trained in lean practices. These specialists have 40+ combined years of work experience in the manufacturing industry and have conducted numerous lean manufacturing workshops for the Illinois Manufacturing Extension Center in Central Illinois. They conduct the workshop for their clients, which include manufacturers up to typically 500 employees. Sessions are designed for a range of typically 13 to 22 participants per session.

The Company and the Products

The simulation consists of a fictitious, but realistic structured company called Buzz Electronics that is trying to produce two lines (design variations) of an electronic security product, the Red Devil and Blue Avenger circuit board assemblies (see figure 2). The Red Devil is supposed to be an industrial model for commercial use and the Blue Avenger is the basic model for residential use. Costs are given to the participants of the workshop to set the stage for the financial reports and to emphasize the importance of the company making a profit. The materials cost for the Red Devil is $7.50 and its selling price is $30. The materials cost for the Blue Avenger is $5.00 and it sells for $20. In addition, there is a labor cost of $7.50 per person per shift and a facility cost of $10 per table per shift.

The participants in the workshop are given an orientation to the company, the products, and the jobs that are available. Initially, there are 13 different positions that need to be filled for the production of the two product lines (See figure 1). The participants are assigned to these positions and given an orientation to the layout of the facility. Tables are set up according to the production facility orientation. Written instructions are provided to the associates at each workstation.

BEE Production Process Orientation

1. Sales Representative	Processes 'Customer Order'
2. Production Scheduler	Generates 'Factory Order' from forecast
3. Kitter(s)	Organizes raw materials for 'Factory Orders'
4. Material Handler	Moves product between ALL workstations
5. Spring Assembler	Inserts Springs
6. Resistor Assembler	Inserts Resistors
7. LED Assembler	Inserts LEDs
8. Diode Assembler	Inserts Diodes
9. Inspector	Conducts functional tests
10. Reworker	Repairs failed boards
11. Warehouse/Ship Clerk	Matches boards to 'Customer Orders'
12. Instruction Crib Attendant	Controls work instructions
13. Production Supervisor	Supervises production

Assembly

Figure 1. The 13 production positions and their job descriptions.
Note. From MEP Principles of Lean Manufacturing Workshop. Copyright 2000. Reprinted by permission.

The assemblies for the Red Devil and Blue Avenger consist of an acrylic pad with blind drilled holes, resistors, diodes, LEDs, and springs. These components are used to complete simple, yet functional PCB assemblies that can be rapidly assembled and tested (see figure 2).

BEE Circuit Board Assembly Example

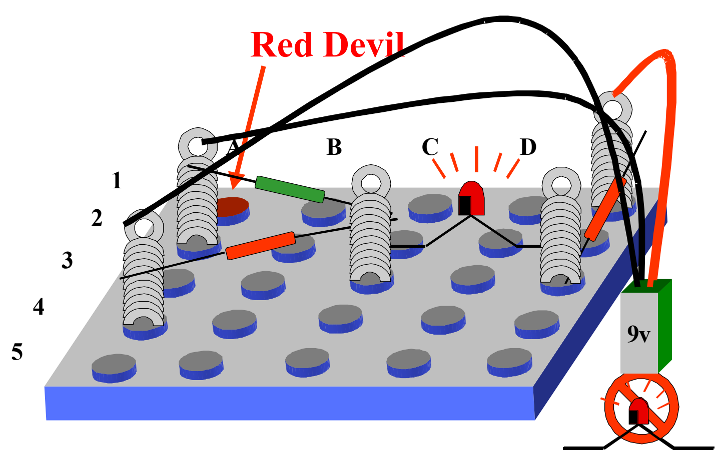

Figure 2. A circuit board assemble example.
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All the jobs consist of assembly and testing tasks. None of the jobs involve any processing. Jobs are assigned to all participants before beginning production of the two circuit board assemblies. The products are made and moved in batches, tested, and defective product sent to a rework station to be repaired. The Red Devil is produced in batches of 4 and the Blue Avenger is produced in batches of 6. The production scheduling process is shown in figure 3. Production forecasts drive the production of product in the first round. The company promises customers it will ship the Blue Avenger product 4 minutes after it is ordered and the Red Devil 5 minutes after it is ordered. The simulated production runs for 20 minutes during each round. There are 4 rounds of production simulated in the course of the workshop.

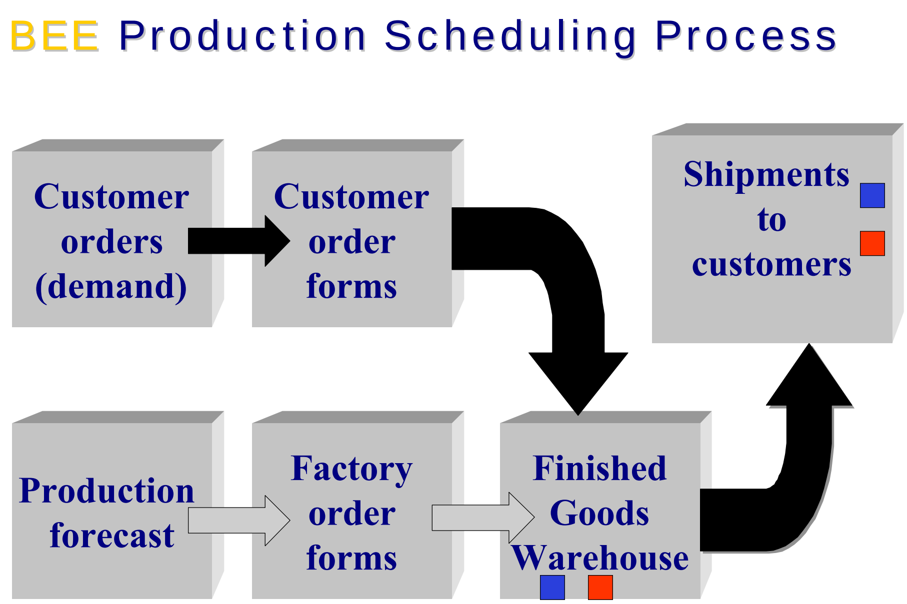


Figure 3. An example of the production scheduling process for the first round of production. Note. From MEP Principles of Lean Manufacturing Workshop. Copyright 2000. Reprinted by permission.

An IMEC staff member role-plays the president/ boss of the company during each production experience. In the first round the president is very dictatorial and uses a top-down management approach. The participants who are role-playing the workers or associates have very little to say about their work environment. The president explains the company policies in an abrupt fashion to the associates before work begins. There are 7 company policies that the president emphasizes to the associates: 1) all shifts are 20 minutes, 2) keep busy at all times, 3) yell if you need parts, 4) handle all parts first-in-first-out, 5) only the material handler can move parts, 6) stay at your workstation, and 7) the boss is always right[13].

Rounds One to Four

The initial round of production is chaos. There is poor flow of the product, problems with communication among the workers, excessive paperwork, lots of work-in-process, disorganization, need for overtime, unbalanced workload, poor layout of the assembly line, etc A second IMEC staff person role-plays an improvement consultant hired by the company president. After each round the improvement consultant brings the associates together in a conference room setting for a de-briefing session to show the company's profits and losses as a result of the 20 minutes of production. A data entry sheet is used to input key data that help determine the success or failure of each round of production (see figure 4). These include such factors as cycle time, work-in-process

Data Entry Sheet

Note: Complete all shaded areas at the end of each round

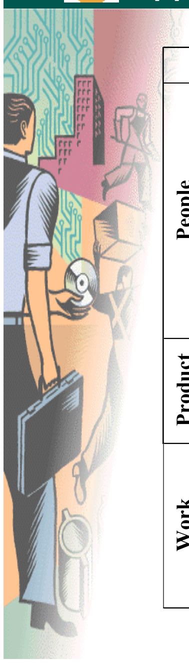
Scenario	Round 1	Round 2	Round 3	Round 4
Average Cycle Time (min.)				
# Units in Ending WIP				
# Units on Time				
# Units Shipped Late				
# Units in Finished Goods Warehouse				
# of Employees				
# of Tables				
# Ft. Traveled				
# Failed				
# Passed				

Figure 4. A data entry sheet used to input the data generated in each round of production. Note. From MEP Principles of Lean Manufacturing Workshop. Copyright 2000. Reprinted by permission.

(WIP), number of units shipped on-time, number of units shipped late, number of units passing inspection, number of units failing inspection, number of units in the finished goods warehouse, number of employees, number of tables used, and distance traveled by the product during production. The input data then automatically flows into two spreadsheets which quantify the performance achieved. The first spreadsheet is the Production Scoreboard, which displays average cycle time, percent delivered on time, number of units in work-in-process (initial WIP and ending WIP), number of units completed, travel distance, square footage required, and first pass quality yield percent. The second spreadsheet is the financial statement, which displays total sales revenue for the round of production, total operating costs, and net income. The first round shows no profit, but instead, a loss.

The associates and improvement consultant discuss what went well and what caused problems on the production line. The company president grills the participant acting as supervisor, requires the supervisor to explain the poor performance, and typically expresses great doubt regarding the supervisors' continued "employment" if the supervisor doesn't improve performance. The improvement consultant then intervenes and gets agreement from the president to allow the consultant to work with the supervisor and workforce to find ways to improve. The associates are asked for suggestions to improve the production and profits of the company. The improvement consultant overviews the history of manufacturing with the group and presents concepts of lean manufacturing (see figure 5).

History of Manufacturing



	Pre-industrial 1890	Mass 1920	Lean 1980
People	▪ Craftsman perform all aspects of task ▪ Self-taught or apprenticeship training	▪ Employees contribute minimally to total product ▪ Training for limited skills ▪ Management makes decisions	▪ Clusters of employees working in team ▪ Extensive continuing training
Product	▪ Customized, non-standard products ▪ Variation in quality	▪ Standardized, focused on volume not quality	▪ Focus on internal/ external customer
Work Environment	▪ Independence, discretion ▪ Variety of skills ▪ responsibility	▪ Obey mgmnt. ▪ Repetitive, mind-numbing work ▪ Limited skills, knowledge, little discretion, simplified tasks	▪ Some discretion, group effectiveness, empowerment, team accountability, work cells

Figure 5. A Powerpoint slide to convey the history of manufacturing and present the concepts of lean manufacturing. Note. From MEP Principles of Lean Manufacturing Workshop. Copyright 2000. Reprinted by permission.

The discussion normally begins with a definition of lean manufacturing. For the purposes of the workshop, lean manufacturing is defined as a systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection[14]. Lean manufacturing needs less of everything to design and produce high quality products economically according to Womack[15].

While discussing the definition, the improvement consultant points out that some lean specialists have traced its roots back to Henry Ford and his staff and the production of Ford automobiles in the 1910s, 1920s and 1930s. Two of Henry Ford's books, *My Life and Work*[16] and *Moving Forward*[17], are cited for the associates as references that describe lean manufacturing techniques. A third book by Levinson[18] entitled, *Henry Ford's Lean Vision – Enduring Principles from the First Ford Motor Plant* is also referenced in the workshop. In large part, this text makes reference to the first recognized text on Lean Manufacturing, *Ford Methods and the Ford Shops* by Arnold and Faurote[19], reprinted in 1971 and 1998 by Ayer Company Publishers, Inc. These references help verify that lean manufacturing practices began in the United States, not Japan. In-fact, the Japanese Toyota Motor Company recognizes the Ford Motor Company as the pioneers of Lean

Manufacturing practices and Japan even sent manufacturing representatives to Dearborn, Michigan to the Ford Plants to learn lean techniques between the two World Wars. In discussing lean manufacturing in the workshop de-briefing session, it is emphasized that today, lean manufacturing has come to the forefront of American industry as companies are forced to do more with less and as a result create additional output at lower costs.

The consultant then guides the discussion in the first de-briefing session to help the associates identify and list gradual lean improvements that will help create additional output at lower costs. Two factors that are the focus of each de-briefing session are "value added" and "waste". The eight wastes of lean manufacturing that are discussed are overproduction, excess inventory, defects, extra processing, waiting, underutilized people, extra motion, and extra transportation[20]. Each of these wastes are defined and some of their causes are identified to help the associates find ways to improve their production process.

The president of the company is then called back into the room to meet with the group and listen to their suggestions for improvements. The associates have to convince the president to accept their suggestions for changes based on work efficiencies and cost improvements. The president (having been urged by the consultant to soften his management style to encourage worker participation), accepts some of the suggestions, rejects others, and the accepted suggestions are then implemented for round two. The changes from round one to round two focus on changing the production line layout, improving the work instructions, improving the visual aids to include color-coded templates, and changing where parts are stored.

The associates produce product for another 20 minute session and then return to the de-briefing room with the improvement consultant. The discussion starts out similar to the de-briefing after round one with much of the focus on what went well and what caused problems on the production line. The president again requires the supervisor to explain the still unsatisfactory performance, albeit improved, which again resulted in a loss, though substantially smaller than the loss in round one. The improvement consultant again intervenes, gets president's agreement for further improvement consulting whereupon the president departs, and the consultant then goes on to explain the lean manufacturing building blocks to the workforce (see figure 6). Five of the lean building blocks are emphasized in the round two de-briefing, workforce practices, quick changeovers, batch size reduction, point of use storage (POUS), and quality at the source. These concepts are explained to the associates and examples of how they improve manufacturing are given.

After the improvement consulting session is finished, the president is called into the room again. The associates suggest further improvements and try to convince the president to approve their suggestions. The improvement consultant guides the associates into changes that focus on storing raw materials at the point of use, re-arranging

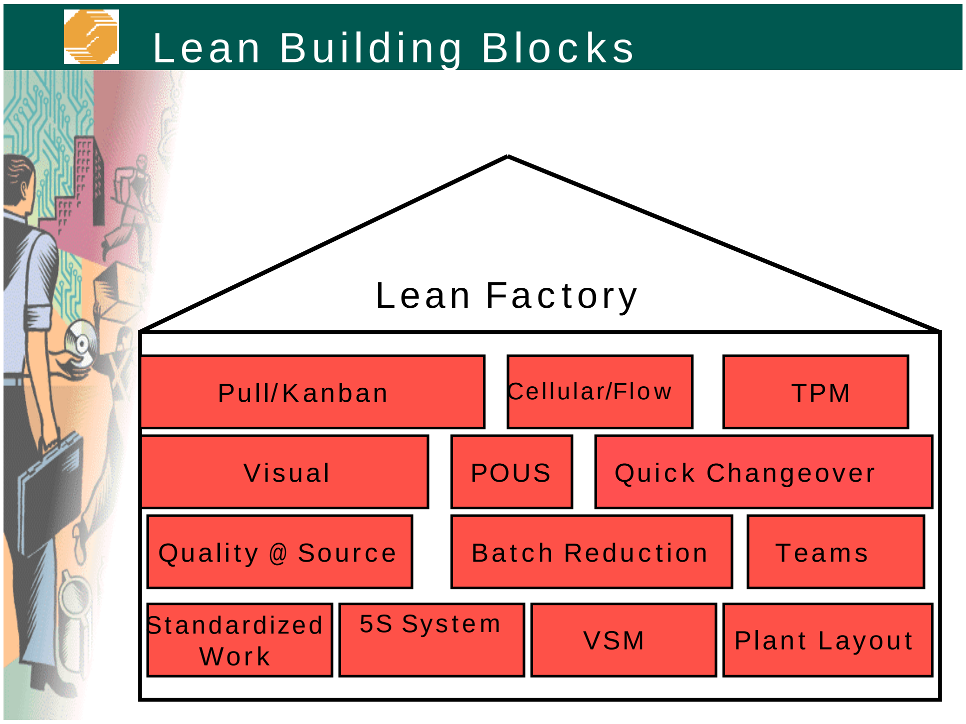


Figure 6. A Powerpoint slide to explain the building blocks of lean manufacturing. Note. From MEP Principles of Lean Manufacturing Workshop. Copyright 2000. Reprinted by permission.

workstations, eliminating material handling, reducing paperwork, reducing the batch size by 50%, and increasing the amount of cross-training among associates.

The changes that the president approves are made and 20 more minutes of production take place in round three. Another de-briefing takes place at the end of round three. The suggestions from workforce have significantly improved financial performance, the president is pleased, and praises their results, asks the workers if they believe there is yet more room for improvement. Participants respond affirmatively, and the president encourages them to work with the consultant to identify more improvements. During this session the improvement consultant introduces 3 more building blocks of lean manufacturing. These include pull systems, cellular manufacturing, and takt time. Push and pull systems are compared and contrasted. The benefits of a pull system are emphasized to the associates. Cellular manufacturing is also explained. Examples are given with regard to designing, constructing, and refining a work cell to persuade the associates to this type of layout in their last round of production. Special attention is also given to the concept of takt time, determining the minimum number of people needed for production, and balancing the rate of production to match the rate of customer demand. Basically, takt time is the customer demand rate and is found by dividing the work time available by the number of units sold. The minimum number of people needed is determined by dividing the cycle time by the takt time. The improvement consultant works with the associates to identify improvements in their production process using these lean building blocks.

By the start of the fourth round of production the president is enthusiastically endorsing improvement suggestions, with the workers empowered to self-implement. The batch size is reduced to one (1) to create continuous flow and a pull system is used. Kanban cards are used between the workstations to control the pull system. The cards are loaded with WIP product before production begins and serve as a visual control of production, since the associates are instructed to not produce until customer demand pulls product from the line, thus emptying the product from the card. Only then can the worker replenish product onto the card. The associates are cross-trained on tasks that need to be done and are empowered to make decisions to help balance the production line. The fourth round also entails abundant use of visual templates that are used beginning in round two and cellular manufacturing that is introduced in round three. A few associates are also assigned to be floaters to help out if needed. Some of the advantages of these improvements become obvious to the associates as they complete the fourth round of production. A final discussion after round four concludes the workshop. Typical examples of improvement that are listed by the associates include an excellent financial report, less stress on the associates, a tremendous increase in the rate of production of a high quality product, and great pride in the performance of the production line they designed. The financial measures taken relate the improvements made to the “Bottom Line”.

Infusing Lean Concepts through Project-Based Curriculum

Careful evaluation of the curriculum is essential in determining where lean manufacturing concepts best fit. In the author's case, the major components of the curriculum are general education courses, department core courses, sequence core courses, and technical electives. Students are introduced to the idea of lean manufacturing in a 200-level management course through lecture and readings. A full unit is devoted to this topic. The students are assigned readings and expected to submit a written essay on the topic. This course consists of majors from other sequences, as well as manufacturing. Manufacturing majors are required to take this course before taking their capstone course, so it sets the stage for more in-depth coverage of lean manufacturing.

The manufacturing capstone course is a 3-credit hour course that meets for two class periods and a total of 5 hours per week. The capstone course is expected to be a culminating experience for students in the sequence and serve as an initial bridge between the academic environment and the real world for the students. As such, a simulated project management activity involving students in the design and mass production of products is a major component of this class. The authors have collaborated over the years in offering the Lean Manufacturing Workshop to the capstone students as they prepare for the mass production of their products.

Through consultation with the sequence advisory board and curriculum research, it was determined that there was a real need to infuse project management and lean manufacturing concepts into the capstone course. The advisory board recommended that students have the opportunity to apply management concepts learned at the 100 and 200-

level through project-based curriculum in upper division courses, especially the capstone course. Projects allow them to work in teams, solve problems, and deal with production issues that normally are only taught as theory in many classes.

The semester begins with the organizing of teams within the class and the identification of team projects. Normally there are 4 groups with 5 students in each group. Each student is expected to research an idea for a senior project and present it to the class. Students are encouraged to review websites, browse at retail stores around the community, and contact professionals within the community for ideas. When searching for ideas the student needs to keep in mind that the product needs to meet certain criteria in order to qualify for a senior project. Some examples of criteria include: 1) a minimum of a three-level bill of material, 2) a minimum of 10 manufactured parts, 3) at least 12 separate operations, etc.

Each student is expected to present their best idea to the class for evaluation. The product ideas are evaluated on fabrication techniques, design, marketability, functionality, material cost, material availability, estimated time needed to produce the tooling, and estimated time to mass produce (pilot production quantity) enough project items for every member in the class. Assigned weights are given to each criteria to determine an average weighted rating. The three criteria weighted the most heavily are time, functionality, and design in their perspective order from highest to lowest.

The top four choices then become the focal point for the senior projects of the class. Normally, each of the four groups is responsible for mass producing one of the products resulting in four unique products each semester. Students are assigned to groups based on their choice of product.

The project begins with team planning and a discussion of the design. Students must apply problem solving and critical thinking skills as they undertake their project. Preuss[21] points out that there are guidelines to help expand a project into a foundational outline for project-based learning. Such criteria and constraints parallel those that are found in industrial practice. Preuss[22] cites Steinburg's[23] work in referring to the following qualities of project based activities: authenticity, academic rigor, applied learning, active exploration, adult relationships and assessment practices.

To help apply the qualities of project-based learning that is referenced by Preuss, each group during the completion of the semester, goes through five checkpoints which come from Klein's[24] unpublished operations manual. The first checkpoint involves submitting the initial part drawings and specifications. The drawings need to include tolerancing and part numbers that match up with a bill of materials. The students also submit a materials plan that includes their bill of materials and unit pricing. Additionally, they submit assembly charts and process charts. Last of all, the students submit a prototype of the product they are designing. Each group presents their prototype and gives a status report on their project.

The second checkpoint consists of submitted revised and new drawings, an updated materials plan, tooling plan, an expanded production plan, and an initial quality plan. Each group has to design and prototype a specified amount of tooling for the production of their product. The tooling plan consists of the drawings and costs for any special tooling required. The production plan includes flow charts, routing sheets, shop floor flow chart, and resource plan in addition to the assembly charts and process charts.

After the second checkpoint is evaluated and feedback is provided to the groups, the students are asked to complete a pilot run of their product. Each group is expected to run approximately 3 completed products for the pilot run using the tooling produced and equipment specified in their production plan. Students finish the semester with each group managing a production run of approximately 22 of their completed products. The production run is evaluated from a management perspective. The fifth checkpoint is a final evaluation of each team's progress throughout the semester.

At the midpoint in the semester the students are asked to participate in the NIST-developed Lean Manufacturing Workshop. The students are exempt from having to attend a week of class in lieu of attending the all-day workshop on a Friday. They make arrangements in advance to be released from any regularly scheduled commitments that day so they can participate in the workshop. It runs from 8:00am until approximately 4:30pm with breaks and a 30 minute lunch period during the day just as it is offered to company personnel. The workshop is conducted by the two authors who are IMEC staff manufacturing experts, trained in lean practices, who donate their time. They role play the president and change consultant during the four rounds of production and de-briefing as described earlier in the paper.

Students are asked to reflect on their learning after participating in the workshop. They are given an assessment evaluation sheet to complete and return. The assessment evaluation sheet consists of questions that ask them to compare and contrast the different management styles they experienced, summarize the quantifiable performance changes for a) first pass quality, b) WIP units, c) sales revenue, d) net profit, e) material costs, and f) labor costs, and respond to questions on takt time. This helps the instructor assess the progress students have made towards understanding lean manufacturing concepts. The students' work is evaluated and discussed when it is returned.

Another assessment evaluation sheet is also given to the students at the end of the workshop to evaluate the instruction, course materials, and content. The evaluations are filled out anonymously and collected for assessing the effectiveness of the instruction. The results are then used to re-assess the delivery of the workshop and make improvements. The workshop is modified slightly each year based on the feedback from the two assessment evaluation methods.

The purpose of offering the workshop at approximately the midpoint of the semester is to expose the students to a simulated lean manufacturing experience that they could then apply in their own culminating mass production project for the course. During the mass production of their product, the students within each group are expected to manage the project and the rest of the students become production associates. This forces the group members whose product is being produced to assume the role of a manager and practice the management concepts of planning, organizing, influencing and controlling[25] that they study earlier in their curriculum. It also allows them to experience first-hand the benefits of lean manufacturing as they attempt to implement what they learned in the workshop and production simulation.

Summary

New technologies and capital investment have often been the focus of improvements in manufacturing in the past. These improvements frequently produced lower costs through faster production speeds. The focus of these improvements was on large batch sizes and faster production, not on eliminating waste. In today's industrial environment, manufacturers are re-thinking many of the traditional ways of lowering costs and improving their profitability. One production method that is receiving considerable attention is lean manufacturing. This method focuses on the elimination of waste and adding value to the product.

This is not an entirely new concept, but can be traced back to back to Henry Ford and his staff and the production of Ford automobiles in the early 1900s. Today it is receiving renewed interest in a weak economy. Lean manufacturing has become one survival tool for manufacturers struggling to gain a competitive edge. To that extent, NIST has developed a workshop to help small to medium-sized manufacturers infuse lean thinking in their organizations and improve their profitability.

While the Lean Manufacturing Workshop was originally intended to serve industrial clients, the authors have found that it is adaptable to a university context as well. Students in a manufacturing capstone course complete the Lean Manufacturing Workshop as part of their preparation to manage the mass production of a product. The workshop helps the students make the connection between new concepts and previous learning experiences. The workshop has helped the students to build on previous knowledge and see successful examples of new concepts. It has also helped to re-affirm their confidence in practicing their newly acquired knowledge on their own production project. This instructional approach helps bridge the gap between what the students are learning and what they will experience in the real world. This should better prepare the students to understand how to help improve the profitability of manufacturing companies and help advance the manufacturing industry.

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Biographical Information

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John has more than 28 years experience in electronic, electro-mechanical, and mechanical system and fixturing design, testing and manufacturing experience. He holds U.S. Patents in the area of information storage and retrieval and has worked with independent inventors and project teams through the product development and commercialization cycle. John works with IMEC project managers to help manufacturers.

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