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From value stream mapping toward a lean/sigma continuous improvement process: an industrial case study

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Though lean manufacturing has been widely recognised for its effectiveness in continuously improving productivity, product quality, and on-time delivery to customers, the cost for hiring a full-time lean manufacturing engineer has kept many small businesses from implementing lean in their facilities. This paper presents a case study of lean implementation at a small manufacturer in the United States. Starting with collecting process information, a current value-stream map was created that reflected the current operation status. A future value stream map was then proposed to serve as a guide for future lean activities. Next, hurdles that kept the company from moving towards future state were identified. The '5 whys' method was employed to reveal the root cause for each hurdle, followed by kaizen events proposed as solutions. In this case study, two kaizen events were proposed. For the first kaizen event, Taguchi experiment design was used to find the optimal machining parameters that reduced variation in a plasma cutting process. It consequently eliminated rework time and improved productivity. In the second kaizen event, implementation of rabbit chasing increased the system flexibility and consequently reduced inventory levels between work stations.

Keywords: value-stream mapping; lean manufacturing; Taguchi experiment design; rabbit chasing; kaizen; quality improvement

1. Introduction

Manufacturing companies have been faced with increasing amounts of pressure from customers and competitors in the past couple of decades. Customers have higher expectations from their purchases, and manufacturers can meet these expectations by increasing a product's quality, reducing delivery time, and minimising product costs – or a combination of the three (George 2002). This has forced the manufacturing industry to implement new production strategies to enhance their competitiveness in the global market place. Although some companies have chosen to move their manufacturing facilities to other developing countries such as Mexico or China, there are many companies that have decided to remain in the United States and implement lean manufacturing in their facilities.

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The past few years have seen the dollar become weaker and weaker, increasing the competitive advantage of manufacturing firms in the USA. Companies in Europe, where the Pound and Euro are very strong, have begun to purchase goods from American suppliers while also relocating sales jobs to America, where manufacturing costs are comparatively cheaper. At the same time that American companies are outsourcing jobs overseas, European firms are expanding their American facilities and searching for new facilities across the USA (Macdonald 2007).

Lean manufacturing was first implemented by Toyota Corporation in response to the mass-production model. When engineers at Toyota researched mass-production systems, they discovered that their mass-production model, which eliminated changeover time by using one machine for each part, was not optimally efficient (Toyota Production System). They discovered that machines downstream were sitting idle until the specific part the machine made was required for production. These idle machines contributed to waste in the process.

Therefore, the engineers from Toyota created a lean manufacturing system. This system focused on the continuous identification and elimination of waste. As a result, the Toyota Production System (TPS) used fewer resources than mass production. Organisations have found that, by identifying and removing waste, as well as implementing key lean tools, they can continuously improve their productivity, increase quality, and become more cost effective (Imai 1997).

The rest of this paper is organised as follows: Section 2 provides information about kaizen and the lean tools used in the case study. Section 3 provides information about the company as well as why they wanted to implement lean manufacturing in their facility. Section 4 provides information about the current manufacturing system and how we collected this information. Section 5 presents the future state of the facility. Section 6 describes the kaizen events performed in the case study. Finally, Section 7 provides the conclusions from this research.

2. Kaizen and lean tools

According to Monden (1998), any task in a manufacturing facility can be classified into one of three categories: incidental work, value-added work, and muda. Incidental processes are processes such as inspection that do not add value to the product, but are required in the current production system. Value-added processes add value to the product, such as the final assembly of a product. Finally, non-value added processes, or muda, are defined as any process that does not add value to the product and is not required by the current production system. Mudas can be classified into seven categories which are also known as the seven deadly wastes. These seven deadly wastes include overproduction, waiting, transportation, over processing, inventory, motion and defects (Womack and Jones 1996). Another way to look at muda is to say that it is any activity that the customer is not willing to pay for.

In order to increase the amount of value-added work in a facility, some companies will simply choose to increase the working hours as shown in Figure 1(b). However, rather than simply achieving the goal of increasing value-added work, the company has also increased incidental work and muda. In such a case, the company's competitive position is not enhanced. Therefore, a better way to increase the amount of value-added work in the facility is to cut down the amount of incidental work and muda. Kaizen was designed for

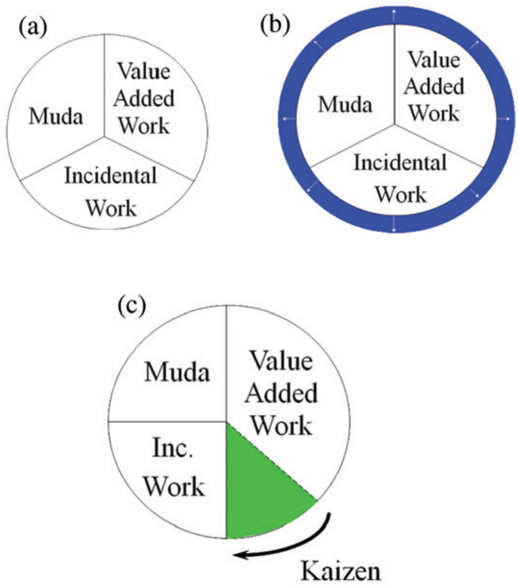


Figure 1. (a) Composition of workers time. (b) Affect of hours increase on composition. (c) Affect of kaizen on composition.

this very purpose: to continually improve the process by identifying and reducing waste. By using kaizen, companies are able to reshape the composition of work, in order to decrease muda and incidental work. The shaded slice in Figure 1(c) is used to illustrate the transformation from incidental work and muda to value added work.

Since the goal of kaizen is to continuously identify and decrease the amount of muda in a system, it is important to identify and separate muda from incidental and value-added work. After identifying muda, the next step is to determine how to reduce it. One common way to reduce muda is through kaizen. The goal of kaizen is to involve every employee in thinking up small improvement ideas on a regular basis. When small improvements are implemented they can make work easier and more enjoyable. It is important to realise that a series of small, strategic improvements can quickly add up to a significant increases in system efficiency (Bodek 2002).

When setting out to do a kaizen activity there are several lean tools available, ranging from value-stream mapping to asking the '5 whys'. Since every case is different, determining which tools to utilise becomes the job of the lean practitioner. Some of the most commonly utilised lean tools are given below, along with a brief description of each tool.

2.1 *Process at a glance*

After a particular product has been identified for improvement, the next step is to determine what is involved in the manufacturing of that particular product. The process at a glance shows which processes are involved and the sequential order of operations. This information typically includes a description of the operation, cycle time, percentage of uptime, and the number of workers required for each operation. Information gathered by this lean tool will be used in subsequent lean activities.

2.2 *Value-stream mapping*

A value stream consists of all the materials and information required in the manufacturing of a particular product and how they flow through the manufacturing system. Value-stream mapping is simply transferring information about the value stream to a 'map', which represents either the current or future state of the manufacturing system. As the name implies, a current-state value-stream map (VSM) shows how both materials and information flow through the processes in the current system. A future-state VSM represents the ideal state of the manufacturing system.

2.3 *The '5 whys'*

After identifying where muda was located throughout the system, it is important to identify the root cause of the muda and reduce or remove it. The '5 whys' method is a process that begins with identifying specific problem and writing it on a piece of paper. This is followed by asking why the problem happens and writing the answer below where the problem was written. If the answer given does not identify the root cause of the problem, the engineers keep asking why until the root cause of the problem is identified. Although the name implies asking why a total of five times, some situations require fewer and some require more than five questions.

2.4 *Kaizen events*

Once the root cause of a problem has been identified, there is a need to find a solution which allows a company to reduce or eliminate muda. Sometimes this is done with the use of kaizen events. During a kaizen event, personnel from across disciplines and the Lean/Six Sigma team work together in order to find solutions for a particular problem in order to make improvements to the current manufacturing system.

2.5 *Standard operation routine sheets*

Standard operation routine sheets are used to show the time relationship between the worker(s) and the manufacturing system. The information required to create the routine sheet are: the time it takes a worker to walk between processes, machine processing times, and manual operation times. Manual operations are tasks that need to be done by the worker between processing cycles, such as loading/unloading, de-burring, and inspection. The information is then turned into a graphical representation that shows what the worker and machines are doing throughout a cycle.

2.6 *Design of experiment*

Design of experiment (DOE) is a systematic method for exploring the cause-and-effect relationship between process variables and output variables. There are two types of DOE that can be performed: full factorial design and fractional design. A full factorial design is the more desirable of the two options, because it performs a more thorough analysis, but it also requires more trials, and thus, more resources. Fractional DOE experiments allow companies to perform DOE, but this more limited method does not uncover all the information that would have been gained with the use of a full factorial design.

3. Company information

Company A is a small electrical manufacturing business in the Midwestern United States. The major products of Company A are industrial switchgears and switchboards. Company A has a wide variety of customers located all over the world, ranging from general contractors, to industrial facilities, to large commercial power grids. All of Company A's products are made to their customers' exact specifications; therefore, it is uncommon for the company to make two identical products. Although the manager had knowledge about how lean manufacturing could help the company, the workers at Company A had yet to complete a lean manufacturing project, and expressed their desire to transform the facility using Lean/Sigma strategy in order to increase the efficiency of their plant. Although Lean/Sigma has potential applications enterprise-wide in Company A, the switchboard unit was chosen as the starting point of this lean transformation project, since it is the major manufacturing section of the facility and involves the highest amount of personnel and equipment. Therefore, a Lean/Sigma team was formed consisting of researchers in collaboration with operators, engineers, and a manager from Company A.

4. Current status

4.1 *Process overview*

The first step in creating a value-stream map is to collect data that represents the current status in the facility. The Lean/Sigma team visited Company A's production facility and performed two walkthroughs with the manufacturing manager, tracing the paths that the material and information flow through the production facility of Company A. For the first walkthrough, the Lean/Sigma team walked with the manufacturing manager from the raw material receiving dock downstream to the finished products shipping dock. This made the Lean/Sigma team familiar with the current flow and the sequence of processes in the facility. Next, the Lean/Sigma team walked from the shipping dock upstream towards the raw material dock. This gives the Lean/Sigma team a better sense of the customer pace that the facility should operate on.

Walking through the facility allowed the Lean/Sigma team to collect the detailed process information that represents the current status of manufacturing system. Figure 2 shows the detailed process time and rough uptime for each process in a sequential order, from the first process to the last one when it is ready to be shipped. Based on this information, the current value-stream map of Company A's facility is generated, as shown in Figure 3.

The standard operation routing sheet (Figure 4) gives a more detailed breakdown of the operations involved in the fabrication stage of manufacturing as well as showing what the worker was doing at a particular time in the fabrication stage. The fabrication stage includes four processes: shearing, plasma cutting, de-burring, and braking. The representative product the Lean/Sigma team studied requires six metal sheets;

Process #	1	2	3	4	5
Process sketch					
Operation description	Shear	Plasma Cut	De-bur	Brake	Cut
Average Cycle time	5 min	47 min	15 min	22.2 min	15 min
Uptime %	100	90	100	100	100
Workers	1	1	1	1	2
Area	Fabrication	Fabrication	Fabrication	Fabrication	Welding

Process #	6	7	8	9	10
Process sketch					
Operation description	Weld	De-bur	Wash	Dry	Paint
Average Cycle time	235 min	45 min	20 min	5 min	20 min
Uptime %	100	100	100	100	100
Workers	2	1	1	1	1
Area	Welding	Finishing	Finishing	Finishing	Finishing

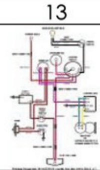
Process #	11	12	13
Process sketch			
Operation description	Bake	Assemble	Wire
Average Cycle time	30 min	480 min	2400 min
Uptime %	100	100	100
Workers Required	1	4	20
Area of Shop	Finishing	Assembly	Wiring

Figure 2. Process detail.

however only two pieces need to go through all four processes; the other four pieces only require the shearing process.

As Figure 4 shows, the operator starts by picking up the first work piece and completing the shearing operation on it, which requires five minutes. Next, the operator moves the sheared work piece to the plasma cutter. Since the plasma cutter is computer-numerically controlled, the operator only needs to be present to load the machine, which requires three minutes, and then the operator can let the machine run itself. While the plasma cutter is cutting the first work piece, the operator walks back to the shearing machine and shears the other five work pieces which requires 25 minutes altogether.

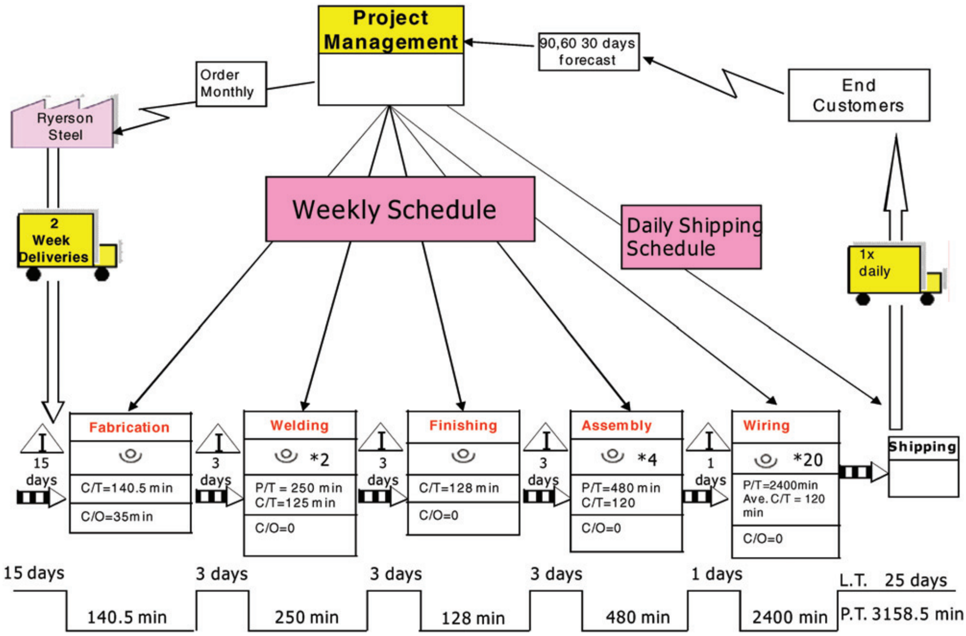


Figure 3. Current value stream map.

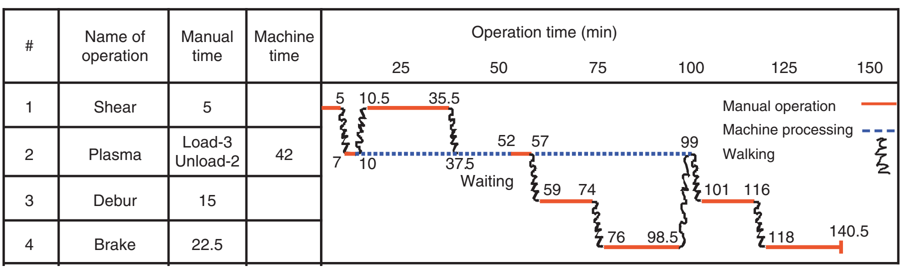


Figure 4. Standard operation routine sheet for fabrication operation.

Since the time it requires to plasma cut the first work piece is longer than what is required for the operator to shear the other five pieces, there is a 14.5 minute period in which the operator has nothing to do, as shown in Figure 4. Upon the completion of plasma cutting the first work piece, the operator sets up the plasma cutter for the second work piece and then begins plasma cutting the second piece. The operator then takes the first work piece to the de-burring and braking processes. After completing the de-burring and braking processes, the operator walks back to the plasma cutter to pick up the second work piece in order to begin to de-burr and brake it. After the second work piece has gone through all four processes, fabrication for the switchboard is complete.

The cycle time of fabrication operation is 140.5 min, which is longer than the cycle times of the other operations. In addition, quality problems were found in the fabrication operation, mostly at the plasma cutter which only has about a 90% uptime capability.

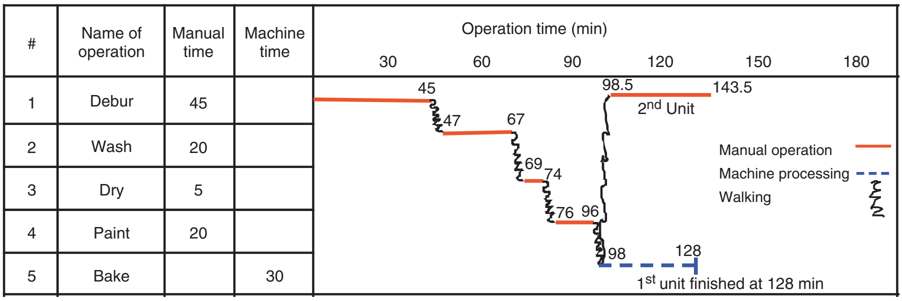


Figure 5. Standard operation routine sheet for finishing operation.

The high rate of rework and defects caused by the plasma cutter caused an increase in the cycle time. The long cycle time of the plasma cutter causes the operator to wait for 14.5 minutes as is indicated on the fabrication operation routine sheet (Figure 4). On the operation routing sheet (Figures 4 and 5), the time required for the operator to move the work piece from one process to another is 2 minutes, and the time required for the operator to walk between processes is 0.5 minute.

After fabrication, the parts are welded together and then sent to the finishing operation (Figure 5). The finishing operation includes five processes: de-burring, washing, drying, painting and baking. The operator takes the unit through all five processes sequentially. As shown in Figure 5, the operator does not need to be present for the entire baking process. Therefore, after starting the baking process, the operator begins production of the next unit. Once the baking process for the first unit is finished, the finishing operation is completed. The cycle time for the finishing operation is 128 minutes.

As the current value-stream map shows in Figure 3, raw materials are ordered monthly with shipments arriving at the company every two weeks. When the Lean/Sigma team toured the facility an inventory level of 15 days was observed. Since shipments arrive every two weeks, the lead time is longer than it would have been if shipments arrived at a smaller interval (such as weekly).

Company A's production control is currently scheduled on a weekly basis by the project manager. There is no communication between the individual working areas. It is clear that the entire production system is based on a push control strategy. There are places on the current VSM where inventory accumulates for long periods of time, which add no value to the product. The total lead time of current Company A facility is about 25 days with a total processing time of 3158.5 minutes.

5. Future state

The information represented on the current value-stream map allowed the team to visualise the current operation situation in the facility. There were many sources of waste in the current system that added no value to Company A's production. Since the purpose of lean manufacturing is to reduce or eliminate waste, the Lean/Sigma team needed to define a future value-stream map that serves as a guide for all future lean projects. The following are the eight steps (Rother and Shook 2003) that the team went through to identify the problems and define the future state.

5.1 *Calculate Company A's takt time and pitch*

Company A is operating on a single eight-hour shift every day with an average of four switchboards being ordered every working day. With this information, the takt time was estimated as follows.

$$\text{Takt time} = 8\ (\text{hours/day})/4\ (\text{pieces/day}) = 2\ \text{hours(day)}$$

The takt time shows that Company A needs to produce one switchboard every two hours in order to meet customer demand. Therefore the production facility of Company A should meet the takt time of two hours.

In Company A's facility, one pallet is used to convey one unit of material, therefore the Pitch is calculated as below.

$$\text{Pitch} = \text{Takt time} * \text{Pallet size} = 120\ \min/\text{unit} * 1\ \text{unit/pallet} = 2\ \text{hours/pallet}$$

5.2 *Determine if finished goods should go to a supermarket or ship directly to customers*

The products of Company A are customer-specific switchboards and the production volume is low. Therefore the Lean/Sigma team decided to ship the products directly to the customers.

5.3 *Identify where to use continuous flow processing*

The major manufacturing areas in Company A's production facility include fabrication, welding and finishing (Figure 2). The current cycle times for these operations are 140.5, 125, and 128 minutes. Although the cycle time for fabrication is 140.5 minutes, the Lean/Sigma team found that the plasma cutter produced a high rate of defects that needed to be reworked. Therefore the team concluded that the cycle time of the plasma cutting machine can be reduced after the process is improved. In addition, the other two operations, welding and finishing, have cycle times that are close to the takt time of customer demand. Thus the Lean/Sigma team sees these three operations as good candidates to form a continuous flow system. The Lean/Sigma team decided to combine these operations into one cell and proposed that the fabrication area should be turned into a cell using a rabbit-chasing system (Black 1991). More details about this will be presented in Section 5.5.

5.4 *Determine where to use supermarket pull mechanisms*

The facility currently operates using a push control mechanism with inventory present between operations (Figure 3). In addition, raw materials are ordered on a monthly basis with shipments arriving every two weeks. This leads to two potential problems: increased inventory levels of raw materials and the possibility of not having raw materials on hand when needed. To help with this problem, the team concluded that two supermarkets be used in the system. One supermarket is used before the rabbit-chasing cell to notify the production manager that there is a need for more raw materials. The second supermarket is used in the rabbit-chasing cell to tell workers the production schedule.

5.5 *Determine the location of the pacemaker*

With the pull mechanism implemented and the rabbit-chasing cell formed, after products go through the rabbit-chasing cell they will be moved to the assembly operation and then to the wiring operation through FIFO (first in first out) lanes. Since all operations downstream of the rabbit-chasing cell are in flow, the rabbit-chasing cell is the pacemaker.

5.6 *Determine how to level the production mix at the pacemaker*

Batching is not desired from a lean perspective, because it will increase inventory levels and therefore increase the lead time. In addition, batching will also make it difficult to track quality problems. Production mix will be levelled at the pacemaker, the rabbit-chasing cell, via the load levelling box which uses production order packets, with each packet corresponding to a single switchboard.

5.7 *Determine the increment of movement at the pacemaker*

The takt time of Company A is two hours; and each switchboard is moved as a unit through Company A's facility. Therefore the pitch is two hours, which means every two hours the product will be moved to the next process; with each switchboard corresponding to one production order packet. Movement at the pacemaker is controlled by the load-levelling box shown in Figure 6. Each column of the load levelling box denotes a pitch increment, in this case two hours. Every morning the project manager will place production order packets in the appropriate time slots in the levelling box, with each packet corresponding to a single switch board. The operator will then retrieve a production order packet from the appropriate slot when they start their new job.

5.8 *Identify the improvements needed to achieve the future state*

The team brainstormed and identified a list of wastes present in the facility using the seven deadly wastes mentioned in the beginning of the paper. The three largest wastes were then identified by the team. These three wastes need to be reduced or eliminated first in order to move the system closer to the one proposed in the future value-stream map. They are:

(1) *Defects*. The plasma cutting machine generated a high rate of defects which required the operator to spend extra non-value added time reworking the products.
(2) *Waiting time*. Welders are sometimes idle while waiting for parts to arrive from the plasma cutting machine.
(3) *Inventory*. There are only two skilled welders in the shop, if one or both of them is sick or takes time off for vacation the inventory levels between fabrication and welding build up.

Based on the above eight steps, a future map for Company A's facility is proposed, which is shown in Figure 6. The future map shows the future status of Company A's desired production system and will offer direction for Kaizen events that are intended to improve the current production system. The details of the future map will be carried out using kaizen events, which are highlighted with light bursts on the future map (Figure 6).

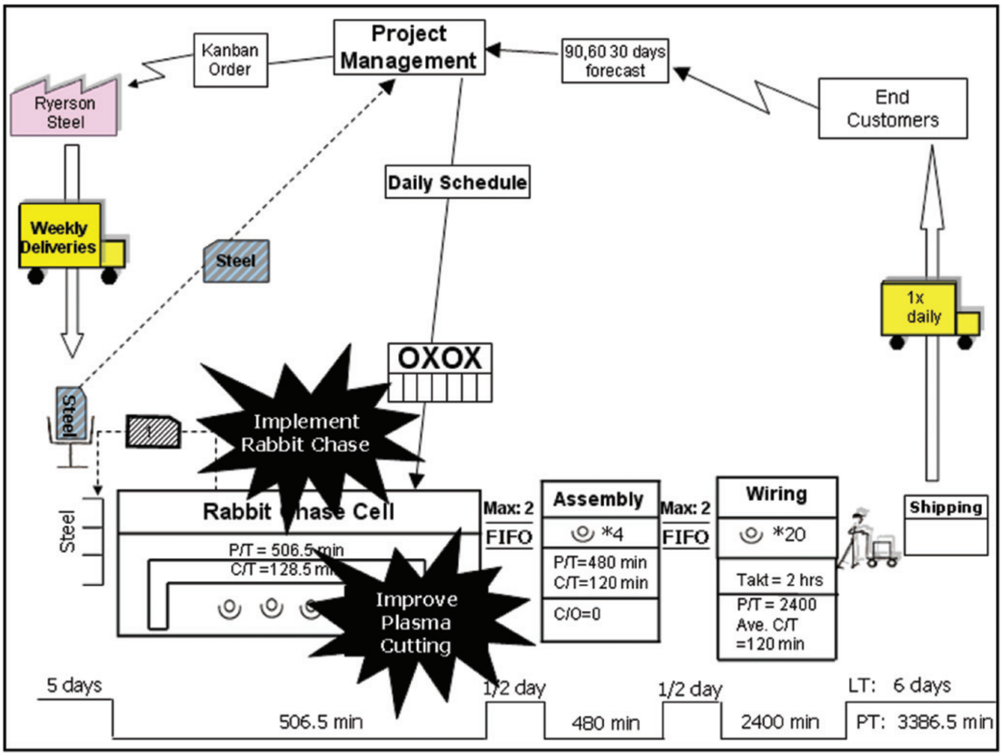


Figure 6. Future value stream map with kaizen light bursts.

6. Kaizen events

The central motif of lean manufacturing is to identify and eliminate muda (waste). The future map gives us the ideal operation status in the future as documented in Figure 6, which serves as the direction to lead the current operation towards. The transition from current status to future status may involve many kaizen projects planned in advance as well as those defined as needed on the way towards the future status. However, due to the constraints in time, money, and resources, only some of them can be completed within the limitations of a company. Based on the three key wastes as presented in the preceding section, the team discussed and defined two immediate kaizen events for eliminating or reducing these wastes, as is indicated with Kaizen light bursting shown in Figure 6. These two kaizen events are hoped to bring Company A's production section closer to the future status. The Lean/Sigma team determined that a seven-month timeframe gave the company enough time to implement the two kaizen events. In order to assist carrying out the Kaizen events, the '5 whys' method (Jones and Womack 1996) was utilised to identify the root cause for each of the wastes that existed in the current manufacturing system.

Kaizen event 1

Reducing waiting time and defects at the plasma cutting machine

Root cause identification. Waiting time was one of the largest hurdles keeping the company from moving towards the ideal future state. Waiting time occurs in the system because the

Problem statement: There is waiting time in the production sector.

1. **Why is there waiting time?**
   - The cycle times are different: 140.5 min in fabrication, 250 min in welding, and 128 min in finishing. The fabrication stage is the bottleneck.
2. **Why is the fabrication stage the bottleneck?**
   - Cycle time of the plasma cutter is 42 minutes, which creates production delay.
3. **Why is the cycle time of the plasma cutter 42 minutes?**
   - The plasma cutter creates defects that need reworked. In addition, inspection time is added for this reason.
4. **Why does the plasma cutter create defects?**
   - The plasma cutter is not working on its optimal parameter settings.
5. **Why does the plasma cutter not work on the optimal parameter settings?**
   - The optimal parameter settings were not available, because no DOE (Design of Experiment) study had been conducted.

Figure 7. '5 whys' for waiting time root cause.

cycle times of fabrication, welding and finishing operations are 140.5, 125 (two stations) and 128 minutes, respectively. The fabrication operation was identified as the bottleneck of the system because it had the longest cycle time, which is approximately 15.5 minutes longer than the fastest operation. Since the production process begins with the fabrication operation, the longer cycle time caused the downstream operations to sit idle while waiting for parts. The Lean/Sigma team utilised the '5 whys' to identify the root cause of the waiting time. The results of the '5 whys' are given in Figure 7.

The '5 whys' analysis revealed that the root cause of why the plasma-cutter in the fabrication stage was producing defects was because it was not working on the optimal parameter settings. Although it would have been easy for company A to replace the aging equipment with a newer machine, they were hesitant to do so because of their limited amount of capital. Therefore the manager of Company A and the Lean/Sigma team then decided to conduct a design of experiment in order to determine the optimal parameter settings for the plasma cutter.

Goal. Process improvement of the plasma cutter through DOE.

Process description. A plasma cutting machine is used to produce holes on work pieces for installing hardware on switchboards. However, some holes do not allow the hardware to pass through for one of two reasons: bevelled edges (Figure 8) and poor circularity (Figure 9). A bevelled edge brings an angle to a hole's side surface, affecting the cylindricity. Poor circularity leads to a poor fit between the workpiece and hardware. These two quality issues are the objectives that need to be optimised through DOE (Gitlow and Levine 2005).

Proposal. In this kaizen event, the Lean/Sigma team sought an efficient way to complete the DOE for the plasma cutter. This process focuses on producing an efficient DOE, because Company A has a limited budget and a timely need to improve plasma cutting. Because of these factors, the team chose Taguchi parameters design because it allows

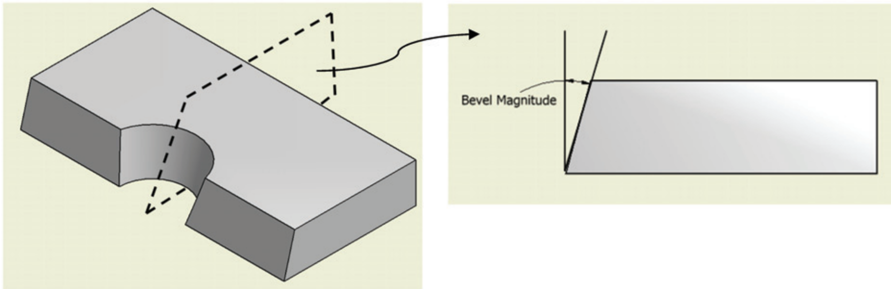


Figure 8. Illustration of bevel.

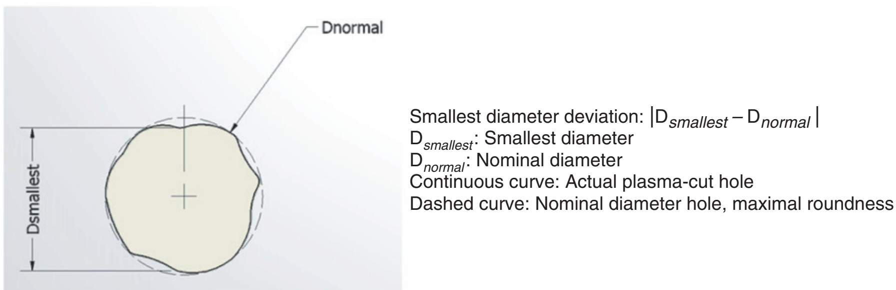


Figure 9. Illustration of smallest diameter deviation.

a reduction in the amount of time and money required for the experiment. By using orthogonal arrays the Taguchi experiment design reduces the number of experimental trials.

Implementation. The Lean/Sigma team studied the plasma cutter and identified four controllable factors (voltage, feed rate, amperage, and tip size) and two uncontrollable noise factors (air pressure and pierce time). An L_9 array is used in the Taguchi experimental design consisting of the four controllable factors, each with three levels. With two non-controllable factors included in the setting, 36 experiments are conducted, compared to 81 parameter combinations (four factors, three levels or 3^4) required in a traditional DOE setting. Experimental trials and data analysis showed that the optimal parameter settings were $A_1B_2C_1D_3$ (tip size: small; feed rate: 93 in/min; voltage: 100V; amperage: 63A). The responses to bevel and circularity deviation are shown in Figure 10 and Figure 11. The optimal combination was then verified with a confirmation run of 30 work pieces with all 30 cuts meeting the quality requirement for the subsequent assemblies. After identifying the optimal parameter settings, the cycle time for the plasma cutter was reduced from 47 minutes to 30 minutes, since the time spent on inspection and rework for the defects was decreased.

Kaizen event 2

Reducing inventory waste.

Root cause identification. Inventory is another key muda observed on the floor of Company A's manufacturing facility. The existence of inventory increases production costs because it ties up money that could be used in other areas of the facility. In addition,

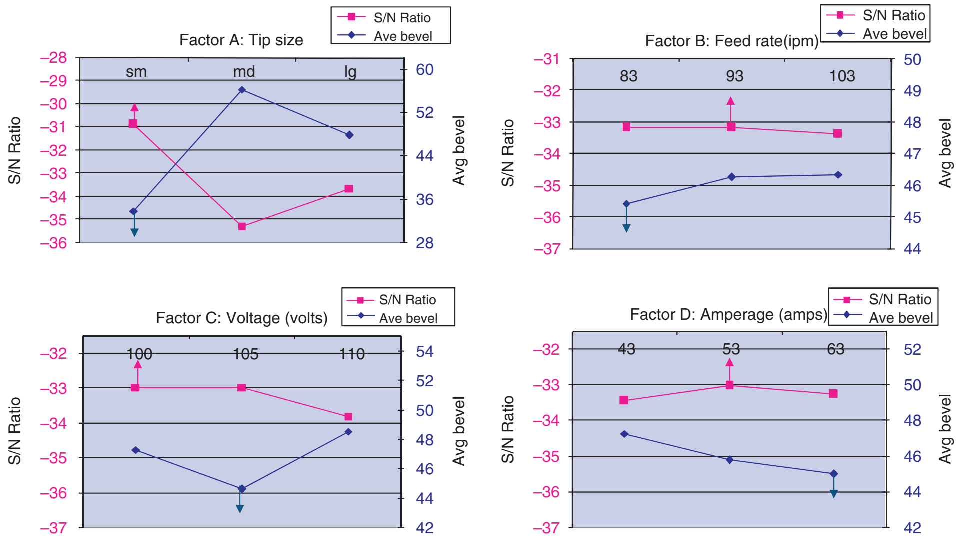


Figure 10. Response graphs for bevel magnitude.

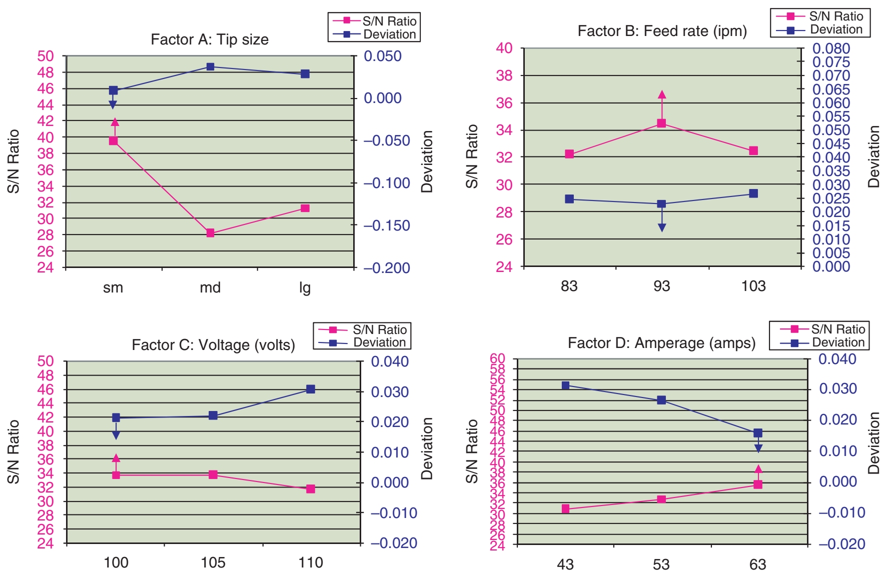


Figure 11. Response graph for circularity deviation.

defects in inventory will increase the difficulty of tracking quality problems. The delays associated with reworking defective parts further impede production efficiency which therefore increases production costs. At the time of the initial walkthrough, the Lean/Sigma team observed a three-day inventory between the fabrication, welding and finishing operations. To eliminate this muda, the Lean/Sigma team is dedicated to first determining the root cause that results in this inventory. The team used the '5 whys' procedure to determine the root cause. The results of this procedure are summarised in Figure 12.

Problem statement: There is inventory in the production sector.

1. **Why is there a lot of inventory between the fabrication and welding areas?**
   - Inventory buildup occurs whenever there are delays in the welding operations.
2. **What causes delays in the welding operations?**
   - Since two welding operators share the load, if one of them is absent, the welding operation delays the other processes. This is because there is no substitution of workers when a welder is unable to be at work.
3. **Why is there no substitution?**
   - Only two operators are trained as welders and skilled welders are a very limited resource in the Midwest.
4. **Why are all employees not trained as welders?**
   - The company does not currently cross-train employees.
5. **Why is there no cross training?**
   - The company does not have a system to cross-train workers

Figure 12. '5 whys' for inventory root cause.

The '5 whys' method reveals that the current system has little flexibility if an operator is missing from the system; particularly in the welding operation, which will lead to the accumulation of inventory. To resolve this situation, there is a need to make the current system design more flexible.

Goals. Re-design the production system to improve system flexibility with the purpose of reducing inventory.

Process description. There are three stages involved in this kaizen event: fabrication, welding, and finishing. Upon the completion of the first kaizen event, the plasma cutting process was improved and the cycle time was reduced from 47 minutes to 30 minutes. Therefore, the cycle time for the fabrication stage is reduced to 128.5 minutes. Since the cycle times for welding and finishing are 125 minutes and 128 minutes respectively, the three areas are more balanced.

Proposal. A rabbit-chasing system (Black 1991) is proposed to integrate the three stages (fabrication, welding, and finishing) into one cell to increase system flexibility and accommodate welding downtime. A rabbit-chasing cell (shown in Figure 13) allows one worker to take the raw materials from the first station and work all the way until finishing the part, and then start over from the first station after the finished part passes inspection. Therefore, each operator is responsible for the production of a single switchboard. Because of this, operators in the rabbit-chasing cell need cross-training to perform all the tasks required to make a switchboard. The team chose a rabbit-chasing system because it offers several benefits:

(1) Every finished frame or switchboard is fully fabricated by one worker; thus, quality problems either from manufacturing or design are easily tracked.
(2) Each worker knows the entire processes; thus, if anyone is on vacation or ill, the system can continue with minimal delays.

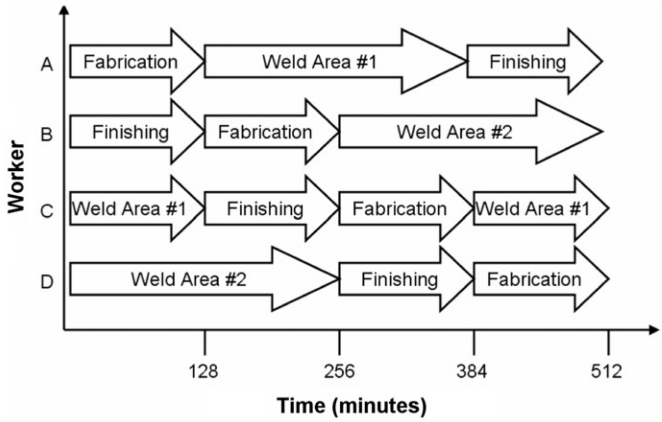


Figure 13. Positions of workers in a four worker rabbit chasing cell. Fabrication (128.5 min), welding (250 min), finishing (128 min).

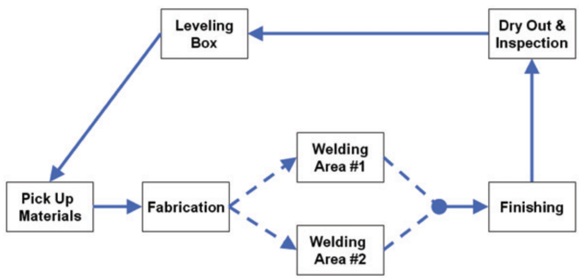


Figure 14. Flow of the proposed rabbit chasing system.

(3) The wait time between fabrication, welding and finishing was eliminated. Consequently the area previously used for inventory storage could be used for other manufacturing functions. The plant layout could even be redesigned to have machines closer to one another to reduce moving and transportation time.
(4) Sometimes the design of a switchboard may change due to a customer request. In this case, the project manager would only need to communicate with the one worker who is making that particular switchboard.

Implementation. A rabbit-chasing system is so named because the workers are essentially chasing each other through the system. As Figure 13 shows, the proposed rabbit-chasing cell will require a total of four workers who will all start in different work cells. At the end of each shift, each worker records the area where he/she was working in order to resume the next day's production where they left off. Figure 13 shows which work area each employee will be working in throughout a work day.

Figure 14 further shows how the rabbit-chasing system will work in Company A's facility. Operator A will start a new job by first going to the levelling box and obtaining the production order packet. This packet contains all the necessary information required for the production of a particular switchboard. Next, Operator A picks up the required raw materials for the switchboard from the raw material storage area. Operator A then moves the material to the fabrication area and completes the fabrication operation. Upon completing fabrication, Operator A moves the work pieces from the fabrication stage to one of two welding areas. The dashed lines indicate that the operator should move to whichever area is not currently occupied by another operator. After completing the welding operation, Operator A moves the welded switchboard framework to the finishing area to complete the finishing operation. The material then moves to the dry-out area for a full inspection before leaving for the assembly area. After the part passes final inspection, Operator A walks back to the load-levelling box to pick up a new production order packet for the next switchboard to be produced. This cycle then repeats.

7. Conclusion

The case study presented in this paper intends to give lean practitioners a reference for implementing lean systems in small manufacturing operations. In this case study, the Lean/Sigma team began the process by identifying the processes involved in manufacturing a representative product. Next, a process at a glance and a current value-stream map were created. A future-state value-stream map was then created which served as a goal for future lean activities. The team utilised the '5 whys' method to identify the root cause for the two largest hurdles that kept the company from moving towards the future state. Kaizen events were then held in order to identify solutions to overcome these hurdles and achieve greater process efficiency.

Implementing lean manufacturing can increase the competitiveness of a company in the global arena. In this case study, Company A reduced their processing times while at the same time improving the quality of their products after lean implementation. Cross-training of their employees allowed them to implement a rabbit-chasing system, which provided the facility with the flexibility that accommodates employee absence. This in turn led to a reduction in the inventory levels between each of the operations. In addition, quality problems become more easily traceable since all operations are completed by one employee. Communication was greatly simplified when a design change occurred. The manager only needs to inform one operator of a design change, rather than having to tell all operators as in the previous system.

The success of the pilot test in the production sector led Company A to adopt the lean concept as an ongoing business strategy. The management was interested in using lean activities to enhance the overall competitiveness of their business. Company A now intends to implement lean strategies in departments such as wiring, engineering design, and project management. It is expected that, eventually, lean manufacturing will be implemented throughout the company.

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