IMPLEMENTATION OF LEAN MANUFACTURING

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ABSTRACT

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Lean manufacturing refers to a manufacturing improvement process based on the fundamental goal of Toyota production system (TPS) in order to minimize or eliminate waste while maximizing production flow (Tapping, 2002). Many manufacturing organizations realize the importance of practicing lean techniques. However, few organizations apply lean techniques with the necessary knowledge and proven tools to achieve it.

A value stream includes all the operations and processes to transform raw materials into finished goods or services, including non-value adding activities. Value stream management is a management tool for planning a production process involving lean initiatives through systematic data capture and analysis (Tapping, 2002). It is a proven process for planning the improvements that will allow companies to develop lean practices.

The purpose of this study is to develop a value stream map for a manufacturing company in Minnesota. This particular tool allows the company to document current lead time, inventory

levels and cycle times to determine the ratio of value added to total lead time of the product line being analyzed. The first step will be to create a current state map to make a picture of the production flow and understand the company’s current cycle times, process communications, and machine equipment capacity. This provides the information needed to produce a future state map by creating a vision of an ideal value flow, although that will not be done in this study. The goal is to identify and eliminate the waste, which is any activity that does not add value to the final product, in the production process.

In order to collect the information needed to complete the project, the researcher will work within the production facility. This will enable the researcher to have a first hand knowledge of the production flow and to be familiar with the activities being performed at the shop floor. In addition, the researcher will observe and collect information related to product families for the practical mapping and product/process flow from start to finish, calculating takt time from data collected by the host company. The researcher will document cycle times, down times, work-in-process inventory (WIP), and material and information flow paths. This information will enable the researcher to visualize the current state of the process activities by mapping the material and information flow and looking for opportunities to eliminate wastes and to improve the process flow. Based on all the information gathered, the company will utilize these results as a plan to map the future state and implement lean manufacturing.

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CHAPTER I

INTRODUCTION

Manufacturing operations are continually striving to increase productivity and output of their operations. Their goal is to satisfy the customer with the exact product, quality, quantity, and price in the shortest amount of time.

Lean manufacturing is more than a cost reduction program or a problem solving approach (Tapping, 2002). The main idea is that an efficient production can be achieved by a comprehensive approach to minimize wastes. This means eliminating excess production and inventory, redundant movement of material, waiting and delays, over processing, excess worker motion, and the need for rework and corrections.

Part of lean manufacturing is reviewing operations for those components, processes or products that add cost rather than value (Tapping, 2002). Each step of the manufacturing process is monitored to determine if it adds value to the product. If it does not add value, the process could be delegated to a subcontractor or outsourcing company in order to focus the staff on value-added operations of its core business.

A value stream is the set of processes required to transform raw materials into finished goods that customers value (Womack & Jones, 1996). In this study, a value stream map will be developed for a manufacturing company in Minnesota. Creating a value stream map will allow the company to document current production lead time, inventory levels, and cycle times in order to determine the ratio of value-added to total lead time of the product family being analyzed, creating a vision of an ideal value flow. The goal is to identify and eliminate the wastes in the production process. The company will use these results in order to map the future state and implement lean manufacturing.

Statement of the Problem

The purpose of this study is to develop a value stream map for XYZ manufacturing company in Minnesota and identify wastes and make recommendations for improvement. It is hoped that the company uses the value stream map for the future implementation of lean manufacturing, in order to increase productivity and improve the quality of goods produced by the company, while at the same time reducing costs, total lead time, human effort, and inventory levels.

Research Objectives

1. Work within the production facility to have a first hand knowledge of the production flow and to be familiar with the activities being performed in the shop floor.
2. Select which value stream to target for the practical mapping.
3. Observe and collect information related to product/process flow from raw material to finished goods for the value stream selected.
4. Determine the current state of the process activities by mapping the material and the information flow.
5. Calculate lean metrics from the value stream map.
6. Look at the current state map for opportunities to eliminate wastes and improve the process flow.

Importance of the Study

The value stream map that will result from this study could reduce costs, improve lead time, increase productivity, and improve quality of the products produced by XYZ company in Minnesota. The impact of not doing the study could be inefficiency and working with an excess amount of work-in-process inventory which will result in delays on delivery orders, higher operating cost, loss of customers, and less sales revenue.

Limitations of the Study

The limitations of the project were that

1. The results of this study are limited to XYZ manufacturing company.
2. The company defined the value stream to be targeted for improvements.
3. The results will be based on data collected from the production activities performed along the value stream selected.
4. The study includes only the development of the current state map for a value stream selected and recommends ways to improve the process.
5. The development of the future state map will not be included in this study.
6. The study does not explain how to implement lean manufacturing.

Assumptions of the Study

It is assumed that by designing a map of the present state of the value stream selected with the necessary technical information and references to develop a future state map, XYZ manufacturing company in Minnesota will have the capacity to develop a future map in an effective way to implement lean manufacturing, in order to increase the productivity and output, as well as to reduce costs, inventory, and time. It is also assumed that all of the work centers involved in the study were working only with the selected value stream.

Definition of Terms

Available Production Time: Determined by taking the shift time and subtracting regular planned downtime events such as breaks.

Available Operating Time: Determined by taking the available production time and subtracting changeover time.

Batch Size: A technique used to run a determined quantity of parts at one operation prior to moving them to the next operations.

Changeover Time: The time that an operator spends at a work center switching the production tools in order to change from one product type to another.

Downtimes: Those are considered break times. Downtimes are regular planned times and usually involve unpaid lunch and paid breaks. During a downtime the production does not run.

Electronic Data Interchangeable: It is a tool that allows companies to process the purchasing order electronically.

Finished Goods: Refers to parts that already have been manufactured and are in the completed stage waiting to be shipped to the customer.

Kaizen: Continual improvement involving everyone within an organization (Ohno, 1998)

Kanban: A tool to achieve just-in-time which consists of a card containing all the information required to be done on a product at each stage along its path to completion and which parts are needed at subsequent processes (Monden, 1993)

Lead Time: The time that parts take to be transformed from raw material to finished goods.

Lean Metrics: A list of measurements that will help for tracking progress toward the targets selected for improvements.

Material Requirement Planning: It is a tool that helps manage the production process. Basically, it is a plan for the production of the components and purchase of materials needed to make an item.

Operating cost: It is all the money that the company spends in order to turn inventory into finished goods.

Operators: Involves those individuals that provide the work hand to perform an operation.

Product Family: Refers to all the parts that are produced within the same value stream. All the parts for the product family group have common production processes and same pattern development.

Raw Material: Material that has been purchased but not changed in any way.

Value Stream: The set of processes, including value-added and non-value-added activities required to transform raw materials into finished goods that customers value (Womack & Jones, 1996).

Work-in-Process: Any product in the production process than began as raw material, but is not a finished good yet.

CHAPTER II

REVIEW OF LITERATURE

This chapter compiles and organizes information about value streams and lean manufacturing that will aid the reader in understanding the specifics of the study.

Definition of Lean Manufacturing

According to Womack, Jones, and Roos (1990), the term “lean” represents a system that utilizes fewer inputs in order to create the same outputs than those created by a traditional mass production system, while increasing the range of different finished goods for the end customer. The term lean manufacturing is synonymous with different names, such as agile manufacturing, just-in-time manufacturing, synchronous manufacturing, world class manufacturing, and continuous flow.

Lean manufacturing is an operational strategy oriented toward achieving the shortest possible cycle time by eliminating waste (Liker, 1997). It is derived from the Toyota production system and its objective is to increase the value-added work by eliminating wastes and reducing unnecessary work. The technique often decreases the time between a customer order and shipment, and it is designed to improve profitability, customer satisfaction, throughput time, and employee motivation.

The benefits of lean manufacturing generally are lower costs, higher quality, and shorter lead times (Liker, 1997). The term lean manufacturing is created to represent less human effort in the company, less manufacturing space, less investment in tools, less inventory in progress, and less engineering hours to develop a new product in less time.

Lean Manufacturing Origins

After World War II, Japanese manufacturers were facing the dilemma of insufficiency of materials, financial problems, and human resources (Ohno, 1988). The problems that the Japanese faced differed from those in America. For many decades America had cut costs by using the mass production system while producing fewer types of end items while for the Japanese the problem was how to cut costs while producing small numbers of many types of end items.

According to Ohno (1988),

> Imitating America is not always bad. We have learned a lot from the U. S. automobile empire. America has generated wonderful production management techniques, business management techniques such as quality control (QC) total quality control (TQC) and industrial engineering (IE) methods. (p. 3)

In the 1940s a German worker could produce three times as much as a Japanese worker, and an American worker could produce three times as much as a German worker (Ohno, 1988). Therefore, the ratio of production between American and Japanese work forces was nine to one. In order to make a move toward improvement, the Japanese leader Toyoda Kiichiro proposed to reduce the gap with America in three years, resulting in the birth of the lean manufacturing practices.

The term lean manufacturing was first used to describe the implementation of what is now considered to be part of lean manufacturing such as a Kanban or just-in-time (JIT). It began as a description of procedures used by the Toyota Motor Corporation from 1950 through the 1980s (Ohno, 1988). Now lean means much more. The Toyota production system started as part of a strategy to survive developed by Taiichi Ohno, presently vice president of the Toyota, in an effort to conserve capital, eliminate waste, reduce inventory, and reduce production times and operating expenses while increasing quality and production flexibility at the same time. The Toyota production system was proved to be successful and implemented throughout the entire company.

Toyota opened its first major operation in the United States in 1984 through a joint venture with General Motors in Fremont, CA (Ohno, 1988). Since then, Toyota has made continuous progress adapting its production system to a diverse workforce and a geographically spread supplier base. The reputation of the company has grown across the world. While most companies have suffered with enormous losses in business cycle decline, Toyota has not lost money since 1960. The major contributor to their success has been Toyota production system.

The Toyota production system has been created on the practice and evolution of one very useful technique that reduces cost and time while challenges every activity in the value stream (Ohno, 1988). It is applying a methodology known as the “Five whys.” By asking why an activity is performed and then asking why after each response, it is frequently possible to get to the origin of the problem. Understanding the root cause assists in successful redesign.

Value-Added versus Non-Value-Added Activities

The process of transforming raw material into finished goods is the objective of any manufacturing company (Tapping, 2002). The processes that make that transformation possible are the result of two different activities: those that add value and those that do not. Value-added activities are considered the actions and the process elements that accomplish those transformations and add value to the product from the perspective of the customer (e. g., tubing, stamping, welding, painting, etc.). Non-value-added activities are the process elements that do not add value to the product from the perspective of the customer such as setting up, waiting for materials, and moving materials.

In the past companies have been focused on the value-added steps (Corner, 2001). The goal was to reduce the value-added component of lead time and not pay too much attention to the non-value-added activities. Today, lean manufacturing strives to improve as much as possible the value-added component of lead time, but focus first on reducing the non-value-added component of lead time.

Five Primary Elements for Lean Manufacturing

The five primary elements to consider when implementing lean manufacturing are manufacturing flow, organization, process control, metrics, and logistics (Feld, 2000). These elements represent the variety of aspects needed to sustain a successful lean manufacturing implementation program. Manufacturing flow addresses physical changes and design standards. Organization identifies people's roles/functions, training in new ways of working, and communication. Process control is directed at monitoring, controlling, stabilizing, and pursuing ways to improve the process. Metrics addresses visible results-based performance measures, targeted improvement, and team rewards/recognition. Logistics provide the definition for operating rules and mechanisms for planning and controlling the flow of material.

Issues in Lean Manufacturing

Lean manufacturing is in direct opposition with traditional manufacturing approaches characterized by use of economic order quantities, high capacity utilization, and high inventory (Feld, 2000). In changing from a traditional environment to one of lean production, cultural issues will emerge quickly, as well as resistance to change. Implementing lean manufacturing techniques will change the organizational culture because everyone needs to be more involved and accountable and people may be laid off. A fast managing change program is needed to accompany the effort. A slow approach generally does not work or achieve significant results.

Lean manufacturing is not a magical solution (Feld, 2000). It involves a change in leadership that requires considerable communication, coordination, and organization which results in a change in the company's culture. Just implementing one lean technique such as a Kanban system will not result in lean implementation. Positive employee reaction to lean manufacturing is essential to success, but does not always occur since becoming lean improves productivity and can reduce the number of workers needed. Laying people off and asking the remaining employees to become more involved may not work.

Feld (2000) stated that in order to create a lean manufacturing environment, the organization needs to be aware of where it is at that point. They must know why they need to change and why change is important. It is necessary to provide the answers to these questions to employees so they become more engaged in the process. "Motivation, tenacity, leadership, and direction all play roles in the successful deployment of a lean program" (p. 7). Feld also stated that roles within the team and the way in which team members interact with one another are important. All members must understand their roles and why they were selected for their assignment.

Types of Wastes

According to Tapping (2002) "the ultimate lean target is the total elimination of waste. Waste, or muda, is anything that adds cost to the product without adding value" (p. 41).

Wastes can be classified into seven categories (Tapping, 2002):

1. Waste of overproducing: Producing components that are neither intended for stock nor planned for sale immediately.

2. Waste of waiting: Refers to the idle time between operations.
3. Waste of transport: Moving material more than necessary.
4. Waste of processing: Doing more to the product than necessary and the customer is willing to pay.
5. Waste of inventory: Excess of stock from raw materials to finished goods.
6. Waste of motion: Any motion that is not necessary to the completion of an operation.
7. Waste of defects and spoilage: Defective parts that are produced and need to be reworked.

Stages of Lean Application

Demand Stage

This stage refers to understanding the customer demand and incorporating it into the lean process (Tapping, 2002). It involves knowing exactly the number of parts or products that the company needs to produce each day. There is an important concept called Takt time that can be used to define the customer demand. The word “Takt” comes from the German word “rhythm,” therefore Takt time determines the rhythm necessary to maintain customer demand. Takt time is calculated based in the following formula:

$$\textit{Takt Time (TT)} = \frac{\textit{Available production time}}{\textit{Total daily quantity required}}$$

Flow Stage

In order to meet customer demand the company needs to implement a flow manufacturing of production to ensure that the customer will receive the right products on time and the right amount (Tapping, 2002).

Leveling Stage

The leveling stage refers to leveling production; it means to spread the work required to achieve customer demand over a shift or a day (Tapping, 2002).

Lean Manufacturing Tools and Techniques

Once the companies find the main sources of wastes, tools such as just-in-time, Kanban systems, production smoothing method, work cells, autonomation, Kaizen, and others will help companies to take corrective actions to eliminate or reduce these wastes (Monden, 1993). Following is a compilation of information regarding to those tools.

Just-in-Time

Just-in-time means that each process receives the right parts needed at the time they are needed and in the amount they are needed to produce an order from a customer with the highest quality (Ohno, 1988). Just-in-time is an important concept in the Toyota production system.

Just-in-time allows companies to eliminate wastes such as work-in-process inventory, defects, and poor delivery of parts (Nahmias, 1997). It is a critical tool to manage activities such as distribution and purchasing, and can be classified into three categories: just-in-time production, just-in-time distribution and just-in-time purchasing.

Henry Ford (1922) found that it was only worth while to buy materials for immediate use, taking into account the state of transportation at the time. If there were never any problems with transportation and an even flow of materials could be depended upon, it would not be necessary to carry any stock because raw materials could go immediately into production, decreasing the amount of money tied up in materials. When transportation can not be depended upon, a larger stock is necessary.

Kanban Systems

A Kanban is a tool to achieve just-in-time (Monden, 1993). It consists of a card containing all the information that is required to be done on a product at each stage along its path to completion and which parts are needed at subsequent processes. This card is usually put in a rectangular vinyl envelope and is used to control work-in-process, production, and inventory flow. A Kanban system consists of a set of these cards, with one being allocated for each part being manufactured and the travel between preceding and subsequent processes. The Kanban system was developed by Toyota to achieve objectives such as reducing costs by eliminating wastes; creating work places that can respond to changes quickly; facilitating the methods of achieving and assuring quality control; designing a work environment that takes into account human dignity, mutual trust, and support; and allowing workers to reach their maximum potential. A Kanban system allows a company to achieve just-in-time production and ordering systems, which allow them to minimize their inventories while still satisfying customer demands.

Lower production times and work-in-process have lead to the idea of incorporating Kanban systems in manufacturing industries (Monden, 1993). These systems are most commonly used to implement the pull type control in production systems which mean reducing costs by minimizing the work-in-process inventory, allowing an organization the ability to adapt to changes in demand, and therefore develop faster production. A pull type production line is a sequence of production stages performing various process steps on parts where each stage consists of several workstations in cycle. Parts are pulled between the production stages in accordance with the rate at which parts are being consumed by the down stream stages. Descriptions of the types of Kanbans most often used today follow.

Withdrawal Kanban. The main function of a withdrawal Kanban is to pass the authorization for the movement of parts from one stage to another (Monden, 1993). The Kanban in Figure 1 shows that the subsequent process (machining) requests the parts from the preceding process (forging). The part, which is a drive pinion, must be made at the forging process and picked up for the subsequent process at the position B-2 of the forging department. The box has shape type B and each of them contain 20 units of the part needed. This Kanban is the fourth of eight sheets issued.

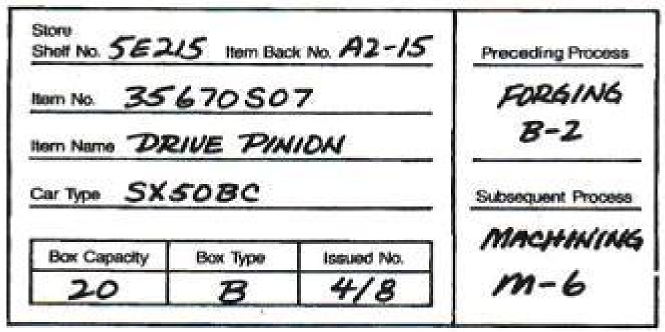

Figure 1. Withdrawal Kanban.

*Production ordering Kanban***.** The primary function of the production Kanban or in-progress Kanban is to specify the kind and quantity of product that the preceding process must produce (Monden, 1993). The Kanban in Figure 2 shows that the preceding machining process SB-8 must produce an item called craft shaft for a car type SX50BC-150 and the part must be placed at store F26-18.

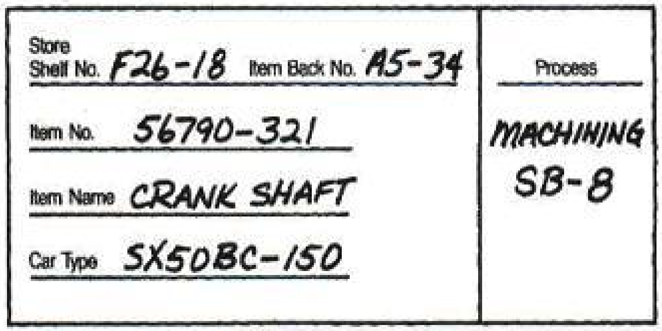

Figure 2. Production ordering Kanban.

Signal Kanban. A signal Kanban is tagged into a box within the production lot (or batch) and is used to specify lot production in the stamping processes. Two types of signal Kanbans are used (Monden, 1993):

1. Triangular Kanban: The triangular shaped Kanban in Figure 3 shows that an order from punch press process # 10 is required when the lot size is down to 200. It is placed on pallet 2 of 5.

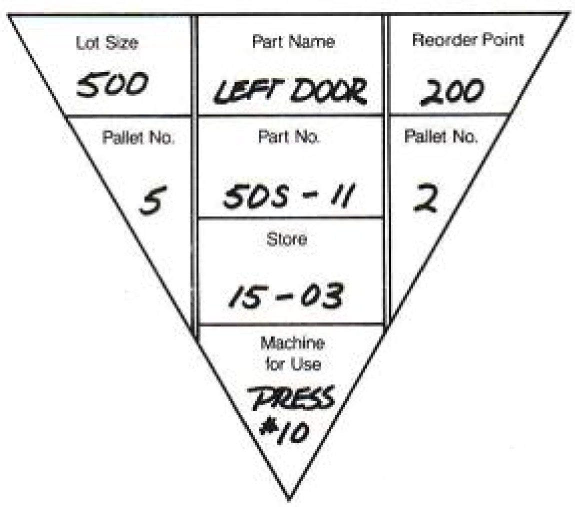

Figure 3. Triangular Kanban.

2. Material requisition Kanban: The rectangular shaped Kanban in Figure 4 shows that the press process # 10 must go to the store 25 to withdraw 500 units of steel board, when the left doors are withdrawn down by two boxes.

Preceding Process	STORE 25 → PRESS #10		Subsequent Process
Back No.	MA 36	Item Name	STEEL BOARD
Material Size	40x3'x5'	Container Capacity	100
Lot Size	500	No. of Container	5

Figure 4. Material requisition Kanban.

Production Smoothing Method

"Heijunka" is the Japanese word for production smoothing (Tapping, 2002). It is a method for planning and leveling customer demand by volume and variety, while keeping the level of production as constant as possible over a specific time period.

Production smoothing is very important state when implementing a Kanban system and reducing idle time regarding labor, equipment, and work-in-process inventory (Monden, 1993). It is the basis of the Toyota production system.

Standardization of Operations

Standardization of worker actions is an important principle in eliminating wastes (Ohno, 1988). It refers to organizing the job and performing it in the most effective way. In a standardized workplace every worker follows the same steps within the production process. The Toyota production system includes in its standard operations three elements:

1. Cycle time: The time necessary to produce one piece or unit.
2. Standard operation routine: The order of operations in which workers process a product.
3. Standard inventory: The minimum amount of work-in-process inventory necessary to process a product.

Autonomation

Autonomation is known as “Jidoka” or “automation with a human touch” (Levinson & Rerick, 2002). It is another aspect of the Toyota production system and was developed by Sakichi Toyoda, the founder of Toyota Motor Company, in an effort for create a machine that stopped automatically if any problem occurred. It exists in a machine automated with an automatic stopping device attached, which makes it possible for machines to prevent problems, such as smalls abnormalities, by itself over simple automation. The goal of autonomation is zero defects, in order to eliminate the risk of a defective product that could be received by a customer. An autonomated machine can then distinguish between a normal and abnormal operation, and also does not need continuous operator consideration.

Using autonomation, Toyota factories can detects the mass production of defects and check and correct machine breakdowns automatically (Monden, 1993). One mechanism used by Toyota to prevent defective work is called “foolproof,” “Baka-Yoke,” or “Poka-Yoke.” It works by putting various checking devices on the implements or instruments in the process.

Poka-Yoke was developed by Shigeo Shingo after World War II (Feld, 2000). It was designed to focus on the pursuit of quality at the source and to capture a response on defects in order to determine a possible root cause. The tools to implement Poka-Yoke could be physical, mechanical, or electrical. They could also be as simple as a checklist for an operator to ensure that all the activities in a determined process are covered.

An autonomated workstation can announce problems using a visual or auditory signal which cues the operator to fix and restart it (Levinson & Rerick, 2002). Also, the operator must check if this problem is a persistent problem that people must continue to correct.

The five types of visual control systems that are frequently used are call lights and an Andon board; standard operations sheets; Kanban tickets; digital display panels; and store and stock indicator plates (Monden, 1993).

Call lights are used to call for a supervisor or general workers for different types of assistance (Monden, 1993). There are different colors of lights, each of which have a different meaning and give a different instruction. Andon boards are used to show when an operator stopped the production line. The Andon board has five colors with the following meanings: red (machine trouble), white (end of production), green (short of materials), blue (defective unit), and yellow (machine setup).

As previously mentioned, standard operations are used to eliminate unnecessary inventory and workers and to eliminate accidents and defective production (Monden, 1993). Standard operations sheets consist of three elements: cycle time, a standard operation routine, and a standard amount of work-in-process. They are used with other kinds of visual control.

Kanban tickets serve as a visual signal to control abnormalities in production (Monden, 1993). The absence of a Kanban ticket on a container can work as a signal that a problem exists. Also, a Kanban ticket can determine whether working overtime is necessary or not.

Digital display panels show the pace of production, the day of production, and the number of units that has been produced during the day (Monden, 1993).

When a product is in storage an address is indicated both over the storage location and on the Kanban in an effort to deliver parts to the correct location. The stock plate indicates the quantity on stock, making inventory control easier.

Work Cells

Cellular operations are a new way to organize a plant that arranges machines in order of production operations (Levinson & Rerick, 2002). Production in these cells is performed in the order in which operations must be completed to produce the end item. When a work cell operation completes the shop order then it is moved to the next operation for additional processing by hand, forklift, or cart.

There are four primary characteristics of the modern work cell organization (Najarian, 2000):

1. Product/process family focus: Production is organized by product rather than by function with equipment dedicated or partially dedicated to a family of products.
2. One at a time production: Operations move creating a batch of one piece. In order to achieve it, one operation must start just after the part comes out from the previous operation.
3. Flexible output levels: The work cells must be flexible and coordinated with regards to customer demand.
4. Operator multi-tasking: In a work cell workers are performing operations on one part and operating numerous similar machines simultaneously.

Henry Ford (1922) stated that the Ford Motor Company started assembling one car in one factory, but as they began to make parts they departmentalized so that each department did only one thing. The factory is now organized so each department makes only one part. The part arrives as raw material and goes through the processes necessary to finish it when it will leave the department.

There are a few benefits to using work cells (Najarian, 2000). One is lower total labor cost since people are working closer and operating many machines simultaneously, improving the efficiency of the work force. Another is reduced material handling which is due to using batches of one good at a time. Improved quality is the third benefit of work cells because producing one good at a time results in easier detections and corrections of defects through the process. Last, work cells reduce work in process because when parts are produced in batches of one good and operations are synchronized, work-in-process inventory is reduced dramatically.

Kaizen

Kaizen involves continual improvement involving everyone within an organization (Ohno, 1988). Kaizen is a Japanese word meaning gradual and orderly continuous improvement. The Kaizen business strategy involves everyone in an organization working together to make improvements without large capital investments. Kaizen is a culture of sustained continuous improvement focusing on eliminating waste in all systems and processes of an organization. This strategy begins and ends with people, and involves leadership that guides people to continuously improve their ability to meet expectations of high quality, low cost, and on-time delivery, therefore transforming companies into superior global forces.

The most important tool for continuous improvement is the 5S Housekeeping, also known as 5S-CANDO, which is a process that includes a set of techniques utilized for cleaning and organizing the workplace (Levinson & Rerick, 2002). 5S reduces wastes by eliminating the searching for tools because everything is in the right place. Preventive maintenance assures that the tools are ready to use, reducing setup time, and the equipments and machines will be running effectively, avoiding unplanned downtime or breakdowns. 5S CANDO comes from the Japanese words Seiri (Clearing up), Seiton (Arranging), Seiso (Neatness), Shitsuke (Discipline), and Seitketsu (Ongoing improvement).

Seiri refers to sorting the workplace and eliminating needless items (Feld, 2000). It means “throw away” and separates the messes from those items that are needed to work easily resulting in a better flow of materials, utilization of space, and organization for operators to move.

Seiton refers to arranging everything within a specific area (Feld, 2000). All items and equipment must be identified with a label and organized in a specific place resulting in an easier way to recognize and find the proper tooling, resources, and materials quickly.

Seiso refers to cleaning everything and doing periodic maintenance (Feld, 2000). Everything should be cleaned, organized, and well maintained at the end of every shift, including the production area, tools, and materials.

Seitketsu deals with the management strategies for institutionalizing the standard activities (Feld, 2000). Managers must establish policies and procedures to keep the area organized, ordered, and clean.

Shitsuke refers to the leadership strategy to implement housekeeping involving training, communications, and motivation as fundamentals leadership practices in order to ensure that everyone follows the 5S standards (Feld, 2000).

Definition of Value Stream

A value stream is the set of processes, including value-added and non-value-added activities, required to transform raw materials into finished goods that the customers value (Womack & Jones, 1996). Value streams bring a specific good or service through three critical management tasks: problem solving (figuring out what needs to be changed), information management (improving information flow), and physical transformation (implementing changes). Tapping (2002) stated that, “There are many value streams within an organization, just as there are many rivers flowing into the ocean” (p. 27).

The value stream can be defined by the customers, but in some cases companies must identify the entire value stream for each product or each product family by themselves (Tapping, 2002). In order to identify the value stream, product quantity analysis (PQ) is used to determine what percentages of part numbers are running in highs volumes. The results of the PQ analysis are represented graphically and the 20:80 rules can be applied to separate the most critical items. Tapping stated that “20:80 means that the 20% of the products types account for 80% of the total quantity of parts produced” (p. 28).

Value Stream Management

Value stream management is a management tool for planning, managing, implementing, sustaining and linking lean-manufacturing improvements to daily work (Tapping, 2002). Value stream management consists of eight steps: committing to lean, choosing the value stream, learning about lean, mapping the current state, determining lean metrics, mapping the future state, creating Kaizen plans, and implementing Kaizen.

The goal for any manufacturer today is to reduce costs and lead times while maintaining the highest quality of its products (Tapping, 2002). In today’s economies the market is very competitive and customers often set the prices or they demand price reductions. Under these scenarios the only way to stay making money is to eliminate waste from your value stream, increasing efficiency and reducing costs. Value stream management is a process that helps organizations systematically identify and eliminate the non-value-added elements from the value stream and generate a design and a plan to implement lean manufacturing.

Value Stream Mapping

Value stream mapping is a visual representation of all the specific activities, including the flow of material and information, which occurs along the value stream selected for a product or family (Tapping, 2002). The value stream mapping process will likely reveal that a significant amount of non-value-added activities are present in your current processes. These activities consume financial and human resources and make longer lead-time without adding value. However, some of these activities are really necessary in the process; therefore the idea is to minimize their impact. Figure 5 below shows the value stream symbols used to describe each process of manufacturing or assembly.

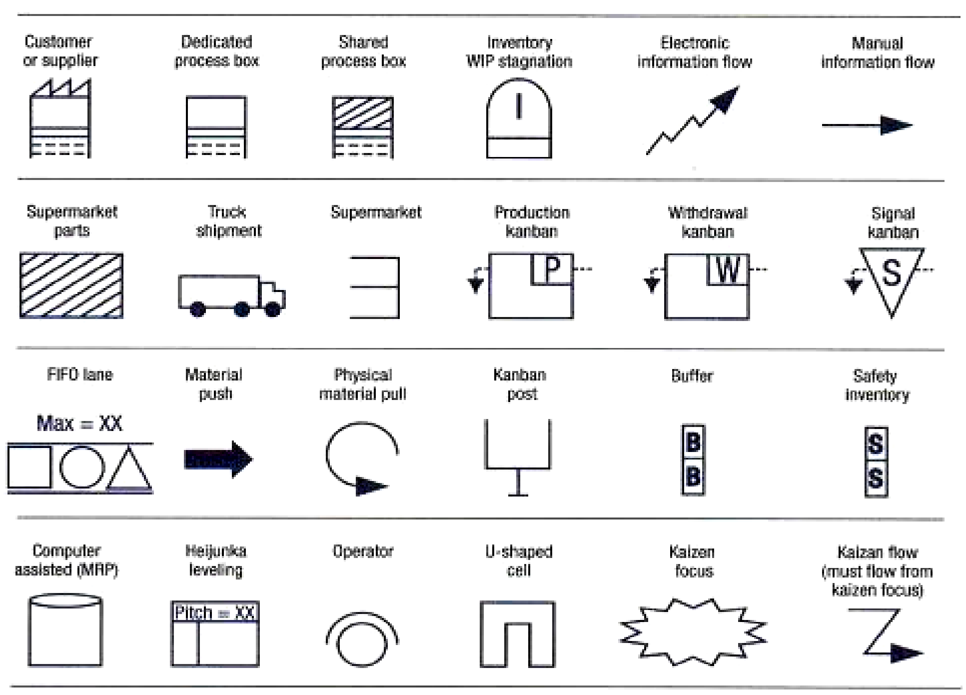

Figure 5. Value stream mapping symbols.

Tapping (2002) stated the following:

Mapping material and information flow will allow you to visualize the entire manufacturing material flow, instead of a single, isolated operation (such as fabrication, welding, or assembly), visualize how operations currently communicate with production control and with each other, see problem areas and source of waste, locate bottlenecks and WIP, spot potential safety and equipment concerns, provide a common language for all manufacturing personnel, and gain insight into how the operation truly is running that day. (p. 80)

There are four steps to value stream mapping (Corner, 2001):

1. Product development: In this step the company must identify customer requirements, quantity required daily, method of transportation, etc.
2. Process design: In this step all the possible information for each process of the value stream selected including cycle time, changeovers times, number of operators, inventory in process, available time, etc. must be collected
3. Preparation: Record as much information as possible and draw the current state map.
4. Planning: Develop the future state map.

Figure 6 shows an example of a value stream map.

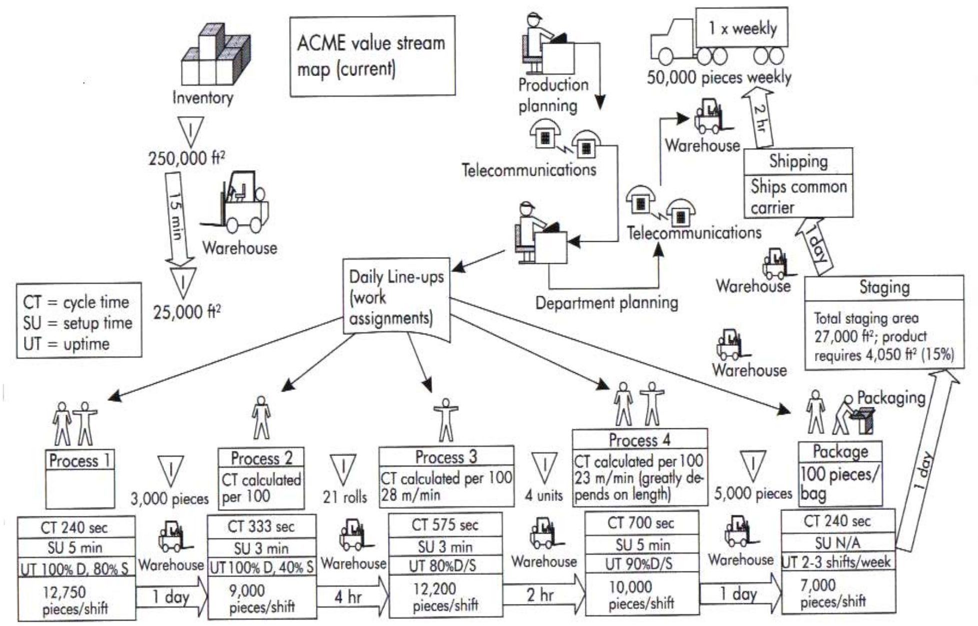

Figure 6. Example of a value stream map.

Summary

This chapter identified some concepts regarding lean manufacturing such as its background, application, tools, and techniques as well as value streams that are important for understanding later parts of this paper

CHAPTER III

METHODOLOGY

The procedures for this study have been chosen to meet each of the project objectives. To have a first-hand knowledge of the production flow and to be familiar with the activities being performed at the floor shop, the researcher went through the facility and identified each operation process involved from raw materials to finished goods, identified all the places where inventory is stored between the processes, and observed how the material flowed from one operation to another.

To select which value stream to target for the practical mapping, the company selected a product family group for improvements. All of the parts for the product family group had common production processes and the same pattern development. In order to perform this activity, the company needed a list of all parts numbers, the quantity ordered over the last year, and all of the processes steps they go through. By identifying the part numbers and the processes involved, the company used a Paretto diagram to see what products they made the most. Table 1 shows a family group of nine resonators for ATVs which was selected by the company as a model to develop a value stream map. Also, refer to Appendix A to see a figure of the resonator.

Table 1

Family of ATV Resonators Selected to Develop a Value Stream Map

Processes	Description
1260968	Weld-silencer, Trail Boss
1260989	Weld-silencer
1261006	Weld-silencer
1261042	Weld-exhaust silencer
1261082	Weld-silencer
1261182	Weld-silencer, Trail Boss
1261215	Weld-silencer
1261233	Weld-exhaust silencer
1261270	Weld-exhaust silencer

Once the value stream was selected, the researcher observed and collected data related to the flow of information and material from raw material to finished goods. Beginning with the information flow, the researcher used the support of the planner to collect information concerning the communication with customers and suppliers, the production controls orders and forecast from customers, the production controls orders and forecast to suppliers, the frequency of orders released to the production supervisor, and the frequency of orders released to each operation within the value stream.

In order to map the current state, the researcher decided to go to the floor to perform a four-day experiment in order to collect data, which began with the receiving area and worked toward the shipping area. The researcher collected information about material flow, inventory between processes, and process attributes including: a) quantity of parts required per month, b) quantity of parts shipped per day and per month, c) number of shipping days per month, d) supplier delivery schedule, e) regular planned down time, f) available production time, g) number of operators per process, h) number of shifts per process,. Also, the researcher collected the following individual metrics at each process involved: a) cycle time, b) changeover time per shift, and c) available uptime.

Once the data was collected and ordered the researcher calculated daily requirements and Takt time, and began to map the current state of the value stream selected. The first step was to become familiar with the value streams symbols and then start drawing the map following the steps mentioned in Chapter II.

After the current state map was developed, the researcher selected the appropriate metrics based on their ability to provide specific measures for a specific operation, as well as a whole calculation for the value stream selected. The researcher also determined how to calculate each of the metrics selected for the entire value stream. Following is a list of the metrics selected:

1. Total value stream work-in-process inventory: The researcher calculated work-in-process inventory between each process and added up the amounts.

2. Number of days of work-in-process inventory: This metric was calculated dividing the total value stream work-in-process inventory by the daily amount of parts required by the customer.

3. Total production cycle time: In order to determine the total cycle time the researcher computed the cycle time for each process and then added up the amounts.

4. Total lead time within the value stream selected: To calculate total lead time, the researcher turned to the floor shop and tracked a part from the moment which the order was released to the time the part was delivered to the customer.

5. Cumulative available uptime: In order to determine the cumulative available uptime, the researcher observed the available uptime for each process and then multiplied the amounts. Available uptime for each process is determined by dividing actual operating time by available production time. Actual operation time for each process is determined by subtracting available production time minus changeover time.

The last step was to look at the current state map for opportunities to eliminate waste and improve the process flow. The researcher identified as much waste as he could in the value stream and made suggestions and recommendations to the company.

CHAPTER IV

RESULTS

The purpose of this study was to develop a value stream map for a family of resonators, for the ATVs in a manufacturing company. This particular tool allows a company to document current lead time, inventory levels, and cycle times to determine the ratio of value added to total lead time of the family group selected.

In order to map the current state, the researcher observed and collected information about material and information flow paths, process attributes, and work-in-process inventory which helped determine metrics for each process and for the entire value stream. Data was collected twice a week for one month on January 14th, 19th, 23rd, and 26th, 2004. This information enabled the researcher to develop the value stream map of the process activities and helped to understand the movement of materials and information along the value stream selected. The resulting information could be used to identify and eliminate waste in the production process and to produce a future state map by creating a vision of an ideal value flow.

Material Flow

The material flow begins at the receiving area as raw material and travels through the plant until it reaches the shipping area as finished goods. The operations involved in the production process are, in sequential order: a) receiving, b) tubing, c) stamping, d) welding, e) painting, and f) shipping. As soon as the raw material arrives, it is moved from the receiving area to the first operation, tubing (tube cutoff / bend) or stamping depending if the raw materials are tubes or coils of steel respectively. After the first operation is completed, the parts are moved to the warehouse stock area where they will be stored until needed. Then the parts will be transported to the weld shop where they are assembled (welded) together to create a resonator. In lots of 100 to 120, the resonators are then moved to the painting area. Once the resonators are received in the painting area, they are inventoried and placed on a stockpile waiting to be processed. The batch size for the painting process is 150 resonators. Once painted, the resonators are moved in lots of 50 to the shipping area where they are inventoried and prepared for transit.

In order to monitor the material flow, the researcher obtained the assistance of the company plant engineer in order to a) identify the nine resonators in the product family which a value stream was to be created for (see table 1, chapter 3), b) determine what parts are used to produce each of these resonators (see Appendix B), c) identify the operations involved in the process (see Appendix C), (d) identify the work centers where the different parts are made (see Appendix C), and (e) group and classify all the work centers in the tubing and stamping processes since they have more than one work center whereas welding and painting only have one work center each (see Appendix C). The criteria necessary to be considered a work center include the use of similar machines, being located in the same physical location within the plant, and utilizing of the same type of raw material and pattern development.

Information Flow

In order to determine the flow of information between suppliers and customers, the researcher obtained the assistance of the company planner. The process begins when production control receives a 12 month forecast and weekly orders via material requirement planning (MRP) systems from customers. Then production control transmits the 12 month forecast and daily orders to suppliers. After that, the production control transmits weekly orders to production supervisor. The last step in the flow of information is when the production supervisor releases daily orders to each operation within the value stream.

Process Attributes

The company plant engineer assisted the researcher to collect the following process attributes which are important because they are used to calculate metrics for the entire process of creating a resonator: daily customer requirements, Takt time, and available production time at each process.

- Three supplier delivery shipments per day
- 20 shipping days per month
- 16,000 resonators produced per month
- Three to five raw material shipments per day
- Regular planned down time is one 15 minute lunch per shift and two 15 minute breaks per shift
- Three eight hour shifts for all processes other than painting, which operates only one shift.

Daily Customer Requirements

The daily requirements were determined dividing the quantity of resonators produced per month (16,000) by the number of shipping days per month (20), resulting in 800 resonators per day.

Takt Time

The Takt time was determined by dividing the available production time per day (1305 minutes) by the total daily quantity of resonators produced (800), resulting in 1.63 minutes.

Availability

The available production time per shift was determined by taking the total available production time per shift, which is equal to eight hours (480 minutes), and subtracting regular planned downtimes events per shift (two 15 minute breaks and 15 minute lunch); therefore the available production time is 435 minutes per shift.

The available production time at each work center is determined by multiplying 435 minutes by the number of shifts that the work center usually operates. The total available production time within a process was determined by adding together the available production time at each work center involved. The tubing process is comprised of five work centers. Each of these work centers run for three shifts (1,305 minutes), which results in 6,525 minutes available for the entire tubing process. The stamping process is comprised of eight work centers. All these work centers run for three shifts (1,305 minutes), which results in 10,440 minutes available for the entire stamping process. The welding process is divided into two different robotic cells. One robotic cell runs for three shifts (1,305 minutes) and the other for one shift (435 minutes), which results in 2,175 minutes available for the entire welding process. As mentioned before, the painting process is available for only one shift (435 minutes).

Individual Metrics

The following processes were used to determine individual metrics at each work center from tubing to painting. Appendix I shows all the individual metrics collected and also includes work centers, part numbers, and tools used.

Number of Operators

In order to determine the number of operators at each work center, the researcher asked the production supervisor and also checked it visually. The operators were counted at each of the work centers and those numbers were added together for each process. See Table 2 for details.

Cycle Time

The researcher determined cycle time by measuring the time needed to make each of the parts involved in the production of the resonators. The instrument used to gather it was a manual timer. The total cycle time within a process was determined by adding together each of the individual cycle times involved (see Table 2).

Changeover Time

The total changeover time for each process was calculated by adding together each of the individual changeover times involved. The changeover time was determined by manually timing how long it takes the operator to setup the work center in order to make a different part. Because the setup process includes change of tools, the researcher obtained the assistance of the company plant engineer to collect information regarding to each of the tool used at each work center. See Table 2 for results.

Table 2

Metrics for Each Process

Process	Operators	Cycle Time	Changeover time
Tubing	5	1.43	240
Stamping	8	5.17	2,400
Welding	10	25	30
Painting	8	145	20

Note: time is expressed in minutes

Available Uptime

The available uptime within a process is calculated by subtracting the changeover time from the total availability and then dividing by the total availability. The results were a) tubing—96%, b) stamping—77%, c) welding—99%, and d) painting—95%.

Work-in-Process (WIP) Inventory

The researcher observed that the numbers of parts varied daily due to the demand and the availability of the work centers. From receiving to painting, the researcher collected information at each of the work centers and between each of the processes involved for the production of the resonators.

The researcher identified and studied all the parts used to produce each of the nine resonators selected for improvements. It is important to note that the researcher collected data from *receiving to welding in parts* and from *welding to painting in resonators* because that is the form in which it was possible to collect the data. A resonator is in parts until they are welded together to actually form one complete unit that can be considered a resonator.

In order to compare the amounts of WIP inventory throughout the entire value stream (from receiving to painting), the researcher needed a way to translate parts into resonators and resonators into parts. This was determined by averaging the number of parts per resonator. The researcher determined that there was an average of 19.44 parts per resonator, with the numbers of parts per resonator varying from 18-20. Appendix B provide specific information on the parts required to make each of the nine resonators and Appendices E-G give detailed information on the parts/resonators observed between the processes on each day that data was collected. Table 3 summarizes WIP in terms of resonators although from receiving to welding the units observed were parts. Table 4 summarizes WIP in terms of parts even though after welding the unit observed by the researcher was in the form of a resonator. An average of the WIP for each process over all four days is also provided.

Table 3

WIP Inventory Between the Processes (In terms of Resonators)

Processes	Day 1	Day 2	Day 3	Day 4	Average
Between Receiving and Tubing	143	0	0	154	149
Between Receiving and Stamping	67	856	642	779	759
Between Tubing and Stamping	103	0	0	114	217
Between Stamping and Welding	11,012	12,033	11,740	12,240	11,756
Between Welding and Painting	497	334	893	523	562
Between Painting and Shipping	2,493	2,499	2,066	2,986	2,511

Table 4

WIP Inventory Between the Processes (In terms of Parts)

Processes	Day 1	Day 2	Day 3	Day 4	Average
Between Receiving and Tubing	2,788	0	0	2,987	2,888
Between Receiving and Stamping	1,300	16,647	12,477	15,136	14,753
Between Tubing and Stamping	2,000	0	0	2,213	2,107
Between Stamping and Welding	214,070	233,926	228,235	237,944	228,543
Between Welding and Painting	9,662	6,493	17,360	10,167	10,920
Between Painting and Shipping	48,464	48,581	40,163	58,047	48,814

There was no WIP inventory between receiving and tubing and between tubing and stamping on days two and three because the work centers at the tubing process were making parts that are not included in the value stream selected. Therefore, only the data gathered on the first and fourth days were used in the average.

The amount of WIP inventory on day one between the receiving and stamping process was low compared to the other days because on day one the plant ran just two shifts and the work centers involved at the stamping process were making parts that were not included in the value stream selected. Therefore, the average between these processes was determined based just on the data obtained on the second through the fourth days.

Metrics for the Entire Value Stream

Once the data was collected, organized, and analyzed the researcher calculated the following metrics for the entire value stream: cumulative available uptime, total WIP inventory, total product cycle time, and total lead time.

Cumulative Available Uptime

The cumulative available uptime, which is the total available uptime for the entire value stream, was determined by multiplying the available uptimes for each of the processes (96% * 77% * 99% * 95%) which results in a cumulative uptime of 70%.

Total Value Stream WIP Inventory

The total WIP inventory was determined from table 3, by adding up WIP inventory between each process resulting in a total of 15,954 resonators within the entire value stream.

Total Value Stream Days of WIP

The total days of WIP within the value stream was determined by dividing the number total value stream WIP (15,954) by the daily amount of parts required by the customer (800 parts), resulting in 20 days.

Total Product Cycle Time

The total production cycle time was calculated by adding up the cycle time determined previously (table 2) for each of the processes, resulting in 177 minutes.

Lead Time

To estimate the lead time (the transformation from a finished product from raw material) within the value stream selected, the researcher turned to the shop floor and tracked one part from the moment it was released to the production floor until the end items were delivered to the customer. The part selected randomly for this purpose was the part number 5243516 (Cap-Exhaust End). The order was released to the supplier on January 20th and the end items were delivered to the customer on February 8th. The result was 461 hours or 19 days, which means it takes at least this long to complete a customer order (see Appendix I).

Conclusion

The preceding information all led to the result of this project, the value stream map for XYZ manufacturing company, which follows in Figure 7. From the map, the researcher evaluated where waste occurs in the process and will be making observations and recommendations on how to make processes leaner in chapter 5.

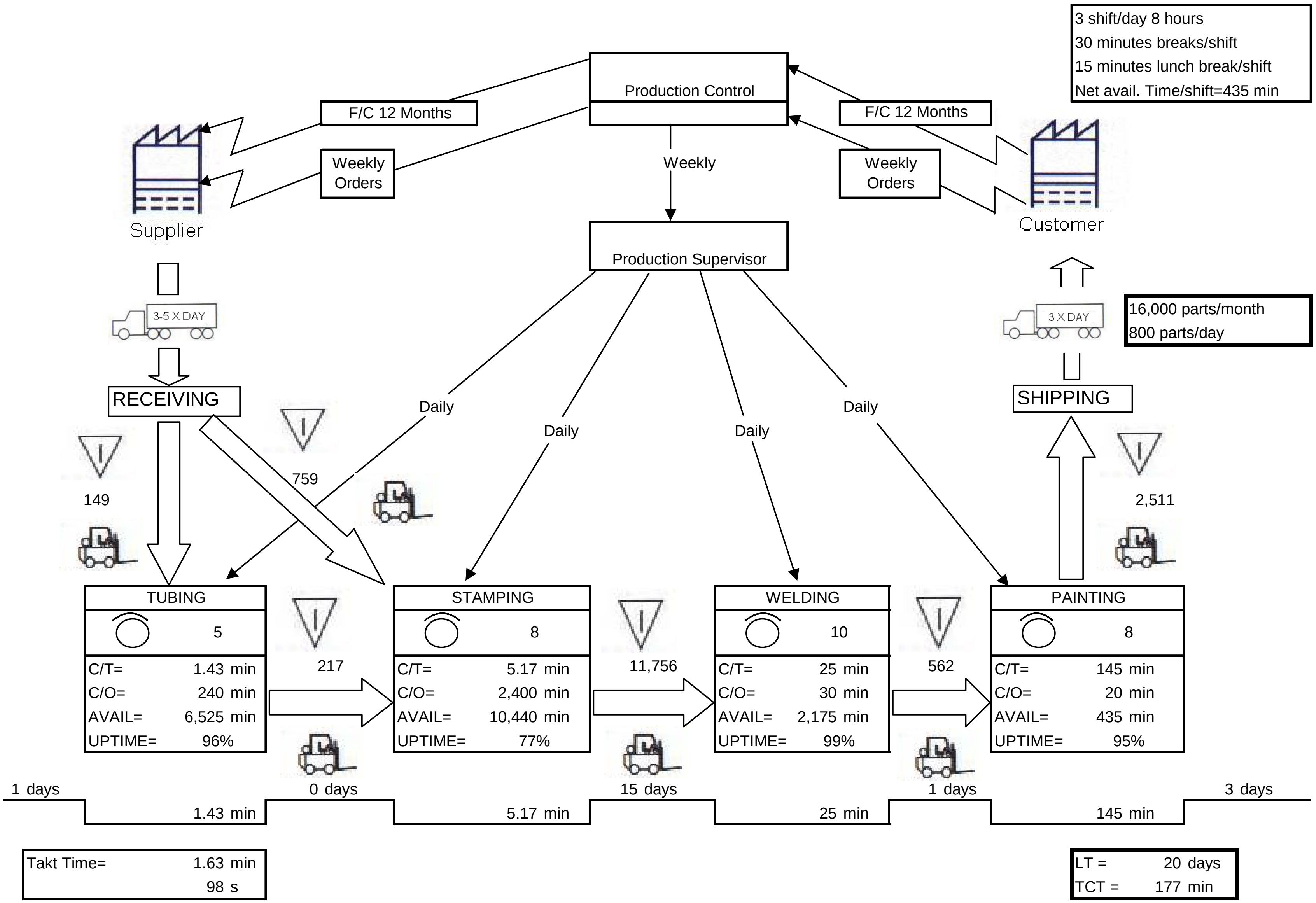

Figure 7. Value Stream map for resonators.

CHAPTER V

DISCUSSION

The purpose of this study was to develop a value stream map for a family of resonators for the ATVs in a manufacturing company. This particular tool allows a company to document current lead time, inventory levels, and cycle times to determine the ratio of value added to total lead time of the family group selected. To identify wastes in the process and evaluate areas for improvement, the researcher examined the current state map that was produced as a result of the study.

Observations

It was found that the time it takes to make one part, or the total product cycle time for the value stream, was 177 minutes. However, the total lead time, which is the time to make a raw material into a finished product, was 20 days. The lead time (20 days) minus the cycle time (177 minutes) is the non-value-added activities such as setting up machines, moving materials, and waiting for materials. This indicates that there is much opportunity for improvement.

The result obtained from the cumulative available uptime reflects that the company is spending an enormous amount of time in setting up the machines. Uptime issues at the stamping process are affecting the results of the total value stream and could be the cause for delays on delivery of orders, and also the reason high inventories are kept between the stamping and welding process. The researcher observed that each operator runs the work center in different ways and that the operators change the tools in different ways, spending between one to two hours to set up the work center. The speed of the process depends of the skills of each operator.

The total number of days of work-in-process inventory is approximately close to the production lead time, which means that the company keeps on hand a safety inventory that is enough to satisfy customer demand during the lead time. If the company had a shorter lead time, that would result in less safety inventory and less funds tied up in inventory.

Some of the parts that were initiated on January 23rd were still incomplete and remained at the stamping process for three days. This event occurred because the work center did not have an operator available to run the press. Also, many of the work centers were not running for the reason that they had mechanical problems due to poor maintenance.

Once the parts were made, they spent too much waiting time before they were moved to the next operation. The researcher observed poor communication either between the machine operators and production supervisor or between the machine operators and forklift operators.

A lot of defective parts were placed anywhere around the stamping and welding processes; there was no specific place to put defective materials. Overall, the place seemed to be fairly dirty and disorganized.

Recommendations

In order to improve the entire production process for the value stream selected, the researcher made the following recommendations.

In order to reduce the changeover time at the stamping process the researcher suggested the application of quick changeover/setup reduction techniques. This setup reduction technique is based on the principles of the single minute exchange dies (SMED) system to dramatically reduce or eliminate changeover time. The systematic process includes analyzing a changeover, then applying quick changeover techniques and strategies to reduce the machine and/or line downtime. Some examples that could be utilized in this situation include

- Utilizing a multi-die function reducing the number of setups per part.
- Setting tools close to the work center, reducing the time that the operator spends looking for the tools.
- Standardization of the setup operations, so each operator must perform the setup in the same way and must run the work center similarly.
- Establishing a standard time to perform a setup. By this approach every operator must perform the setup of the work center in the same period of time.
- Because some tools can produce different parts, the company should take advantage of that and produce all the parts the tool can produce at once.

In order to improve communications, the researcher suggested the utilization of a visual control system, as mentioned in chapter 2. Some of the techniques that could be applied include call lights and Andon board lights, standard operations sheets, digital display panels, and a monitor screen and clock at each work center. Call lights and Andon board lights could be used to call immediately for a supervisor or general workers for different types of assistance (e.g. move material, problem in the line, etc). Standard operations sheets could be used for the first line supervisors to eliminate unnecessary inventory and workers and to eliminate accidents and defective production. These sheets measure all three elements (cycle time, a standard operation routine, and a standard amount of work-in-process) every certain period of time. Digital display panels are another recommendation which would normally be used to show the pace of production (Takt time), the day of production and the number of units that has been produced during the day. This would inform every person at the plant about exactly at what rate they must be working in order to satisfy customer demand. Another recommendation is to implement a monitor screen at each work center showing the parts' specifications, a drawing, steps to assemble, etc. Last, setting clocks at each work center in order to determine how much time an operator is spending to set it up would be beneficial.

In order to reduce waiting time between each operation, the researcher suggested the utilization of Kanban systems. As mentioned, a Kanban is a tool to achieve just-in-time. It consists of a card containing all the information that is required to be done on a product at each stage along its path to completion and which parts are needed at subsequent processes. By the utilization of this tool the parts can be moved quickly from one work center to another, improving the material flow and reducing the work-in-process between processes.

In order to increase the capacity of the plant without capital investments and also to avoid unplanned equipment downtime, the researcher suggested the implementation of total productive maintenance (TPM), which is a process to increase the efficiency as well the useful life of the equipment involved. One of the key elements of this technique is employee involvement, so each operator must take care of the work center he or she operates, maintain it, and report any damage as it occurs.

In order to improve the housekeeping the researcher suggested the implementation of 5S techniques for the workplace standardization and organization, especially at the stamping and welding processes. As mentioned, this technique includes the implementation of five steps:

remove all unneeded items, create locations for the needed items, keep everything clean after utilization, set standards and procedures, and employee involvement.

The goal of this study was to collect necessary information and develop a value stream map for a family of resonators for ATVs in a manufacturing company. The value stream map served as a tool for the researcher to make observations and recommendations to improve processes at the company. It is hoped that the company implements these recommendations and improves operations as a result.

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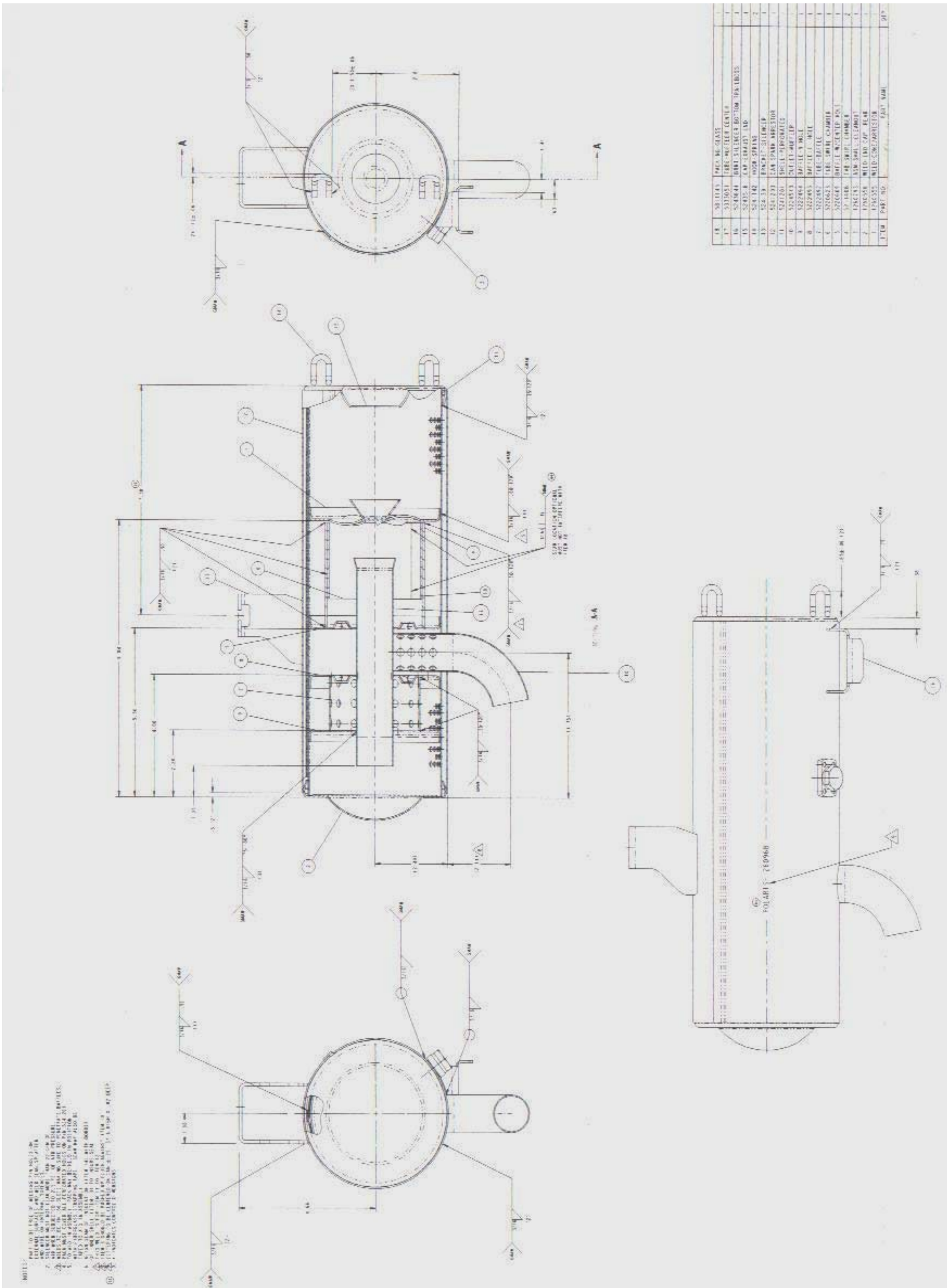
Appendix A

Details of a Resonator



Appendix B

Quantity of Parts per Resonator

Part number	Part name	Resonator number								
		1260968	1260989	1261006	1261042	1261082	1261182	1261215	1261223	1261270
1260555	Weld-cone arrestor	1	1	-	1	1	1	1	1	-
1260556	Weld-end cap. Rear	1	1	-	1	1	1	1	1	-
1260793	Asm-small cleanout	1	1	1	1	1	1	1	1	1
5211408	Tab-swirl chamber	2	2	2	2	2	2	2	2	2
5220609	Baffle-w/center	1	1	1	1	1	1	1	1	1
5220623	Tube-swirl chamber	1	1	1	1	1	1	1	1	1
5220760	Arrestor-spark	-	-	1	-	-	-	-	-	1
5222491	Cone-percussion	-	-	-	-	-	-	-	-	-
5222492	Tube-baffle	1	1	-	1	1	1	1	1	-
5222493	Baffle-11 hole	1	1	-	1	1	1	1	1	-
5222494	Baffle-9 hole	1	1	1	1	1	1	1	1	1
5222496	Cap-end rear	-	-	1	-	-	-	-	-	1
5224543	Outlet-muffler	1	1	-	1	1	1	1	1	-
5224850	Outlet-muffler	-	-	1	-	-	-	-	-	1
5241201	Shell-perforated	1	1	1	1	1	1	1	1	1
5241203	Can-spark arrestor	1	1	1	1	1	1	1	1	1
5241522	Bracket-muffler top	-	-	-	2	-	-	-	2	2
5241742	Hook-spring	2	2	2	2	2	2	2	2	2
5242001	Bracket-silencer	-	2	2	-	2	-	-	-	-
5243516	Cap-exhaust end	1	-	-	-	-	1	1	-	-
5243519	Cap-silencer inlet	-	1	1	-	1	-	-	-	-
5243644	Bracket-silencer	1	-	-	-	-	1	-	-	-
5244005	Bracket- silencer	-	-	-	-	-	1	-	-	-

Appendix B (Continued)

Quantity of Parts per Resonator

Part number	Part name	Resonator number								
		1260968	1260989	1261006	1261042	1261082	1261182	1261215	1261223	1261270
5244188	Cap-exhaust end	-	-	-	1	-	-	-	-	-
5244780	Cap-exhaust end	-	-	-	-	-	-	-	1	1
5246241	Bracket-can front	-	-	-	-	-	-	1	-	-
5246242	Bracket-can rear	-	-	-	-	-	-	1	-	-
5333057	Tube-muffler center	1	1	1	1	1	1	1	1	1
5811143	Packing-glass	1	1	1	1	1	1	1	1	1
Total parts		19	20	18	20	20	20	20	20	18

Note. Dashes indicate that the part is not contained by the resonator.

Appendix C

Sequence of Operations and Work center per Part

Number	Part name	Operation	Description of operation	WC	Process
5211408	Tab-swirl chamber	0020	Progressive complete	PL104	Stamping
5220609	Baffle-w/center Hole	0020	Progressive complete	PL112	Stamping
5220623	Tube-swirl chamber	0020	Progressive complete	PL130	Stamping
5220760	Arrestor-spark	0020	Progressive complete	PL112	Stamping
5222491	Cone-percussion	0020	Progressive complete	PL104	Stamping
5222492	Tube-baffle	0020	Progressive complete	PL110	Stamping
5222493	Baffle-11 hole	0020	Progressive complete	PL112	Stamping
5222494	Baffle-9 hole	0020	Progressive complete	PL112	Stamping
5222496	Cap-end rear	0020	Progressive complete	PL126	Stamping
5224543	Outlet-muffler	0020	Bend	PL261	Tubing
		0040	Pierce	PL250	Stamping
5224850	Outlet-muffler	0020	Bend	PL231	Tubing
		0040	Saw cut and deburr	PL239	Tubing
		0060	Vibratory deburr	PL602	Tubing
5241201	Shell-perforated	0020	Blank and pierce	PL110	Stamping
5241203	Can-spark arrestor	0020	Blank and pierce	PL110	Stamping
5241522	Bracket-muffler top	0020	Progressive complete	PL130	Stamping
5242001	Bracket-silencer hanger	0020	Progressive complete	PL104	Stamping
5243516	Cap-exhaust end	0020	Pierce, blank and form	PL112	Stamping
		0040	Form outer flange	PL104	Stamping
5243519	Cap-silencer inlet	0020	Pierce, blank and form	PL112	Stamping
		0040	Form outer edge	PL104	Stamping
5243644	Bracket-silencer bottom	0020	Progressive complete	PL112	Stamping
		0040	Secondary cutoff	PL155	Stamping
5244005	Bracket- silencer	0020	Progressive complete	PL130	Stamping
5244188	Cap-exhaust end	0020	Pierce, blank and form	PL112	Stamping
		0040	Form complete	PL104	Stamping
5244780	Cap-exhaust end	0020	Pierce, blank and form	PL112	Stamping
		0040	Form complete	PL104	Stamping
5246241	Bracket-can front	0020	Progressive complete	PL126	Stamping
5246242	Bracket-can rear	0020	Progressive complete	PL126	Stamping
5333057	Tube-muffler center	0020	3L cutoff	PL244	Tubing
		0040	Flare	PL249	Stamping

Note. WC = Workcenter; PL = product line; 0020 = first operation; 0040 = second operation; 0060 = third 0peration.

Appendix D

Data Collected Day 1

Table D1

WIP Inventory Between Receiving and Tubing Processes for Day 1

Part number	Description	WIP
5224543	Outlet-muffler	2,788
Total		2,788

Table D2

WIP Inventory Between Receiving and Stamping Processes for Day 1

Part number	Description	WIP
5243519	Cap-silencer inlet	1,300
Total		1,300

Table D3

WIP Inventory Between Tubing and Stamping Processes for Day 1

Part number	Description	WIP
5224543	Outlet-muffler	2,000
Total		2,000

Table D4

WIP Inventory Between Stamping and Welding Processes for Day 1

Part number	Description	WIP
1260793	Asm-small cleanout	176
5211253	Baffle	10,801
5211408	Tab-swirl chamber	76,233
5220609	Baffle-w/center hole	15,112
5220623	Tube-swirl chamber	6,490
5220760	Arrestor-spark	11,880
5222491	Cone-percussion	8,429
5222492	Tube-baffle	4,414
5222493	Baffle-11 hole	3,468
5222494	Baffle-9 hole	6,714
5222496	Cap-end, rear	10,478
5224543	Outlet-muffler	319
5224850	Outlet-muffler	1,198
5241201	Shell-perforated	6,399
5241203	Can-spark arrestor	5,585
5241391	Bracket-silencer	0
5241522	Bracket-muffler, top	12,145
5241742	Hook-spring	1,072
5242001	Bracket-silencer hanger	1,727
5243516	Cap-exhaust end	1,451
5243519	Cap-silencer inlet	218
5243644	Bracket-silencer,bottom,trailboss	1,835
5244005	Bracket-silencer	1,297
5244188	Cap-Exhaust,End.486od X 1.77id	2,889
5244780	Cap-Exhaust,End,4.86odx1.93id	2,421
5246241	Bracket-can, front	320
5246242	Bracket-can, rear	5,258
5333057	Tube-muffler, center	12,678
5811143	Packing-glass	3,063
Total		214,070

Table D5

WIP Inventory Between Welding and Painting Processes for Day 1

Part number	Description	WIP
1260968	Weld-silencer, Trail Boss	0
1260989	Weld-silencer	0
1261006	Weld-silencer	283
1261042	Weld-exhaust silencer	147
1261082	Weld-silencer	25
1261182	Weld-silencer, Trail Boss	3
1261215	Weld-silencer	0
1261223	Weld-exhaust silencer, 700	0
1261270	Weld-exhaust silencer	39
Total		497

Table D6

WIP Inventory Between Painting and Shipping Processes for Day 1

Part number	Description	WIP
1260968	Weld-silencer, Trail Boss	9
1260989	Weld-silencer	8
1261006	Weld-silencer	133
1261042	Weld-exhaust silencer	265
1261082	Weld-silencer	318
1261182	Weld-silencer, Trail Boss	1
1261215	Weld-silencer	4
1261223	Weld-exhaust silencer, 700	1,755
1261270	Weld-exhaust silencer	0
Total		2,493

Appendix E

Data Collected Day 2

Table E1

WIP Inventory Between Receiving and Stamping Processes for Day 2

Part number	Description	WIP
5241201	Shell-perforated	10,647
5222496	Cap-end rear	6,000
Total		16,647

Table E2

WIP Inventory Between Stamping and Welding Processes for Day 2

Part Number	Description	WIP
1260793	Asm-small cleanout	0
5211253	Baffle	8,686
5211408	Tab-swirl chamber	70,993
5220609	Baffle-w/center hole	12,342
5220623	Tube-swirl chamber	9,387
5220760	Arrestor-spark	9,110
5222491	Cone-percussion	6,314
5222492	Tube-baffle	21,392
5222493	Baffle-11 hole	7,273
5222494	Baffle-9 hole	10,019
5222496	Cap-end, rear	7,858
5224543	Outlet-muffler	2,850
5224850	Outlet-muffler	673
5241201	Shell-perforated	3,779
5241203	Can-spark arrestor	9,845
5241391	Bracket-silencer	0
5241522	Bracket-muffler, top	7,778
5241742	Hook-spring	0
5242001	Bracket-silencer hanger	8,548

Table E2 *(Continued)*

WIP Inventory Between Stamping and Welding Processes for Day 2

Part number	Description	WIP
5243516	Cap-exhaust end	2,041
5243519	Cap-silencer inlet	2,644
5243644	Bracket-silencer,bottom,trailboss	1,218
5244005	Bracket-silencer	680
5244188	Cap-Exhaust,End.486od X 1.77id	1,392
5244780	Cap-Exhaust,End,4.86odx1.93id	3,510
5246241	Bracket-can,front	2,020
5246242	Bracket-can,rear	5,258
5333057	Tube-muffler, center	14,573
5811143	Packing-glass	3,743
Total		233,926

Table E3

WIP Inventory Between Welding and Painting Processes for Day 2

Part number	Description	WIP
1260968	Weld-silencer, Trail Boss	0
1260989	Weld-silencer	0
1261006	Weld-silencer	0
1261042	Weld-exhaust silencer	263
1261082	Weld-silencer	1
1261182	Weld-silencer, Trail Boss	68
1261215	Weld-silencer	1
1261223	Weld-exhaust silencer, 700	0
1261270	Weld-exhaust silencer	1
Total		334

Table E4

WIP Inventory Between Painting and Shipping Processes for Day 2

Part number	Description	WIP
1260968	Weld-silencer, Trail Boss	9
1260989	Weld-silencer	8
1261006	Weld-silencer	21
1261042	Weld-exhaust silencer	1,209
1261082	Weld-silencer	174
1261182	Weld-silencer, Trail Boss	165
1261215	Weld-silencer	4
1261223	Weld-exhaust silencer, 700	880
1261270	Weld-exhaust silencer	29
Total		2,499

Appendix F

Data Collected Day 3

Table F1

WIP Inventory Between Receiving and Stamping Processes for Day 3

Part number	Description	WIP
5244188	Cap-exhaust end	4,464
5243516	Cap-exhaust end	2,180
5222493	Baffle-11 hole	850
5220760	Arrestor-spark	5,000
Total		12,477

Table F2

WIP Inventory Between Stamping and Welding Processes for Day 3

Part Number	Description	WIP
1260793	Asm-small cleanout	0
5211253	Baffle	5,892
5211408	Tab-swirl chamber	64,709
5220609	Baffle-w/center hole	14,950
5220623	Tube-swirl chamber	6,095
5220760	Arrestor-spark	5,818
5222491	Cone-percussion	20,209
5222492	Tube-baffle	18,598
5222493	Baffle-11 hole	4,479
5222494	Baffle-9 hole	6,877
5222496	Cap-end, rear	10,829
5224543	Outlet-muffler	56
5224850	Outlet-muffler	1,545
5241201	Shell-perforated	7,693
5241203	Can-spark arrestor	6,695
5241391	Bracket-silencer	0
5241522	Bracket-muffler, top	12,751

Table F2 *(Continued)*

WIP Inventory Between Stamping and Welding Processes for Day 3

Part number	Description	WIP
5241742	Hook-spring	0
5242001	Bracket-silencer hanger	7,604
5243516	Cap-exhaust end	1,645
5243519	Cap-silencer inlet	2,167
5243644	Bracket-silencer,bottom,trailboss	822
5244005	Bracket-silencer	3,063
5244188	Cap-Exhaust,End.486od X 1.77id	709
5244780	Cap-Exhaust,End,4.86odx1.93id	1,919
5246241	Bracket-can,front	2,020
5246242	Bracket-can,rear	5,258
5333057	Tube-muffler, center	11,431
5811143	Packing-glass	3,743
Total		228,235

Table F3

WIP Inventory Between Welding and Painting Processes for Day 3

Part number	Description	WIP
1260968	Weld-silencer, Trail Boss	0
1260989	Weld-silencer	0
1261006	Weld-silencer	0
1261042	Weld-exhaust silencer	114
1261082	Weld-silencer	153
1261182	Weld-silencer, Trail Boss	16
1261215	Weld-silencer	1
1261223	Weld-exhaust silencer, 700	460
1261270	Weld-exhaust silencer	149
Total		893

Table F4

WIP Inventory Between Painting and Shipping Processes for Day 3

Part number	Description	WIP
1260968	Weld-silencer, Trail Boss	9
1260989	Weld-silencer	8
1261006	Weld-silencer	21
1261042	Weld-exhaust silencer	222
1261082	Weld-silencer	206
1261182	Weld-silencer, Trail Boss	305
1261215	Weld-silencer	4
1261223	Weld-exhaust silencer, 700	1,062
1261270	Weld-exhaust silencer	229
Total		2,066

Appendix G

Data Collected Day 4

Table G1

WIP Inventory Between Receiving and Tubing Processes for Day 4

Part number	Description	WIP
5224543	Outlet-muffler	2,987
Total		2,987

Table G2

WIP Inventory Between Receiving and Stamping Processes for Day 4

Part number	Description	WIP
5220623	Tube-swirl chamber	9,523
5241203	Can-spark arrestor	942
5222493	Baffle-11 hole	2,007
5244188	Cap-exhaust end	2,664
Total		15,136

Table G3

WIP Inventory Between Tubing and Stamping Processes for Day 4

Part number	Description	WIP
5224543	Outlet-muffler	2,213
Total		2,213

Table G4

WIP Inventory Between Stamping and Welding Processes for Day 4

Part Number	Description	WIP
1260793	Asm-small cleanout	212
5211253	Baffle	5,236
5211408	Tab-swirl chamber	63,179
5220609	Baffle-w/center hole	14,183
5220623	Tube-swirl chamber	9,328
5220760	Arrestor-spark	10,310
5222491	Cone-percussion	19,553
5222492	Tube-baffle	17,942
5222494	Baffle-9 hole	6,112
5222496	Cap-end, rear	10,064
5224543	Outlet-muffler	23
5224850	Outlet-muffler	1,436
5241201	Shell-perforated	6,928
5241203	Can-spark arrestor	8,310
5241391	Bracket-silencer	0
5241522	Bracket-muffler, top	12,533
5241742	Hook-spring	1,152
5242001	Bracket-silencer hanger	7,240
5243516	Cap-exhaust end	3,352
5243519	Cap-silencer inlet	1,985
5243644	Bracket-silencer,bottom,trailboss	665
5244005	Bracket-silencer	2,906
5244780	Cap-Exhaust,End,4.86odx1.93id	1,810
5246241	Bracket-can,front	1,703
5246242	Bracket-can,rear	4,941
5333057	Tube-muffler, center	10,666
5811143	Packing-glass	4,236
Total		237,944

Table G5

WIP Inventory Between Welding and Painting Processes for Day 4

Part number	Description	WIP
1260968	Weld-silencer, Trail Boss	0
1260989	Weld-silencer	0
1261006	Weld-silencer	134
1261042	Weld-exhaust silencer	114
1261082	Weld-silencer	20
1261182	Weld-silencer, Trail Boss	136
1261215	Weld-silencer	118
1261223	Weld-exhaust silencer, 700	0
1261270	Weld-exhaust silencer	1
Total		523

Table G6

WIP Inventory Between Painting and Shipping Processes for Day 4

Part number	Description	WIP
1260968	Weld-silencer, Trail Boss	9
1260989	Weld-silencer	209
1261006	Weld-silencer	21
1261042	Weld-exhaust silencer	126
1261082	Weld-silencer	267
1261182	Weld-silencer, Trail Boss	342
1261215	Weld-silencer	204
1261223	Weld-exhaust silencer, 700	1,322
1261270	Weld-exhaust silencer	486
Total		2,986

Appendix H

Individual Metrics Collected

Process	Part number	Operators	WC	C/T (min)	Tool	C/O (min)
Tubing	5224543	1	PL-261	0.21	9280678	60
	5224850	1	PL-231	0.24	9121682	60
	5224850	1	PL-239	0.75	-	30
	5224850	1	PL-602	0.12	-	30
	5333057	1	PL-244	0.11	-	60
Stamping	5211408	1	PL-104	0.08	9121424	90
	5222491			0.08	9113225	90
	5242001			0.08	9121517	90
	5243516			0.08	9121193	90
	5243519			0.08	9121193	
	5244188			0.08	9122194	90
	5244780			0.08	9122349	90
	5222492	1	PL-110	0.21	9121474	120
	5241201			0.21	9121786	120
	5241203			0.21	9121782	120
	5220609	1	PL-112	0.21	9122361	120
	5220760			0.21	9120849	120
	5222493			0.21	9121902	120
	5222494			0.21	9121902	
	5243516			0.21	9121901	120
	5243519			0.21	9121901	
	5244780			0.21	9121901	
	5243644			0.21	9121952	120
	5244188			0.21	9121952	
	5222496	1	PL-126	0.05	9122284	120
	5246241			0.05	9122562	120
	5246242			0.05	9122563	120
	5220623	1	PL-130	0.21	9122467	120
	5241522			0.21	9121196	120
	5244005			0.21	9122135	120
	5243644	1	PL-155	0.13	9122035	90
	5333057	1	PL-249	0.14	9120499	30
	5224543	1	PL-250	1.00	9415008	60

Appendix H *(Continued)*

Individual Metrics Collected

Welding	1260968 1260989 1261006 1261042 1261082 1261182 1261215 1261223 1261270	10	PL-535	25	-	30
Painting	1260968 1260989 1261006 1261042 1261082 1261182 1261215 1261223	8	PL-608	145	-	20

Note. WC = workcenter; C/T = cycle time; C/O = changeover time; PL = Product line; Dashes indicate that the tool number was not collected.

Appendix I

Lead Time

Process	Operation	Date in	Time in	Date out	Time out	LT (hr)
Delivery	From supplier	20-jan	10:00 am	22-jan	3:30 pm	53.5
Receiving	Unloading	22-jan	3:30 pm	22-jan	4:00 pm	0.50
Stamping	Queue time before OP-020	22-jan	4:00 pm	22-jan	5:00 pm	1.00
	OP-020	22-jan	5:00 pm	22-jan	7:30 pm	2.50
	Queue time before OP-040	22-jan	7:30 pm	23-jan	12:30 pm	17.00
	OP-040	23-jan	12:30 pm	23-jan	4:50 pm	4.33
QA test	QA-press	23-jan	4:50 pm	26-jan	11:30 am	67.00
WH stock	Queue time before weld	26-jan	11:30 am	28-jan	7:00 am	43.50
Welding	Weld shop	28-jan	7:00 am	1-feb	11:00 pm	112.00
Painting	Queue time before paint	1-feb	11:00 pm	2-feb	7:00 am	8.00
	OP-020	2-feb	7:00 am	4-feb	3:00 pm	56.00
	Queue time after paint	4-feb	3:00 pm	7-feb	3:00 pm	72.00
Delivery	To customer	7-feb	3:00 pm	8-feb	3:00 pm	24.00
Total						461

Note. LT = lead time; WH = Warehouse; OP = Operation; QA = quality assurance; 020 = first operation; 040 = second operation.