

**AC 2009-244: HANDS-ON PLASTIC PROCESSING FOR A
LEAN-MANUFACTURING PROJECT**

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Hands-on Plastic Processing for a Lean Manufacturing Project

Lean manufacturing has proven to be an effective strategy to increase productivity and cost competitiveness in the manufacturing industry. Lean manufacturing has been integrated into the existing manufacturing curriculum. In a senior-level manufacturing course, hands-on plastic manufacturing experiments were implemented to allow the students to conduct small scale manufacturing, use value streaming mapping (VSM) techniques to identify the wastes, and improve the process using the Kaizen tools. The experimental manufacturing consists of three steps: 1) the open molding process, 2) the flash removal process, and 3) the packaging process. During the open molding process, a liquid pre-polyurethane is mixed with a curing agent and placed into silicone rubber molds. Through a series of the manufacturing experiments, students developed the VSM of their processes and identify the wastes, which include the waiting time of polymer curing, movement for acquiring a mold release spray, etc. After the Kaizen session, students improved their process by changing the plant layout and improving their set-up and process parameters. According to the student feedback, the hands-on manufacturing experiments was an effective project to review concepts of lean manufacturing, apply lean manufacturing tools to identify wastes or ‘non-value-added’ activities in factories, and suggest how to minimize or eliminate them.

1. Introduction

Lean thinking has been well known as an effective strategy to provide and increase the value delivered to the customer. Lean is based on the Toyota Production System (TPS), which is a more flexible manufacturing system than the traditional mass-production system. Lean manufacturing, developed from TPS, utilizes fewer resources and results in a larger variety of products and at the same time high levels of product quality and service [1,2]. Lean manufacturing has been widely applied in many US manufacturing industries. The lean manufacturing strategy has been employed not only at the large manufacturing firms, but also at small manufacturing companies such as job shops [3,4]. As a result, Washington State University Vancouver Mechanical Engineering Industry Advisory Board has highly recommended to the program to implement lean manufacturing into the curriculum. As a result, a three credit elective course entitled “Advanced Manufacturing Engineering” includes lean manufacturing in the course content. The main objectives of the course are 1) Describe various modern manufacturing processes for various engineering material systems, 2) Understand metrology and geometric dimensioning and tolerancing (GD&T) and apply them into assembly processes, and 3) Define lean/6-sigma tools and develop value stream map (VSM) in manufacturing. Table 1 shows the main topics of the class. Lean manufacturing was taught for the last 4 weeks of instruction.

The subjects taught in class are the following:

- Definition of lean manufacturing and muda (wastes)
- Value stream mapping (VSM)
- Takt time and line balancing
- Kaizen methodology

A hands-on-project (a plastic manufacturing experimental project) was assigned in 11th week. Then, the students conducted their projects on the last week of the semester. Throughout the lean manufacturing instruction and the project, students are expected to use manufacturing system tools such as facilities layout, line balancing, and VSM techniques to identify the existing process and *kaizen* (continuously improve) the process. This article discusses a novel approach to fostering lean manufacturing instruction and a hands-on project that allowed students to work in a team, conduct plastic processing, learn about kaizen tools, and experience/witness the efficiency of their contributions on site.

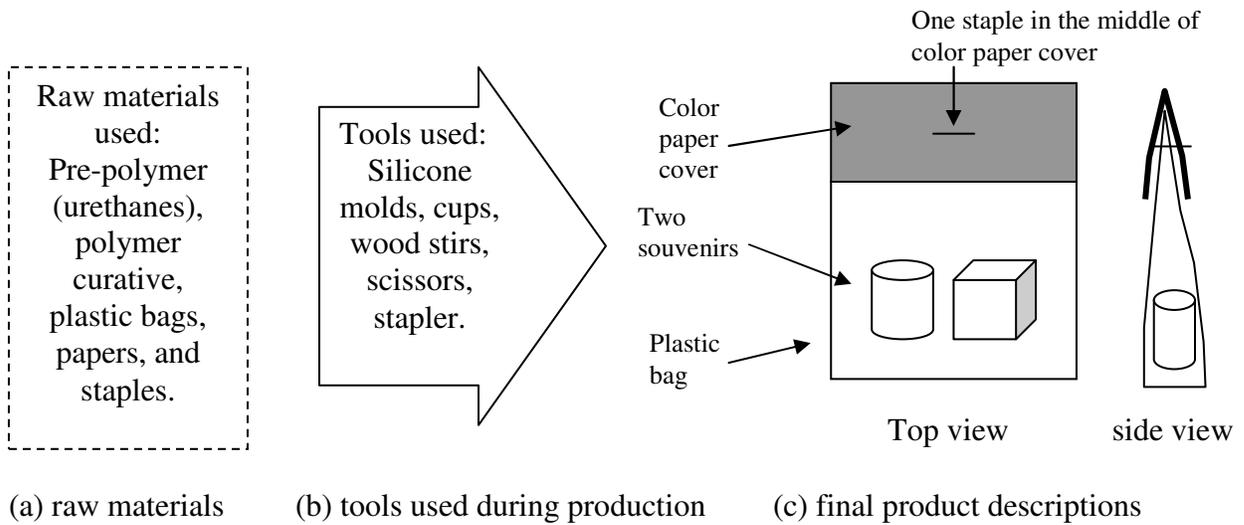
Table 1 Topics for the “Advanced Manufacturing Engineering (MECH476)” course

Weeks	Topics
1-3	Metrology/Geometric Dimensional and Tolerancing
4-5	Assembly processes
6-8	Powder metallurgy/Ceramic/Composite processing
9-10	Rapid prototyping processes
11-12	Lean Manufacturing/Value Stream Mapping
13-14	Quality improvement tools/Kaizen Practices

2. Hands-on plastic processing project

The goal of this hands-on project is to use manufacturing system tools such as facilities layout, line balancing, and Value Stream Mapping (VSM) techniques to identify an existing plastic manufacturing process and *kaizen* (continuously improve) the process. A team of five students worked together to manufacture the plastic school souvenirs, which were manufactured using the open silicone molding process. Total of four teams were created for the projects. Raw materials, tools used, and final product descriptions are shown in Figure 1. The instructor prepared 12 silicone molds for the project.

There are three steps in this project: 1) Production run with the existing manufacturing system defined by the instructor, 2) Kaizen meeting, and 3) Production run with the modified manufacturing system defined by the student team. Details in each step will be introduced in the following sections.



(d) A final product example

Figure 1. Raw materials, tools used, final product descriptions, and a final product example for the project.

2.1 Production run with the existing manufacturing system

Before the project begins, the instructor gave some training for the manufacturing processes in the project. All students are familiar with conducting the open silicone molding process, deburring the plastic products, and packaging the products. Before the production run, the instructor prepared all necessary raw materials and tools on the tables. The five different jobs were assigned to their team members. The production system defined by the instructor had four production-related jobs (Plastics Processing Engineer (PPE), Quality Assurance Engineer (QAE), Finishing Engineer (FE), and Packaging Engineer (PE)) and one timer to run time study during production. The production layout defined by the instructor was shown in Figure 2. The initial plant layout has six stations:

1) plastic process station, 2) spray station, 3) quality assurance station, 4) finishing station, 5) packaging station, and 6) shipping station.

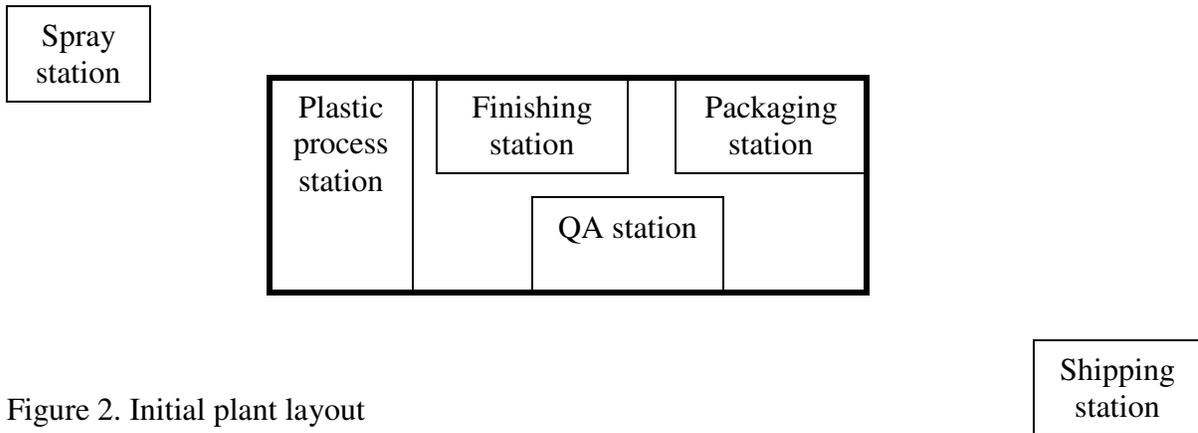


Figure 2. Initial plant layout

To start production, the PPE would spray two silicone molds with a parting agent at the spray station. He would then take them back to the plastic processing station and proceed to mix the liquid pre-polymer and the curative. When mixed, the polymer was poured into the molds and allowed to cure. When cured, the parts were removed and sent to the QAE by a simulated “cart,” which was a paper bowl. These “carts” were used for transportation of parts between all stations.

Upon receiving the new parts, the QAE would inspect them for excess material around the edges (defects). If defects were noted, the parts were placed in a cart along with a hand written instruction to correct the defects. The cart was then sent to the finishing station. If no defects were noted, the parts were sent to the PE for packaging.

There, the FE would simulate a machining process by cutting off the excess plastic with a pair of scissors. When this was completed, the parts were placed back in the cart and returned to the QAE, where they would be re-inspected. Parts with uncorrected defects would be returned to the FE, while acceptable parts would be sent by cart to the PE.

The PE did everything from cutting and folding the paper top section of the package to inserting products in groups of two (a “unit” or a “product”) into clear plastic bags. A paper top was then centered on and stapled to each bag. Assembled packages were then carted back to the QAE, who inspected the package for parts count and neatness of assembly. Unacceptable packages would be sent back to the PE for re-work, while acceptable ones would be carted by the QAE to the shipping area.

The timer observed each station and recorded operator cycle time for each engineer.

The first 8 hours of production was simulated by a 20 minute production period. During adjustment to an 8 hour period, it was assumed that each operator would average 85%

efficiency throughout the day. Figure 3 briefly introduced the major steps in the initial production run.

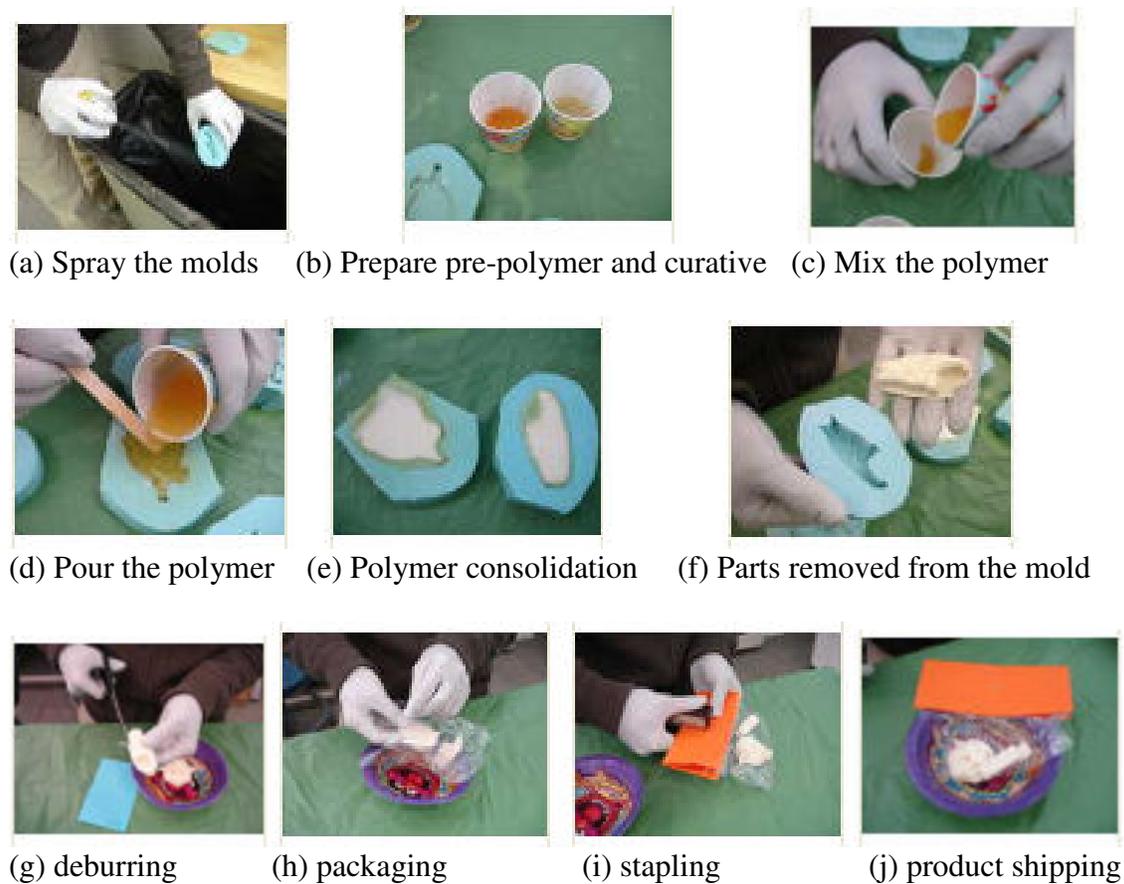


Figure 3. Major manufacturing steps in the initial production run.

2.2 Kaizen meeting

When they completed the initial production run with the existing manufacturing system, the students realized that there were a lot of wastes or *Muda*. After conducting brief VSM analysis, the students had a Kaizen meeting to reduce the wastes identified and improve the manufacturing system. This 15 to 30 minute meeting allows the students to have brainstorming to identify reasons of the low production and produce worthwhile ideas for improvement. By the end of the meeting, the students were asked to document the detailed plan for improvement.

2.3 Production run with the modified manufacturing system

The students conducted their 2nd production run, which was substantially modified as a result of the Kaizen meeting. Often the students streamlined the production layout and re-

arrange the manufacturing jobs to increase a degree of flexibility. Similar to the initial production run, the production of 1 day (8 hours) was simulated by a 20 minute production period. The timer observed each station to conduct the time study and recorded operator cycle time for each engineer. After the 20 minute production run, the students share the time study results for their project reports. Each student was asked to write an individual project report.

3. Project Results and Discussions

The students were asked to calculate their total production and manufacturing cost per a product in order to evaluate their performance for the projects [5,6]. For the initial production runs, average of 9 products were manufactured and the average cost for manufacturing was \$ 3.23 per a product. After conducting the initial production run, the students identified a number of wastes during the process. Table 2 shows the summary of the wastes identified by the students during the Kaizen meeting.

Table 2. Examples of the wastes found during the initial production run

Types of the wastes	Examples of the wastes found during the initial production run
Overproduction	Not found
Transportation	The PPE was always busy moving molds for spraying.
Motion	The PPE was always busy preparing molds, mixing, pouring, or un-molding
Waiting	Too much waiting for the QAE. The QAE's job was relatively quick by comparison. There was substantial idle time for both the QAE and FE.
Unnecessary Processing	The QAE inspected the products from every single step in the production line.
Inventory	Not found
Rework/Rejects/Repairs	Under-fill during silicone molding was found.
Underutilized workers	The PPE was overworked, and the skills of the other engineers were under-utilized.

The students expressed that the Kaizen meeting was a very interesting process and many excellent ideas were gleaned from the communication, which occurred during this meeting. Because the students learned some of the Kaizen tools such as line balancing, they tried to incorporate those into their next production run. In addition, the student teams want to eliminate the wastes such as waiting and transportation from their production. After the Kaizen meeting, all teams modified their plant layout and reassigned the jobs to the engineers. Some team improved the silicone molding process and the usage of production tools. Table 3 shows how the students improved their production runs.

Table 3. Kaizen meeting results summary

	Kaizen items incorporated into the production run
Layout change	<p>Eliminating QA station and implement of single-piece flow. Layout example:</p>
Job reassign	<p>Combining QA, machining, and packaging into one job. Having two engineers in the polymer processing station. Giving the packager the de-molding job. New position to set up for molding.</p>
Mfg tool improvement	<p>The stir sticks could be reused. The pre-polymer and curative container cups could be reused.</p>
Others	<p>Optimizing the amount of resin used to perform each run of parts. Standardizing the mix time for the liquid pre-polymer and the curative.</p>

Table 4 shows the production performance measures before and after the Kaizen meeting for all teams. After implementing the items from the Kaizen meeting, the average number of products was improved from 9 to 20.5. The main reason of this improvement in the production output is to streamline the production and all the production steps were redesigned to operate at the defined takt time (60 sec). The students expressed that all the people were quite busy at the 2nd production run. In addition to production output increase, the manufacturing cost for one product was decreased from \$3.23 to \$2.27. This is mainly due to saving raw materials (liquid pre-polymer and curative) through optimizing the amount of polymer for one product and reusing some tools (cups and stirs).

Table 4 Summary of production performance measures before and after the Kaizen meeting.

Performance measures	Initial production run		Production run after Kaizen	
	Total production (for 20 min.)	Mfg cost per a product	Total production (for 20 min.)	Mfg cost per a product
	# of products	\$/product	# of products	\$/product
Team 1	9	2.99	25	2.74
Team 2	12	2.83	15	2.43
Team 3	7	4.43	22	1.96
Team 4	8	2.68	20	1.93
Average	9	3.23	20.5	2.27

The student evaluations for this project were very positive. Some of the student comments on the course evaluation were:

- The project was very practical. I think I can use lean manufacturing technique at work.
- Always to good to have hands-on lab during class
- This project was just like a true production line. It was very interesting how much we can pull out of a 15-minute talk.
- I learned how to process polymeric materials. Exciting to manufacture cougar heads.
- Fun, fun, fun!

Despite the success of the project, the instructor noted there was room for improvement in some aspects of the exercise. First, the students should have enough knowledge in lean principals before the initial production run. Because the instructor gave a few homework questions related to lean manufacturing prior to the project, the students did not understand some of key concepts well when conducting the project. The instructor observed that students often misunderstood the definition of the takt time. Second, the quality standard for the product was not well established. There were only few rejects found by the QAE during production. As a result, the students eliminate the quality assurance jobs from the production to eliminate the unnecessary process. Finally, more efficient assessment tools should be implemented into this project. Our assessment tool (project report evaluation and student feedback) did not successfully address how the project contributed to students increase in technical skills in lean manufacturing. The authors learned that identified project objectives and assessment design (e.g. the Student Survey) must be carefully aligned.

4. Summary and Findings

The presented hands-on project provides a benefit to students' implementing the lean manufacturing tools to identify and eliminate the wastes in production. While most lean manufacturing projects used manufacturing simulations (cutting papers or writing numbers on the paper cups, etc), this lean manufacturing project used a true material processing technique, which is the silicone molding process. The lean manufacturing principals (VSM, 8 wastes, etc) were covered in the classroom and the students used them during the hands-on manufacturing laboratory project. The students identified waiting, transportation, and underutilized people as most common wastes during the production. After implementing lean manufacturing tools into their existing production run, the student teams achieved 127% increase in production output and 30% decrease in manufacturing cost per a product. Most teams implemented single-piece flow to the production layout and assigned the work based on the takt time. In terms of lessons learned, the lean principals should be instructed thoroughly to the students before the initial production run. Quality standard for the product should be well established.

Assessment tools should be carefully designed to probe for evidence of intended student learning outcomes.

5. References

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