Value Stream Mapping: Recreating an Industrial Environment in an Educational Setting

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Abstract

Recreating industrial environment in the classroom helps students prepare for workplace. Manufacturing students need to be prepared for applying lean manufacturing (LM) concepts in real life. Value stream mapping (VSM) is one tool that can be used for implementing LM technique. This work aims to apply VSM in the Simulated Industrial Manufacturing Company (SIMCO) class at Indiana State University. In SIMCO, mass production technique was used to manufacture products such as diploma frames. Therefore, there was a need to use LM technique to minimize the waste and maximize the flow. It is known that VSM can identify continued opportunities to enhance value, eliminate waste, and improve flow. In this work, four steps were followed while implementing VSM: identifying the product, creating a current state value stream map, creating a future state value stream map, and creating an action plan. Takt time, process cycle time, and process cycle efficiency (PCE) were computed for prior and post states for comparison. Although PCE did not improve, takt time, cycle time, budget, and number of required employees were significantly reduced.

Introduction

Simulated Industrial Manufacturing Company (SIMCO) is completely laboratory-oriented capstone course designed to help students practice more hands-on activities. The class is offered once a semester at Collage of Technology of Indiana State University. The course is similar to an industrial experience in the sense that each student brings to the enterprise/class various skills, abilities, talents, and knowledge; all have to work together to pool their expertise to achieve the final goal of producing an item of high quality, made to specifications, on schedule, and within a budget. Many products are manufactured in SIMCO such as diploma frames, clocks, coffee tables, etc. SIMCO consists of eight departments: manufacturing and production, design, quality, sales and marketing, purchasing, human resources, safety, and packaging. Each department should contribute to the process of

developing one product. Machines that are available in the SIMCO lab include planer, belt sander, table saw, miter saw, router, and speed sander.

The researchers focused on using the diploma frame product to describe the process of production and usage of machines. The process of producing the diploma frame product can be summarized as the following: First, the sanding process provides a smooth surface on both sides of the wood and an exact thickness. Second, the edge joining process connects the wood pieces at a 90-degree angle. Third, the miter saw process allows workers to cut the wooden piece into exact angles 45 degree. Fourth, students use the router machine to cut the edges of the frame. There are two types of routing the edges: routing the inside edge with 3/16 inch bit and routing the outside edge with 5/32 inch bit. Also, a Kreg machine is used to make a screw cut on all the wooden pieces. This process is important for assembling the wooden pieces. Fifth, the face jointing process provides a smooth surface on the thicker edge on both sides of wooden board. Next, poly seal painting is used to paint the wooden piece by using brush and touch up pens. The last step is assembling the diploma frame pieces by using screws.

Many factors necessitate organizational change in SIMCO. These can be summarized by five important factors. First, number of student workers: the average number of students (employees) in the class is 25. These employees can be more effective and productive by eliminating unnecessary tasks and positions. Also, the large number of employees leads to difficulty in managing them and creating more problems and conflict between them. Second, the price of raw material is relatively expensive as we buy for each class in less quantity than a real industry. By the end of each semester, some of the materials become waste from the unused raw material and unsold finished products. The next factor is the high volume of the inventory, which takes storage room for raw materials and finished goods that are not in demand. The fourth factor is the quality of products, which is acceptable but not high level. Finally, demand of the products in SIMCO is low. It may be because of low quality of the product compared with products in the market or to poor marketing strategy. All these reasons encouraged us to reorganize the production process in SIMCO. Some of the unnecessary tasks would be eliminated and replaced with tasks that will add value to customers and improve the overall performance and quality of the product.

This research aims to apply the technique of value stream mapping (VSM) in the SIMCO class and measure the effectiveness of the new procedure (lean production). In SIMCO, mass production technique is used to manufacture products such as diploma frames, clocks, coffee tables, etc. Therefore, there is a need to use lean manufacturing technique in this class to minimize the waste and maximize the flow. VSM is used to identify opportunities to enhance value, eliminate waste, and improve flow. Four steps will be followed in order to fulfill the value stream mapping: identifying the product, creating a current state value stream map, creating a future state value stream map, and creating an action plan. Takt time, process cycle time, and process cycle efficiency (PCE) analyses are used to evaluate and create the current state and future value stream maps.

Literature Review

This section presents a brief review of literature relevant to the research.

Lean Manufacturing

Lean, as defined by Womack and Jones [22], is the process for doing more with less and less, less human effort, less equipment, less time, and less space, while coming closer and closer to providing customers exactly what they want. It is also a business system and a generic process management philosophy with a systematic approach to eliminate waste through techniques such as just-in-time, continuous improvement [2], and pull system [21]. Lean manufacturing and its key principles were developed or derived from the Toyota production system (TPS), which is more generally known as lean manufacturing [6, 16]. TPS is defined by Ohno as the absolute elimination of waste and as an effort to make product in a continuous flow with minimum interruption [15].

According to Womack and Jones [22], there are five key principles of lean thinking:

- *Define value from the customer perspective:* Value needs to be specified from the standpoint of the end customer. If the customer does not pay for an activity, it is considered as non-value-added and it should be eliminated.
- *Identify the value stream:* The value stream is the set of all the specific actions required to produce a specific product or service. All of the steps in the value stream should be identified for each product family and every action and every practice that does not create value must be eliminated.
- *Make the process flow:* The materials should flow through the system with minimum interruption and waiting.
- *Pull from the customer:* The customer should pull the product from the source as needed rather than the source process pushing products onto the customer. In other words, no upstream function or department should produce a good or service until the customer downstream asks for it.
- *Head toward perfection:* After implementing these steps, the managers and teams of employees should eliminate further waste and pursue perfection through continuous improvement.

Lean technique is not a concept but a philosophy that every organization and work environment is looking to implement to eliminate waste (non-value added activities) and save on labor, material, and machines costs [17]. Lean techniques use the standardized work practices to minimize efforts and improve products quality to not just meet customers' expectations but to exceed them [3, 7].

Advantages and Goals for Lean Production

There are many advantages and goals for lean production. These can be summarized by

- *Improve quality:* To stay competitive in today's marketplace, a company must understand its customers' needs and design its services processes to meet their expectations and requirements [24, 22].
- *Eliminate waste:* Waste is any activity that consumes time, resources, or space but does not add any value to the product or service [5]. Waste can be due to any of the following: overproduction, motion, transportation, waiting time, set up time, processing time, inventory, defective product, and underutilized workers [5, 13, 4].
- *Reduce time:* Reducing the time it takes to finish an activity from start to finish is one of the most effective ways to eliminate waste and lower costs [22].
- *Reduce total costs:* To minimize cost, a company must produce only to customer demand. Overproduction increases a company's inventory costs because of storage needs [1, 23].

Value Stream Mapping (VSM)

The value stream mapping (VSM) technique was helpful to implement the lean production in SIMCO. This technique was used to analyze the current situation and developing new production process that aims to minimize waste, maximize flow, and improve customer satisfaction by improving the product quality. A value stream can be defined as all the steps—both value added and non-value added—needed to transform a product or service from its raw materials state into a marketable item. Managing the value streams involves a process for measuring, understanding, and improving the flow and interaction of all the associated tasks to keep the cost, service, and quality of a company's products and services as competitive as possible [19]. VMS can identify continued opportunities to enhance value, eliminate waste, and improve flow. There are four steps an organization can use to implement value stream in their production processes: identifying the product, creating a current state value stream map, creating a future state value stream map, and creating an action plan [12].

Method of Investigation

In order to improve the production in SIMCO, lean manufacturing technique has been used. A comparison has been made between the SIMCO class of Spring 2012 (after lean implementation) and the previous mass production process used in Spring 2011. The comparison helped the researchers to evaluate the effectiveness of lean manufacturing technique in classroom sittings. The VSM analysis has been helpful to improve the production process at SIMCO. Smart Draw Software is used to develop the maps.

Collecting and tracking the needed time for each process is important in this research. Data have been collected by the students of SIMCO class using a digital stopwatch. The time in seconds for each process has been measured three times, and the average of the three trials has been calculated. This method is used to calculate different factors and to build the current VMS that is described in the next section. Also, it helped in measuring the cycle time for each process [18]. Different mathematical equations have been used. PCE has been calculated as

PCE = Customer Value Added Time/Process Cycle Time   (1)
[20]

Process cycle time is the sum of design time, manufacturing planning time, manufacturing control time, and manufacturing lead time. Thus, cycle time is the sum of value-added and non-value added time [8].

Takt time is calculated as
Takt Time = Net Time available to work/ Time demand   (2)
[9]

Assumptions

It is assumed that the year of production in SIMCO is the academic year that consists of two semesters of 16 weeks each. The class meets twice per week and two hours each day. Also, it has been assumed that the walking time is constant because the production processes have taken place in the same SIMCO lab without any changes in machine locations.

Findings

Findings of this research can be summarized by three main points: organizational structure, budget, and production process and cycle time.

Organizational Structure

Spring 2011. Organizational structure was a functional structure, which provided organization according to a job's (or an individual's) purpose within the organization. Functional organizations are most easily recognized by departments that focus on a single function or goal. Figure 1 shows the organization chart for SIMCO Spring 2011 before the change.
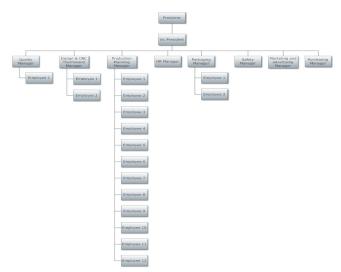

Figure 1. Organization structure for SIMCO in Spring 2011

Spring 2012. Matrix structures were developed in SIMCO to create the best results of managing the company. The matrix structure creates teams for organizational projects that need to be completed and, in creating teams, draws together the most qualified employees for the project from various areas of the organization. Instead of utilizing only department heads, which would be common in the functional and divisional structures, the matrix structure focuses more on project heads or managers who oversee a diverse group of individuals from different parts of a company. The matrix structure can become confusing, though, due to the greater level of decentralization, because it is not always clear who is in the leadership role in a group. A matrix structure is considered most effective for companies that operate internationally or across a wide range of geographical area. Figure 2 shows the organizational structure for SIMCO Spring 2012 after the change.
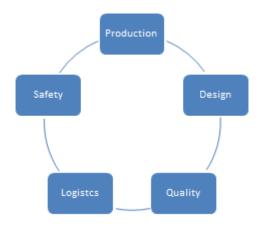

Figure 2. Organization structure for SIMCO in Spring 2012

Eight departments (in the old structure) were reduced to five areas by using the matrix structure. The packaging department was integrated into the production area and the purchasing department into the sales and named as logistics area. The human resource department has been eliminated, and there is no need for it with the matrix structure that eliminates the centralized management.

Budget

Spring 2011. Table 1 includes the budget for producing 35 diploma frames.

Table 1. Budget for SIMCO Spring 2011

QTY	Description	Unit price	Total
75.00	White Oak (Board Feet)	$ 2.50	$ 187.50
35.00	S. S. Glass 15.25" x 12.75"	$ 3.90	$ 136.50
35.00	Blue Matting	$ 3.90	$ 136.50
35.00	Gold Matting	$ 3.90	$ 36.50
35.00	1/8 in. Foamcore Board	$ 1.00	$ 35.00

1.00	Custom Frame – Turn Buttons	$ 5.00	$ 5.00
1.00	90 Degree Corner Clamp	$ 34.99	$ 34.99
1.00	1" Fine Thread Pan Head Screws (1000 count)	$ 25.99	$ 25.99
4.00	Clamps	$ 29.99	$ 119.96
	20% Discount	$ - 36.19	$ -36.19
4.00	4" All-purpose Glue Sticks (24 pack)	$ 4.97	$ 19.88
1.00	MinWax Polycrylic Semi-gloss (1 Qt.)	$ 16.57	$ 16.57
1.00	6-Pack Foam Brush 2"	$ 2.98	$ 2.98
1.00	Finish Factor 12-Pack Terry Towels	$ 7.46	$ 7.46
			$ 828.64

Spring 2012. Table 2 includes the budget for producing 10 diploma frames; according to course history, the demand for the diploma frame product is 10 units per semester. Therefore, there is no need to order material for more than 10 units unless more units are requested by customers.

Table 2. Budget for SIMCO Spring 2012

Description	Quantity	Price Per Unit	Total Cost
Frame	5	$12.31	$61.55
Backing 1	10	$3.41	$57.94
Backing 2	10	$3.41	$57.94
Frame Glass	10	$4.34	$43.40
1 pack of 10 30"x20"	1	$39.97	$39.97
Gunstock Color	1	$6.27	$6.27
16oz Bottle	1	$6.75	$6.75
TOTAL			$ 273.82

Thus, total budget has been reduced from pre-change value of $ 828.64 to $ 273.82. Figure 3 shows the budget difference between Spring 2011 and Spring 2012.
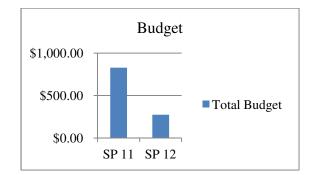
Figure 3. SIMCO budget for Spring 2011 and Spring 2012

Production Process and Cycle Time

Spring 2011. The number of diploma frames to be produced was determined based on the capacity of the SIMCO class (i.e., 35 students). Company departments were formed based on the number of the enrolled students. Goals were to manufacture diploma frames in large quantity (35 frames) and in standard form.

There were fifteen main processes for producing the diploma frame product. These steps are shown in Table 3 and Figure 4.

Table 3. The production processes for SIMCO Spring 2011

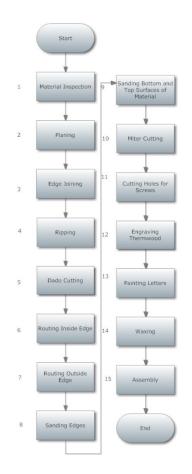| NO	Process Name
1.	Material Inspection
2.	Planning
3.	Edge Joining one side to create 90 degree angle
4.	Ripping
5.	Dado Cutting
6	Routing Inside Edge
7	Routing Outside Edge
8.	Sanding Edges
9.	Sanding Bottom and top surfaces
10.	Miter Cutting
11.	Cutting holes for screws
12.	Engraving upper and lower pieces with Thermwood
13.	Painting Letters
14	Waxing
15	Assembling

Figure 4. Flow chart for SIMCO Spring 2011

Table 4 shows the time in seconds for each of the value added process for producing 35 frames by mass production technique. Also, the time for each process has been summarized in Figure 5. These data helped in creating the current value stream mapping shown in Figure 6.

Table 4. Total time for each process for SIMCO Spring 2011

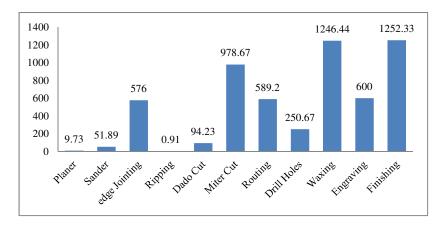| Step	Total Time (Second)
Planer	9.73
Sander	51.89
edge Jointing	576
Ripping	0.91
Dado Cut	94.23
Miter Cut	978.67
Routing	589.2
Drill Holes	250.67
Waxing	1246.44
Engraving	600
Finishing	1252.33
TOTAL	5650.07

Figure 5. Total time for each process in second for SIMCO Spring 2011
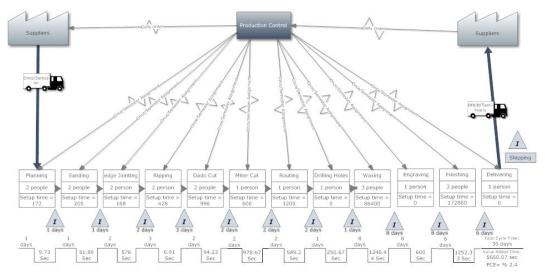

Figure 6. Value stream mapping for SIMCO Spring 2011

Three parameters have been computed: takt time, process cycle time, and PCE. As mentioned earlier, the year of production in SIMCO is the academic year that consists of two semesters, 16 weeks for each semester. The class meets twice per week and two hours for each day. Therefore, the time available for each day is 110 minutes (= 6600 sec) excluding the breaks and clean up. Based on the actual sale of the diploma frames, annual demand was 20. Demand has been computed by dividing the annual demand by 64 days per year (2 days/ week → 8 days/ month → 32 days/ semester → 64 days/year); daily demand = 0.3125 piece/day. From the value stream map, it can be found that the value added time was 5650.07 sec and total process cycle time (PLT) was 36 days (37×6600 = 237600 sec). From equation 1, PCE= 5650.07/ 237600 =2.4%. From equation 2, takt time= 6600/0.3125= 21120 sec/piece. Table 5 summarizes the result of the calculations.

Table 5. The production measurements for mass production

Measurement	Result
Daily demand	0.3125 pieces/ day
Takt time	21120 sec/piece
PCE	2.4%
Process cycle time	237600 Sec
Value added time	5650.07 Sec
Non-value added time	231949.93 sec

Spring 2012. The production process in Spring 2012 was changed using lean manufacturing concepts. The change was accomplished in four important steps: advertising the product to determine actual demand, determining the number of employees to meet the demand, computing required materials, and giving customers the choice to customize their frame. It was found that the demand of this product was 10 frames (annual demand = 20). Prior to the change, 25 students (employees) were needed to produce 35 diploma frames. After the change, 6 employees were needed to produce 10 frames. Thus, the rest of the students could engage in other organizational or manufacturing functions instead of working on production. The new method has eliminated the number of processing steps from 15 to 10 by eliminating the unnecessary processes and by doing the following:

1. *Purchasing finished wood:* This eliminates the time needed to inspect the incoming material and reduced production steps such as planning and sanding the unfinished wood.
2. *Using best practices*: This has been applied by changing the production process that start from changing the product design and making it simpler and can be done by few simple steps and few machines.
3. *Changing the production processes:* The waste has been eliminated by changing some of the production processes such as the way of connecting the edges. The joint process has been changed from using screw to biscuit connection, which has reduced the time needed for edge joining from 250.67 seconds to 12.9 seconds. Table 6 compares the time in seconds needed for the main processes for SIMCO in Spring 2011 and Spring 2012.

Table 6. Main production processes in SIMCO Spring 2011 and Spring 2012

Main Processes for SIMCO Spring 2011 (in Seconds)		Main Processes for SIMCO Spring 2012 (in Seconds)	
Finishing	1252.33	Finishing	1627
Waxing	1246.44	Waxing	57
Miter Cut	978.67	Miter Cut	59.7
Engraving	600	Engraving	765.3
Routing	589.2	Routing	65.1
Dado Cut	94.23	Dado Cut	46.1
Drill Holes	250.67	Biscuit cut	12.9

These steps are explained in Table 7; Gantt and flow charts are shown in Figures 7 and 8, respectively.

Table 7. The production processes in SIMCO Spring 2012

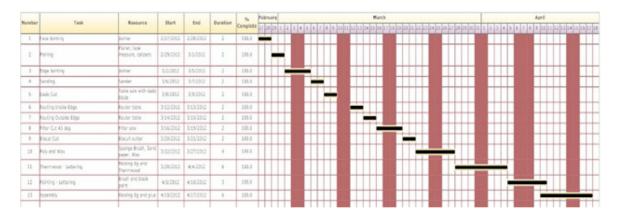| No	Process
1	Rough Cut
2	Dado Cut
3	Routing
4	45° Cut
5	Biscuit Cut
6	Sanding
7	Thermwood Routing
8	Pre-Stain
9	Stain
10	Assembly

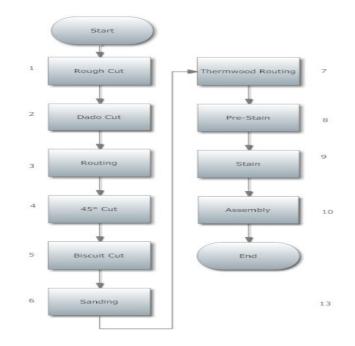Figure 7. Gantt chart for SIMCO Spring 2012

Figure 8. Flow chart for the production process in SIMCO Spring 2012

Table 8 explains the time in seconds for each of the value added process for producing 10 frames. Also, the time for each process has been summarized in Figure 9. Flow chart and time for each process have helped in creating the value stream mapping which has been shown in Figure 10.

Table 8. Time for each process per second

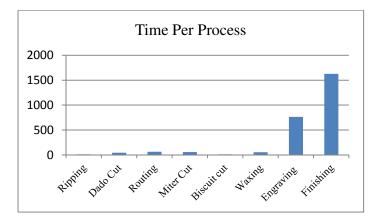| Process	Time in seconds
Ripping	15.2
Dado Cut	46.1
Routing	65.1
Miter Cut	59.7
Biscuit cut	12.9
Waxing	57
Engraving	765.3
Finishing	1627
Total	2648.3

Figure 9. Time needed for each process mapping that has been shown in Figure 10
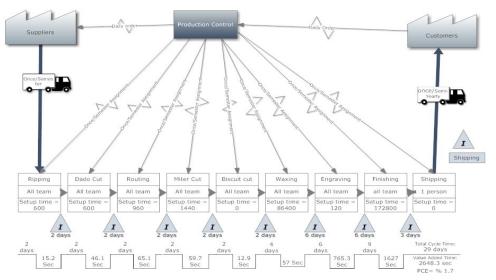

Figure 10. VMS for SIMCO Spring 2012

Three parameters have been computed: takt time, process cycle time, and PCE. As mentioned earlier, the year of production in SIMCO is the academic year that consists of two semesters, 16 weeks for each semester. The class meets for two hours, twice per week, but because of the new procedure, the time that is available for each day is 90 minutes excluding the breaks and clean up. Daily demand = 20/64 = 0.3125 piece/ day. From equation 2, takt time = (90×60 sec)/0.3125 = 17280 sec/piece. From the value stream map, value added time was 2648.3 sec and total process cycle time was 29 days × 90 min × 60 sec (156600 sec). From equation 1, PCE= 2648.3 / 156600 =1.7 %.

Table 9 summarizes the result of the calculations:

Table 9. Measurements for lean production in SIMCO Spring 2012

Measurement	Result
Daily demand	0.3125 piece/ day
Takt time	17280 sec/piece
PCE	1.7%
Process cycle time	156600 Sec
Value added time	2648.3 Sec
Non-value added time	153951.7 sec

Conclusion

From the previous section, it can be concluded that the new procedure was effective in reducing the takt time from 21,120 sec /piece to 17,280 sec /piece. Also, the process cycle time has been reduced from 237,600 sec to 156,600 sec. In addition, non-value added time has been reduced from 231,949.93 sec to 153,951.7 sec. Moreover, the new process helped in reducing the budget of producing this product from $828.64 to $273.82. The new process gives the rest of SIMCO students the opportunity to engage in different organizational and production activities other than producing the diploma frames. Table 10 summarizes the difference between production process for SIMCO in Spring 2011 and Spring 2012.

Table 10. Production measurements for SIMCO in Spring 2011 and Spring 2012

Measurement	Spring 2011	Spring 2012
Daily demand	0.3125 pieces/ day	0.3125 pieces/ day
Takt time	21120 sec/piece	17280 sec/piece
PCE	2.40%	1.7%
Process cycle time	237,600 Sec	156,600 Sec
Value added time	5,650.07 Sec	2,648.3 Sec
Non-value added time	231,949.93 Sec	15,3951.7 Sec
budget	$ 828.64	$273.82
Employees	25 employees	6 employees

It is clear from Table 10 that VMS helped the researchers improve the SIMCO class significantly. Looking at the post-change data, PCE did not improve; but other parameters such as cycle time, non-valued added time, takt time, budget, and number of required employees to make the diploma frames, were all reduced significantly.

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