# LEAN MANUFACTURING TOOLS AND TECHNIQUES IN THE PROCESS INDUSTRY WITH A FOCUS ON STEEL

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Submitted to the Graduate Faculty of

School of Engineering in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2003

UNIVERSITY OF PITTSBURGH

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## ABSTRACT


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University of Pittsburgh, 2003

This research addresses the application of lean manufacturing concepts to the continuous production/ process sector with a focus on the steel industry. The goal of this research is to investigate how lean manufacturing tools can be adapted from the discrete to the continuous manufacturing environment, and to evaluate their benefits on a specific application instance. Although the process and discrete industry share several common characteristics, there are areas where they are very different. Both manufacturing settings have overlap, but at the extreme, each has its unique characteristics. This research attempts to identify commonalities between discrete and continuous manufacturing where lean techniques from the discrete side are directly applicable. The ideas are tested on a large steel manufacturing company (referred to as ABS). Value stream mapping is used to first map the current state and then used to identify sources of waste and to identify lean tools to try to eliminate this waste. The future state map is then developed for a system with lean tools applied to it. To quantify the benefits gained from using lean tools and techniques in the value stream mapping, a detailed simulation model is developed for ABS and a designed experiment is used to analyze the outputs of the simulation model for different lean configurations. Generalizations of the results are also provided.

ACKNOWLEDGMENTS

I would like to thank Allah my lord for giving me the strength, patience, and guidance to go through this research. I wish also to thank my country Kuwait and the University of Pittsburgh for giving me the opportunity to pursue my degree in higher education.

I wish to express my genuine appreciation to my advisor, Dr. Rajgopal for his unlimited support, direction, advice, and patience with me during the preparation for this dissertation.

I am very thankful to all my committee members Dr. Needy, Dr. Bidanda, Dr. Wolfe, and Dr. Hegde for their valuable comments and suggestion. I wish also to thank Dr. Needy for her guidance during this research.

I would like to thank Mr. Bob Oster and Mr. Mark Lesnick for their assistance in collecting the data used in this research.

I also would like to thank my wife Abrar for the invaluable support and patience during the course of this work. My thanks also go to my beloved son Abdullah for his good manners. I also would like to thank my parents for their moral support; without them I would not be where I am right now.

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# 1.0 INTRODUCTION

## 1.1 Background

This research addresses the application of lean manufacturing concepts to the continuous production/ process sector with a focus on the steel industry. After World War II, Japanese manufacturers, particularly in the automotive industry, were faced with the dilemma of shortages of material, financial, and human resources. Eiji Toyoda and Taiichi Ohno at the Toyota Motor Company in Japan pioneered the concept of the Toyota Production System, or what is known today in the US as "Lean Manufacturing." The basic idea behind the system is eliminating waste. Waste is defined as anything that does not add value to the end product from the customer's perspective. The primary objective of lean manufacturing is to assist manufacturers who have a desire to improve their company's operations and become more competitive through the implementation of different lean manufacturing tools and techniques.

Quickly following the success of lean manufacturing in Japan, other companies and industries, particularly in the US, copied this remarkable system. The term "lean" as Womack and Jones (1994) define it denotes a system that utilizes less, in terms of all inputs, to create the same outputs as those created by a traditional mass production system, while contributing increased varieties for the end customer. Lean is to manufacture only what is needed by the customer, when it is needed and in the quantities ordered. The manufacture of goods is done in a way that minimizes the time taken to deliver the finished goods, the amount of labor required, and the floor-space required, and it is done with the highest quality, and usually, at the lowest cost.

## 1.2 Problem Statement

Major businesses in the United States have been trying to adopt new business initiatives in order to stay alive in the new competitive market place. Lean manufacturing is one of these initiatives that focuses on cost reduction by eliminating non-value added activities. These tools and techniques of lean manufacturing have been widely used in the discrete industry starting with the introduction of the original Toyota Production System. Tools including just in time, cellular manufacturing, total productive maintenance, single-minute exchange of dies, and production smoothing have been widely used in discrete parts manufacturing sectors such as automotive, electronic and appliance manufacturing.

Applications of lean manufacturing to the continuous process industry have been far fewer. In part, it has been argued that this is because such industries are inherently more efficient and present relatively less need for such improvement activities. Managers have also been hesitant to adopt lean manufacturing tools and techniques to the continuous process industry because of reasons such as high volume and low variety products, large inflexible machines, and the long setup times that characterize the process industry. As an example, it is difficult to use the cellular manufacturing concept in a process facility due to the fact that equipment is large and not easy to move.

While it seems that some lean manufacturing tools are difficult to adapt in the process industry, others are not. For example, Cook and Rogowski (1996) and Billesbach (1994) used just-in-time concepts at a process facility, and both reported good results. This research is driven by the fact that while researchers and practitioners have widely used lean manufacturing tools in the discrete industry, nobody has systematically investigated how to apply lean tools and techniques to a continuous process facility due to the differences exhibited between the two manufacturing environments. In order to compete in today's global competitive market the continuous process industry also needs to look for more ways to gain a competitive edge.

## 1.3 Research Objective

The goal of this research is to investigate how the tools of lean manufacturing can be adapted from the discrete to the continuous manufacturing environment and to evaluate their benefits at a specific industrial concern. The research hypothesizes that there are big opportunities for improvement in the process industries if lean tools are utilized. Although the process and discrete industry share several common characteristics, there are also areas where they are very different. Both manufacturing settings have overlap, but at the extreme, each has its unique characteristics. The objective is to look at commonalities between discrete and continuous manufacturing where lean techniques from the discrete side are directly applicable, and to also examine ways to do so in other areas where this may not be quite so straightforward.

The objective is to systematically demonstrate how lean manufacturing tools when used appropriately can help the process industry to eliminate waste, have better inventory control, better product quality, and better overall financial and operational procedures. In this research the steel industry will be used to represent the continuous process industry, and much of the work will be carried out at an actual steel manufacturing facility, whose identity is protected by referring to it as the ABS Company.

## 1.4 Research Approach

The initial step in this research is to systematically study and define the history of the lean manufacturing concept and its different tools and techniques. It will then examine where most of the lean tools and techniques have been used. This will be followed by a literature review of the process industry and a study of the findings regarding applications of lean concepts to continuous manufacturing, and the steel industry in particular.

The next step is to develop a taxonomy of the continuous process industry with respect to its product/process characteristics and the relative balance of discrete and continuous operations. This taxonomy is used to contrast the process industry and to characterize the process industry into distinguishable groups. Next, this taxonomy is used to examine and identify specific lean manufacturing tools and techniques that could be applicable.

To study the effect of lean tools in the process sector the steel industry is used to illustrate the procedures of implementing lean tools at a process facility. First, value stream mapping is used to map the current state for ABS. This is used to identify sources of waste and then identify lean tools to try to reduce this waste. The future state map is then developed for a system with lean tools applied to it. Second, a simulation model is developed for ABS to quantify the benefits gained from using lean tools and techniques in the value stream mapping. For those lean tools that cannot be directly quantified by the simulation, a proposed methodology to implement them at ABS is developed, and a subjective evaluation of its benefits is provided.

# 2.0 BACKGROUND AND LITERATURE REVIEW

## 2.1 The History of Lean

After World War II Japanese manufactures were faced with the dilemma of vast shortages of material, financial, and human resources. The problems that Japanese manufacturers were faced with differed from those of their Western counterparts. These conditions resulted in the birth of the "lean" manufacturing concept. Toyota Motor Company, led by its president Toyoda recognized that American automakers of that era were out-producing their Japanese counterparts; in the mid-1940's American companies were outperforming their Japanese counterparts by a factor of ten. In order to make a move toward improvement early Japanese leaders such as Toyoda Kiichiro, Shigeo Shingo, and Taiichi Ohno devised a new, disciplined, process-oriented system, which is known today as the "Toyota Production System," or "Lean Manufacturing." Taiichi Ohno, who was given the task of developing a system that would enhance productivity at Toyota is generally considered to be the primary force behind this system. Ohno drew upon some ideas from the West, and particularly from Henry Ford's book "Today and Tomorrow." Ford's moving assembly line of continuously flowing material formed the basis for the Toyota Production System. After some experimentation, the Toyota Production System was developed and refined between 1945 and 1970, and is still growing today all over the world. The basic underlying idea of this system is to minimize the consumption of resources that add no value to a product.

In order to compete in today's fiercely competitive market, US manufacturers have come to realize that the traditional mass production concept has to be adapted to the new ideas of lean manufacturing. A study that was done at the Massachusetts Institute of Technology of the movement from mass production toward lean manufacturing, as explained in the book "The Machine That Changed the World" (Womack, Jones and Ross, 1990), awoke the US manufactureres from their sleep. The study underscored the great success of Toyota at NUMMI (New United Motor Manufacturing Inc.) and brought out the huge gap that existed between the Japanese and Western automotive industry. The ideas came to be adopted in the US because the Japanese companies developed, produced and distributed products with half or less human effort, capital investment, floor space, tools, materials, time, and overall expense (Womack et al., 1990).

## 2.2 What Is Lean?

The new uprising in the manufacturing goods and service sector has created great challenges for US industry. The customer driven and highly competitive market has rendered the old-fashioned managerial style an inadequate tool to cope with these challenges. These factors present a big challenge to companies to look for new tools to continue moving up the ladder in a global, competitive, growing market. While some companies continue to grow based on economic constancy, other companies struggle because of their lack of understanding of the change of customer mind-sets and cost practices. To get out of this situation and to become more profitable, many manufacturers have started to turn to lean manufacturing principles to elevate the performance of their firms.

The basic ideas behind the lean manufacturing system, which have been practiced for many years in Japan, are waste elimination, cost reduction, and employee empowerment. The Japanese philosophy of doing business is totally different than the philosophy that has been long prevalent in the US. The traditional belief in the west had been that the only way to make profit is to add it to the manufacturing cost in order to come up with a desired selling price (Ohno, 1997; Monden, 1998). On the contrary, the Japanese approach believes that customers are the generator of the selling price. The more quality one builds into the product and the more service one offers, the more the price that customers will pay. The difference between the cost of the product and this price is what determines the profit (Ohno, 1997; Monden, 1998). The lean manufacturing discipline is to work in every facet of the value stream by eliminating waste in order to reduce cost, generate capital, bring in more sales, and remain competitive in a growing global market. The value stream is defined as "the specific activities within a supply chain required to design, order and provide a specific product or value" (Hines and Taylor, 2000).

The term "lean" as Womack and his colleagues define it denotes a system that utilizes less, in term of all inputs, to create the same outputs as those created by a traditional mass production system, while contributing increased varieties for the end customer (Panizzolo, 1998). This business philosophy goes by different names. Agile manufacturing, just-in-time-manufacturing, synchronous manufacturing, world-class manufacturing, and continuous flow are all terms that are used in parallel with lean manufacturing. So the resounding principle of lean manufacturing is to reduce cost through continuous improvement that will eventually reduce the cost of services and products, thus growing more profits.

"Lean" focuses on abolishing or reducing wastes (or "muda", the Japanese word for waste) and on maximizing or fully utilizing activities that add value from the customer's perspective. From the customer's perspective, value is equivalent to anything that the customer is willing to pay for in a product or the service that follows. So the elimination of waste is the basic principle of lean manufacturing. For industrial companies, this could involve any of the following (Womack et al., 1990; Ohno, 1997; Monden, 1998; Shingo, 1997; Mid-America Manufacturing Technology Center, 2000):

- Material: Convert all raw materials into end products. Try to avoid excess raw materials and scrap.
- Inventory: Keep constant flow to the customer and to not have idle material.
- Overproduction: Produce the exact quantity that customers need, and when they need it.
- Labor: Get rid of unwarranted movement of people.
- Complexity: Try to solve problems the uncomplicated way rather than the complex way. Complex solutions tend to produce more waste and are harder for people to manage.
- Energy: Utilize equipment and people in the most productive ways. Avoid unproductive operations and excess power utilization.
- Space: Reorganize equipment, people, and workstations to get a better space arrangement.
- Defects: Make every effort to eliminate defects.
- Transportation: Get rid of transportation of materials and information that does not add value to the product.
- Time: Avoid long setups, delays, and unexpected machine downtime.
- Unnecessary Motion: Avoid excessive bending or stretching and frequently lost items.

Waste sources are all related to each other and getting rid of one source of waste can lead to either elimination of, or reduction in others. Perhaps the most significant source of waste is inventory. Work-in-process and finished parts inventory do not add value to a product and they should be eliminated or reduced. When inventory is reduced, hidden problems can appear and action can be taken immediately. There are many ways to reduce the amount of inventory, one of which is reducing production lot sizes. Reducing lot sizes however, should be followed by a setup time reduction so as to make the cost per unit constant as the famous economic order quantity formula states (Karlsson and Ahlstrom, 1996). At Toyota, Shingo developed the concept of single minute exchange of dies (SMED) to reduce set up times (Shingo, 1997); for instance, setup times in large punch presses could be reduced from hours to less than ten minutes. This has a big effect on reducing lot sizes. Another way to reduce inventory is by trying to minimize machine downtime (Shingo, 1997). This can be done by preventive maintenance. It is clear that when inventory is reduced other sources of waste are reduced too. For example, space that was used to keep inventory can be utilized for other things such as to increase facility capacity. Also, reduction in setup times as a means to reduce inventory simultaneously saves time, thus reducing time as a source of waste.

Transportation time is another source of waste. Moving parts from one end of the facility to another end does not add value to the product. Thus, it is important to decrease transportation times within the manufacturing process. One way to do this is to utilize a cellular manufacturing layout to ensure a continuous flow of the product. This also helps eliminate one other source of waste, which is energy. When machines and people are grouped into cells, unproductive operations can be minimized because a group of people can be fully dedicated to that cell and this avoids excess human utilization. Another source of waste is defects and scrap materials. Total prductive maintenance is one way to eliminate defects and scrap. Manufacturing parts that are fault-free from the beginning has profound consequences for productivity (Hayes and Clark, 1986).

There is no question that the elimination of waste is an essential ingredient for survival in today's manufacturing world. Companies must strive to create high-quality, and low cost products that can get to the customers in the shortest time possible. There are sets of tools that were developed at Toyota and that can be utilized to eliminate or at least reduce the sources of waste.

## 2.3 Lean Manufacturing Tools and Techniques

Once companies pinpoint the major sources of waste, tools such as continuous improvement, just-in-time production, production smooting, and others will guide companies through corrective actions so as to eliminate waste. In the following sections a brief description of such tools is given.

### 2.3.1 Cellular Manufacturing

Cellular manufacturing is one of the cornerstones when one wants to become lean. Cellular manufacturing is a concept that increases the mix of products with the minimum waste possible. A cell consists of equipment and workstations that are arranged in an order that maintains a smooth flow of materials and components through the process. It also has assigned operators who are qualified and trained to work at that cell.

Arranging people and equipment into cells has great advantage in terms of achieving lean goals. One of the advantages of cells is the one-piece flow concept, which states that each product moves through the process one unit at a time without sudden interruption, at a pace determined by the customer’s need. Extending the product mix is another advantage of cellular manufacturing. When customers demand a high variety of products as well as faster delivery rates, it is important to have flexibility in the process to accommodate their needs. This flexibility can be achieved through grouping similar products into families that can be processed on the same equipment in the same sequence. This will also shorten the time required for changeover between products, which will encourage production in smaller lots. Other benefits associated with cellular manufacturing include:

- Inventory (especially WIP) reduction
- Reduced transport and material handling
- Better space utilization
- Lead time reduction
- Identification of causes of defects and machine problems
- Improved productivity
- Enhanced teamwork and communication
- Enhanced flexibility and visibility

### 2.3.2 Continuous Improvement

Continuous improvement is another fundamental principle of lean manufacturing. Kaizen, which is the Japanese word for a continuous endeavor for perfection, has become popular in the west as a paramount concept behind good management. Kaizen is a systematic approach to gradual, orderly, continuous improvement. In manufacturing settings improvements can take place in many forms such as reduction of inventory, and reduction of defective parts. One of the most effective tools of continuous improvement is 5S, which is the basis for an effective lean company. 5S is a first, modular step toward serious waste reduction. 5S consists of the Japanese words Seiri (Sort), Seiton (Straighten), Seiso (Sweep and Clean), Seiketsu (Systemize), and Shitsuke (Standardize). The underlying concept behind 5S is to look for waste and then to try to eliminate it. Waste could be in the form of scrap, defects, excess raw material, unneeded items, old broken tools, and obsolete jigs and fixtures (Monden, 1998).

The first S, Seiri, deals with moving those items that are not currently being used on a continuous basis (e.g., items that will not be used for the next month or so) away from those that are. Moving those items and tossing away needless items will make material flow smoothly, and workers move and work easily (Feld, 2000).

Seiton has to do with having the right items in the right area. Items that do not belong to a given area must not be in that area. For a given workplace area tools must be marked and arranged as belonging in that area. This will make it easier to move those items that are not labeled from that area. Arranging items in the right place will make tools, jigs, fixtures, and resources noticeable, detectable, and easy to use (Feld, 2000).

Seiso deals with cleaning and sweeping the work place methodically. The workplace should look neat and clean and ready to use for the next shift. The work place should be maintained on a regular basis (e.g., daily). All tools and items should be in the right place and nothing should be missing. A well-maintained workplace creates a healthy environment to work with (Feld, 2000).

Seiketsu is maintaining a high standard of housekeeping and workplace arrangement. A regular audit should be run and scores should be assigned for areas of responsibilities. If every area has people assigned to it then everyone has responsibility to maintain a high standard of housekeeping and cleaning (Feld, 2000).

Shitsuke is management’s accountability to train people to follow housekeeping rules. Management should implement the housekeeping rules in a practiced fashion so that their people can buy into it. Management should walk the shop floor, explain what they want from people, reward those who follow and instruct those who do not (Feld, 2000).

Taken together, 5S means good housekeeping and better workplace organization. Kaizen tools such as 5S are not only a means to increase profitability of a firm but also allow companies to reveal potential strengths and capabilities that were hidden before (Hirai, 2001). Sweeny (2003), and Cox (2002) have reported good results implementing 5S. Further, benefits of implementing 5S will be described later.

### 2.3.3 Just-In-Time

Closely associated with lean manufacturing is the principle of just-in-time, since it is a management idea that attempts to eliminate sources of manufacturing waste by producing the right part in the right place at the right time. This addresses waste such as work-in-process material, defects, and poor scheduling of parts delivered (Nahmias, 1997). Inventory and material flow systems are typically classified as either push (traditional) or pull (just-in-time) systems. Customer demand is the driving force behind both systems. However, the major difference is in how each system handles customer demand. Just-in-time is a tool that enables the internal process of a company to adapt to sudden changes in the demand pattern by producing the right product at the right time, and in the right quantities (Monden, 1998). Moreover, just-in-time is a critical tool to manage the external activities of a company such as purchasing and distribution. It can be thought of as consisting of three elements: JIT production, JIT distribution, and JIT purchasing. More details are given for each in the following sections.

2.3.3.1 Just-In-Time Production. Lean manufacturing is about eliminating waste wherever it is. One of the most important steps in the implementation of lean manufacturing is JIT. Monden (1998) and Levy (1997) both agree that JIT production is the backbone of lean manufacturing. Just-in-time production is about not having more raw materials, work in process or products than what are required for smooth operation.

JIT utilizes what is known as a “pull system”. Customer demand, which is the generator of the order sends the first signal to production. As a result, the product gets pulled out of the assembly process. The final assembly line goes to the preceding process and pulls or withdraws the necessary parts in the necessary quantity at the necessary time (Monden, 1998). The process goes on as each process pulls the needed parts from the preceding process further up stream. The whole process is coordinated through the use of a kanban system.

Shipments under JIT are in small, frequent lots. A kanban is used to manage these shipments. Kanban is an information system that is used to control the number of parts to be produced in every process (Monden, 1998). The most common types of kanbans are the withdrawal kanban, which specify the quantity that the succeeding process should pull from the preceding process, and the production kanban, which specifies the quantity to be produced by the preceding process (Monden, 1998).

The withdrawal kanban, which is shown in Figure 1 shows that the subsequent machining process requests the parts from the preceding forging process. The part that must be made at the forging process is the drive pinion and it can be picked up at position B-2 of the forging department. A box of type B must contain 20 units of the part needed and this kanban is the fourth out of eight sheets issued (Monden, 1998). The kanban shown in Figure 2 is a production type kanban that shows that the preceding machine SB-8 must produce a crankshaft for the type of car specified. The part produced must be stored at shelf number F26-18.

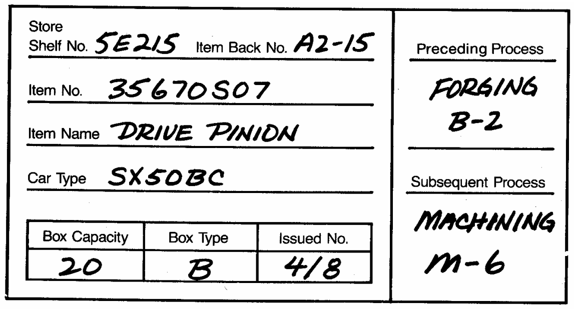



Figure 1 Withdrawal Kanban (Source: Monden, Y., Toyota Production System-An Integrated Approach to Just-in-time, 1998).

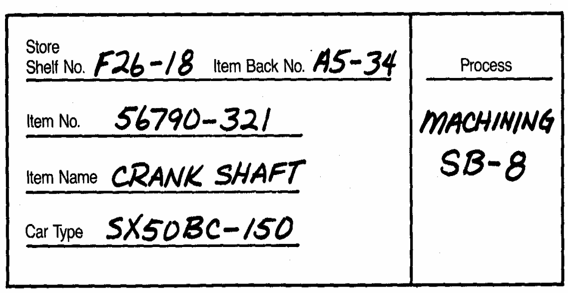



Figure 2 Production Kanban (Source: Monden, Y., Toyota Production System-An Integrated Approach to Just-in-time, 1998).

A supplier kanban is another type of kanban that is used between the supplier and the manufacturer under JIT. Lean manufacturing requires quick deliveries and in order to achieve this, many manufacturers require their suppliers to deliver items just in time. In order to achieve JIT delivery, suppliers have to adjust from the traditional run sizes to smaller lot sizes. The supplier kanbans circulate between the manufacturer and the supplier. The kanban is delivered at predefined times from the manufacturer to the supplier. For example, if parts were conveyed twice a day (8 a.m. and 10 p.m.), the truck driver would deliver the kanban at the supplier's store at 8 a.m. which is a signal to the supplier to produce the required quantity. At the same time the driver picks up the parts that are completed at 8 a.m. that morning along with the kanban attached to the boxes containing these parts. These are the kanbans that would have arrived the previous night at 10 p.m. signaling the production of the parts (Monden, 1998).

By utilizing a kanban system under JIT, smaller lot sizes and huge inventory reductions can be achieved. Under JIT production raw material, subassemblies and finished product inventory are kept to a minimum and the lean manufacturing principles are followed to eliminate inventory as a source of waste. Another type of waste that is eliminated under JIT production is overproduction. Since every process is producing at a pace no higher than that of the subsequent process's requirements, the need to produce more than what is needed is diminished.

2.3.3.2 <u>Just-In-Time Distribution</u>. JIT effectiveness depends heavily on having a strategic alliance between buyers and suppliers. By having a third-party logistics distributor, companies can focus on their core competencies and areas of expertise leaving the logistics capability to logistics companies (Simchi-Levi, D. et al., 2000; Quinn and Hilmer, 1994). Third-party logistics (3PL) refers to the use of an outside company to perform all or part of the firm's materials management and product distribution functions (Simchi-Levi, D. et al., 2000). 3PL can support just-in-time distribution (JITD) by providing on time delivery to customers or distributors, technological flexibility such as EDI and flexibility in geographical locations. (Simchi-Levi, D. et al., 2000; Raia, 1992).

JITD requires the exchange of frequent, small lots of items between suppliers and customers, and must have an effective transportation management system because the transportation of inbound and outbound material can have a great effect on production when there is no buffer inventory (Spencer, Daugherty and Rogers, 1994). Under JITD having a full truckload sometimes is difficult due to the frequent delivery of smaller lots, which in turn will increase the transportation cost. However, to get over the problem Monden (1998) states that instead of having one part loading, using a mixed loading strategy makes it possible to have full truckloads and increase the number of deliveries.

Another important factor that is essential to JITD is EDI. In order to have effective product deliveries between suppliers and their distributors or customers, an EDI system must be in place. In the traditional product delivery system suppliers always have to keep finished goods inventory or have to alter their production schedules to respond to demand surges. Under EDI suppliers can look at all the shipment and inventory data and adjust their production schedule accordingly (Simchi-Levi, D. et al., 2000). To stay competitive under JITD, it is very important to share information in the whole supply chain because suppliers can adjust their production schedules and narrow their delivery windows as more product data become available to them. Other benefits of EDI include cost reduction, cycle time reduction, stockout reduction, and inventory reduction.

2.3.3.3 Just-In-Time Purchasing. Ansari and Mondarress (1986) and Gunasekaran (1999) define just-in-time purchasing (JITP) as the purchase of goods such that their delivery immediately precedes their demand, or as they are required for use. The idea of JITP runs counter to the traditional purchasing practices where materials are brought well in advance before their use. Under JITP activities such as supplier selection, product development and production lot sizing become very critical.

Customer-supplier relationships are a very important part of JITP. Under JITP it is necessary to have a small number of qualified suppliers. Having quality-certified suppliers shifts the inspection function of quality and piece-by-piece count of parts to the supplier's site where the supplier must make sure that parts are defect free before they are transported to the manufacturer's plant. Another important factor of JITP is product development. Buyers must have a "Black Box" relationship with the suppliers where suppliers participate heavily in design and development. The benefits of sharing new product development and design innovation include a decrease in purchased material cost, increase in purchased material quality, a decrease in development time and cost and in manufacturing cost, and an increase in final product technology levels (Simchi-Levi, D. et al., 2000).

EDI is very important under JITP. The ultimate goal of JITP is to guarantee that production is as close as possible to a continuous process from the raw material reception until the distribution of the finished goods (Gunasekaran, 1999). EDI can support JITP by reducing the transaction processing time and meeting the specialized needs of buyers by helping them to synchronize their material movement with their suppliers. Although under JITP the carrying cost of materials is increased due to frequent small lots, this cost is offset by a decrease in the cost of processing a purchase order and by the decreased inventory holding cost.

Some of the benefits of JIT are (Nahmias, 1997):

- Eliminating unnecessary work-in-process, which results in reduction of inventory costs.
- Since units are produced only when they are needed, quality problem can be detected early.
- Since inventory is reduced, the waste of storage space will be reduced.
- Preventing excess production can uncover hidden problems.

### 2.3.4 Production Smoothing

In a lean manufacturing system it is important to move to a higher degree of process control in order to strive to reduce waste. Another tool to accomplish this is production smoothing. Heijunka, the Japanese word for production smoothing, is where the manufacturers try to keep the production level as constant as possible from day to day (Womack et al., 1990). Heijunka is a concept adapted from the Toyota production system, where in order to decrease production cost it was necessary to build no more cars and parts than the number that could be sold. To accomplish this, the production schedule should be smooth so as to effectively produce the right quantity of parts and efficiently utilize manpower. If the production level is not constant this leads to waste (such as work-in-process inventory) at the workplace.

### 2.3.5 Standardization of Work

A very important principle of waste elimination is the standardization of worker actions. Standardized work basically ensures that each job is organized and is carried out in the most effective manner. No matter who is doing the job the same level of quality should be achieved.

At Toyota every worker follows the same processing steps all the time. This includes the time needed to finish a job, the order of steps to follow for each job, and the parts on hand. By doing this one ensures that line balancing is achieved, unwarranted work-in-process inventory is minimized and non-value added activities are reduced. A tool that is used to standardize work is what is called "takt" time. Takt (German for rhythm or beat) time refers to how often a part should be produced in a product family based on the actual customer demand. The target is to produce at a pace not higher than the takt time (Mid-America Manufacturing Technology Center press release, 2000). Takt time is calculated based on the following formula (Feld, 2000):

$$Takt\ Time\ (TT) = \frac{Available\ work\ time\ per\ day}{Customer\ demand\ per\ day}$$

2.3.6 Total Productive Maintenance

Machine breakdown is one of the most important issues that concerns the people on the shop floor. The reliability of the equipment on the shop floor is very important since if one machine breaks down the entire production line could go down. An important tool that is necessary to account for sudden machine breakdowns is total productive maintenance. In almost any lean environment setting a total productive maintenance program is very important.

There are three main components of a total productive maintenance program: preventive maintenance, corrective maintenance, and maintenance prevention. Preventive maintenance has to do with regular planned maintenance on all equipment rather than random check ups. Workers have to carry out regular equipment maintenance to detect any anomalies as they occur. By doing so sudden machines breakdown can be prevented, which leads to improvement in the throughput of each machine (Feld, 2000).

Corrective maintenance deals with decisions such as whether to fix or buy new equipment. If a machine is always down and its components are always breaking down then it is better to replace those parts with newer ones. As a result the machine will last longer and its uptime will be higher. Maintenance prevention has to do with buying the right machine. If a machine is hard to maintain (e.g., hard to lubricate or bolts are hard to tighten) then workers will be reluctant to maintain the machine on a regular basis, which will result in a huge amount of lost money invested in that machine.

Researchers including Nicholls (1994), Taylor (1996), Suehiro (1992), Ljungberg (1998), Nakajima (1989) and others have reported good results implementing TPM. Further, benefits of implementing TPM will be described later.

### 2.3.7 Other Waste Reduction Techniques

Some of the other waste reductions tools include zero defects, setup reduction, and line balancing. The goal of zero defects is to ensure that products are fault-free all the way, through continuous improvement of the manufacturing process (Karlsson et al., 1996). Human beings almost invariably will make errors. When errors are made and are not caught then defective parts will appear at the end of the process. However, if the errors can be prevented before they happen then defective parts can be avoided. One of the tools that the zero-defect principle uses is poka-yoke. Poka-yoke, which was developed by Shingo, is an autonomous defect control system that is put on a machine that inspects all parts to make sure that there are zero defects. The goal of poka-yoke is to observe the defective parts at the source, detect the cause of the defect, and to avoid moving the defective part to the next workstation (Feld, 2000). Ohno at Toyota developed SMED in 1950. Ohno's idea was to develop a system that could exchange dies in a more speedy way. By the late 1950's Ohno was able to reduce the time that was required to change dies from a day to three minutes (Womack et al, 1990). The basic idea of SMED is to reduce the set up time on a machine. There are two types of setups: internal and external. Internal setup activities are those that can be carried out only while the machine is stopped while external setup activities are those that can be done while the machine is running. The idea is to move as many activities as possible from internal to external (Feld, 2000). After all activities are identified then the next step is to try to simplify these activities (e.g., standardize setup, use fewer bolts). By reducing the setup time many benefits can be realized. First, die-change specialists are not needed. Inventory can be reduced by producing small batches and more variety of product mix can be run. Line balancing is considered a great weapon against waste, especially the wasted time of workers. The idea is to make every workstation produce the right volume of work that is sent to upstream workstations without any stoppage (Mid-America Manufacturing Technology Center press release, 2000). This will guarantee that each workstation is working in a synchronized manner, neither faster nor slower than other workstations.

### 2.4 From Lean Manufacturing to Lean Enterprise

The elimination of waste is a process that examines the system as a whole. The big picture is to look at the interdependent segments of the company starting from raw materials to distribution and sales of finished goods. Womack and Jones define the lean enterprise as "a group of individuals, functions, and legally separate but operationally synchronized companies" (Womack and Jones, 1994). By managing the whole system we are looking to manage the value adding activities holistically and not as a sum of separate parts (Dimancescu, Hines, Rich, 1997).

Making an enterprise lean means that workers, managers, suppliers, and customers are all considered as powerful assets of the company.

Managers have recognized that in order to deliver to the customer satisfaction and the best quality product, the organization must focus on the critical main processes rather than concentrating on individual functions or departments. These processes should serve two main objectives. The first is to make the customer believe in the organization as a qualified provider of a product, and the second "is to demonstrate a capability that will win an order" (Dimancescu et al., 1997). To accomplish this, companies and managers should put more efforts to elevate the whole enterprise as opposed to focusing on the performance of persons, functions, and parts of the company.

Lean enterprise is an extension of lean manufacturing. However, lean enterprise goes further by concentrating on the firm, its employees, its partners, and its suppliers, to bring value to the customer from his or her perspective. The lean enterprise tries to line up and coordinate the value creating process for a finished product or service along the value stream. It tries to thoroughly examine all the steps that are needed to bring a new product or service from idea to production, from order to delivery, and from raw material to final delivered product. These steps can be perfectly accomplished by including all parties involved. All processes are continually examined against the customer's definition of value, and non-value added activities and waste are forcefully and methodically eliminated.

There are three different types of activities that exist in almost all organization (Monden, 1998):

1) Value adding activities: These include all the activities that the customer envisions as valuable either in a product or as a service. Examples include converting iron ore (with other things) into

cars, forging raw material, and painting a car body. To define a value adding activity, one should ask if a customer would be willing to pay for the activity.

2) Necessary non-value adding activities: These are activities that in the eye of the final customer do not make a product or service more valuable but are necessary under the current operating conditions. Such waste is difficult to remove immediately and should be targeted for longer-term change. Examples include walking long distances to pick up parts, or unpacking vendor boxes. These can be removed by changing the current layout of a line or organizing vendor items to be delivered unpacked.

3) Unnecessary non-value adding activities: These include all the activities that the customer envisions as not valuable either in a product or as a service, and are also not necessary under the current circumstances. These activities are pure waste and should be targeted for immediate removal. Examples include waiting time, stacking of products and double transfers.

There are a lot of companies that are implementing lean manufacturing. However, many of these are still coping with mastering the idea due a lack of understanding of its core concepts. So it might seem that when companies are still not capable of lean manufacturing they should not even look ahead to a lean enterprise. Womack and Jones argue this point by noting that in order for any one member of the supply chain to keep up the momentum, it is important for all parts of the chain to pull together. This means that if one member becomes lean other members of the value stream will not share the benefits unless they all participate in the process (Womack et al., 1994).

## 2.5 Overview of Supply Chain Management

The greater expectation of customers, the fierce competitive market and the flow of materials to the market with shorter lead-times have forced many companies to focus more on their supply chain management. A typical supply chain consists of raw material suppliers, manufacturers, distributors, and end customers. Raw materials are shipped to the production facility where they get converted to end-products and then those end-products are shipped to the end users (customers). In order to minimize cost and waste throughout the system, effective supply chain management and integration are required starting from the raw materials and finishing with the end customer.

Supply chain management is "a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed in the right quantities, to the right locations, and at the right time" (Simchi-Levi, D., Kaminsky, p., Simchi-Levi, E., 2000). The ultimate goal of supply chain management is to minimize the systemwide cost and waste. Thus the emphasis centers around the integration of raw material suppliers, manufacturers, and the end customer.

In order to become lean, a company must have an integrated supply chain starting from the front (suppliers), through the middle (manufacturers and distributors), to the end (customers). Here "integrated" means that coordination and cooperation must be achieved in each and every part of the enterprise as a whole, as opposed to looking for individual pieces only, so as to reduce the cost of the whole system. Thus total cost and waste starting from transportation and distribution to raw material, work in process, and finished goods must all be minimized. The following section examines how integration can be best done at the front, middle, and back of the supply chain.

### 2.5.1 Customer Integration

In today's flexible and speedy market, greater weight is given to customer value and satisfaction. Companies today can no longer rely only on financial metrics to check their status but must also look for other metrics such as customer satisfaction and value. Customer satisfaction is the concept of how well the current customers are utilizing the company's product and what their feelings are of its service (Simchi-Levi, D. et al., 2000). By evaluating current customers the company can gain insight into areas that need improvement and generate ideas for service and product satisfaction. Another important concept is customer value. Customer value is how the customer perceives the whole spectrum of what the company offers in terms of products and services (Simchi-Levi, D. et al., 2000). Basically, customers are always looking for better product quality, lower prices, value-added services, more flexibility, and shorter lead time.

One of the principles of supply chain management is the ability to respond to customer requirements in a fast and flexible way. This response includes the physical distribution of the product and the status of an order, and access to this information. Customers are always concerned with their order status, and sometimes they value that even more than a reduced lead time (Simchi-Levi, D. et al., 2000). Permitting customers to have access to their order status can develop more trust between them and the company. FedEx was the first to use a tracking system where a customer can check on their package status at any given time. Allowing customers to participate in the initial design process can also improve the customer value. Dell, one of the leading PC companies through its direct business model, allows customers to build up their own PC systems.

Value-added services could play a big role in relationships between customers and companies. It is no longer enough to have a quality product; this should be followed by quality service. Support and maintenance are very important from a customer perspective especially those technical products that require constant service after purchasing. Having good value-added services can generate more revenue (e.g., charging a small fee for customer service support) and in addition, it closes the gap between the company and its customers. A company can gain more insight into improving their service and support, and this is another benefit of value-added services (Simchi-Levi, D. et al., 2000). Access to information is one of the value-added services and we saw in the previous paragraph how FedEx allow its customers to track their packages.

### 2.5.2 Supplier Integration

One of most important components of the lean enterprise is the front end of the supply chain. Suppliers are an important factor contributing to the success of going lean. Given that material costs account for over half of the cost of goods sold for most firms, companies cannot view their suppliers as strangers; rather they should be viewed as a part of the team (Hall and Mark, 1992).

Supplier integration was introduced first in the automotive industry and one of the pioneers in this was Toyota. In 1950 Toyota started a new move toward development of components supply. Toyota structured its suppliers into different functional tiers with suppliers in each tier having different responsibilities. Toyota's first-tier suppliers were assigned the task of working with the product development team. The suppliers were told to develop a specific product in a car to meet given performance specifications. Toyota then asked its suppliers to present a trial product for testing, and if the product worked as specified the suppliers would get the production order. The Toyota philosophy was to encourage all the first-tier suppliers to communicate and share information with each other so as to improve the design process.

Suppliers were not reluctant to share information with each other because each supplier specialized in different types of components, and thus they did not have to compete with each other (Womack et al., 1990).

2.5.2.1 Level of Integration. Managers look for opportunities to compete in continuously growing markets. One of these opportunities is supplier integration in product development and design. For example, in order to expedite product introduction to market a company has to take advantage of a supplier's capabilities. However, there are different levels of supplier integration depending on how deeply the company wants its suppliers to be involved. A study that was conducted by the University of Michigan identifies different levels of supplier integration as follows (Simchi-Levi, D., et al., 2000):

- None: The supplier is not involved in design. Material and subassemblies are supplied according to customer specifications and design.
- White Box: This level of integration is informal. The buyer "consults" with the supplier informally when designing products and specifications, although there is no formal collaboration.
- Gray Box: This represents formal supplier integration. Collaborative teams are formed between the buyer's and supplier's engineers, and joint development occurs.
- Black Box: The buyer gives the supplier a set of interface requirements and the supplier independently designs and develops the required component.

### 2.5.3 Manufacturer Integration

The connecting link between the supplier and the customer in the supply chain is the manufacturer. Most of the core processes in term of the actual production take place at the manufacturer's site. As mentioned previously the main goal of a supply chain is to reduce the systemwide costs and waste. It is in this middle portion of the supply chain where most of the wastes exist. For example, inventory holding and set-up costs, transportation costs and lead time create a big challenge to the supply chain in terms of how best these should be managed.

Integration between the supplier, manufacturer, and distributor are required to effectively manage inventory in the system. In order to minimize the inventory at the manufacturer, an effective inventory policy will depend on the specific nature of the supply chain. For example, if an electronic data interchange (EDI) system is in use, it must be designed so that the supplier, manufacturer, and distributor can share data. If information is shared the variability in the system is reduced, better demand forecasting is achieved, and inventory (particularly at the manufacturer) is reduced.

Another important waste that exists in the supply chain is long lead times. To satisfy their customers the manufacturer (or the retailer) must have a short lead-time and precise delivery (Simchi-Levi, D., et al., 2000). One way to reduce the lead-time is to have an efficient EDI system where all parties involved in the supply chain are linked; this can cut the portion of lead time that is related to order processing, paperwork, and transportation delays (Simchi-Levi, D. et al., 2000).

By having an integrated supply chain many of the wastes that occupy the system can be eliminated or diminished. This includes inventory in all its forms, overproduction at the manufacturer's site, long lead time, and many others. Minimizing these wastes will have a significant effect on minimizing the system-wide cost.

## 2.6 Discrete vs. Continuous Manufacturing Systems

Manufacturing systems are classified into two major classes; discrete manufacturing and continuous manufacturing (also referred to as the process industry). Discrete manufacturing refers to making discrete products such as an engine, an automobile, a drive shaft, a coffee maker, or a washing machine. On the other hand, continuous manufacturing includes making products that are measured or metered rather than being counted. Examples include paint, steel, textile, flat glass, resin, oil, and flour (Needy and Bidanda, 2001).

In manufacturing there are three different general classifications in term of production plants: job-shop production, batch production, and mass production. Job-shop production system is also known as intermittent production, and is characterized by low-volume, high variety products. Job-shops consist of two different production layouts. The first is a process-type layout, where resources including machines and humans are arranged into functions. A given shop consists of the same set of machines and operators who are specialists for these particular types of machines. For example, a department may consist of lathes or milling machines only. Semi-finished parts move in lots from one department to the other and the output end-product is produced in small lots. In this setting it is not necessary that all jobs travel to the same number of work centers or even to the same machines in the work centers (Needy et al., 2001). This type of layout requires highly flexible and general-purpose machines so as to handle the variety of work involved. Examples include making prototypes of new products, or making user-specific machines, tools, or dies, space vehicles, or machine tools (Groover, 1980). The second type is a fixed site (or project) type layout. It is characterized by having a physically large product where movable equipment and manpower must move to the product position. This type of layout requires multi-skilled workers to build the product according to the exact customer specifications. Examples include road construction, shipbuilding, aircraft building, or bridge building. The job-shop production system is normally associated with discrete-product manufacture.

The second type of production system is batch production. In batch production medium volume and medium variety of products are produced. Medium size lots of the same product may be produced once or at recurring intervals. General-purpose machines combined with specially designed jigs and fixtures designed for higher production rates are used in batch production. Examples of products produced by batch production include furniture, electronic equipment, household appliances, and lawn mowers. Usually batch production is associated with discrete-product manufacture, however, it can be linked to the process industry where some chemicals are produced in batches (Groover, 1980).

The third kind of production system is mass production. High volume low variety products characterize mass production. It requires expensive and special-purpose machines to satisfy the high demand rates for a product. Two types, quantity production and flow production can further distinguish mass production. In quantity production normally standard machines (e.g., injection molding, and punch presses) are devoted for production of one type of product with high demand rate. Examples of products in quantity production include screws, nails, plastic molded products and components for automobiles (Groover, 1980). The other type of mass production is flow-shop production. There are two types of flow-shop production. The first is a product-type flow line. In this setting parts move through a connected and uninterrupted sequence of machines (or lines). Each line is arranged in a way so that only one product can be produced. The process is repetitive, producing large volumes of products in each line. Highly dedicated and automated machines are used. This type of flow line is associated with the manufacture of discrete products. An example would be manufacture of plastic safety helmets (Needy et al., 2001). The other type of flow-shop production is the continuous flow line. Nondiscrete parts or quantities of a product are put into huge bulk containers. This type of flow line is associated with the continuous process industry. Examples include crude oil refineries, chemical process plants, food processing, and steelmaking process (Groover, 1980; Needy et al., 2001). Figure 3 below shows a schematic of the classifications of production plants.

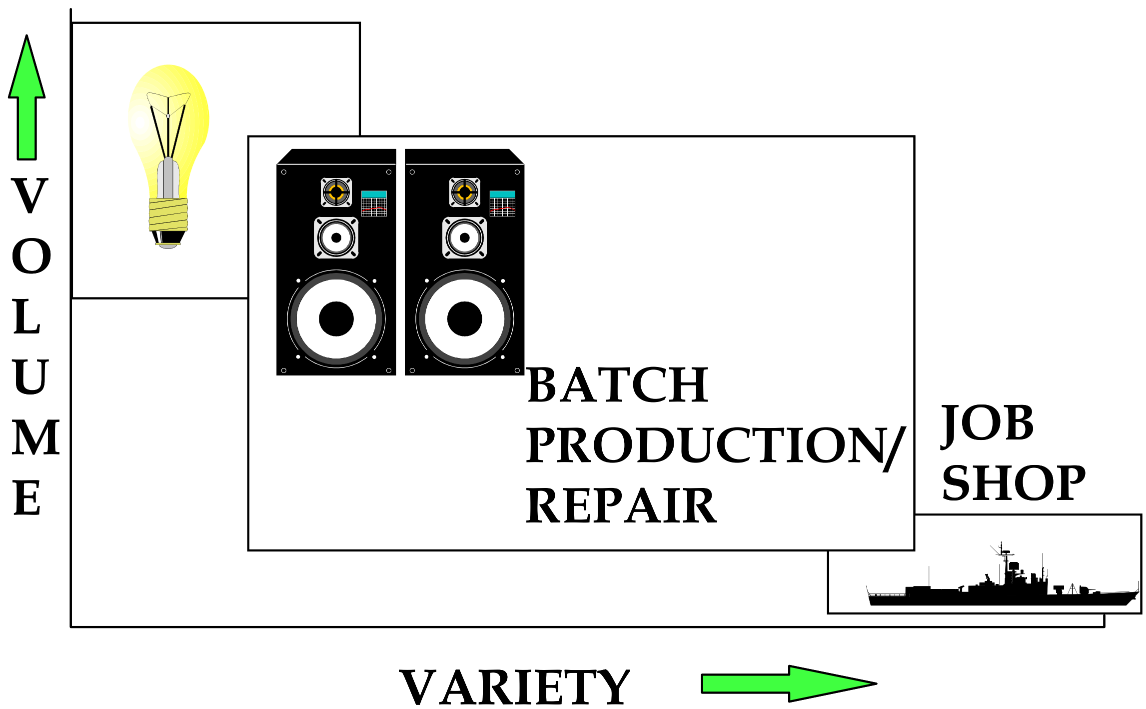



Figure 3 A classification of production plants (Source: B. Bidanda and R. E. Billo, presentation to Fleet Maintenance Facility-Cape Breton, February 1997.)

Following is a summary of the different characteristics of job shop production and mass production (flow-shop) (Hall et al., 1992):

Job-shop Characteristics

- Plan and control by lots
- Low volume, high variety
- Work orders or lot tickets issued
- Varying routings
- Process information travels with job
- Job costing
- Multipurpose equipment
- Organization and plant layout by functional department (type of process such as drilling, grinding, and so forth)

Flow-shop Characteristics

- Plan and control by output rates
- High volume, low variety
- Flow control (no individual job orders)
- Standard routings and fixed flow path
- Process costing
- Equipment dedicated to a limited range of tasks
- Organization and plant layout by product line

### 2.6.1 Application of Lean In Discrete Industry

Since the introduction of the Toyota Production System, the lean concept has spread all over the world. The apparent success of Toyota in implementing a lean manufacturing system has led many of the world's automotive industries to try to implement this new idea of "lean" at their own companies. In this new era the application of lean manufacturing is seen in almost all companies in the automotive industry in Japan, Europe and North America. Most of the lean manufacturing ideas have been applied at the component assembly level, especially in discrete manufacturing. In the automotive industry the bulk of the work involved in making a car is carried out at the assembly level. This is due to the huge number of parts involved in building a car. These individual parts are first assembled at the component plants and then the final assembly of these parts is carried out at the assembly plant (Womack et al., 1990).

The success of the Toyota production system has led the way for many companies in the discrete manufacturing industry to become lean in order to reduce cost through waste reduction and continuous improvement. The lean manufacturing concept is now being widely used in component assembly operations in a variety of industries, e.g., automotive, electronics, and cameras (Dimancescu et al., 1997). In the United States many other companies particularly in the discrete industry have adapted lean manufacturing tools and techniques. These include industries like shipbuilding, telecommunication equipment, office furniture, appliances, and computer part assembly. Other areas that have implemented lean manufacturing, particularly in Europe, include motorcycles and scooters, clothing, amusement park equipment, construction of vacuum pumps, air conditioning systems for cars, and bicycle components (Panizzolo, 1998).

In a recent study done by Industryweek in 2001, a survey was conducted on the adoption of lean manufacturing tools and techniques. The study included 313 telephone interviews and 2,511 responses from mail surveys (Strozniak, 2001). The results of the survey illustrate that 32% of manufacturers use predictive or preventive maintenance, an increase from 28% in 2000 and 20% in 1999. Also 23% of manufacturers are using continuous-flow production, up from 21% in 2000 and 18% in 1999, and 19% of manufacturing firms have adopted cellular manufacturing, an increase from 17% in 2000. Less than 20% of manufacturers adapted other lean tools such as lot-size reductions, bottleneck/constraint removal, and quick-changeover techniques (Strozniak, 2001). Another lean manufacturing tool that has been widely used in the discrete industry is JIT. The automotive industry has been strongly influenced by the fundamental concept of JIT. Toyota for example led the way in using JIT where JIT principles have been used with its suppliers (Womack et al., 1990). In the fifties, the Japanese shipyards implemented JIT in their steel deliveries from steel mills (Schonberger, 1982). White (1992) states that JIT practices have been implemented in industries like electronic/electric, transportation equipment, health and medical components, and machinery.

### 2.6.2 Continuous Process Industry and Lean

A big part of the success of lean manufacturing has come from the automotive industry, especially in the assembly line type process. Other discrete manufacturing companies such as electronics followed the footsteps of the automotive industry by implementing lean concepts. Most of these companies have also succeeded in implementing lean. The challenge today is to adapt the ideas of lean and implement them in a continuous process manufacturing environment.

High volume, low variety products, and inflexible processes characterize the continuous process manufacturing environment. Managers have been slow to adapt the ideas of lean into these processes. The fear comes from the inflexibility of the process where it is more difficult to reduce the lot size. For example, in the continuous process industry setup times are typically long and it is costly to shut down the process for a changeover. The big confrontation nonetheless, is not to be shaken off by these distinct characteristics of the process industry. Sandras (1992) states that the differences that are distinctive to the process industry from the standpoint of JIT (which is a lean tool) must be sorted out from those that are familiar in the discrete industry. He further stresses that those characteristic that are difficult to address must be sorted out from those that are not as hard (Sandras, 1992).

The process industry can be thought of as producing materials rather than producing items as in the discrete manufacturing industry. These two industries have features in common. However, the big difference is in the continuity of operation. In the process industry it can be so expensive to shut down a process that it creates a big challenge from the logistical standpoint (White, 1996). Ultimately however, within a continuous process manufacturing environment, almost always, discrete parts are produced. The lean manufacturing concept can be applied to those processes where discrete parts are produced (Billesbach, 1994). The idea is to take those practices that are used to eliminate waste in discrete manufacturing and apply them to the constraints that are common to the process industry. 'Some of the unique constraints, while difficult technically, may not be difficult from a JIT perspective (e.g. environmental issues)' (Sandras, 1992). After those constraints are eliminated, one is left with the distinctive and difficult issues for each industry. One should then keep an eye on these by trying to minimize their impact while gradually trying to get rid of them.

One of the lean tools that has been implemented in the process industry is Just-in-time. At DuPont's May plant in Camden, South Carolina where textiles are produced JIT was used to fix the problem of product shortages, excessive backlogs, and lost or misplaced yarn at the spinning area. A pull system was utilized using a kanban like approach (Billesbach, 1994). The results were promising: 96% reduction in WIP, working capital decline of $2 million, and product quality improvement of 10%. The lean manufacturing principles adopted by the DuPont plant can be utilized by many continuous process industries (Billesbach, 1994).

In the process industry, JIT principles can focus more on the nonproduction activities such as material movement, distribution and storage. Dow Chemical is a company that supplies chemical products to different customers. One of the problems that existed between the company and one of its customers was excess inventory and long lead time. At the customer site more tank carloads were there than what was actually needed. To reduce the inventory and lead time and to have better demand forecasts, JIT principles were used between Dow and its customer. As a result, demand forecast accuracy increased 25%, average distribution lead time decreased 25%, and inventory was reduced from sixteen to six tank carloads (Cook and Rogowski, 1996).

JIT has traditionally been associated with the manufacturing process. However, recently there has been work done in JIT purchasing in the process industry. Roy and Guin (1999) discuss the implementation of JIT in purchasing at a steel plant in India. They define JIT in purchasing to broadly mean regular ordering and regular deliveries in smaller lots from local and quality certified vendors, at the time of their use, at the point of consumption, and in the right quantity and quality. First they identified JIT demand and JIT vendors, then they developed a freight consolidation model (FCM) that can be utilized to transport these items from the supplier to the buyer. Roy and Guin developed a cost-effective algorithm for this task. A significant amount of saving was demonstrated using FCM.

## 2.7 Value Stream Mapping

A value stream is a collection of all actions value added as well as non-value added that are required to bring a product or a group of products that use the same resources through the main flows, from raw material to the arms of customers (Rother and Shook, 1999). These actions are those in the overall supply chain including both information and operation flow, which are the core of any successful lean operation. Value stream mapping is an enterprise improvement tool to assist in visualizing the entire production process, representing both material and information flow.

The goal is to identify all types of waste in the value stream and to take steps to try and eliminate them (Rother and Shook, 1999). Taking the value stream viewpoint means working on the big picture and not individual processes, and improving the whole flow and not just optimizing the pieces. It creates a common language for production process, thus facilitating more thoughtful decisions to improve the value stream (McDonald, Van Aken, and Rentes, 2002). While researchers and practitioners have developed a number of tools to investigate individual firms and supply chains, most of these tools fall short in linking and visualizing the nature of the material and information flow in an individual company.

At the level of the individual firm many organizations have moved toward becoming lean by adapting different lean tools such as JIT, setup reduction, 5S, TPM, etc. In many of these cases firms have reported some benefits; however, it was apparent that there was a need to understand the entire system in order to gain maximum benefits. For example, Gelman Science, Inc., a manufacturer of micro porous membrane filtration products started their lean journey by implementing setup reduction. Some reductions were realized, but throughput stayed the same. So in order to attain noteworthy improvements they decided to use value stream mapping to visualize the entire flow and select lean tools that yielded maximum benefits (Zayko, Broughman, and Hancock, 1997).

Lately, and in particular over the last few years a number of companies have utilized value stream mapping. The application crosses over different types of industries and organizations such as automotive, aerospace, steel, and even non-manufacturing industries including information technology. One application of value stream mapping was found in steel manufacturing. A current state map was created for a steel producer, a steel service center and a first-tier component supplier (Brunt, 2000). The map shows the activities from hot rolling steel through delivery to the vehicle assembler. The overall goal of the study was to improve the supply chain performance lead-time. The current state map identified huge piles of inventory and long lead-time. A future state map was then developed. On the future state map target areas were subjected to different lean tools including kanban, supermarket, continuous flow and EDI. The results obtained by implementing the future state map were reduction in lead-time from between 47 and 65 days to 11.5 days, and a reduction of cycle time from 7262 sec to 6902 sec (Brunt, 2000).

Another application of value stream mapping is in aircraft manufacturing (Abbett and Payne, 1999). Current and future state maps were developed with the objective of reducing lead-time according to customers requirements. The implementation of the future state map attained lead-time reduction from 64 to 55 days. Lean tools such as kanban and continuous flow were utilized to help achieving this reduction. An application of value stream mapping was also found in the distribution industry (Hines, Rich, and Esian, 1998). Partsco a distributor of electronic, electrical, and mechanical component decided to map the activities between the firm and its suppliers. Partsco introduce EDI which allowed the firm to work with its suppliers effectively and more quickly. In a short time period the company was able to reduce the lead-time from 8 to 7 days.

Value stream mapping can serve as a good starting point for any enterprise that wants to be lean. Rother and Shook (1999) summarize other benefits of value stream mapping as follows:

- It helps you visualize more that just the single process level (e.g., assembly, welding) in production. You can see the entire flow.
- Mapping helps you not only see your waste but also its source in the value stream.
- It provides a common language for talking about manufacturing processes.
- It ties together lean concepts and techniques, which help you avoid "cherry picking."
- It forms the basis for an implementation plan. By helping you design how the whole door-to-door flow should operate a missing piece in so many lean efforts value stream maps become a blueprint for lean implementation.

Value stream mapping is a pencil and paper tool, which is created using a predefined set of icons (shown in Figure 4 below). There are a lot of benefits to drawing value stream maps by hand with paper and pencil. Manual mapping lets us see what is actually happening in a shop floor value stream, rather than being restrained to a computer. Also, the process of quickly drawing and redrawing a map acts as a plan-do-check-act cycle that deepens our understanding of the overall flow of value or lack thereof.

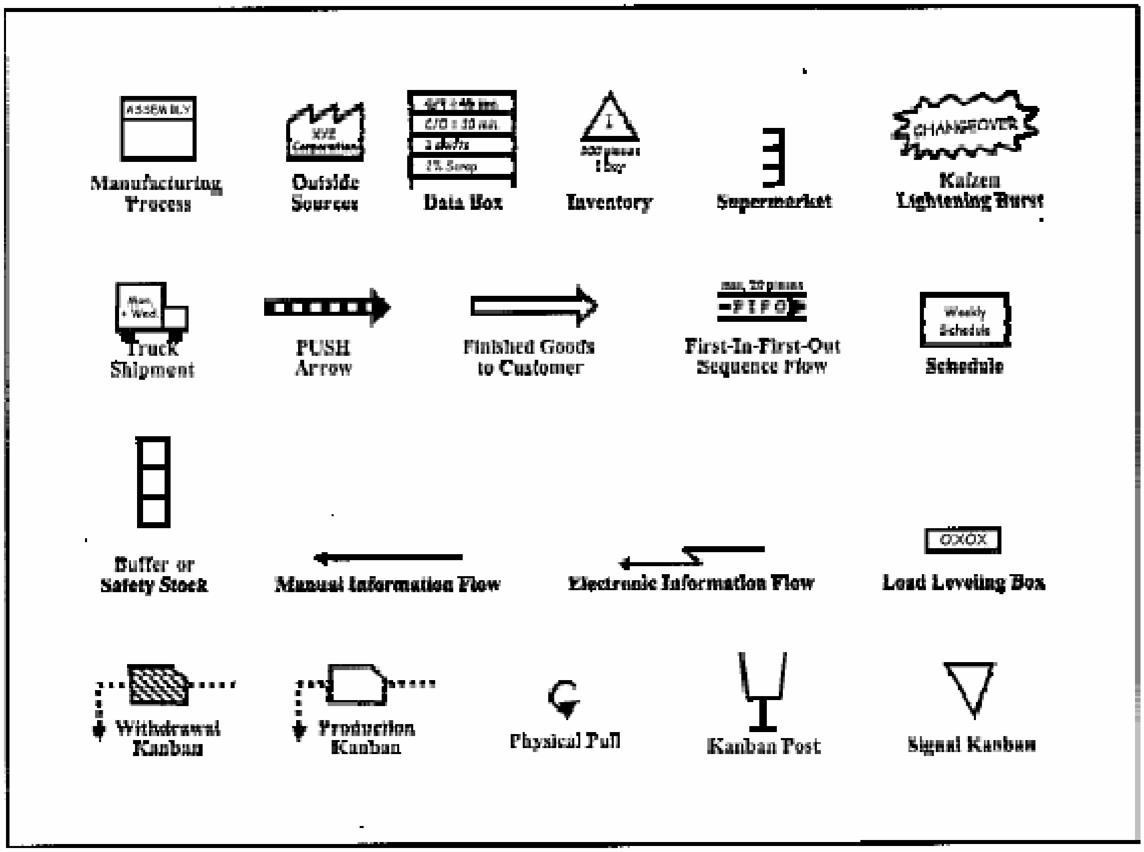



Figure 4 Icon used for value stream mapping (source: M. Rother and J. Shook, 1999)

The first step in value stream mapping is to choose a product family as the target for improvement. Customers care only about their products and not all products so that it is unrealistic to map everything that passes through the shop floor. Drawing all of the product flow in one company would be too complex. Identifying a product family can be done either by using the product and process matrix to classify similar process steps for different products or by choosing products that use the highest volume.

After choosing a product family the next step is to draw a current state map to take a snapshot of how things are being done now. This is done while walking along the actual pathways from the actual production process. Drawing material flow on the current state map should always start with the process that is most linked to the customers, which in most cases is the shipping department, and then working ones way up to the upstream processes. The material flow is drawn at the lower portion of the map. At each process all the critical information including lead-time, cycle time, changeover time, inventory levels, etc. are documented. The inventory levels on the map should correspond to levels at the time of the actual mapping and not the average because it is important to use actual figures rather than historical averages provided by the company.

The second aspect of the current state map is the information flow that indicates how each process will know what to make. The information flow is drawn on the upper portion of the map. The information flow is drawn from right to left on the map and is connected to the material flow previously drawn. After the completion of the map a timeline is drawn below the process boxes to indicate the production lead-time, which is the time that a particular product spends on the shop floor from its arrival until its completion. A second time called the value-added time is then added. This time represents the sum of the processing times for each process.

The third step in value stream mapping is to create the future state map. The purpose of value stream mapping is to highlight the sources of waste and help make target areas for improvement visible. The future state map is nothing more than an implementation plan that highlights what kind of lean tools are needed to eliminate the waste and where they are needed in the product value stream. Creating a future state map is done through answering a set of questions with regards to issues related to building of the future state map, and technical implementation related to the use of lean tools. Based on the answers to these questions, one should mark the future state ideas directly on the future state map. After creating the future state map the last step is to carry it out by trying to implement the different ideas generated by the future state map on the actual value stream.

## 2.8 Simulation and Value Stream Mapping

The decision to implement lean manufacturing is a tough one, especially for companies that rely on traditional manufacturing systems. It is hard because of differences between the traditional and lean manufacturing systems in a number of aspects including raw material procurement, inventory management, employee management, and production control. For traditional manufacturers, the difficulty of implementing lean arises because its distinctive requirements make it hard to predict the magnitude of the gains that can be achieved by implementing lean. As a result, the decision on whether or not to implement lean manufacturing often comes down to one's belief in lean manufacturing, reported results of others who have implemented lean, and rules of thumb on the expected payback. For many companies, this is too little justification to make them buy into implementing lean (Detty and Yingling, 2000). This brings us to the next question of how we can make value stream mapping a more viable tool.

In many situations the future state map can be evaluated without much difficulty, whereas many other cases this might not be easy. For example, predicting the levels of inventory through the production process is not possible with only a future state map because with a static model one cannot observe how the level of inventory will be affected for different scenarios (McDonald, et al., 2002). In order to help an organization consider lean techniques a supplementary tool for value stream mapping is needed that can quantify the gains during the early planning and assessment stages. This tool is simulation, which is capable of generating resource requirements and performance statistics, while remaining flexible to the details of the organization.

Simulation can be used to reduce uncertainty and create dynamic views of the inventory levels, lead-times, and machine utilization of the process for a giving future state. This enables the quantification of payback derived from using the principles of lean manufacturing and their impact on the total system. Moreover, simulation can be used to explore alternative future state maps generated by different responses to design questions. It can also assist organizations considering lean manufacturing to quantify, at the planning and evaluation stage, the benefits they can expect from applying lean manufacturing. Simulation is adaptable to the specific circumstances of the organization, and is capable of generating resource requirements and performance statistics for both the proposed future state map and the existing operation. The information provided by the simulation would enable management to assess the performance of the lean system in absolute terms and, most importantly, relative to the well understood, existing system it is designed to replace (Detty and Yingling, 2000).

Simulation can quantify the performance improvements that can be anticipated from applying the lean manufacturing principles of continuous flow, just-in-time inventory management, total preventive maintenance, setup reduction, and level production scheduling. It has the capability of demonstrating the gains of lean through the whole manufacturing system including warehousing and WIP levels, transport and conveyance requirements, effectiveness of production control, and system response to market. On the other hand, some of the very important benefits from applying lean manufacturing principles do not readily lend themselves to quantification by simulation, e.g., those that are the result of employee empowerment, continuous improvement, and 5S.

Many researchers have used discrete event simulation in a lean manufacturing environment. At Dupont Wilmington they were faced with a logistical problem in product distribution and railcar requirements. Two simulation models were developed to assess whether new railcars are needed or fleet reduction was in order. The simulation recommended a 25%

reduction in fleet thereby preventing a $1 million investment in new railcars (White, 1996). Savasar and Al-Jwawini (1995) developed a simulation model to investigate the effects of variability in processing times and demand on the performance of JIT systems and to compare pull systems to push systems for withdrawal policies that use various kanban levels. Welegama and Mills (1995) used simulation to answer questions faced by a chemical company regarding transforming from traditional to JIT system and examined different designs for the JIT system. Also, Galbriath and Standridge (1994) used simulation to validate modifications to a traditional system as it was being converted to a JIT system.

Detty and Yingling (2000) used an Arena simulation model to assist a consumer electronics company with the decision to implement lean manufacturing by quantifying benefits gained from applying lean principals. However, the literature has only one paper regarding the use of simulation to supplement value stream mapping. McDonald, Van Aken, and Rentes (2002) used simulation for a high-performance motion control products manufacturing system to demonstrate that simulation can be a very crucial tool in assessing different future state maps. They demonstrate that simulation can provide and examine different scenarios to complement those obtained from future state mapping.

## 2.9 Summary

It is clear that lean manufacturing is a powerful tool that when adopted can create superior financial and operational results. Managers, however, have been reluctant to adapt lean manufacturing tools to the process industry due to the distinctive characteristics of the process industry. The preceding literature review suggests that JIT and kanban approaches have been applied at some process facilities and good results have been reported. On the other hand, the literature suggests that nobody has systematically examined the use of lean manufacturing tools and techniques at a process facility. Also, the literature suggests that value stream mapping is a good startup tool for companies that want to become lean, because it unveils wastes in the value stream. Simulation can be used to support value stream mapping for companies that want to become lean by predicting the results before lean is implemented.

In order to adapt lean manufacturing tools to the process industry, one needs to thoroughly examine different characteristics of the same and develop a systematic approach to best utilize these techniques at a process facility.

# 3.0 A TAXONOMY OF THE PROCESS INDUSTRY

## 3.1 A Common Misconception

Process industries have normally been lumped together on the basis of the fact that they are designed to produce nondiscrete products. As a result, people have often ignored the distinct characteristics of the different types of process industries. While the process sector as a whole shares much in common, there are unique characteristics that are product specific. Defining the entire process industry solely based on the fact that it produces nondiscrete material displays a simplistic understanding of this sector. Discrete materials are those that can preserve their solid form with or without being put in a container or being packaged. On the other hand, nondiscrete materials can often expand, evaporate, or dry out if they are not put into a container, including materials like liquids, pulps, gases, and powders. While almost all process industries use nondiscrete materials, many of them also use discrete materials.

Prior taxonomies have used process manufacturing and process flow production in parallel to describe the process industry when in fact these two expressions mean different things. Process manufacturing is defined as "production that adds value by mixing, separating, forming, and/or performing chemical reactions. It may be done in either batch or continuous mode" (Cox and Blackstone, 1998). On the other hand, process flow production is defined as: "A production approach with minimal interruption in the actual processing in any one production run or between runs of similar products. Queue time is virtually eliminated by integrating the movement of the product into the actual operation of the resource performing the work" (Cox and Blackstone, 1998). Thus process industries all use process manufacturing; however, not all of them neccessarly utilize process flow production techniques.

## 3.2 Process Industry Groups

Process industries have typically been classified into different industry sets. Each industry set is further classified on the basis of different products specific to that industry. Table 1 lists some different process industry sets and their products.

Table 1 Industries sets and types of products

| Process Industry Set | Type of Products |
|---|---|
| Glass, Ceramics, Stone, and Clay | Lighting Products, Flat Glass, Fiber Optics Glass, Glass Containers, Concrete, Gypsum, Cement, Paving and Plaster, Abrasives and Asbestos |
| Steel and Metal | Coils, Sheets, Slabs, Bars, Stainless Steel and Structural Steel, Sheet Metal, Primary Smelt Refining, Nonferrous Metals |
| Chemicals | Drugs, Soap, Paint, Inorganic Chemicals, Organic Chemicals, Cosmetics, Plastic Products, Agricultural Chemicals, and Resins |
| Food and Beverages | Meat products, Dairy products, Canned Food, Bakery Products, Sugar Cane Refineries, Sugar beet Refineries, Oil, Malt Distillers, and Soft Drinks |
| Textile | Cloth, Carpeting, Towels, Cord and Twine, Automotive Upholstery, Reinforcing Materials, Bulletproof Vests, and Decorative Braids and Ribbons |
| Lumber and Wood | Logging, Wood Containers, Mobile Homes, Misc. Wood Products, and Panel Products |
| Paper and Pulp | Cardboard, Calendar, Printer's Paper, Packaging Material |

The taxonomy herein will use an alternative viewpoint to contrast the process industries and to characterize them into distinguishable groups. In order to do this, a set of dimensions is chosen for the classification. In the following sections, a detailed and structured framework is developed for different characteristics of the process industry. The different types of the latter are classified according to (a) the product characteristics and (b) material flow characteristics. We also address the question of when a product eventually becomes discrete in the process. At the end of this taxonomy we address where the steel industry in particular fits into this taxonomy and what the opportunities for lean are in the process industry.

### 3.2.1 Product Characteristics

The product characteristic dimension in the process industry can be described primarily on the basis of two metrics: raw materials and product volume. The process industry has always been tagged with the label of producing high-volume products. However, it is important to note that this is not necessarily true and that product volume often depends on the specific industry within the process sector.

Raw materials are those items that are used as inputs that are converted by manufacturing processes into finished products. Almost all the process industries obtain their primary raw materials from mining, agricultural, or other process industries. Usually these raw materials vary in terms of their quality and this variability often determines the product that will be produced. Examples include the amount of carbon in the coke used to make steel, or crude oil from different oil fields that have different sulfur content (Taylor, Seward, and Bolander, 1981). This variation is always found in all the process industries due to the inherent characteristics of the raw materials.

There are also differences in the variety of raw materials used in process industries. In other words, products can be produced from a small or large variety of raw materials. For example, in feed blending the process requires a large number of different raw materials to be used in the blending operations. Another example of a process industry that requires a large number of raw materials is the paint industry, where a wide range of raw materials (including pigments, synthetics, solvents, drying oils, plasticizers, and driers) are used to produce different types and colors of paints. In the food industry the raw materials used also have a limited shelf life so for example, it might be very critical to have a constant flow of fresh fruits and vegetables on a daily basis.

On the other hand, there are segments in the process industry that use a relatively low variety of raw materials as inputs. For example, in the steel industry iron ore, coke and limestone are mixed together to form molten steel. In the beverages industries a relatively small number of raw materials are used; in the making of soft drinks, water (the main raw material for soft drinks), artificial flavor, and sugar are mixed together.

Process industries can have different classifications in terms of the variety of raw materials used as input. Figure 5 shows such a classification. It should be noted that this is a general classification, and that within each product set there might be individual products at the low and high side of the spectrum. For example, in the food industry, some products such as meat processing require only meat as the main raw material, whereas ice cream requires raw materials such as milk products, flavors, sweeteners, stabilizers, emulsifiers, and other ingredients such as fruit and nuts (Shreve and Brink, 1977).

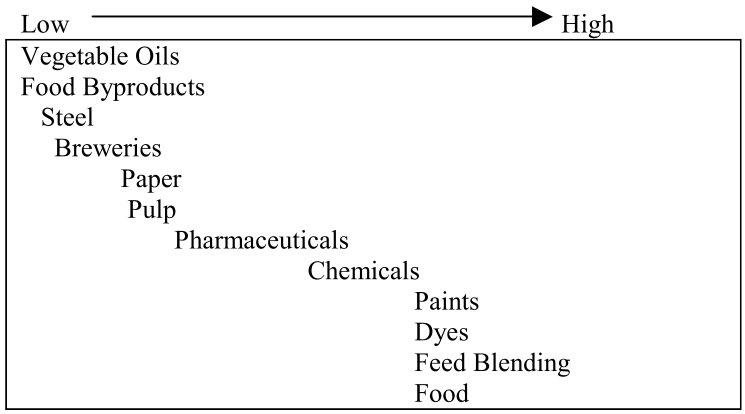



Figure 5 Classification of the process industry based on raw material variety

The second product characteristic by which the process industries can be contrasted is product volume. Product volume refers to the amount of output (finished products) that a process produces. These again differ from one process industry to the other. For example, in the pharmaceutical industry, some drugs might be produced in small quantities for very specific market segments, so that the quantity of the final product is comparatively small. On the other hand, the production of beverages or breweries tends to be in high volumes to satisfy the higher market demand. In some process industries the product volume can go on any side of the spectrum depending on the product made. For example, in the dyes industry some of the intermediates, which are a source of raw materials that go into making dyes are made in large quantities, whereas others such as aniline and phenol are produced in short cycles for the medicinal field (Shreve and Brink, 1977). Figure 6 shows a general classification based on product volume.

Low → High

Drugs
Specialty chemicals
Steel products
Paper
Paints
Breweries
Beverages

Figure 6 Classification of the process industries based on product volume

From the above description with regard to the product characteristics one can see that industries with low variety of raw materials and high product volume are inherently more efficient than other and in such cases some lean tools may not be needed or even feasible. Thus the beverage industry, which is characterized as high volume and low variety of raw material has continuous flow of product, which does not require many stops between workstation because of the high volume, which makes it by nature to have continuous flow. This rules out the use of kanban or small batches. Also, the raw material variety is low which means relatively less changeover between products and relative ease in maintaining high levels of quality and consistency. However, in order to maintain this high quality, tools such as TQM and kaizen are needed. Conversely, paint or specialty chemicals with their high variety of raw materials and low to medium volumes might be suited for some lean tools that are not needed in the former. For example, setup reduction is a good lean tool to develop in these industries in order to expedite the switchover from one product to another.

### 3.2.2 Material flow Characteristics

Material flow characteristics are those that have to do with the production plant environment. The process industries have typically been tagged as being a flow shop type environment where the manufacturing unit travels in continuous flow fashion through highly automated and specialized equipment with few routings and minimal interruption. In fact, process industries (like the discrete ones) have their own material flow systems. Material flow systems are typically distinguished into three different classes: job shop, batch shop, and flow shop (continuous process). Each of these systems has its own characteristics in term of equipment and flexibility. Different process industries can be grouped into some point in the continuum of these systems based on equipment arrangement and flexibility.

Equipment in any industry can be classified as general purpose or specialized, and these two may in turn be further classified as dedicated or non-dedicated. Dedicated general-purpose equipment might be used to produce different products but their use is restricted to a specific operation for one or limited number of products (Cox and Blackstone, 1998). For example, in the paint industry some of the equipment used is general purpose but considered dedicated, where dedication is basically for different color groups. In the organic chemical industry, general-purpose equipment might be dedicated to certain products that may be chemically different but share certain operations. Non-dedicated, general-purpose equipment is used to produce different products, with equipment use not limited to any particular type of products. For example, in the resins industry the equipment is normally general purpose with other chemical plants using the same or similar equipment to manufacture other products, and the equipment is non-dedicated with different products (different types of plastics) being able to use the same equipment. Another process industry that uses non-dedicated, general-purpose equipment is the food industry. For example, in the baking industry general-purpose equipment such as ovens and freezers are used and they are non-dedicated because many different products can share them.

The second type of equipment used in the process industry is the specialized variety. These in turn could be dedicated or non-dedicated. For example, in the pharmaceutical industry, and particularly in making tablets, some of the equipment used is dedicated and specialized. It is dedicated to certain products, and specialized since it is designed only for making tablets in the pharmaceutical industry (Dennis, 1993). On the other hand, the beverage industry uses non-dedicated but specialized equipment. The equipment (e.g., tank) is considered to be specialized since it is designed specifically to produce carbonated beverages and it is not dedicated because any type of flavor can be made in any tank (Dennis, 1993).

This is a general classification of the type of equipment used in the process industry. It must be thus noted that in the process industry a plant might use both general purpose and specialized equipment, and these in turn can be dedicated or non-dedicated. As an example, in the pharmaceutical industry some of the equipment used for producing mouthwash is general purpose (with other industries using the same equipment for other products), while some of the equipment is specialized only to make specific mouthwash products (Dennis, 1993).

The type of equipment and the facility layout dictate the flexibility inherent in the manufacturing system. This in turn determines the extent to which lean principles can be adapted. In general dedicated specialized, equipment provide the least amount of flexibility, while non-dedicated, general purpose equipment allows for the most. There are process industries that have minimal flexibility in their manufacturing system. For example, in the pharmaceutical industry the arrangement of the equipment does not allow for much flexibility in the system. The manufacturing system is continuous with respect to the manner in which the equipment is arranged in a sequence in accordance with the manufacturing steps involved in producing the products. The product follows one route and there is no interruption in the flow. The production of beverages is another example of a continuous manufacturing system with no flexibility. The mixers (tanks) are arranged in accordance with the sequence of operation. The product follows one route by going through mixing and filtering operations (Dennis, 1993). However, the production of extruded plastic, which is used in the automotive industry, toys, housewares, and cassettes, the manufacturing system is considered a batch system. Even though the series of equipment is connected together by pipelines, the products are produced in lots and there are some decoupling inventories (Dennis, 1993). All the same, flexibility is still rather low due to the fact that the number of parallel machines to produce a product is small.

On the other hand, other systems are more flexible. The production of ice cream, which is considered partly continuous and partly batch is a process with a moderate amount of flexibility. Part of the equipment is arranged in the operational sequence while others are arranged in a functional layout. The mixing and homogenizing of the ice cream is continuous with no flexibility, while the fruit vats and fruit fillers are flexible due to the large number of parallel equipment. The product can travel through different routes after mixing.

There are also examples in the process industries of systems that display high flexibility. For example, in specialty chemicals and particularly in the production of organic dyes, the manufacturing system is considered to be a job shop type system. The equipment is arranged in a functional layout fashion and production is in lots. The product variety is high (dyes are used in food, drug, and cosmetics) and there is a requirement for high equipment flexibility and many routing alternatives. Another example of a process industry that has a high degree of flexibility is the paint industry. In the paint industry a large number of customized products are produced in lots. High flexibility exists due to parallel functional equipment and many routing options. In Figure 7 we present a general classification of process industries with respect to equipment arrangement and flexibility and resulting materials flow.

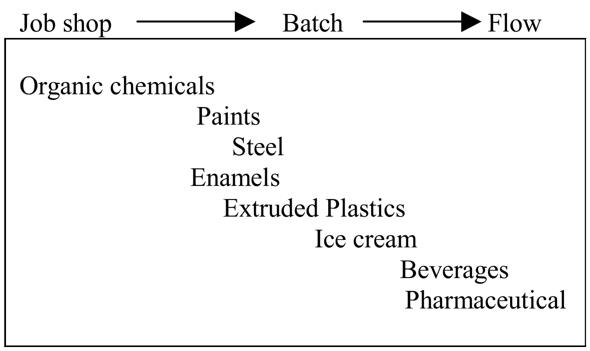



Figure 7 Classification of the process industries with respect to equipment arrangement and flexibility.

### 3.2.3 When do Nondiscrete Units Become Discrete in the Process?

Almost all process industries are typically described as being purely continuous. In fact, almost all of these manufacturing systems are actually hybrids. By hybrid we mean that their nondiscrete units eventually become discrete at some point during the manufacturing process. In the following discussion we will attempt to answer the question of when during the manufacturing process the nondiscrete parts become discrete. We do this by developing a general taxonomy that classifies different process industries on an “early,” “middle,” or “late” scale in their manufacturing process to describe when their nondiscrete units eventually become discrete.

Discrete operations are those that are performed on a single unit, or a group of units simultaneously. These include operations like metalworking, assembly, finishing and packaging (Cleland and Bidanda, 1990). Discrete operations produce products that are sold in units or multiples of units. Examples include cars, circuit boards, and telephones. On the other hand, continuous operations are those in which the operation does not produce distinct or discrete units. These include operations such as refining gasoline from crude oil, grinding flour, or producing chemicals for industrial application (Cleland and Bidanda, 1990). Continuous operations produce products that are sold in lots or containers. Examples include soda sold in various sizes of cans or bottles, or propane gas sold in containers of various sizes. The production of an item frequently involves both continuous and discrete operations. When this is the case, the continuous operation typically heads the discrete operation. The discrete operation takes place later in the sequence where shaping, assembling, finishing and packing operations are performed (Cleland and Bidanda, 1990).

We start with the textile industry where the nondiscrete units become discrete relatively early in the manufacturing process. After wool or cotton is fed into a spinning machine in a spinning mill, the yarn is then sent to cutting machines which produce discrete units for different applications including clothes, gloves, flags, blankets and others. These units are dyed and finished before being shipped in batches.

Next there are process industries that have their nondiscrete units become discrete approximately during the middle of the process. For example, in the steel industry the process starts with liquid steel going from the blast furnace to an oxygen furnace and finally to continuous casting. At this stage the steel comes out of the continuous casting machine as semi-finished discrete units in the form of slabs or bars. The slabs might then be sent to a hot strip mill, pickling and then on to the cold rolling mill before being sent to the customers. In the steel making process one can see that the nondiscrete units become discrete approximately in the middle of the process. The metal industry in general is one where discrete units are produced toward the middle of the process. Just like with steel, metal scraps might be mixed in an induction furnace and then the molten liquid is sent to the caster to form an ingot (discrete, semi-finished metal). The ingots are rolled and sent to the sheet mill before they are sent to customers.

Finally, there are process industries where products become discrete at the point of containerization or during the last process just prior to the point of containerization. For example, in making sugar, discrete units are not produced until the final step in the manufacturing process where the sugar crystals are packaged. Starting from the processing of sugar cane until the last granulation process, the process is continuous where nondiscrete mixed liquid travels through the process. Another example of a process industry that produces nondiscrete units at the last step before containerization is the paint industry. The manufacturing of paint starts with the mixing of oils, resins and pigments in a big blending tank and the process ends with the packaging of different paints into containers of various sizes. The manufacturing process becomes discrete only when different paint types are packaged at the end of the process. The manufacture of gases is another process that produces discrete units only upon containerization. For example, the production of hydrogen starts with feeding reactants through a continuous chemical process to produce the required hydrogen. The hydrogen is finally put into containers for use by different industries. It must be noted that some gases are never put into containers and the gas is fed by pipeline directly to the point of demand. Figure 8 gives a general classification of when the nondiscrete units become discrete in various process industries.

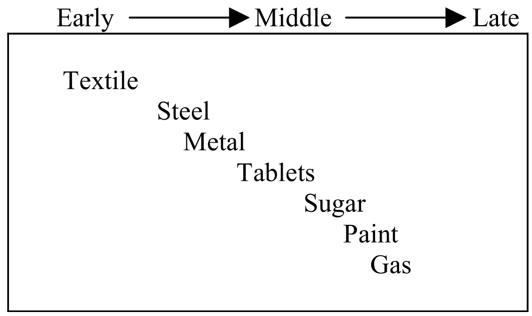



Figure 8 Classification of process industries based upon transformation into discrete units.

## 3.3 Opportunities for Lean

Based on the ideas in this chapter, the steel industry is one where the amount of raw material used may be considered to be at the low end compared to other process industries. As far as product volume goes, the steel industry final output may be considered to be at the middle to the upper end of the scale compared to other process industries. In term of flexibility and equipment, the steel industry would also lie in middle of the scale. It may be considered as having specialized, general-purpose and dedicated equipment. The amount of flexibility tends to lean toward the higher end at the finishing mill where coils can take many alternative routings according to the product type, and there exist a number of similar machines that can process products in parallel. The steel industry has its nondiscrete products become discrete relatively towards the middle of the manufacturing process.

Based upon the taxonomy developed the steel industry may be viewed as a good candidate in terms of implementing lean manufacturing. The fact that it has reasonable flexibility through the alternative routing and the parallel machines represented by a number of hot mill furnaces, a number of annealing furnaces, multiple pickle lines at the finishing end, and the fact that its nondiscrete products become discrete relatively early or during the middle of the manufacturing process makes it more attractive to lean manufacturing. Thus tools like a kanban pull system, production leveling, setup reduction, TPM, 5S, and others can be possibly adapted in this environment.

In general, the taxonomy provides us with guidelines on what aspects of a specific industry make it a candidate for lean. While all techniques may not be easy to apply to all industries, one can identify appropriate tools for specific industries based on their product and process characteristics and the amount of flexibility that is possible. Thus industries such as metals and textile are a good fit for lean manufacturing. The metal industry manufacturing setting resembles that of steel, which makes it a good choice for lean tools such as JIT, setup reduction, TPM, and 5S. The textile industry is a process where the product becomes nondiscrete early in the process, which also makes it adaptable to lean manufacturing tools. For example, setup reduction and production leveling could be adapted to switch from one product type (gloves, clothes, etc.) to another.

Specialty chemicals is another industry that has a higher amount of flexibility in terms of equipment. The manufacturing system is considered to be a job shop type system and equipment is arranged in a functional layout fashion where one machine can process many different products. In this industry cellular manufacturing can be adapted by having different cells for different product groups. Since this industry has parallel, dedicated, general-purpose or specialized equipment each cell can have those dedicated machines according to the products that can use them.

In terms of the raw material variety and product volume it was stated earlier that industries with low raw material variety and high product volume such as beverages would be a good fit for certain lean tools but not others. It should be emphasized that this does not mean that process industries that are not in this category do not have any chance to implement lean. Rather specific lean tools should be examined to see which one would apply easily and which one would not. For example, beverages, breweries, and paper industries are industries that tend to have high product volume. This by nature makes their process flow in a continuous manner; however, it would be hard for these industries to rearrange their equipments into cellular fashion. It is also unrealistic to introduce kanban pull system is such an environment. Also, setup reduction might not fit in these industries due to dedicated equipment, high volume and low variety of raw materials. However, in these industries the fact that the products move in continuous flow manner make the need for TPM more important in order to keep equipment reliabilities high. Finally, techniques such as 5S and visual system can be implemented in any industry.

Industries that are on the other side of high raw material variety and low product volume can also utilize some lean tools that are applicable to such an environment. For example, paint, specialty chemicals and drug industries could utilize tools such as setup reduction for the quick changeover to satisfy the production of small lots. Also tools such as 5S and visual systems could easily be applied.

As discussed above, the opportunities for implementing lean manufacturing in the process industry are on hand in almost all cases but to a varying degree. In the following chapters we use the steel industry to examine and identify specific lean manufacturing tools and techniques and demonstrate how these tool could be applied, and we demonstrate how the steel industry can benefit from lean manufacturing. Also the research contribution section contains brief discussion on which lean tools other process industries can implement to follow the footsteps of the steel industry. Figure 9 and Figure 10 show a general applicability of lean manufacturing tools in the process industry with the regard to the taxonomy developed. Figure 9 is developed for the product characteristics dimension and when the product eventually becomes discrete while Figure 10 is developed for the material flow dimension and when the product eventually becomes discrete. In both figures one should note that 5S and VS are universally applicable and for the other tools the degree of applicability depends on the specific process industry characteristic.

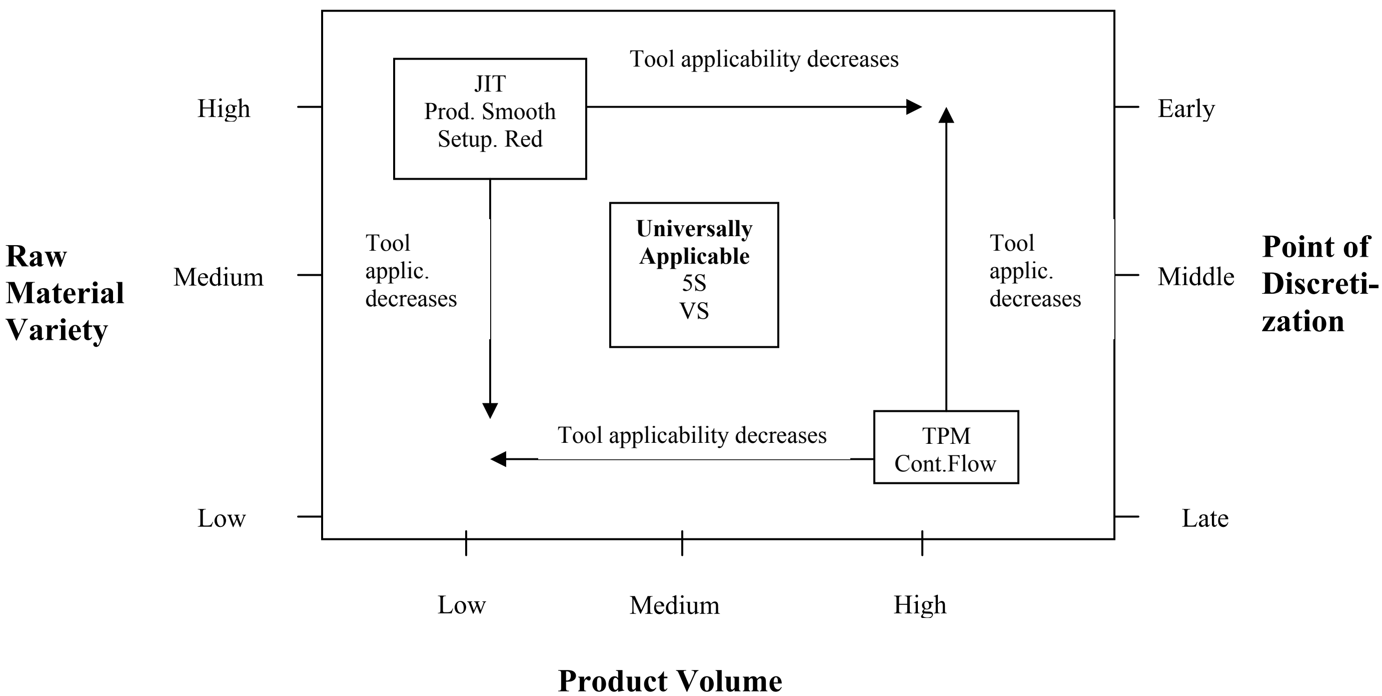



Figure 9 General guidelines for applying lean tools in the process industry: product characteristics.

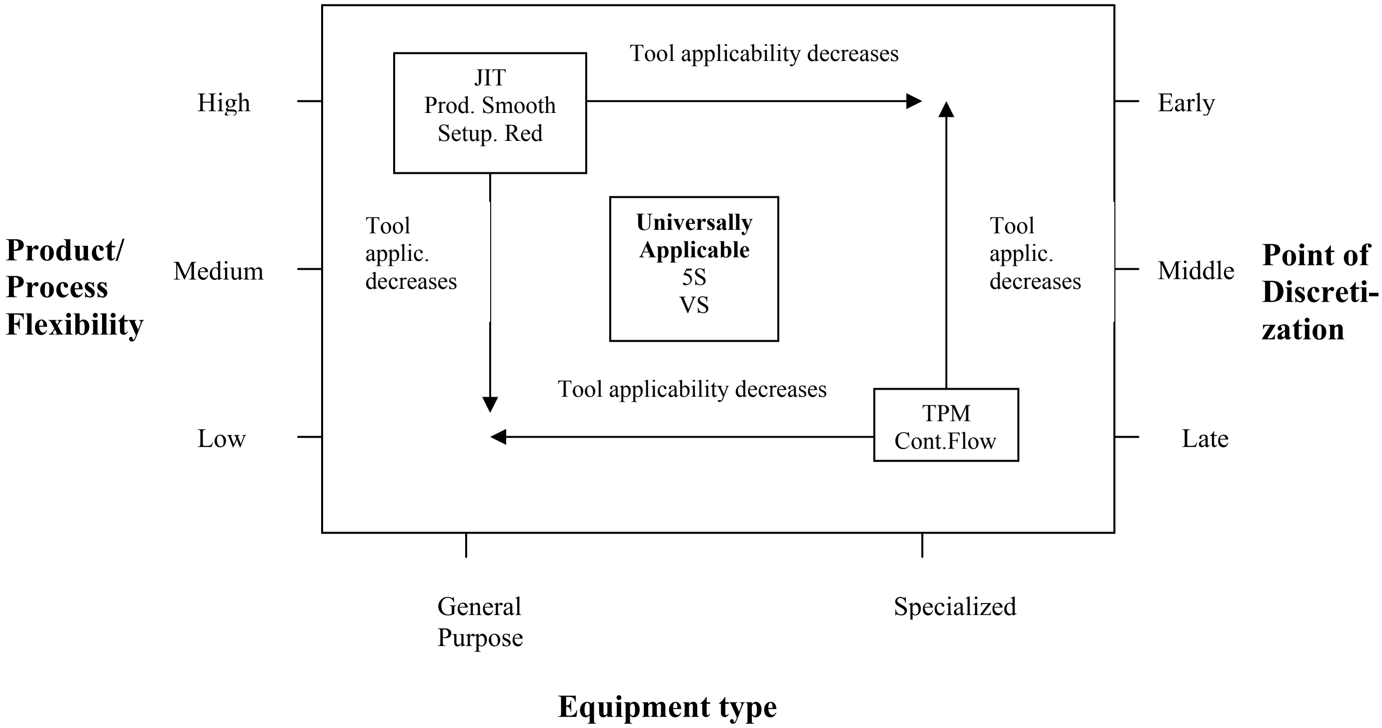



Figure 10 General guidelines for applying lean tools in the process industry: material flow characteristics.

# 4.0 OVERVIEW OF THE METHODOLOGY

As discussed in Chapter 2, the tools and techniques of lean manufacturing have been widely used in the discrete manufacturing industry. In Chapter 3 a taxonomy for the continuous process industry with a focus on steel industry was developed and discussed demonstrating how lean principles could be applied to the continuous sector. Opportunities for lean in other process industries were also discussed. In order to study the extension of these tools to the continuous process industry, it is very important to understand the process parameters involved in the latter, and with steel in particular.

The first reason for choosing the steel industry is that the steel supply chain is a continuous process in the front end but as one moves downstream the process become more discrete, which makes it more applicable to lean tools. The second reason was proximity and local contacts. The steel company studied will be called ABS to maintain confidentiality as per the company's request.

First, we explain the basic principles of the steelmaking process. Second, we report on a survey of steel companies with regard to the use of lean manufacturing in this sector. This survey was developed and conducted in order to understand the current levels of lean implementations and to understand some of the driving forces behind the decision to go lean.

In the following chapters we use value stream mapping to map the current and the future state at ABS. The goal is to identify all types of waste in the value stream, and to try and take steps to eliminate them. The current state is created first and waste is identified, and then the future state is developed to identify and eliminate the sources of waste that the current state map identifies.

In order to quantify the benefits of lean manufacturing simulation is then used to support value stream mapping. This is done by building a detailed simulation model for ABS's entire facility, which is then used to evaluate the benefits from various versions of the future state map. An experimental design is developed to assess the effect of the use of lean manufacturing at ABS from the simulation model.

Finally, for those lean tools that cannot be quantified by the simulation, a proposed methodology is presented to address their use and the potential benefits gained by ABS when implementing these tools.

## 4.1 Overview of the Steelmaking Process

The steelmaking process starts with mixing iron ore, limestone and coke (made from coal) in a blast furnace and heating to temperatures of over 3000° F by blasts of hot air using the carbon in the coke as a reducing agent. Once in a molten state, the hot air removes oxygen and other impurities to produce molten iron (pig iron) (William, Samways, Carven and McGannon, 1985). In the process, the iron absorbs some carbon. The carbon is removed in steelmaking furnaces by mixing molten iron and scrap to produce steel of the desired carbon contents. There are different types of steelmaking furnaces; these include the basic oxygen furnace, open-hearth furnace, and electric-arc furnace. (William et al., 1985).

After the carbon removal process, different alloys such as manganese, aluminum and silicon might be added to the molten stream during tapping from the furnace to the ladle. The molten steel coming from the ladle is dispensed (teemed) into a large mould where it is allowed to cool and solidify to form an ingot. The ingot is then reheated to the correct and uniform temperature at an oven called a soaking pit. This heated ingot is then rolled in primary mills into shapes known as blooms (long pieces of steel with square cross-section), billets (resembles a bloom, but with smaller cross-section), and slabs (long, thick, flat pieces of steel, with a rectangular cross-section). These three forms of steel are referred to as semi-finished steel product. A more modern way to transform the molten steel into the desired shapes is by using continuous casting machines. Molten steel is poured into a big reservoir mold in the continuous-casting machines where it solidifies. At the end of the machine, it is cut into the desired shapes of blooms, billets, or slabs.

The blooms, billets or slabs are transported to the hot rolling mill for rolling into steel products that include plates, bars, structural shapes, wires, nails, sheets, coils, and tubular products, which can be used by different manufacturing industries (William et al., 1985). Figure 11 summarizes the different steps involved in the steelmaking process from raw material to finished products. The steel industry is characterized by having a batch process at the front where blooms, billets and slabs are produced using continuous casting machines. However, as one moves toward the back of the process, a job shop type process exists. Other characteristics of the steel industry can be can be summarized as:

- Equipment is large and inflexible in term of product mix.
- Products are bulky which limits the choice of transportation mode.
- Shut downs are normally long.
- Equipment set-up and changeover costs can be substantial.
- Some processes must be performed in batches.

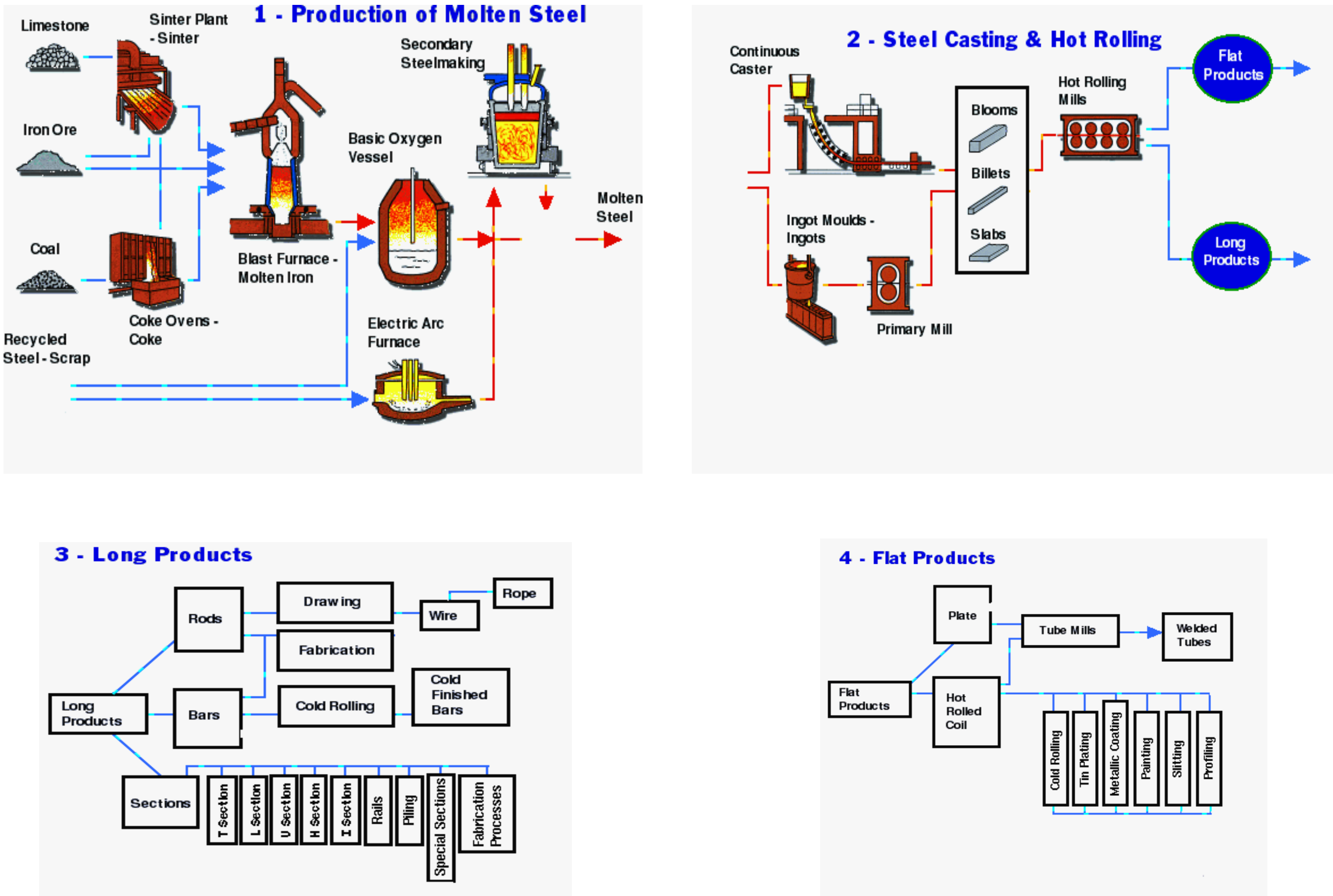



Figure 11 Steelmaking process (source: www.uksteel.org.uk/stlmake2.htm)

## 4.2 A Brief Survey of the Steel Industry

An issue that has not been addressed in the literature is the implementation of lean manufacturing within the steel industry. We therefore decided to survey a sample of steel companies with regard to the use of lean manufacturing. The purpose of the survey was to gain some understanding of the current levels of lean implementations and the driving forces behind the attempt to go lean. The survey looked at steel companies all over the United States, but was restricted to integrated steel plants only. Integrated steel plants (as opposed to so called mini-mills) are those that start from raw iron ore rather than scrap steel and typically have steel-making capacity of 2 million tons or more per year. The contact information was obtained from the steel plant database.

A total of 23 surveys were sent to different integrated steel plants all over the U.S. Four surveys were returned by mail and two were collected by telephone as a follow up for a total of six surveys. On average the survey took ten minutes to complete, either directly or on the telephone. Companies were given one month to respond to the mail survey. If there was no response within a month a follow up phone call was made to attempt to complete the survey over the phone. Two of the companies that were followed up over the telephone declined to fill out the survey. In the rest of the companies that were contacted, either the contact person had left the company and no other contact was available, or the contact person was not qualified to complete the survey.

The geographical locations of the companies that completed the survey were scattered mostly in the eastern part of the United States, with one in the mid-east and one in the western part. Five of the companies produced flat products and one produced long products. A copy of the survey may be found in Appendix A. The identities of the companies are protected but the results of the survey are summarized in Table 2. The table also identifies the title of the interviewee.

As we can see from the table, all companies reported that becoming cost competitive was the driving force behind implementing lean. All six companies reported using TPM, five reported using or making some effort at using JIT and TQM, and some also reported using 5S and setup reduction. Three companies are in the early stages of their lean implementation (0-25%), two in the middle (26-50%) and only one in an advanced stage (51-75%). Some of the challenges faced by these companies when implementing lean include: changing historical rules within the company, union issues, automation issues, employee training, and changing employee mind set.

Their reported gains from implementing lean include reduction of cost, customer satisfaction, reduction of machine downtime, and having a better and safer work place.

It is clear from the survey result that steel company are starting to see the need for the use of lean manufacturing techniques in order to stay competitive in today's global market. The survey confirms that by reporting the majority of the top management in the companies to be very supportive to carry out the lean initiatives. They are slowly adapting those lean techniques and trying to change the old mind set on how the steel business is run.

Table 2 Summary of the survey data

| | Company1 | Company2 | Company3 | Company4 | Company5 | Company6 |
|---|---|---|---|---|---|---|
| **Tile of Interviewee** | Quality System Coordinator | Control and Business Service | Corp. Strg & Development Mgr. | Internal consultant | Supt. Qual. & Process Tech | Director of Eng. and Tech |
| **Driving force** | Long M/C downtime, Customer push us to implement lean, reduce cost | Become cost competitive | Liquidity | Losing money | Economics, save money | Cost related upper management decision |
| **Lean tools used** | JIT, TPM | JIT, TQM, TPM | JIT, TPM, TQM | TPM, TQM, 5S, Cell Mnfg | JIT, TPM, setup reduction, TQM | JIT, TPM, setup reduction, TQM |
| **How far along implementation** | 0-25% | 51-75% | 26-50% | 26-50% | 0-25% | 0-25% |
| **Expectation from lean** | Improve cost | Better customer service, lower cost, higher cash flow | Cost competitive | Clean & safer workplace, better planning procedures | Lower cost, reduce inventory | Improve cost, customer satisfaction, employee satisfaction |
| **Results obtained from lean** | Reduced M/C downtime | See improvement in cost | Process improvement, cut cost significantly | Made profit for entire year since implementing lean, clean & safer workplace | Save some money | Improve customer satisfaction, improve cost |
| **Challenges faced when implementing lean** | N/A | Changing historical rules | Union issues, Automation issues | Employee training | Inflexibility of union | Change employee mind set |
| **Support of top management** | Neutral | Very supportive | Very supportive | Very Supportive | Neutral | Very supportive |

# 5.0 VALUE STREAM MAPPING AT ABS

In this chapter we start with a description of the production process at ABS. In the next section we build the current state map for ABS, followed by the creation of the future state map in Section 5.3. The adaptation of specific lean tools such as JIT, setup reduction and TPM is also described.

## 5.1 Description of ABS

ABS produces several products that are used primarily in appliance manufacturing. The focus of this value stream mapping (VSM) is on one product family, the annealed product type. ABS produces three types of the annealed product: open coil annealed, hydrogen batch annealed, and continuous annealed.

ABS's processes for this product family start with a blast furnace where on a daily basis raw material including skips of iron ore, coke, and limestone are charged at the top of the furnace. The extremely hot and melted raw material that forms liquid iron is then poured into sub-ladles (essentially, large bins for holding liquid iron) from the tap hole at the bottom of the furnace. The liquid iron travels in the sub-ladle to the Basic Oxygen Process (BOP) where scrap is added and oxygen is blown in to burn off excess carbon and obtain the initial form of liquid steel. Depending on the grade of the final steel to be produced this initial liquid steel can go either to a Ladle Metallurgical Facility (LMF) or a Degasser to further refine and remove impurities from the liquid steel. The refined liquid steel then goes to a dual-strand continuous caster where steel slabs are cast in accordance with specific customer widths.

The hot slabs are then shipped on railroad and rack cars from the continuous caster process to the finishing mill facility. Upon arrival the slabs are unloaded at the slab yard where they are stacked in a warehouse waiting to go to the hot mill. The slabs are then sent to the hot mill where each slab is charged into one of five reheat furnaces. In the reheat furnace, a slab is heated to about 2400° Fahrenheit and then reduced to a sheet (coil) by passing it through several sets of rollers. Straps are placed around the hot rolled coils and they are then transferred to an area called raw coil storage where they wait an average of three days to cool off.

From the raw coil storage the product goes to the pickling process. In the pickling process, coils are welded into longer lengths and then passed through an acid bath to clean them and remove scale and rust that have bonded on to the coils as a result of the rolling process. At the exit of the pickle lines, coils are sheared to the exact coil size to match customer requirements. After pickling the banded coils go to the cold-reduction mill where they are again sent through sets of rollers to further reduce them in thickness. These rollers take the coils at atmospheric temperature and roll them down to thinner gages according to customer specifications.

Annealing is the next process after cold rolling, where the hard and brittle coils coming from cold rolling are softened so they can be strong and formable. There are three types of annealing processes; open coil annealing, continuous annealing, and hydrogen batch annealing. Open coil annealing (OCA) is a process where a wire is run through the middle of a rolled coil to expand it. The coil goes into a furnace where the heat goes completely through the band since it has been expanded. Products made by open coil annealing include stovetops and washing machines. Hydrogen batch annealing (HBA) is used to provide uniform metallurgical properties and improved surface cleanliness. Continuous annealing (CA) is used for doors of refrigerators and other appliances.

After annealing, the coils go to the temper mill where the final metallurgical properties are determined, the degree of flatness is established, and the desired surface roughness is reached. After finishing from the temper mill the coils are packed and then shipped to the final customer. Figure 12 shows the coil movement at ABS through the manufacturing process at the finishing mill.

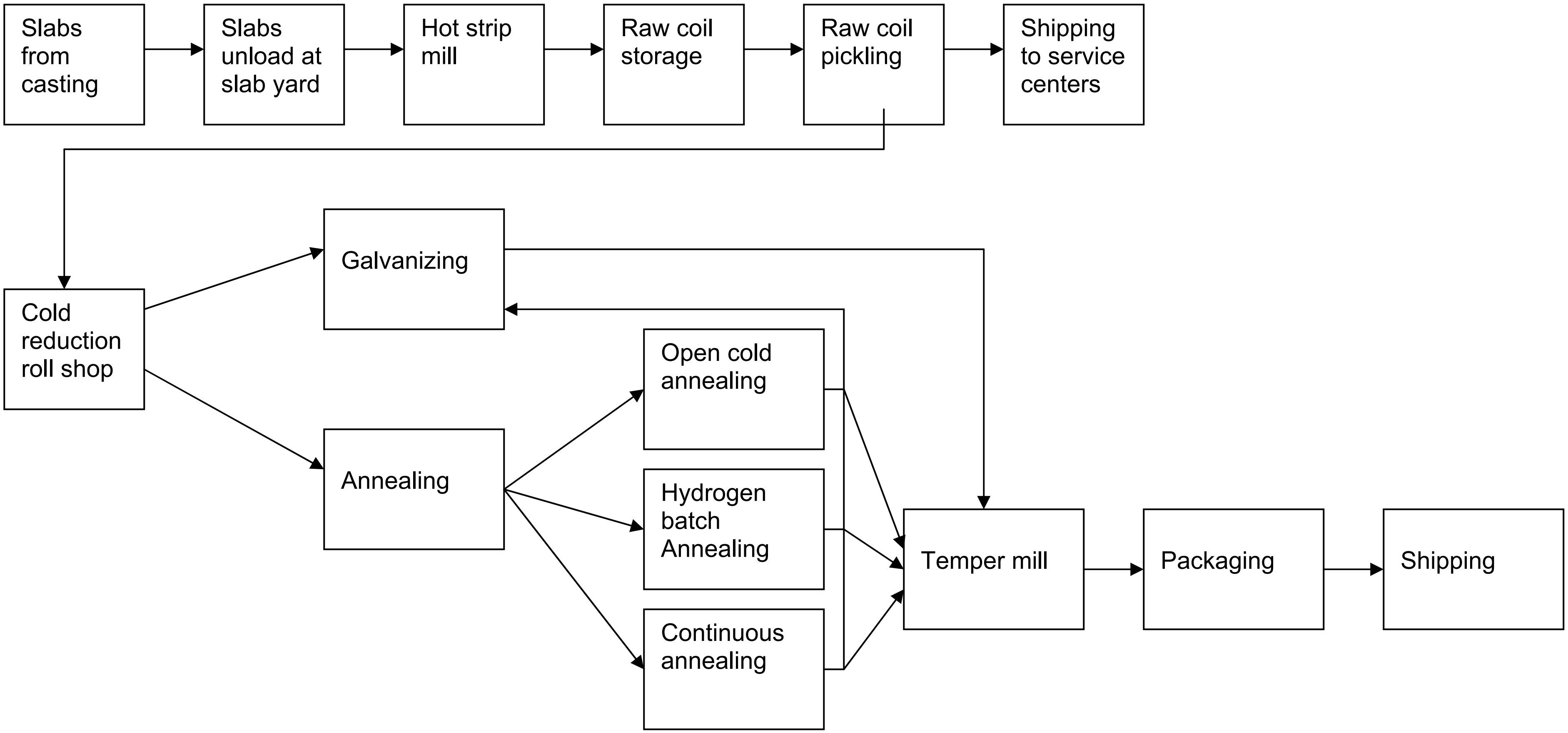



Figure 12 Coil movement through the manufacturing process at the finishing mill.

## 5.2 Value Stream Mapping: Current State Map

Business planning receives through Electronic Data Interchange (EDI) and the telephone, schedules from two types of customers: repeat and spot business (open market). The repeat schedule is received on a weekly basis where major ABS customers call or send through EDI their requirements for the weeks ahead. Since these are committed customers the quantity and the order delivery time is more or less fixed. On the other hand, spot customers generate daily schedules. On a daily basis the open market customers check their warehouse level for inventory, if this level drops below a certain point they send in their requirements through EDI or by telephone.

Business planning usually has two scheduling groups. One is for the hot end liquid steel, which usually includes the blast furnace and caster. The second is the finishing mill scheduling group that handles the product from the hot strip mill through shipping. When an order comes in, business planning puts it in and estimates the date by which they think they can make it. They rough-schedule it on the production units on a weekly basis. Next they put a routing on the order (which units it has to go across) and put a plan week on it. This schedule is sent out to the hot end and the finishing mill plant so that it can be scheduled and produced. At each producing facility they execute the plan and try to hit the target orders.

Business planning also includes making sure that enough raw material is available, and that there is enough capacity on each unit. The schedule should be feasible and balanced. This schedule on the operating side becomes the basis to monitor day-by-day and week-by-week increments against how well they are in accordance with the schedule. The schedules can then be updated further on an as-needed basis to daily or even bi-daily schedules. These are then used to push orders through the production facility.

On average, the customer demands add up to a total of 76,500 tons per month (2,550 tons per day on average). The distribution by product is as follows:

- 8,500 tons per month of open coil annealing
- 10,000 tons per month of continuous annealing
- 58,000 tons per month of hydrogen batch annealing

ABS uses three types of transportation modes: truck, rail, and barge. The shipments go to different customers on a daily or weekly basis. The plant works on a continuous basis for 24 hours a day all year long except for major shutdowns and runs a 3-shift operation in all production departments except for continuous annealing, which runs two shifts. Each shift is 8 hours long.

All data for the current state map were collected according to the approach recommended by Rother and Shook (1999). Data collection for the material flow started at the shipping department, and worked backward all the way to the blast furnace process, gathering snapshot data such as inventory levels before each process, process cycle times, number of workers, and changeover times (a summary of the data can be seen in Table 3). Except for the inventory levels, all other times recorded on the current state map are based on average time. As shown in the current state map (see Figure 13 on page 80), starting from the blast furnace until the continuous caster all process are regarded as the hot end. As shown in the map, inventory levels are very low for the hot end where the flow is continuous and the liquid steel moves in a ladle in a batch size of one. The only place that might have more than one sub-ladle waiting is the area between the blast furnace and the BOP. This is shown in the current state map of 1,384 tons of liquid iron in inventory (one ladle is approximately 250 tons) and is due to the fact that the blast furnace releases the ladles faster than the BOP can process them. In fact according to the workers there, 60% of the ladles are waiting an average of 45 minutes between those two processes.

Table 3 Summary of the data in the current state map for ABS

| **Process** | **Description** | **Cycle Time (Sec)** | **Machine Reliability (%)** | **Changeover Time (min)** | **Observed Inventory (tons)** | **Observed Inventory (days)** | **Notes** |
|---|---|---|---|---|---|---|---|
| Blast Furnace | Uses two blast furnaces | 8,100 | 99.5 | - | 91,000 | - | |
| BOP Shop | Uses two oxygen furnaces | 2,700 | 99 | - | 1,384 | 0.54 | |
| LMF | Refine liquid steel | 2,400 | 100 | - | 250 | 0.098 | |
| Degasser | Refine liquid steel | 2,400 | 100 | - | 250 | 0.098 | |
| Continuous Caster | Uses dual strand | 2,700 | 99 | 8-12 | 750 | 0.29 | Changeover is twice a day |
| Hot Mill | Uses 5 reheat furnaces | 9,000 | 99.5 | 120 (backup rolls)<br>35 (work rolls) | 36,345 | 10.33 | Changeover is once a week for backup rolls and twice a week for work rolls |
| Pickling | Uses 84 and 64 pickle lines | 240 | 100 | 15 | 45,000 for all products. 32,200 for annealed products | 17.56 all products | Changeover is once every 1.5 days |
| Continuous Annealing | Uses 15 furnaces and 24 bases | 600-1,500 | 100 | - | 2,600 | 1 | - |

Table 3 (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cold Reduction | Computer controlled 5 stands mill | 420 | 88 | 120 (backup rolls) 9 (work rolls) | 10,000 for all products. 4,241 for annealed products | 3.9 all products | Changeover is once a week for backup rolls and 18 times a day for work rolls |
| Open coil Annealing | Uses 13 furnaces and 24 bases | 64,800-72,000 | 96 | - | 4,459 | 1.75 | - |
| Hydrogen batch annealing | Uses 31 furnaces and 58 bases | 54,000-90,000 | 99 | - | 16,000 | 6.27 | - |
| Temper Mill | For final metallurgical properties | 420 | 97 | 90 (backup rolls) 7 (work rolls) | 9,276 for all products. 8904 for annealed products | 3.64 all products | Changeover is twice a week for backup rolls and 8 times a day for work rolls |

The finishing mill, which starts with the hot strip mill and extends all the way through shipping (as indicated in the current state map) is the other part of the material flow. Here again the product is pushed through different processes until it is ready for shipping, which is the last process shown in the map. Looking at the current state map, the small boxes in the map represent the process and the number inside the box is the number of workers at each process. Also, each process has a data box below, which contains the process cycle time (CT), machine reliability (MR), the number of shifts, and the changeover time (CO). It should be noted that these data where collected while walking the shop floor and talking to the foreman at each workstation.

Looking at the current state map one observes that there are two inventory triangles ahead of some processes, one for the annealed products and one for all products. This just indicates that other products could be scheduled to use the process in addition to the annealed products considered herein so that the total inventory is actually higher. After collecting all the information and material flows, they are connected as indicated by arrows in the map, representing how each workstation receives its schedule from business planning.

The timeline at the bottom of the current state map in Figure 11 has two components. The first component is the production lead-time (in days), which is the sum of each inventory triangle before each process. The lead-time for one inventory triangle is calculated by dividing the inventory quantity into the daily customer requirements. For example, the lead-time for the inventory triangle ahead of pickling is 17.65 days; this is calculated by dividing 45,000 tons, which is the total inventory ahead of the pickling by 2550, which is the daily average demand rate for the annealed product. The total observed production lead-time is 46 days. Here we do not consider the amount of raw material at the beginning of the production, the reason being that ABS own their mines and raw material sources and the raw material is thus not an issue for them. The second element of the timeline is value-added time (or processing time), which is 5 days (or 429,030 seconds). This time is calculated by adding the processing time for each process in the value stream. The cycle time for each process is the average cycle time, which is determined by using actual data from the company. We should mention here that this value-added time include 3 days which is the time for coils to cool down after processing at the hot strip mill. Therefore, the percentage of value added time to the non-value added time (lead-time) is approximately 11%.

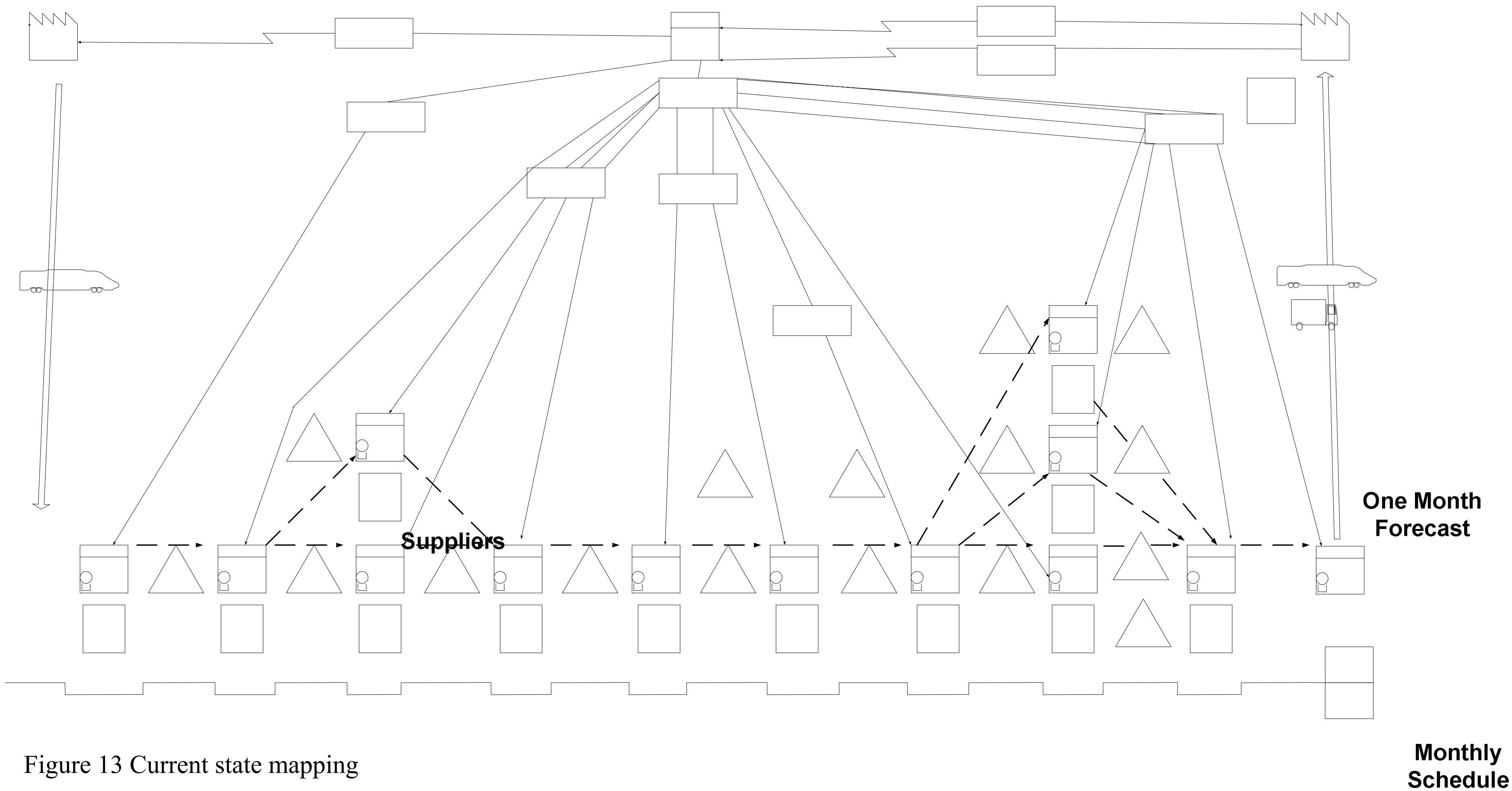



Figure 13 Current state mapping

## 5.3 Value Stream Mapping: Future State Map

Describing and defining the future state map actually starts while developing the current state map, where target areas for improvement start to show up. Looking at the current state map for ABS several things stand out: (a) large inventories, (b) the huge difference between the production lead-time (45 days) and the value added time (5 days), which is only about 11% of the total, and (c) each process producing to its own schedule. The goal of lean manufacturing is to aid in improving the satisfaction of customer requirements through the whole value stream. In our current state map we view inventory and lead-time as two equivalent things and try to identify lean manufacturing tools to drive them down and create the ideal state map. The basic philosophy is that the more the inventory, the longer any item must wait for its turn; therefore, the reduction of lead-time and inventory will expose and force other kinds of wastes to surface, creating the opportunity for their removal.

Reducing inventory and attaining on-time completion will automatically generate quality improvements. For example, reducing work in process will reduce the amount of defects to be repaired, which in turn will improve quality. Also less WIP means that tracing the root cause of a defect will be easier. In order to address these issues we follow a systematic procedure where we try to answers a set of questions. This allows one to come up with an ideal future state map that will help in trying to eliminate the different types of waste in the current manufacturing system at ABS.

### 5.3.1 Takt Time

**Question 1**: What is takt time?

"Takt time" refers to the rate at which customers are buying products from the production line; i.e., the unit production rate that must be met to match customer requirements. Takt time is calculated as follows:

$$\text{Takt time} = \frac{\text{Available work time per day}}{\text{Customer demand per day}}$$

The throughput required for the annealed products is an average of 76,500 tons per month. Assuming that ABS runs 30 days per month, the average daily requirement is 2,550 tons per day. The average coil weight is 20 tons, so this translates to approximately 127 coils per day. ABS continuously runs three shifts per day, which translate to 1,440 working minutes per day. The result is approximately 11.3 minutes takt time per coil:

$$\text{Takt time} = \frac{\text{24 hrs * 60 min/hr}}{127} = 11.3\,\frac{\text{min}}{coil}$$

This takt time does not mean that a coil has to be made in 11.3 minutes, but rather that one must be completed every 11.3 minutes on average. Customer demand is met in 11.3 minutes, but the process time is dependent upon the sum of process times at each workstation. For example, for a coil that has to go through continuous annealing, a coil must be introduced at the beginning of the pickle line process every 11.3 minutes; however, it will take approximately 1 hour for the coil to pass through all the workstations and finish processing. So every 11.3 minutes a coil is taken in FIFO order at the start of the pickle line.

### 5.3.2 Finished Goods Supermarket

**Question 2**: Will we produce directly to the shipping or to a finished goods supermarket?

A "supermarket" is nothing more than a buffer area (space allocated for product storage) for products that are ready to be shipped, located at the end of the production process (Rother and Shook, 1999).

The shipping department can use a kanban signal to authorize the movement of the product from the supermarket. The amount of space designated would depend on the number of kanbans allocated to the supermarket. For example, each kanban is attached to a limited number of coil cradles or allowable space in the supermarket; whenever the inventory level in this space falls below a certain level it sends a signal to replenish the supermarket.

On the other hand, producing directly to shipping requirements means that only the units that are ready to be shipped are produced. Currently ABS produces all the annealed products and sends them directly to a shipping area where they are stored with other products waiting to be shipped. However, this is done "on the fly" where products are stored based on a push system. The coils can wait a long time in the warehouse before being shipped. Even though the coils are bulky, it is believed that ABS should produce to a supermarket (warehouse); moving the coils is not a significant issue due to the existence of the C-hook crane that can move the coils freely. ABS should designate an area at the warehouse (which would be called the supermarket) and store the coils based on a kanban system. Whenever the supermarket inventory is below a certain level this would trigger the temper mill to schedule the annealed products to replenish the supermarket according to the pitch, which will be addressed in more detail in Question 7.

### 5.3.3 Pull System Supermarket

**Question 3**: Where will ABS need to use a pull system supermarket inside the value stream?

A pull system supermarket is a system for "all seasons," meaning that it can work in the steel industry as well as any other discrete industry regardless of the scheduling restrictions encountered. As we will explain in the next question the hot end at ABS is a continuous flow process by design, so that there is no need to introduce a supermarket. The introduction of a supermarket is necessary at the finishing end where large amounts of inventory exist between different workstations.

ABS will produce the annealed products to a finish-goods supermarket as indicated in Question 2. Once a shipment of coils is withdrawn from the shipping supermarket, the corresponding kanban is sent to the temper mill where it is placed in a load-leveling (or heijunka) box. This will be further addressed and explained in Question 7. Six additional supermarkets are needed to create a continuous flow at the finishing mill, one before the pickling line, one before cold reduction process, one before the temper mill and one before each of the three annealing processes (HBA, OCA, CA).

The first supermarket will be used ahead of the pickling area. The hot strip mill pushes coils to pickling, which makes the inventory accumulate in front of the pickling line. Both of these lines are shared resources (i.e., other products can use them), so a kanban pull system will be used to regulate the replenishment of this supermarket. The pull system requires a customer and suppliers (Rother and Shook, 1999). The customer here is the pickling and the supplier is the hot strip mill. A pull signal from the temper mill (addressed in Question 7) is utilized here to move the kanbans (essentially a coil for each kanban) from the supermarket to cold reduction.

The same pull signal will be sent to hot strip mill to replenish the supermarket whenever the number of coils in the supermarket drops to a trigger point.

The second supermarket will be designed to stabilize the production of the annealed products in the pickling area. The inventory between pickling and cold reduction is large and both workstations are shared resources. Also, ABS runs its schedule in batches according to coil width, gauge, and product, so it is necessary to set up a supermarket to accommodate schedule changes. A kanban pull system will be used to regulate the replenishment of this supermarket. One should note that whenever the supermarket is full, the pickling process could run other products (other than annealed products) so that it is not idle. Also, pickling no longer receives a schedule from business planning for the annealed products.

The third, fourth, and fifth supermarkets will be place at the front of the annealing workstations respectively. For example, with HBA the supermarket will be used for coils that are ready to be placed in the HBA furnaces. A kanban pull system according to a signal is also used here to send coils to the HBA and this signal is sent to the cold reduction mill to indicate production to replenish the supermarket. The same thing will apply for the supermarkets ahead of CA and OCA. For the third, fourth, and fifth supermarkets the cold reduction mill will no longer need to receive a schedule for the annealed products from business planning and the cold mill can run other products types when those supermarkets are at their capacities.

The last supermarket will be placed ahead of the temper mill. Since 96% of the products that go to the temper mill come from annealing, this supermarket area will be dedicated to those products. A withdrawal kanban signal will be used to send coils to the temper mill and the same signal will be sent to one of the annealing lines to initiate production to restock the supermarket.

Please refer to Figure 27 (the Future State Map) on page 137 for the location of each of the above supermarkets. The supermarkets or the kanban system that will be used will enable ABS to reduce its inventory and as a result, its lead-time. The working conditions for the kanban system are simple though effective. For example, the pickle line (supplier) is allowed to process the next coil in line as long as there is an empty coil spot in the supermarket to take the coil before of the cold mill. By definition, if the supermarket is at its capacity then this means that the cold mill does not need another coil. In this case there are two things that can be done; either the pickle line should slow its production rate to match that of the cold mill or it should be halted. The second option is costly in a steel mill. So in this case what can one do? Of course, the supermarket is only designed for the annealed products and in the following questions we will address how a production order will be released and the time increment at which those orders will be released. The answer to the question is that if the supermarket is full the pickle line can be switched to satisfy other product types until the time of the next order for the annealed product is reached. In doing so we prevent producing more than the capacity of the supermarket and also satisfy requirements for other product types while avoiding shutting down the pickle line.

Our next step is to decide how each supermarket that is controlled by a kanban pull system should look. First, a simple rule is that coils are not allowed to be piled on top of each other, nor are they allowed to be placed on the floor. Each coil must be placed in a coil cradle, where the number of cradles depends on the number of kanbans for that supermarket (the number of kanbans will be addressed in Question 7).

Requiring every coil in a supermarket to be in a cradle puts an upper limit on the amount of inventory in the supermarket and in turn, lead-time will go down. If inventory is limited to a predefined number of coils (kanbans), the space between coils will be increased and thus handling damage, which is one of the most common types of defects in a steel mill will be reduced. Also, when lead-time goes down this means faster delivery and more satisfied customers (The Hands-On Group, 2000). Besides reducing the number of defects on the shop floor, the supermarket will speed up the discovery of defects, and thereby the probability of finding the root cause of a defect early in the process will increase. It is very critical to discover the defect early, particularly in the steel industry because as a coil moves downstream in the process more value is added to it and discovering the defect late can be very costly. For example, a defective prime product can be relegated to non-prime status and usually there is a significant penalty (dollars per ton) for that. Another benefit of the supermarket is that it provides a visual means for the people on the shop floor to control the inventory and take immediate action if unexpected things happen. It is clear that kanban controlled supermarket system can unveil many types of waste that exist on the shop floor, so that remedial action can take place to reduce or eliminate these wastes.

### 5.3.4 Continuous Flow

**Question 4:** Where can continuous flow be used?

In most steel mills, the hot end (liquid steel) and the finishing mill (solid steel) are located in the same area; however, at ABS the two are nine miles apart. The manufacturing assets in the steel industry are such that they cannot easily be moved into the classical cellular arrangement and batch sizes are often fixed. However the steel industry itself is based on continuous flow manufacturing. For example, even though the workstations are not arranged in cellular fashion at the hot end at ABS, starting from the blast furnace through the BOP, the degasser or LMF and finally the continuous caster, the flow is continuous since the liquid steel moves in a ladle in a batch size of one. At the finishing mill however, the slab can move through one of many possible routings. Aside from the restriction that the steel industry does not lend itself to cellular flow, the different cycle times and down times of the workstations makes it difficult to introduce a continuous flow (see Figure 14). Also, many of the workstations are restricted to different schedules depending on width, gauge and product type so that it is unrealistic to join these workstations at the finishing mill to obtain a continuous flow. Therefore, in the steel industry developing a flow is not the issue. Rather, developing a system to enable pull by the customer should be the focus.

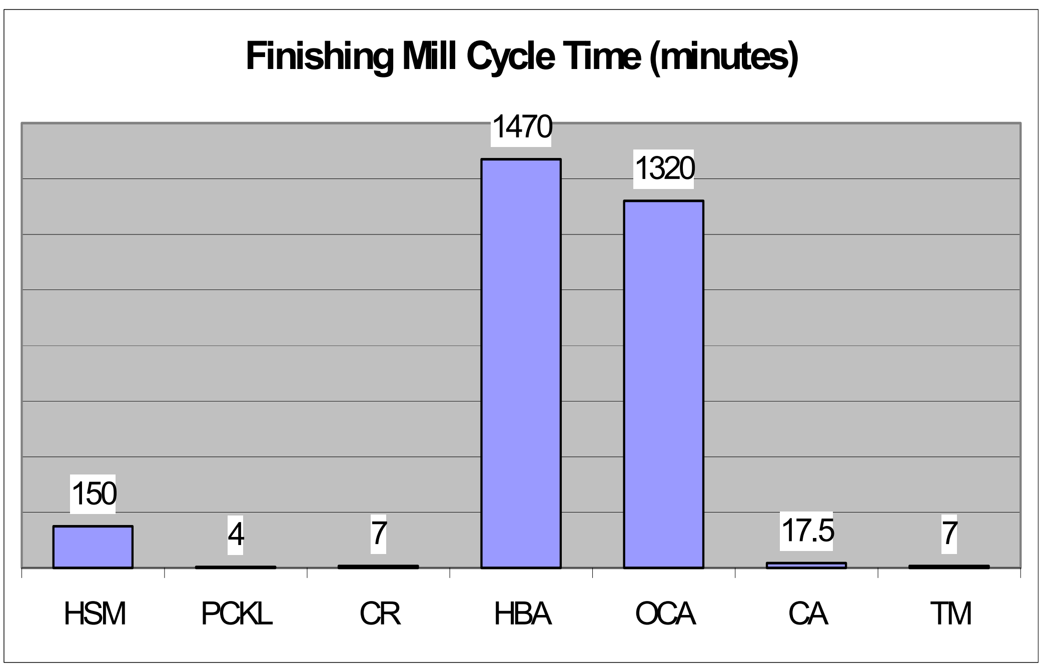



Figure 14 Finishing mill cycle time

The introduction of supermarkets that are controlled by a kanban system forces the whole steel mill to pace every workstation to the speed of the bottleneck, which as was explained in the previous question to be between the pickle line and cold mill. This is true for every process. Thus the mill begins to take the uniqueness of an assembly line where every product starts to flow rather than stop and start. It was explained in the previous question that whenever the supermarket between the pickle line and the cold mill is full the pickle line could switch to making other product types. This is true for all supermarkets in the system. By doing so we are creating continuous flow and trying to maintain this flow by switching to other products, which by definition means no machine is stopped and no product is waiting. The manufacturing workstations are required to communicate and synchronize like never before, shifting the focus from optimizing individual processes, to optimizing the total steel mill.

### 5.3.5 The Pacemaker

**Question 5**:What single point in the production chain (the “pacemaker” process) should ABS schedule?

To stop overproduction at any workstation in the value stream, only one point in the supplier-to-customer value stream needs to be scheduled. This point is called the pacemaker process, because this point sets the pace of production for all the upstream processes and it ties the downstream and the upstream processes together. Every workstation upstream produces by a pull signal from the next downstream process and flow downstream from the pacemaker must occur in a continuous manner. The pacemaker process is usually the most downstream continuous flow in the value stream, so there should be no supermarket downstream of the pacemaker process (Rother and Shook, 1999).

For ABS, as mentioned previously the hot end is located in a different facility than where the finishing mill is, which makes the scheduling of one process unrealistic. For this reason one schedule will be released to the continuous caster to set the base for the hot end production area and our pacemaker process for the finishing mill is clearly the temper mill. The temper mill will set the base for the entire production at the finishing mill.

In the future state, a heijunka box or level loading box (Rother and Shook, 1999) will be placed near the temper mill. Kanbans will be inserted in the box coming from business planning according to the planned schedule. The schedule is determined according to a production sequence for the annealed products. The production sequence to match the daily demand will be explained in the next question.

### 5.3.6 Production Leveling

**Question 6**: How should ABS level the production at the pacemaker process?

The basis for addressing this question is to distribute the production of the three annealing processes uniformly over the production time at the pacemaker process. This means that several batches of the same sequence must be scheduled. This will allow ABS to avoid long lead-time, large amount of in-process and finished goods inventory, and quality problems, and in general, avoiding wastes related to overproduction. We will assume here that the scheduling width and gauge for the coils are fixed.

ABS processes three variations of the annealed product. They are HBA, OCA, and CA. ABS should send a schedule to the pacemaker process (temper mill) that would ensure making every part at a constant rate. A formula will be used (Monden, 1993) that determines the product sequence that levels the mix and has a constant rate for the three different products. The formula is:

$$d_{ij} = (j - 0.5) * (T / D_i) \qquad i = 1,2,...,n \text{ and } j = 1,2 \ldots D_i$$

where

n= the number of different products to be made

$D_i$= the integral number of units demanded per day for product i.

T= $D_1+D_2+\ldots+D_n$ be the total number of units of all products to be made

j= the index for the job (unit) of product i

$d_{ij}$= ideal completion or due date for job (unit) j of product i.

For our case n=3, $D_i$, which is the average daily requirements for the annealed products are: 97 HBA, 14 OCA, and 15 CA. Thus T is equal to 126. Ordering these jobs according to $d_{ij}$ sorted (shown in Table 4) one can see a pattern start to develop, yielding the following schedule (HBA-HBA-HBA-HBA-HBA-HBA-HBA-CA-OCA)-(HBA-HBA-HBA-HBA-HBA-HBA-HBA-CA- OCA)…etc. This schedule is the optimal sequence to smooth the production.

Table 4 Due date calculation for the annealed products

| **Product (i)** | **Unit (j)** | **$d_{ij}$** | **$d_{ij}$ (sorted)** | **Product-unit** |
|---|---|---|---|---|
| HBA | 1 | 0.649485 | 0.649485 | HBA - 1 |
| | 2 | 1.948454 | 1.948454 | HBA - 2 |
| | 3 | 3.247423 | 3.247423 | HBA - 3 |
| | 4 | 4.546392 | 4.2 | CA - 1 |
| | 5 | 5.845361 | 4.5 | OCA - 1 |
| | 6 | 7.14433 | 4.546392 | **HBA -4** |
| | 7 | 8.443299 | 5.845361 | **HBA - 5** |
| | 8 | 9.742268 | 7.14433 | **HBA - 6** |
| | 9 | 11.04124 | 8.443299 | **HBA -7** |
| | 10 | 12.34021 | 9.742268 | **HBA - 8** |
| | 11 | 13.63918 | 11.04124 | **HBA - 9** |
| | 12 | 14.93814 | 12.34021 | **HBA - 10** |
| | 13 | 16.23711 | 12.6 | **CA - 2** |
| | 14 | 17.53608 | 13.5 | **OCA - 2** |
| | 15 | 18.83505 | 13.63918 | *HBA - 11* |
| | 16 | 20.13402 | 14.93814 | *HBA - 12* |
| | 17 | 21.43299 | 16.23711 | *HBA - 13* |
| | 18 | 22.73196 | 17.53608 | *HBA - 14* |
| | 19 | 24.03093 | 18.83505 | *HBA - 15* |
| | 20 | 25.3299 | 20.13402 | *HBA - 16* |
| | 21 | 26.62887 | 21.43299 | *HBA - 17* |
| | 22 | 27.92784 | 21.76411 | *CA - 3* |
| | 23 | 29.2268 | 22.5 | *OCA - 3* |
| | 24 | 30.52577 | 22.73196 | **HBA - 18** |
| | | | 24.03093 | **HBA - 19** |
| OCA | 1 | 4.5 | 25.3299 | **HBA - 20** |
| | 2 | 13.5 | 26.62887 | **HBA - 21** |
| | 3 | 22.5 | 27.92784 | **HBA - 22** |
| | 4 | 31.5 | 29.2268 | **HBA - 23** |
| | | | 30.52577 | **HBA - 24** |
| CA | 1 | 4.2 | 31.2 | **CA - 4** |
| | 2 | 12.6 | 31.5 | **OCA - 4** |
| | 3 | 21.76411 | | |
| | 4 | 31.2 | | |

### 5.3.7 The Pitch

**Question 7**: What increment of work (the "pitch") will be consistently released to the pacemaker process?

Depending on the sequence determined by the last question, how often should we release and withdraw (the "pitch") the increment of production from the pacemaker process? The pitch is the basic time unit of the production schedule for a product family. In other words, it is the material transfer interval at the pacemaker process. The pitch is calculated by multiplying the takt time by the finished-goods transfer quantity at the pacemaker process. Since there is no container size involved in the steel industry, meaning that we can move one coil at a time, the number of kanbans will be the same as the number of the current daily demand for OCA and CA. However one kanban will correspond to 7 coils for HBA. Table 5 shows the number of kanbans required:

Table 5 Number of kanbans required by product

| Product | Daily demand (coils) | Transfer lot size (coils) | Required number of Kanbans |
|---|---|---|---|
| HBA | 97 | 7 | 14 |
| OCA | 14 | 1 | 14 |
| CA | 15 | 1 | 15 |

Given a takt time of 11.3 minutes, and considering that the transfer lot size is 9 coils, the pitch is approximately 1.5 hours. This means that ABS will perform paced release of work instruction according to the pitch and a paced withdrawal of finished goods at the temper mill.

This means that the material handler will arrive at the temper mill and remove the required kanbans from the load leveling box (the next increment of work) of the temper mill and move the just finished coils from the previous pitch to the shipping area supermarket (one day worth of inventory will be available in the future state map in the shipping supermarket and this can be adjusted as needed at ABS). The heijunka box (load leveling box) that is shown in Figure 15 must be divided into spaces equivalent to 1.5 hours that represent the frequency of introducing the kanban (work increment) to the temper mill. The heijunka box has a column of kanban slots for each pitch interval and a row of kanban slots for each of the annealed product. At ABS, the number of pitches required for every product will be calculated as the number of daily requirements for every product divided by the transfer quantity, which is shown Table 6. The time interval required for every product to remove each kanban from the heijunka box is calculated by dividing the available daily time by the number of pitches for every product (Table 7).

| | 8 | $9^{30}$ | 11 | $12^{30}$ | 2 | $3^{30}$ | 5 | $6^{30}$ | 8 |
|---|---|---|---|---|---|---|---|---|---|
| HBA | $HK_1$ | $HK_2$ | $HK_3$ | $HK_4$ | $HK_5$ | $HK_6$ | $HK_7$ | $HK_8$ | $HK_9$ |
| OCA | $OK_1$ | $OK_2$ | $OK_3$ | $OK_4$ | $OK_5$ | $OK_6$ | $OK_7$ | $OK_7$ | $OK_8$ |
| CA | $CK_1$ | $CK_2$ | $CK_3$ | $CK_4$ | $CK_5$ | $CK_6$ | $CK_7$ | $CK_7$ | $CK_8$ |

Figure 15 The heijunka box (load leveling box) for ABS

Table 6 Number of pitches for every product

| Product | Number of Pitches per day |
|---|---|
| HBA | 97 / 7=14 |
| OCA | 14 / 1=14 |
| CA | 15 / 1=15 |

Table 7 The time interval required for every product to withdraw per shift

| **Product** | **Material transfer time** |
|---|---|
| HBA | 1440 (min) / 14=102 min |
| OCA | 1440 (min) / 14=102 min |
| CA | 1440 (min) / 15=96 min |

Below we illustrate by the following steps how the paced withdrawal and the load leveling box will work:

1. The material handler will take three kanbans ($HK_2$, $OK_2$, and $CK_2$) for the HBA, OCA, and CA from the box at 9:30 a.m. Each kanban represents 1 coil for OCA and CA and 7 coils for HBA. The reason we see the kanban in each slot of the heijunka box is because their material transfer time is approximately equal to the pitch, which is shown in Table 7.
2. This signals the production of these three products to be pulled from the production process.
3. The material handler removes the material from the previous pitch initiated at 8 a.m. ($HK_1$, $OK_1$, and $CK_1$) to the shipping supermarket.
4. The process begins to pull the two coils representing HCA, OCA, and CA from the temper mill supermarket.
5. If the supermarket is below the trigger point, the three products will be pulled from the supermarket, and the annealing processes also start to produce to refill the supermarket.
6. The same sequence explained in Step 5 is followed all the way through the pickle line if needed.
7. Repeat all the above steps for the whole day.

### 5.3.8 Process Improvement

**Question 8**: What process improvement will be needed to achieve the future state design?

In order to accomplish the material and information flow envisioned by ABS, improvement and actions must take place to implement the future state. It is unrealistic to expect to obtain the benefits of the supermarkets, kanban control, takt time, the pitch, production leveling, continuous improvement, and other changes discussed in the previous question without process improvement steps involving specific lean tools.

The following sections address what lean tools are feasible to implement at ABS in order to achieve the desired gains and the ideal state map. The lean manufacturing tools will appear as "kaizen bursts" in the future state map.

## 5.4 Setup Reduction

Set up reduction at different workstations is one of the major tools that ABS must implement. The changeover times required at different processes at ABS are shown in Table 8. Changeovers take place at four workstations as shown in the table. There are two types of changeovers at ABS, one for backup rolls and one for work rolls. Also, there is a tundish changeover for the caster

Table 8 changeover times required at different processes at ABS

| Process | Setup time for backup rolls (min) | Number of Times | Setup time for work rolls (min) | Number of times |
|---|---|---|---|---|
| Hot strip mill | 120 | Once a week | 35 | Twice a day |
| Pickling | - | - | 15 | Once every 1.5 days |
| Cold reduction | 120 | Once a week | 15 | 18 times a day |
| Temper mill | 90 | Twice a week | 15 | 8 times a day |
| Caster | Tundish change UNIF(12,14) | Twice a day | - | - |

The hot strip mill at ABS is known as a four-high mill meaning that there are two rolls at the top and two rolls at the bottom. The work rolls, through the use of hydraulic pressure, are responsible along with the backup rolls for the shape of the steel. The changeover for backup rolls is done manually in all of the workstation. However, the changeover for the work rolls is done manually at the hot strip and pickling mill and via an automatic roll changer at the cold and temper mills. A tundish changeover is required at the caster twice a day after a certain number of heats in the caster.

In order to allow faster response to the downstream usage we recommend using setup reduction principles to reduce the time for the different changeovers at ABS. The basic concept behind setup reduction is to cut down the shutdown losses accompanying changeover. In order to reduce the time required for changeover for the different processes at ABS the following steps are suggested:

1. Separate the external and the internal setup. The goal is to divide tasks that can be accomplished while the machines are still running (external set-up) from tasks that must occur when the machine is stopped (internal set-up). For each changeover operation a

checklist including every single item necessary for running the next operation, such as tools, necessary workers, and standards is documented. Then it is determined what must be done when the machine is stopped (internal) and what can be done while the machine is running (external). For ABS this means preparing the next roll to be placed on the mill while the mill is running. The next roll to be placed in the mill must be polished, hoses and wires must be placed on it, and bolts must be tightened. Rather than waiting to do this while the machine is stopped (internal setup) we suggest carrying out those activities while the machine is running as an external setup.

2. Use an automatic roll changer for the backup rolls; currently at ABS the changeover for backup rolls is done manually by using a lifting device that takes most of the time spent during the movement of the rolls. A suggestion is to use an automatic roll changer, which will place the roll on a panel and move it from the roll warehouse to the required mill. Currently this is done only for the work rolls at the cold and temper mill. Using an automatic roll changer can cut a lot of the time involved in changeover.
3. Transporting of parts and tools to machine should also be identified and reorganized. These can be externalized, cutting time even more, meaning tools and parts can be gathered while the machine is still running, whereas previously they were gathered after the machine was shut down.
4. Finally, preparing rolls should be ready to be placed on the mill adjacent to the process. For example, if a work roll is to be placed on the cold mill next, the roll must be within a short distance of the cold mill. This means bringing the roll from the roll warehouse before the machine is stopped.

## 5.5 TPM

One of the major causes of machine breakdowns is the lack of a total productive maintenance program. Many steel mills do not have the luxury of replacing equipment due to the characteristics of the steel industry. Steel mills often load their equipment to maximum capacity, leaving long times between necessary regular maintenance. For example, at ABS a scheduled shut down is done every two months to carry out maintenance activities for the blast furnace. Table 9 shows planned maintenance times for the hot end at ABS. The longer the time interval between scheduled maintenance, the higher the probability of having machine failures, and thus the higher the expected number of quality defect. Table 10 shows the distribution of failures times at ABS. If the blast furnace is down due to breakdown, this would be very costly in a steel mill where orders have to be backlogged and there will be no metal flowing through the system which means that the operations are placed in a very expensive overhaul position.

Table 9 Maintenance time for hot end at ABS

| **Process** | **Maintenance uptime (min)** | **Maintenance Downtime (min)** |
|---|---|---|
| BF1 | 86,400<br>(60 days) | 960 |
| BF2 | 87,840<br>(61 days) | 960 |
| BOP | 43,200<br>(30 days) | 960 |
| LMF | 43,200<br>(30 days) | 960 |
| Degasser | 44,640<br>(31 days) | 960 |

Table 10 Failures time distributions at ABS

| Process | Unplanned Uptime (min) | Unplanned Downtime (min) |
|---|---|---|
| BF1 | EXPO (20,160) (≈14 days) | UNIF (120, 240) (2,4 hrs) |
| BF2 | EXPO (20,160) (≈14 days) | UNIF (120, 240) (2,4 hrs) |
| LMF | EXPO (24,480) (≈17 days) | UNIF (1440,2880) (24,48 hrs) |
| Degasser | EXPO (24,480) (≈17 days) | UNIF (1440,2880) (24,48 hrs) |
| Caster | EXPO (20,160) (≈14 days) | UNIF (180,480) (3,8 hrs) |
| Pickling | EXPO(20,160) (≈14 days) | UNIF (120,300) (2,5hrs) |
| Cold mill | EXPO(17,280) (≈12days) | UNIF(120,300) (2,5hrs) |
| Temper mill | EXPO(17,280) (≈12days) | UNIF(120,300) (2,5hrs) |

Another problem that exists in steel mills is the length of the down periods. Having extensive down times due to scheduled maintenance will cause disruption to the whole process. The success of the kanban pull system heavily depends on the reliability of the equipment. In the future state design a pitch of 1.5 hours was determined to release kanbans to the system, and a scheduled maintenance period of say 10 hours is going to disturb the flow of the system. Therefore, in a lean manufacturing environment machine down times becomes an intolerable situation requiring a different approach for maintenance. In order to avoid all the havoc that can be caused by machine failure and long down times the following TPM activities are suggested:

1. Split scheduled maintenance. Splitting the scheduled maintenance time means separating the maintenance process into small portion that are done more often. For example, instead of scheduling one 16 hour maintenance down period for the blast furnace every

two months, we would like to accomplish the same amount of work in 4 hours done every three weeks. By doing this we would eliminate minor abnormalities in the equipment conditions that are usually overlooked and delayed for a long time. Also, we would have less frequent failures, improve machine uptime and eliminate costly overhauls.

2. Each individual unit requiring maintenance must be sequenced such that the inventory shortages created by shutdowns flow down through the process. For example, maintenance on the pickle line causes the kanbans in the supermarket ahead of the cold mill to be depleted. Therefore, maintenance is then performed on the cold mill, permitting the pickle line to replenish the supermarket ahead of the cold mill, and causing the supermarket in front of the annealing lines to empty. Maintenance is then done on the annealing lines, and so on.
3. Schedule unplanned down time as needed. Rather than looking at a calendar and assessing what attention the equipment needs, ABS should examine the 'vital signs' and infer what the equipment is trying to tell us. This can be done through constant monitoring, reliability analysis, and condition measurement. First, a simple visual observation during machine run time at predetermined time period can be done at each workstation. Checking a list of items such as machine cleanliness, roll wear, and machine speed can be done. For example, if the pickle line is not running at its normal speed the line must be stopped and the problem must be investigated. Second, reliability analysis can be done by collecting data on machine failures and downtime and analyzing failure frequencies for each machine. Lastly, condition measurement implies attaching sensors and devices such as vibration analysis equipment and calibration devices on each

machine that can detect anomalies. Some critical parameters of each machine can be measured and compared to standards. ABS should focus on processes that have more than one resource to schedule unplanned downtimes as a start, so that coils would not be backed up.

## 5.6 JIT

In order to achieve the full benefits of the supermarket kanban system ABS should utilize the just-in-time pull system. The kanban system explained in Question 3 is based on utilizing a pull system for the annealed products. The procedures necessary to implement the kanban pull system are simple yet powerful in maintaining efficiencies with minimum inventory. The basic idea is that we are only responding to ABS's actual customer demand for the annealed product family. The following steps are required at ABS to implement JIT :

1. A work center may produce a part only when a "downstream" work center signals its need. At ABS the pitch will control this signal. Small amounts of work will be released from the temper mill according to the kanbans in the load leveling box and at the end of the day all actual customer demand is satisfied.
2. Effectively, the kanban signal released from the temper mill pulls parts through the system. Control is maintained by adding and removing kanbans from the load leveling box thereby controlling the amount and type (essentially annealed products) of WIP held between work centers.
3. If any given supermarket has the right amount required by the pitch then there is no need for the process upstream to produce. Essentially, the coils will be pulled from the supermarket that will allow the upstream product to satisfy other types of products. For

example, the pickle line can roll galvanized product if the supermarket after it is above a certain trigger point.

For the above three tools (setup reduction,TPM, JIT) simulation will be used in the next two chapters to evaluate the benefits gained by implementing them at ABS. The simulation will provide the level of inventory and lead-time for the future state map. The future state map will no longer be just a snap shot, but a moving picture and the simulation model offers outputs that are hard to obtain with only value stream mapping.

## 6.0 THE SIMULATION MODEL

The simulation models for both the current state and the proposed future state were developed using System Modeling Corporation's Arena 5 package.

All the statistical distributions used in the simulation (including that for processing times, transfer times, delay times, and others) were determined by using the input analyzer of Arena and these can be found in Table 11 below. All data was either gathered on site or provided by ABS. The blast furnace was modeled as a process that has two resources (Blast Furnace 1 and Blast Furnace 2). At the blast furnace it usually takes 8 hours per cast from when it is charged at the top of the furnace until it reaches the tap hole at the bottom. Each cast contains a certain number of skips of billets, coke, and trims; the three primary raw materials used in steel making.

Table 11 Estimated process time distributions for ABS processes

| Process | Process time distribution (min) |
|---|---|
| Blast furnace | NORM (180,19.9) |
| BOP | NORM (65.7,6.48) |
| Degasser | ERLA (1.18,4) |
| LMF | ERLA (3.12,7) |
| Continuous caster | NORM (43,1.96) |
| HSM | NORM (150,5.3) |
| Pickling | NORM (4,1) |
| Cold reduction | ERLA (0.956,4) |
| Open coil annealing | UNIF (1080,1200) |
| Continuous annealing | TRIA (10,17.5,25) |
| Hydrogen batch annealing | UNIF (900,1500) |
| Temper mill | UNIF (2,7) |

On average one gets two heats out of each cast. A heat is a batch of molten iron that comes out from the bottom of the blast furnace that is held in holding bins (ladles). Therefore, in order to model the blast furnace, the assumption was made that a batch of two ladles (heats) will be simultaneously processed at one of the available furnaces. Essentially at the start of the model, an entity will be batched with another entity where each entity will represent a heat (or ladle). At the exit of the blast furnace process the ladles are then assigned a grade based on the chemical composition and other content required. Since it is impossible to include all the grades for this research we decided that the ladles would be assigned the three most commonly used grades at ABS; i.e., the grades that represent the highest percentage of what ABS melts.

The next process for a ladle is the BOP (Basic Oxygen Process) shop. At the BOP shop two ladles arrive (unbatched from the blast furnace) approximately every two and a half hours, where each ladle spends some time at an oxygen furnace. Depending on the grade of the steel the ladle will then go to either the degasser or the LMF (Liquid Metallurgy Furnace) process where it spends an interval of time that is probabilistic in nature.

The next process is the continuous caster. The modeling of this process requires extra effort and some assumptions. The continuous caster converts the liquid steel into slabs using one of two strands. To estimate the percentage of liquid by volume for a particular heat that goes to each strand historical data was used. The data contained the number of slabs that went to the north strand and those that went to the south strand including each slab width. By adding the numbers of all those slabs that went to the north strand, a total was obtained and the same was done for the south strand. Then the total number of slabs for each strand divided by the sum of the number of all slabs for both strands estimated the percentage for each strand. Since the length (239 inches) and the thickness (8.5 inches) are the same for all slabs, the width (range from 28-66 inches) is proportional to the volume. For example, for an average 250 ton heat, 41% can go to north strand and the other 59% would go to the south strand. To determine the number of slabs coming out of each strand for a particular heat, the total number of slabs for a given heat was determined. This was estimated from a distribution from the historical data obtained from ABS.

The distribution for the total number of slabs for a particular heat was found to be N~(20.8, 3.5). When a heat arrives to the caster a number is generated from this distribution. This number is then multiplied by the previous percentage for each strand to estimate the number of slabs coming out of each strand for a particular heat.

The finishing mill where the slabs go to after being cast was modeled by using a sequence. Depending on the grade of the slabs, the slab can follow one of many different routings in the production process. All the slabs first visit the hot strip mill. Usually the slabs coming out of the caster have to be reheated to a desired temperature before being rolled. Because of the fact that the hot end and the finishing mill are a distance apart, this requires the slabs to be reheated more; the slabs cool down during the transfer and ABS therefore has five reheat furnaces. The hot strip mill was modeled by running a batch of 100 slabs in each of the five available reheat furnaces and then having each slab go to a rolling operation for roughly one minute. Next, the slabs can take one of several routings depending on the product type. Based on the data given by ABS each grade can have the types of products shown in Table 12. It should be noted that “Others” stands for all the other grades that were not used in the simulation. The distribution percentages for the products for a given grade were estimated using historical data from ABS and are also given in Table 12.

When a slab arrives at the finishing mill it chooses from a discrete distribution the product type and then follows the sequence that this product takes at the production facility. For example, the product sequence for A40 hydrogen batch annealed product would be: Hot Strip Mill-Pickling-Cold Mill-Batch Annealing-Temper Mill.

The pickling line was modeled by batching two coils from the same grade before they enter the line (in practice the coils are bonded together). For the hydrogen batch annealing each furnace can take three coils, so this was modeled by batching three coils before they move into the furnace. The same modeling approach was done for the continuous annealing process where a furnace can take two coils. All the other processes where modeled as handling one coil at a time according to appropriate processing time distributions

Table 12 Product types for each grade

| Grade | Product made | Percentage (%) |
|---|---|---|
| A40 | Hot rolled | 9.06 |
| | Hot rolled pickled | 1.26 |
| | Galvanize 2 | 0.14 |
| | Galvanize 3 | 27.34 |
| | Hydrogen Batch Annealing | 39.12 |
| | Continuous Annealing | 12.73 |
| | Open Coil Annealing | 10.28 |
| L50 | Hot rolled pickled, | 1.34 |
| | Galvanize 1, | 11.08 |
| | Galvanize 2 | 52.26 |
| | Hydrogen Batch Annealing | 0.86 |
| | Continuous Annealing | 34.67 |
| A60 | Open coil Annealing | 100 |
| Others | Hot rolled | 5.47 |
| | Hot rolled pickled | 0.74 |
| | Galvanize 1 | 1.93 |
| | Galvanize 2 | 8.09 |
| | Galvanize 3 | 35.09 |
| | Hydrogen Batch Annealing | 35.76 |
| | Open Coil Annealing | 10.60 |
| | Continuous Annealing | 2.29 |

## 6.1 Simulation Verification and Validation and Transient Period

Considerable effort is required to verify and validate a large system such as this. Verification is the process that makes certain that the simulation model mimics the real system (Law and Kelton, 1991). Since this model is large with many types of entities (grades and products) in the system, verification required that every kind of product be traced and checked whether it follows its sequence. In order to see if the model represents the real system, the first thing that was done was to examine the SIMAN code.

Arena is based on the SIMAN language. Arena modeling consists of two system frames: the model frame and the experiment frame (Kelton, R. Sadowski, and D. Sadowski, 2002). Whenever a simulation model is run in Arena these two SIMAN language files are generated. For our model an extensive review of these files was carried out. The model file that contains the model logic was examined and the steps that each entity goes through during the simulation run were verified. Figure 16 shows the LMF process module as an example. The entity arrives at this module and an internal counter is incremented. It then enters a queue, waits to seize the LMF, experiences a delay for the processing time, and finally releases the LMF resource. The experiment file, which defines the experimental conditions was also examined and it was verified that all the resources, counters, variables, attributes, and other experimental conditions are included. Figure 17 shows a portion of the experimental file that defines the queues in the model. The verification for both the model and experiment files required extensive effort to trace and check the model logic and the system conditions. For the complete SIMAN code see Appendix B.

```
;   Model statements for module: Process 27
;
3$      ASSIGN:    LMF furnace.NumberIn=LMF furnace.NumberIn + 1:
           LMF furnace.WIP=LMF furnace.WIP+1;
224$    STACK,     1:Save:NEXT(198$);

198$    QUEUE,     LMF furnace.Queue;
197$    SEIZE,     2,VA:
           LMF,1:NEXT(196$);

196$    DELAY:     LMF Time,,VA:NEXT(239$);

239$    ASSIGN:    LMF furnace.WaitTime=LMF furnace.WaitTime + Diff.WaitTime;
203$    TALLY:     LMF furnace.WaitTimePerEntity,Diff.WaitTime,1;
205$    TALLY:     LMF furnace.TotalTimePerEntity,Diff.StartTime,1;
229$    ASSIGN:    LMF furnace.VATime=LMF furnace.VATime + Diff.VATime;
230$    TALLY:     LMF furnace.VATimePerEntity,Diff.VATime,1;
195$    RELEASE:   LMF,1;
244$    STACK,     1:Destroy:NEXT(243$);

243$    ASSIGN:    LMF furnace.NumberOut=LMF furnace.NumberOut + 1:
           LMF furnace.WIP=LMF furnace.WIP-1:NEXT(5$);
```

Figure 16 SIMAN Model File for the LMF Process Module

```
QUEUES:    Galv1.Queue,FIFO,,AUTOSTATS(Yes,,):
     Batch Coils for BA.Queue,FIFO,,AUTOSTATS(Yes,,):
     Galv2.Queue,FIFO,,AUTOSTATS(Yes,,):
     Galv3.Queue,FIFO,,AUTOSTATS(Yes,,):
     Shipping.Queue,FIFO,,AUTOSTATS(Yes,,):
     Batch for slabs in Nstrand.Queue,FIFO,,AUTOSTATS(Yes,,):
     LMF furnace.Queue,FIFO,,AUTOSTATS(Yes,,):
     CA.Queue,FIFO,,AUTOSTATS(Yes,,):
     Degasser furnace.Queue,FIFO,,AUTOSTATS(Yes,,):
     Batch Slabs for HSM furnace.Queue,FIFO,,AUTOSTATS(Yes,,):
     Cold reduction.Queue,FIFO,,AUTOSTATS(Yes,,):
     Batch for PK.Queue,FIFO,,AUTOSTATS(Yes,,):
     Blast Furnace Process.Queue,FIFO,,AUTOSTATS(Yes,,):
     Pickling.Queue,FIFO,,AUTOSTATS(Yes,,):
     Temper mill.Queue,FIFO,,AUTOSTATS(Yes,,):
```

Figure 17 SIMAN Experiment File for the Queues

The second method used to verify the model is a trace study. A careful trace study was carried out by tracing an entity once it is created until it is disposed from the system. The "Step" feature provided by Arena was used to control the execution of the model and each entity was stepped through the different modules in the system. The trace study verified the model logic and proper system behavior. Finally, a detailed animation was used and it was verified that the model sufficiently replicated the real system.

Validation of the model calls for comparing outputs of the simulation to those from the actual system. Actual data was available from ABS to compare with the simulation output. Before running the simulation a decision has to be made on the stopping criteria for the model. On average, ABS plans to run 32 heats daily in the BOP shop. It was therefore, determined that the terminating condition for the model would be to equal 32 heats. This is equivalent to 24 hours of production. Simulation provides user-defined variables for each process when it is created. For the BOP the variable "Bop.NumberOut=32" was used in the terminating condition field provided by Arena to represent the stopping condition for the model. Other performance measures that we used include inventory at the finishing mill and the total time in the system time, for which the actual data was available. The simulation model was run for a one-year period, which is equivalent to an expected 11,520 heats out of the BOP, so that the model can be validated when it is in steady state. Table 13 below shows the actual versus the simulation results that were obtained by running the model. It should be noted that the figures represent average values. Looking at the table, simulation numerical outputs are within the range of the actual data.

Table 13 Performance measures for Actual vs. Simulation

| Performance Measure | Actual Range | Simulation |
|---|---|---|
| System terminating time | 12 months (11,520 heats) | 12.27 months (11,520 heats) |
| Entity lead-time | [30-49 days] | 34 days |
| Hot strip mill INV | [1000-5,000] | 3,703 slab |
| Cold mill INV | [250-2,000] | 1,755 coil |
| HBA INV | [250-1,750] | 620 coil |
| CA INV | [100-750] | 121 coil |
| OCA INV | [100-750] | 636 coil |
| Temper mill INV | [150-750] | 653 coil |
| Number of Coils per month | [9,000-9,800] | 9,466 coil |

The simulation model in this case may be classified as a non-terminating one according to the description in Law and Kelton (1991). The initial conditions for a non-terminating simulation do not matter. Since the system at time zero will be empty, a transient (warm up) period was required for the system to load itself with entities and subsequently reach steady state.

The warm up for our simulation model was established by carrying out five replications with each having a run length of 1 year (Bop.NumberOut=11,520). The five replications examined successive observations of various performance measures, which included total work-in-process inventory in the system, workstation inventory, and the average entity time in the system (average lead-time per entity). It was decided that the maximum value across the individual warm-up periods for each performance measure would be used in the model. The overall appropriate performance measure was determined to be the total work-in-process inventory since this took the longest time to reach steady state. This is explained next.

Figure 18 shows the transient period for the total work in process inventory in the system. It was determined that the warm up period is 60,000 minutes (42 days). Figure 19 shows the average inventory in front of the hot strip mill for the five replications as a function of the simulation run time. The warm up period was established after 20,000 minutes (14 days) of the simulation run time. Figure 20 shows the warm up period for the average entity time in the system. As shown in the figure the transient period was found at 60,000 minutes (42 days) of the simulation run time

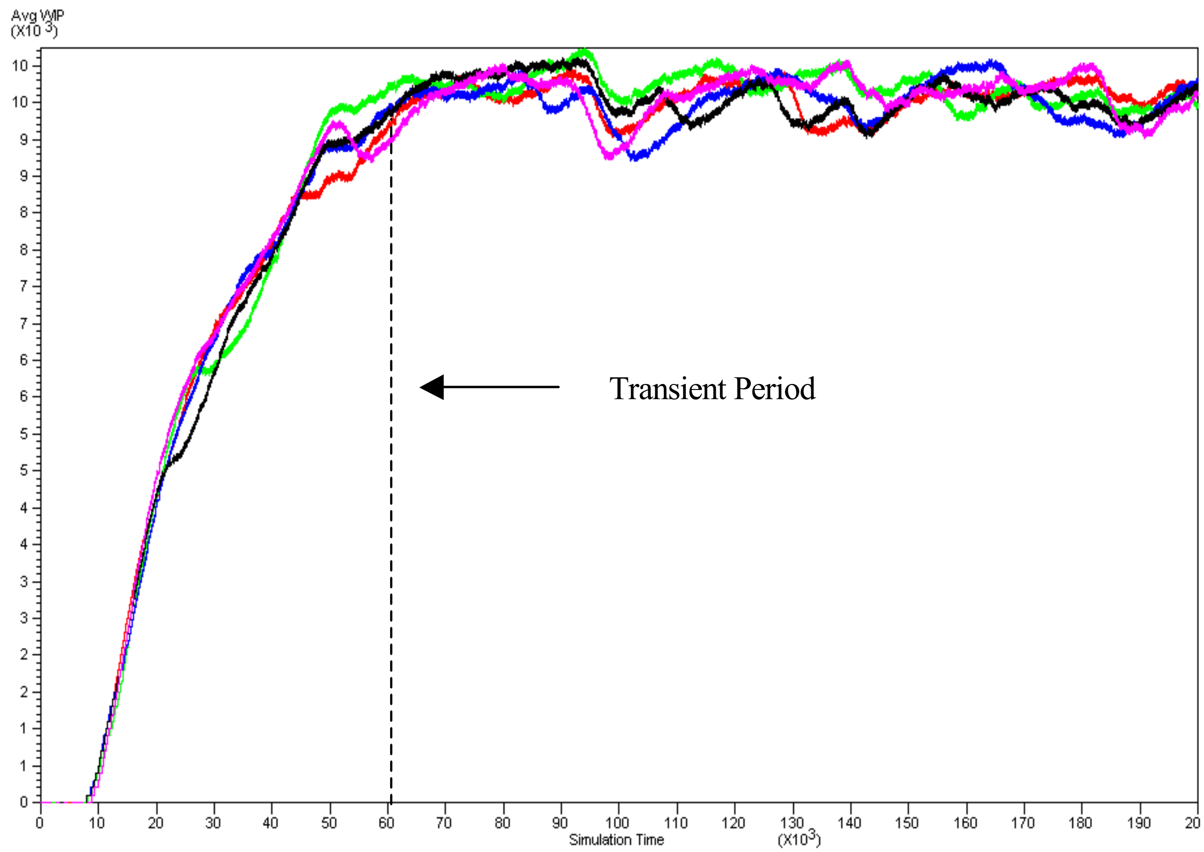



Figure 18 Transient period analysis for the average WIP inventory for 5 replications

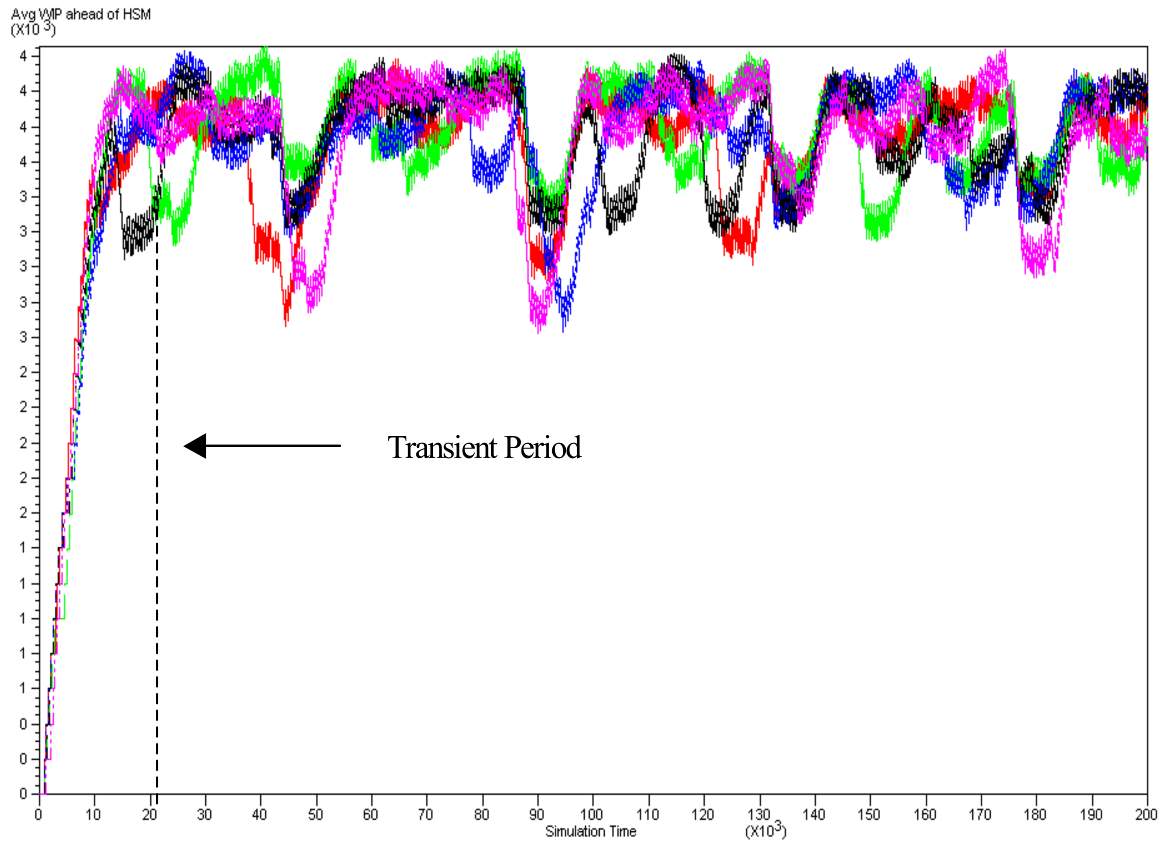



Figure 19 Transient period analysis for the average WIP ahead of HSM for 5 replications

Based on the warm-ups, we decided to use the maximum warm up period that turned out to be the one for the total work in process inventory performance measure. Since the warm up period is reasonably short relative to total simulation run (1 year) we decided to use the truncated replication method to carry out the statistical analysis for this simulation model (Kelton, et al., 2002). The performance of the system is analyzed by averaging the data from several replications of run length of 1 year (Bop.NumberOut=11520), with each replication having a warm up period of 42 days. The data for the simulation model is collected after the transient period. The performance measure that will be used to determine the number of replication will be the total time in the system (average entity lead-time). Five replications will be used for this model. We decided to stick with the same number of the initial number of replications. The reason for this is the fact that the half width for the 95% confidence interval for lead-time turned out to be 222 and the average entity lead-time for the five replication was 39,460, which represents 0.6% absolute error in the point estimate (39460), which is sufficiently small.

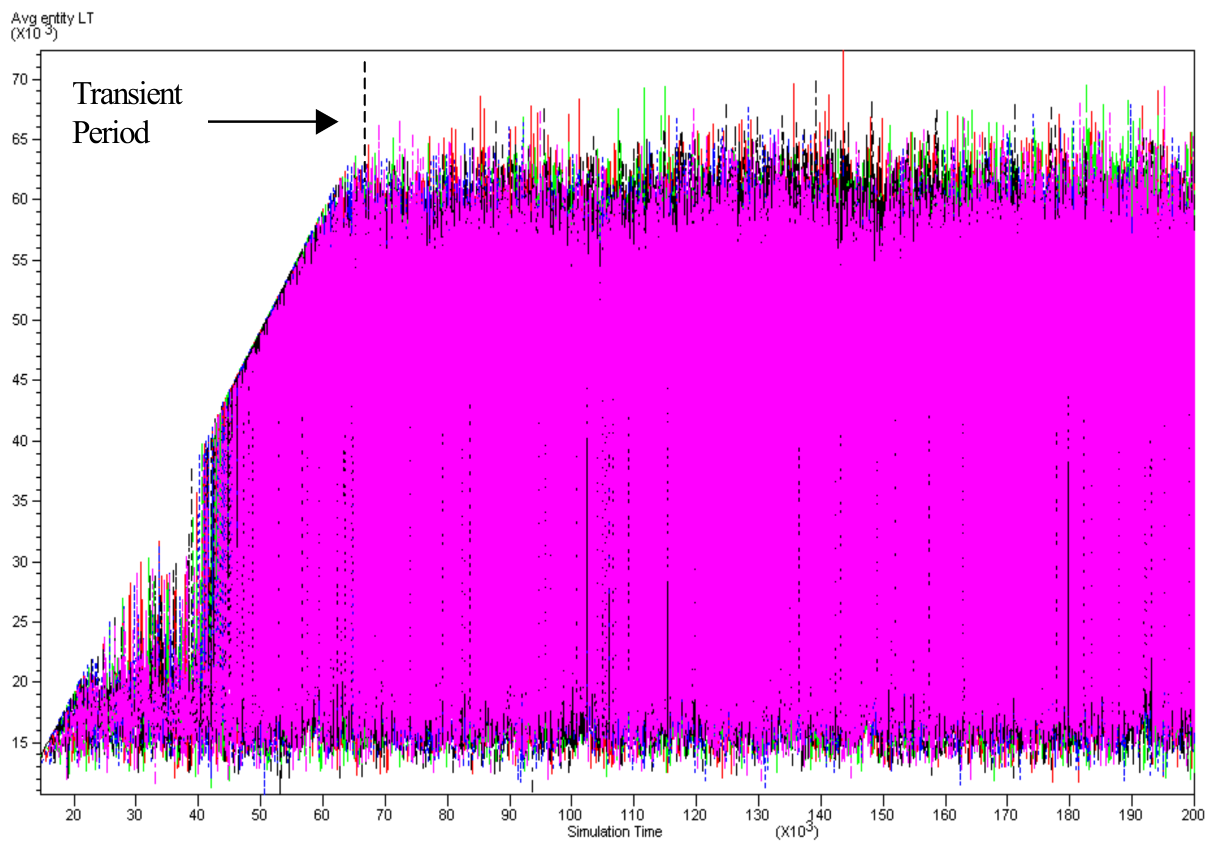



Figure 20 Transient period analysis for the average entity time in system for 5 replications

# 7.0 SIMULATION IN SUPPORT OF VALUE STREAM MAPPING

In order to evaluate the future state map and the impact of lean manufacturing tools addressed under Question 8 in the future state map (Chapter 5) simulation is used. Simulation can help supplement value stream mapping by (a) evaluating the impact of the proposed map, (b) analysis, evaluation, and improvement for different scenarios of the future state map, and (c) for documenting areas of improvement. Focus is on three lean manufacturing techniques that can be quantified, namely the production system, total productive maintenance, and single minute exchange of dies.

To analyze the situation on hand and evaluate different scenarios for the future state map, a full factorial design was used with the simulation. The analysis will involve the three factors mentioned in the previous paragraph: the production system, TPM, and setup reduction. By a full factorial design it is meant all possible combinations of these levels of these factors are investigated and replicated using the simulation model. For example, in our case if there are $n_1$ levels of the production system, $n_2$ levels of TPM, and $n_3$ levels of setup reduction, then each replicate contains all $n_1 n_2 n_3$ possible treatments.

The experiment was run using a $2^k$ factorial design where 2 is the number of levels for each factor and k is the number of factors. In this case k is equal to three and each factor will be examined at two levels, which will be explained in the next sections. We decided to use two primary performance measures: lead-time and work-in-process inventory. The reason for selecting these two measures became apparent when looking at the current state map, where lead-time compared to value added time is huge and WIP inventory is also very large. By reducing lead-time and WIP inventory considerable savings and quality improvement will be automatically gained. Lead-time is also correlated with WIP inventory; in general, the larger the WIP the longer the lead-time, and vice versa.

## 7.1 Production System

A push system and a hybrid (push and pull) system will be the two levels used for the production system factor. The push system represents the current situation at ABS where coils are pushed through the system. The hybrid system however, is designed according to the future state map. Starting from the pickling line a kanban pull system will be used to pull the work through the system to fill the actual demand. As mentioned in Question 4 in the development of the future state map (Chapter 5), at ABS the products follow a continuous flow from the blast furnace to the finishing mill, where the continuous flow is interrupted. The way that the hybrid system will work is that the system will continue to push work through the hot end until it reaches the hot strip mill at the beginning of the finishing end. However, from the buffer area between the hot mill and the pickling line onwards the system will be based on a kanban pull system where the annealed products will be pulled from upstream workstations starting with the pickle line all the way to the shipping area. In this hybrid system slabs are manufactured partly in a process-oriented flow (hot end) and partly as coils in a product-oriented flow (finishing end). The junction between the hot mill and the pickling line will be the push-pull boundary. As mentioned under Question 4 for the future state map, the purpose of this system is to maintain the flow while developing a system to enable pull by the customer.

The hybrid system was modeled in the simulation by using a push system up to the hot strip mill; essentially, this means that this part of the system is the same as the current situation at ABS. On the other hand, starting from the pickling line the system was modeled as a pull system using kanbans to control the inventory between the workstations. The kanban pull system is modeled by having each kanban between a pair of workstations modeled as a resource. An arriving entity seizes one kanban and a workstation at the same time. As soon as the workstation finishes processing the entity, the workstation is released; however, the kanban is retained. The entity then proceeds to the next workstation. At this point the entity seizes the workstation and a kanban from the kanban set for this latter workstation, while simultaneously releasing the kanban from the previous workstation. Thus a kanban from one workstation is held until the entity receives a kanban from the subsequent workstation. This ensures that the former does not begin work until it gets a pull signal from the latter. In other words, the part retains the kanban from the former workstation until it receives the next kanban authorization movement to the following workstation (Marek, Elkins, and Smith, 2001).

At the pull side of the hybrid system the total WIP is limited to the sum of the number of kanban cards across each kanban set. Each kanban set is represented by a supermarket as defined previously under the description of the future state map. Since each coil in the supermarket will have a kanban card attached to it, the average system WIP level may be found by calculating the sum of the average utilizations of the kanban resources in the simulation. The number of coils for each supermarket will be determined by heuristically changing the corresponding number of kanbans in the simulation until the desired throughput is attained. Since each kanban set is defined as a resource, it is straightforward to change the number of kanbans in the simulation. The hybrid system must arrive at a throughput in the range of 9000-9800 coils (order completed per month). This throughput rate is chosen based on historical data. A throughput of approximately 9200 coils was obtained by having 1000 kanbans at the pickle supermarket, 100 at the cold reduction, 10 at each of open coil annealing and hydrogen batch annealing, 20 at continuous annealing, and 45 at the temper mill. The reason why the number of kanbans before the pickling line is large (1000) is because this is the boundary point of the push and pull system and as one moves away from this point the number will decrease because of the nature of the pull system. Also it should be noted that for this simulation only the annealed products would be pulled; so in the simulation their value stream will be different from the other products in the system, where the rest of the products are being pushed.

The comparison of WIP inventory for the push and the hybrid system will be based only on the inventory ahead of the pickle line and downstream to the temper mill. The reason for this is that the difference between the two systems in terms of WIP inventory will be after the push-pull boundary point; all earlier inventory levels are identical since the systems being compared are identical up to this point.

## 7.2 TPM

The two levels for the TPM factor are labeled “without” and “with.” The “without” level represents current maintenance procedures followed by ABS as explained in Question 8 in the future state map. The “with” level will be the proposed TPM procedure, which was also explained in Question 8. The latter procedure splits the scheduled maintenance time, i.e., separates the maintenance process into smaller portions that are done more frequently. Also, each individual unit requiring maintenance must be planned in such a way that the inventory shortages that have been created by work stoppage for maintenance flow down through the process. An example that was previously mentioned is when the pickle line is maintained then the kanbans in the supermarket after it in front of cold rolling would empty; therefore, the next maintenance in performed on the cold mill, permitting the pickle line to restock its supermarket, and so on.

Here it is stressed that the point that changing to a TPM environment can significantly reduce random machine breakdowns and in turn, inventory and lead-time. First, if production workers at each machine learn how to carry out the job of simple monitoring maintenance at each machine as explained in Question 8 this would directly improve the availability of the machine. By doing so, the production workers who would be the best judges of the condition of the equipment would address the issue immediately. This in turn would minimize the risk of having a machine break down if things were postponed. Also, this will reduce the need for maintenance staff if the production staff is carrying out these activities.

Second, based on the TPM literature, researchers have proved that there is significant reduction in machine breakdown when TPM is implemented. Nicholls (1994) proved through mathematical modeling of the operation of an ingot mill in an aluminum smelter that when TPM is implemented a significant reduction of unscheduled maintenance can be achieved. Taylor (1996) also developed a linear programming model to schedule planned maintenance activities at an aluminum smelting plant in a TPM environment. The model showed that TPM could be used to eliminate or significantly reduce machine breakdowns and the need for overtime among maintenance staff.

Third, TPM is usually defined in terms of overall equipment effectiveness (OEE), which in turn is a function of down time and other production losses (Nakajima, 1989). Suehiro (1992) states that machine breakdowns and minor stoppages account for 20-30% of OEE. Ljungberg (1998) also reported that breakdowns account for 20% of OEE. Under a TPM environment the OEE can increase due to the reduction or elimination of the unplanned down time. Volvo Gent reported that the OEE in the company increased from 66-69% before implementing TPM to 90% after TPM where most of the increase is a result of the elimination of machine breakdowns and minor stoppages (Ljungberg, 1998). Similarly, Avon Cosmetics report significant increase of OEE after TPM was implemented at its pump spray line (Ljungberg, 1998).

Westinghouse Electric Company's Windsor plant reported significant savings under TPM. From March to September 2002, their OEE averaged 45%. That is, when they used the equipment, it only produced good products 45% of the time. After implementing TPM the OEE rose from 45% to 55% in October 2002 and went to 72% in January 2003. Also machine capacity increased by 60% and rework and overtime costs was reduced by $65,000 per year (CONNSTEP, 2003).

It is believed that implementing TPM at ABS would significantly reduce machine breakdowns and minor stoppages. The question is by how much? We must mention that the data provided to us by ABS are based on operators' judgment and are ad hoc in nature. Only data for the blast furnace and the continuous caster were based on extensive statistical data collection. We therefore, make an intelligent guess from the above literature and our own judgment that with TPM the unplanned breakdown would go down 25 to 50%. As one study revealed, equipment monitored using TPM experienced a failure rate of 25% of that for unmonitored equipment (Moore, 1997). If more actual data about the frequency of the failures, mean time to failure, mean time to repair, minor outages, and other breakdown data from ABS were available, then a statistical analysis could estimate the unplanned down time under TPM more scientifically.

Table 14 and Table 15 show the proposed TPM times at the hot end and the finishing mill. The maintenance times for the TPM were chosen based on an optimistic but reasonable approach. For example, it is unreasonable to stop the blast furnace every week for maintenance because it is the driving force for the whole process. On the other hand, it is not unrealistic to maintain the blast furnace once every three weeks.

One of the important issues that has to be taken into consideration with the proposed TPM program is to make sure that the time for each of the different maintenance tasks for a given process does not exceed the total proposed (reduced) maintenance downtime. This issue was discussed with ABS and it was confirmed that the proposed downtime should be feasible. An example to illustrate this is the 64-pickle line. When it is time to carry out maintenance for the pickle line there are different tasks that needs to be completed. However, some of these are tasks that are less critical than others and can be done during the next scheduled maintenance. So within the proposed down time for the pickle line the critical tasks can be carried out in the dedicated time period, while the less critical ones are done in the next down period. In another word, the critical tasks can be done once every one or two weeks and the non-critical tasks can be done once every month. For example, replacing the worn plates on the walking beam and installing fiberglass shield on the south side of the welder for the pickle line are tasks that are not critical, which means that they could be carried out once every month or two. On the other hand, tasks such as replacing crop shear top pinch roll or changing the top pinch roll are critical, which indicate that they should be maintained once every one or two weeks. By doing that it is insured that the four-hour window dedicated for maintenance on the pickle line is long enough to fit the different tasks. Similar analyses need to be conducted on other equipment as well in order to ensure feasibility.

Table 14 Proposed TPM times at hot end

| Process | Maintenance uptime (min) | Maintenance Downtime (min) |
|---|---|---|
| BF1 | 30240 (21 days) | 240 |
| BF2 | 31680 (22 days) | 240 |
| BOP | 20160 (14 days) | 240 |
| LMF | 20160 (14days) | 240 |
| Degasser | 21600 (15days) | 240 |

Table 15 Proposed TPM times at finishing mill

| Process | Maintenance uptime (days) | Maintenance Downtime (min) | Day |
|---|---|---|---|
| HSM | 7 | 240 | Monday |
| 84 Pickle | 7 | 240 | Tuesday |
| 64 Pickle | 7 | 240 | Wednesday |
| CRM | 7 | 240 | Thursday |
| TM | 7 | 240 | Friday |

## 7.3 Setup Reduction

The two levels for the setup reduction factor are also labeled “without” and “with.” The “without” level is the current situation at ABS with setup times the same as they are now. The “with” level will assume that the proposed setup reduction procedure explained in Question 8 in the future state map will enable ABS to drive their changeover times down. Again, the changeover reduction times were selected based on a reasonable and optimistic approach, with values that are realistic for ABS to drive their changeover time down (see Table 16 below) according to the procedures explained in Question 8 in the future state map.

Looking at Table 16 the setup time for the hot strip mill was reduced from 35 to 10 minutes for the backup rolls and 120 to 20 for the work rolls. Also, the setup time for cold reduction was reduced from 15 to 5 minutes for the backup rolls and 120 to 20 for the work rolls. Other setup times were also reduced accordingly for other processes. Note that a "dash" in Table 16 means that a setup is not required for that particular process.

Table 16 Proposed setup reduction times at ABS

| **Process** | **Setup time for backup rolls (min)** | **Setup time for work rolls (min)** |
|---|---|---|
| Hot strip mill | 20 | 10 |
| Pickling | - | 5 |
| Cold reduction | 20 | 5 |
| Temper mill | 20 | 5 |
| Caster | (4.8,5.6) | - |

## 7.4 Lead-Time Performance

The first factorial design experiment we ran was to study the effect of the three factors, each with two levels, on the production lead-time. To reiterate, the factors are the production system, TPM, and setup reduction. For each level-factor combination the experiment is replicated five times using the simulation model and is completely randomized. Thus, eight simulation runs were carried out, each with five replications. The results of the runs are as follows:

Table 17 Data for average lead-time (in days) for the factorial designs

| | TPM | | | |
|---|---|---|---|---|
| | Without | | With | |
| | Setup reduction | | Setup reduction | |
| **Production system** | **Without** | **With** | **Without** | **with** |
| **push** | 34.36 34.25<br>34.36 34.19<br>34.12 | 34.22 34.03<br>33.87 34.23<br>34.49 | 27.28 27.39<br>27.13 27.33<br>27.39 | 27.01 27.30<br>27.77 27.26<br>27.56 |
| **hybrid** | 19.17 19.28<br>19.03 19.18<br>19.23 | 19.03 19.26<br>18.99 19.06<br>19.20 | 12.13 12.11<br>12.14 12.11<br>12.13 | 12.12 12.11<br>12.13 12.10<br>12.12 |

The numbers in each level-factor combination represent the average lead-time in days for each coil for that replication. Without any formal analysis it is clear by just looking at Table 17 that going from a push to a hybrid system has a major effect on lead-time. Using TPM also appears to have a significant impact on lead-time. On the other hand setup reduction seems not particularly significant in this particular instance. The formal analysis was conducted to include main effects (single factor), two factor interactions, and three factor interactions.

Analysis of Variance (ANOVA) was used to formally study the results and determine the significance and magnitude of all effects and interactions. The statistical analysis was done using Minitab. The estimated effects and coefficients for the fitted regression model and the ANOVA table are shown in Table 18 and Table 19 respectively.

Table 18 Estimated Effects and Coefficients for Lead-time

| Term | Effect | Coef | SE Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 23.1968 | 0.02424 | 956.95 | 0.000 |
| Prod Sys | 15.1605 | 7.5803 | 0.02424 | 312.71 | 0.000 |
| TPM | 6.9315 | 3.4657 | 0.02424 | 142.97 | 0.000 |
| Setup Red | 0.0075 | 0.0037 | 0.02424 | 0.15 | 0.878 |
| Prod Sys*TPM | -0.0615 | -0.0307 | 0.02424 | -1.27 | 0.214 |
| Prod Sys*Setup Red | -0.0015 | -0.0007 | 0.02424 | -0.03 | 0.976 |
| TPM* Setup Red | 0.0415 | 0.0207 | 0.02424 | 0.86 | 0.398 |
| Prod Sys*TPM*Setup | 0.0405 | 0.0202 | 0.02424 | 0.84 | 0.410 |

Table 19 Analysis of Variance for Lead-time

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 3 | 2778.87 | 2778.87 | 926.288 | 4E+04 | 0.000 |
| 2-Way Interactions | 3 | 0.06 | 0.06 | 0.018 | 0.78 | 0.513 |
| 3-Way Interactions | 1 | 0.02 | 0.02 | 0.016 | 0.70 | 0.410 |
| Residual Error | 32 | 0.75 | 0.75 | 0.024 | | |
| Pure Error | 32 | 0.75 | 0.75 | 0.024 | | |
| Total | 39 | 2779.69 | | | | |

The ANOVA output from Minitab sums up the main effects for the three factors in one measure, which is shown written in the ANOVA table as “Main Effects” as shown in Table 19. The p-value for the main effect is virtually equal to zero, so that we may conclude that some or all of the main effects are significant. Minitab uses the t test to judge the significance of each factor and the interactions between factors. The t tests shown in Table 18 reveal that the production system and TPM are significant and that setup reduction, the 2-way interactions, and the 3-way interactions are not significant.

Before we accept the conclusions from the ANOVA table, the adequacy of the underlying model is checked. This is done through the residuals analysis. The normal probability plot of the residuals in Figure 21 does not reveal anything particularly troublesome. Figure 22 shows a plot of the residuals versus order of the data; again the plot does not reveal any serious problem.

From the plots there is no reason to suspect any violation of the independence or constant variance assumption.

To assist in the practical interpretation of this experiment, Figure 23 presents plots of the two main effects that are significant (production system and TPM). The main effect plots are just graphs of the marginal response averages at the levels of the two factors.

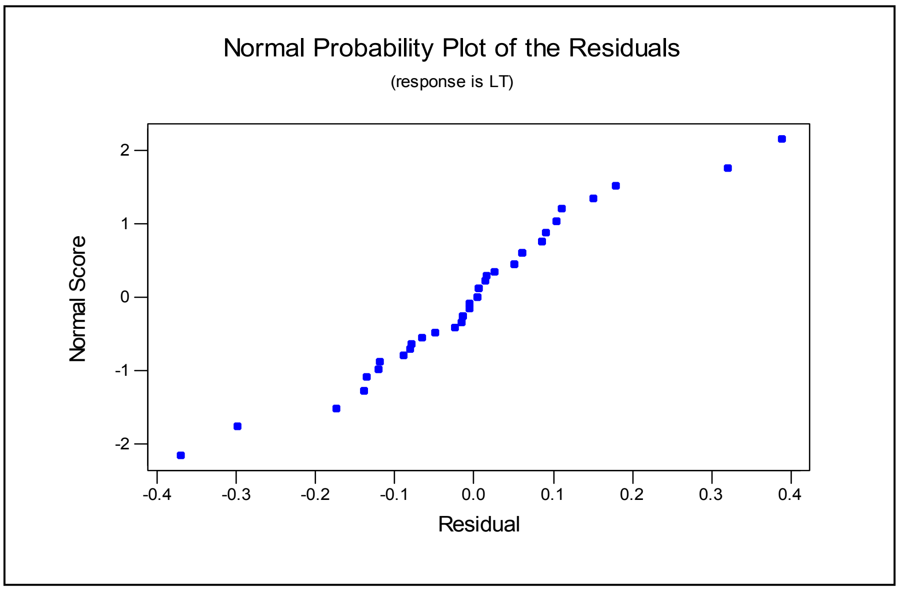



Figure 21 Normal probability plot of residuals

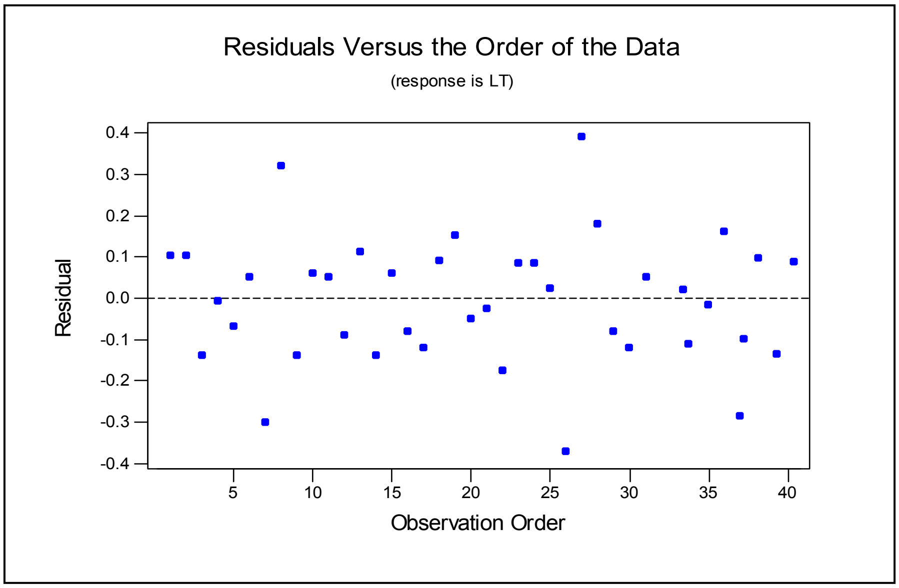
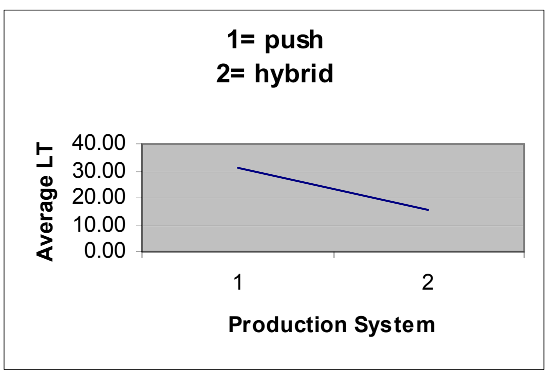



Figure 22 Plot of residuals versus time



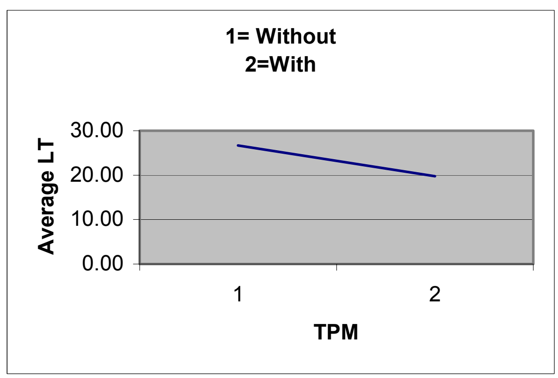




Figure 23 Main effects plots for Average lead-time

It may be seen that both factors have negative main effect that is, going from push to hybrid system will decrease lead-time and going from "without TPM" to "with TPM" also decreases the lead-time. The results clearly call for the use of hybrid system as well as TPM.

## 7.5 Inventory Performance

The second factorial design experiment ran was to study the effect of the same three factors (each with two levels) on WIP inventory. As mentioned earlier the WIP inventory is the sum of WIP at the pickling line and all the way to the inventory at the temper mill. Only this portion of the WIP is considered because for the production system factor the systems are identical up to the push-pull boundary point at the pickling line. As mentioned earlier for the hybrid production system the WIP inventory is just the sum of the average utilizations of the kanban resources (recall that each kanban set is modeled as a resource in the simulation model). For each level-factor combination the experiment is replicated five times using the simulation model and is completely randomized. This means that again, eight simulation runs were carried out each with five replications. The WIP inventory shown in Table 20 is in units of 100. The results of the runs are as follows:

Table 20 Data for average WIP Inventory (number of coils) for the factorial designs

| **Production system** | **TPM: Without** | | **TPM: With** | |
|---|---|---|---|---|
| | **Setup reduction** | | **Setup reduction** | |
| | **Without** | **With** | **Without** | **With** |
| **push** | 96.09 96.09<br>96.28 96.11<br>96.41 | 95.74 96.23<br>96.28 96.62<br>96.16 | 74.74 75.00<br>74.63 74.76<br>74.99 | 74.72 74.81<br>74.76 74.92<br>75.21 |
| **hybrid** | 10.32 10.38<br>10.31 10.37<br>10.32 | 10.36 10.34<br>10.33 10.31<br>10.29 | 10.38 10.35<br>10.36 10.35<br>10.30 | 10.38 10.32<br>10.35 10.34<br>10.30 |

The numbers in each level-factor combination represent the average WIP inventory for that replication. The result here appears to be similar to those of the previous section. Once again, ANOVA was used to analyze all effects and interactions formally. The estimated effects and coefficients for the fitted regression model and the ANOVA table are shown in Table 21 and Table 22 respectively.

Table 21 Estimated Effects and Coefficients for WIP inventory

| Term | Effect | Coef | SE Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 47.9328 | 0.02431 | 1971.85 | 0.000 |
| Prod Sys | 75.1895 | 37.5948 | 0.02431 | 1546.56 | 0.000 |
| TPM | 10.6685 | 5.3342 | 0.02431 | 219.44 | 0.000 |
| Setup Red | -0.0115 | -0.0058 | 0.02431 | -0.24 | 0.815 |
| Prod Sys*TPM | 10.6785 | 5.3393 | 0.02431 | 219.64 | 0.000 |
| Prod Sys* Setup Red | -0.0235 | -0.0117 | 0.02431 | -0.48 | 0.632 |
| TPM* Setup Red | 0.0135 | 0.0067 | 0.02431 | 0.28 | 0.783 |
| Prod Sys*TPM*Setup | 0.0115 | 0.0057 | 0.02431 | 0.24 | 0.815 |

Table 22 Analysis of Variance for WIP inventory

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 3 | 57672.8 | 57672.8 | 19224.3 | 8E+05 | 0.000 |
| 2-Way Interactions | 3 | 1140.3 | 1140.3 | 380.1 | 2E+04 | 0.000 |
| 3-Way Interactions | 1 | 0.0 | 0.0 | 0.0 | 0.06 | 0.815 |
| Residual Error | 32 | 0.8 | 0.8 | 0.0 | | |
| Pure Error | 32 | 0.8 | 0.8 | 0.0 | | |
| Total | 39 | 58813.8 | | | | |

As shown by the ANOVA the p-value for the main effect is almost zero, so that we may conclude that some or all of the main effects are significant. The t tests shown in Table 21 reveal that the main effects of production system and TPM are significant and that setup reduction and the 3-way interaction are not significant. Interestingly, the table shows that the 2-way interaction between the production system and TPM is also significant. The adequacy of the underlying model is checked through the residuals analysis. The normal probability plot and the plot of the residuals versus order of the data are shown in Figure 24 and 25 respectively.

To better understand the practical interpretation of this experiment, Figure 26 presents plots of the two significant main effects (production system and TPM) as well as the production system-TPM interaction.

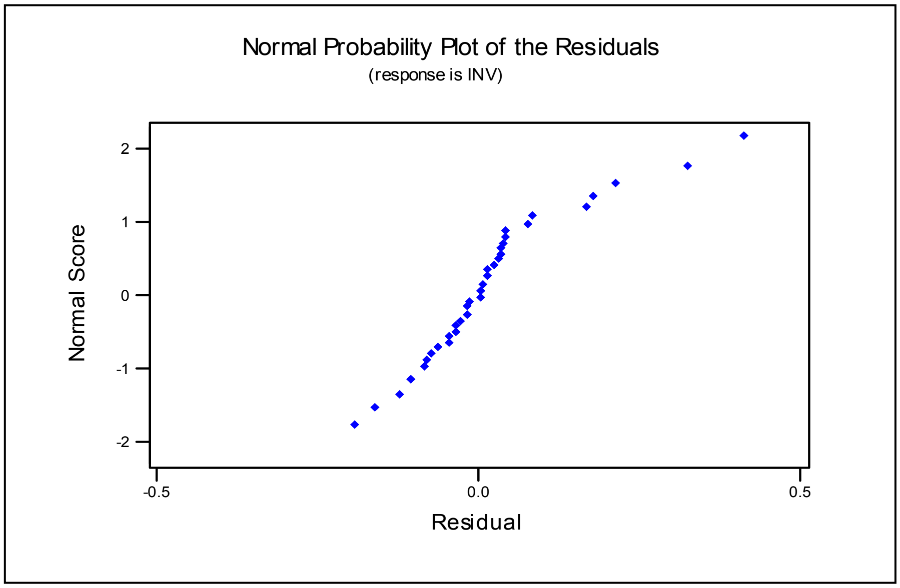



Figure 24 Normal probability plot of residuals

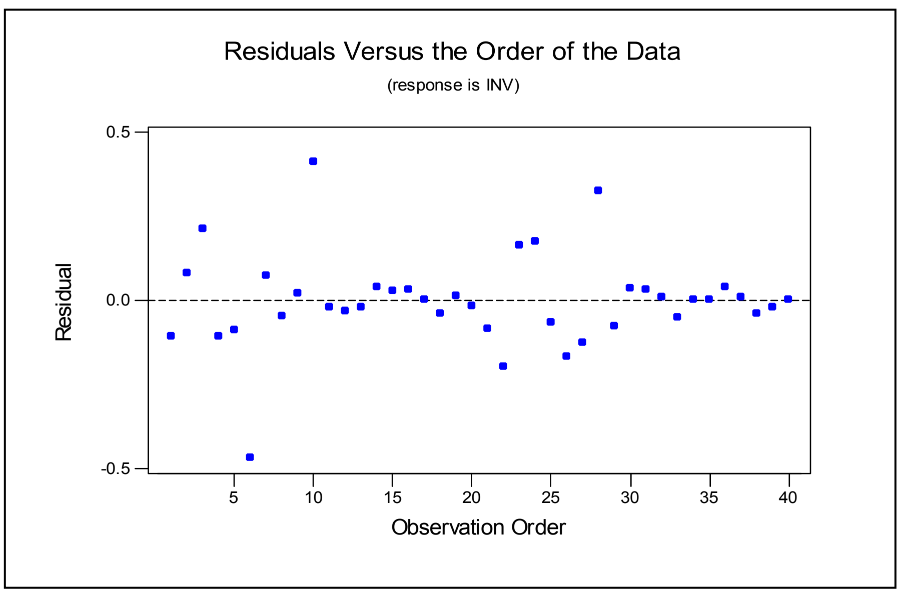
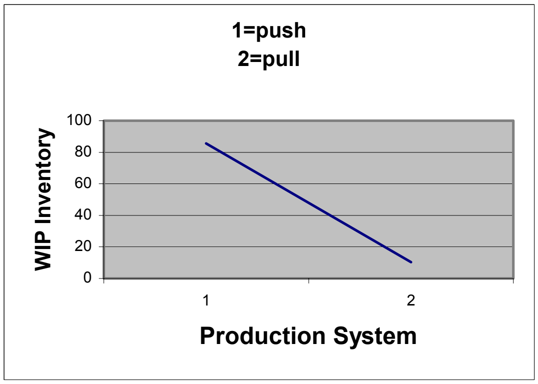
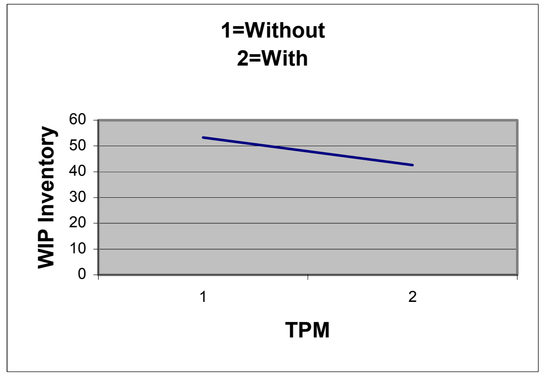



Figure 25 Plot of residuals versus time



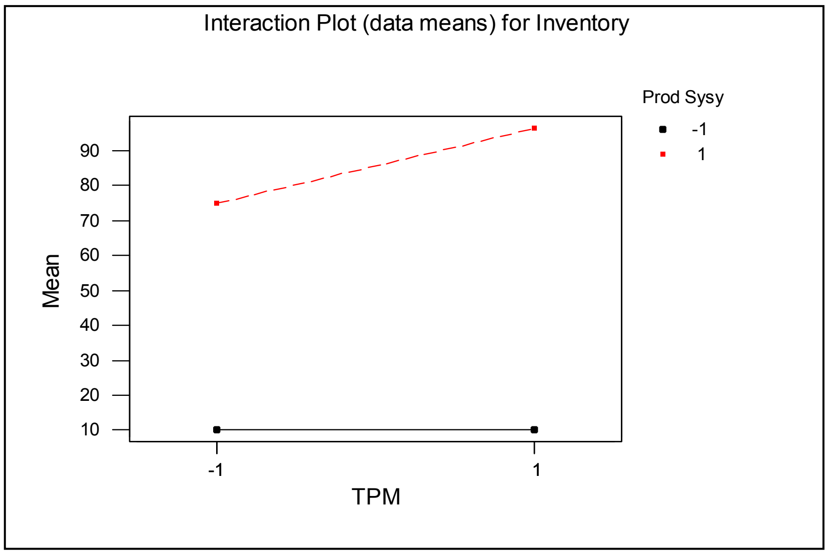




Figure 26 Main effect and interaction plot for inventory

Note that both factors have a negative main effect that is, going from push to hybrid system will decrease WIP inventory and going from no TPM to TPM also will decrease WIP inventory. Also the significant interaction between production system and TPM is indicated by the lack of parallelism of the lines. Note that for the production system 1 represents the push and –1 the hybrid while for TPM 1 represent "without TPM" and –1 represent "with TPM." The interpretation of the interaction graph is that going from no TPM to TPM when the production system is a hybrid will not change the level of WIP inventory whereas going from no TPM to

TPM when the production system is a push system will decrease the level of WIP inventory. An intuitive explanation for this is that the WIP inventory in the pull system is dependent on the number of kanban cards that is predetermined before the run. This makes the change in WIP inventory for the hybrid production system (WIP inventory is the sum of the average utilization of the kanbans, which are modeled as resources) to show no significant change when using TPM. Even though TPM was found to be significant, the kanban pull system is so powerful in reducing the WIP inventory that the effect of TPM is relatively small. However, with a standard push system TPM has significant benefits with respect to WIP. This will be confirmed in the following analysis. In summary, based on the results, in order to drive WIP inventory down the use of a hybrid system with TPM is clearly in order.

Additional analysis was performed to determine the effects of setup reduction and TPM on a push system. This experiment involved two factors, each with two levels. We used the same data from the previous experiment but only for the push system.

Analysis of Variance (ANOVA) was used to determine the effect and magnitude of these effects. The estimated effects and coefficient for the fitted regression model and the ANOVA table are shown in Table 23 and Table 24.

Table 23 Estimated Effects and Coefficients for WIP inventory production system is push

| Term | Effect | Coef | SE Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 85.5275 | 0.04816 | 1776.05 | 0.000 |
| TPM | 21.3470 | 10.6735 | 0.04816 | 221.64 | 0.000 |
| Setup Red | -0.0350 | -0.0175 | 0.04816 | -0.36 | 0.721 |
| TPM* Setup | 0.0250 | 0.0125 | 0.04816 | 0.26 | 0.799 |

Table 24 Analysis of Variance for WIP inventory production system is push

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 2 | 2278.48 | 2278.48 | 1139.24 | 2E+04 | 0.000 |
| 2-Way Interactions | 1 | 0.00 | 0.00 | 0.00 | 0.07 | 0.799 |
| Residual Error | 16 | 0.74 | 0.74 | 0.05 | | |
| Pure Error | 16 | 0.74 | 0.74 | 0.05 | | |
| Total | 19 | 2279.22 | | | | |

As shown from the ANOVA the p-value for the main effect is almost zero, signifying that some or all of the main effects are significant. The t tests shown in Table 23 reveal that the main effect of TPM is significant and that setup reduction and the 2-way interaction are not significant. Based on the results and the significance of the TPM factor it can be concluded that even under a push system TPM can have a significant effect on the WIP inventory.

## 7.6 Discussion

In the above experiments factorial designs were used to study the use of simulation for assessing the benefits of incorporating lean manufacturing tools into the future state map for ABS. This study was with respect to two primary performance measures: lead-time and WIP inventory. Three lean manufacturing tools were used to asses their impact on the future state map at ABS.

The first experiment was for judging the effects of the production system, TPM, and setup reduction on lead-time. For this particular company the experiment revealed that using a hybrid production system and TPM could potentially reduce the current average lead-time from 34.26 to 12.12 days, a reduction of almost 65%. The lead-time would not go down further if setup reduction were used and the analysis of the factorial design confirmed that setup reduction was not significant.

The second experiment was proposed to study the effect of the same three lean manufacturing tools on WIP inventory. Again the experiment revealed that using a hybrid production system and TPM could potentially drive the current average inventory level starting from the pickle line all the way until the temper mill from 96.19 to 10.34 coils, a reduction of almost 89%. Also, the experiment revealed an interaction between two factors: the production system and TPM. The interaction indicated that TPM would not have a critical effect on WIP inventory with a hybrid system but it would if incorporated within a push system. Also, the experiment again revealed that setup reduction does not seem to have a significant effect on WIP inventory in this instance.

The third experiment fixes the production system as a push system and determines the effect of setup reduction and TPM on that system. The experiment reveals that TPM would have a major effect on WIP inventory, whereas setup reduction would not. Under TPM, even if a push system is used the current average inventory level starting from the pickle line all the way until the temper mill could potentially go down from 96.19 to 74.82 coils, a reduction of almost 22%.

It can be concluded that the analysis of the results showed that a hybrid production system and TPM have enormous effect on both lead-time and WIP inventory whereas setup reduction did not for this particular instance. However, this does not necessarily mean that setup reduction is not a valuable lean tool for ABS. Rather, the effect of the hybrid system and TPM outweigh the advantages of setup reduction in this particular case.

The results are also intuitive; a reduction of WIP inventory could be expected to automatically reduce lead-time and vice-versa since those two measures are correlated. Also, if the current push production system remains at ABS, TPM can still have a significant effect on reducing WIP Inventory.

It should be noted that the results of the analysis detail potential gains, and there might be obstacles that preclude the full benefits of the above-mentioned lean tools. For example, as mentioned earlier maintenance staff might be reduced if breakdowns are reduced under the proposed TPM program. However, union contracts might not allow for such a thing. Another obstacle might be management resistance. The steel industry is one where managers seem to strongly believe in the traditional way of doing business, which could bring resistance against a kanban pull system for example. However, it should be clear from the simulation analysis that very significant benefits are possible if lean tools are implemented

## 7.7 The Future State Map Revisited

The future state map for the annealed product for ABS is shown in Figure 27. The results of the experiment are documented on the future state map. Also on the map, the proposed lean tools including tools that will be discussed in the next section are shown as kaizen bursts to highlight the improvement areas. Also shown are the supermarkets between each process after the hot strip mill.

Note that the starting inventory for the shipping supermarket is one day worth of demand as we mentioned previously and this can be adjusted accordingly by ABS. As we can see in the map, ABS receives two schedules only; one at the continuous caster for the hot end and the other one at the temper mill for the finishing end. With the new improvement at ABS the percentage of the value added time (5 days) to the non-value added time (12.84 days) is 39% for the future state map.

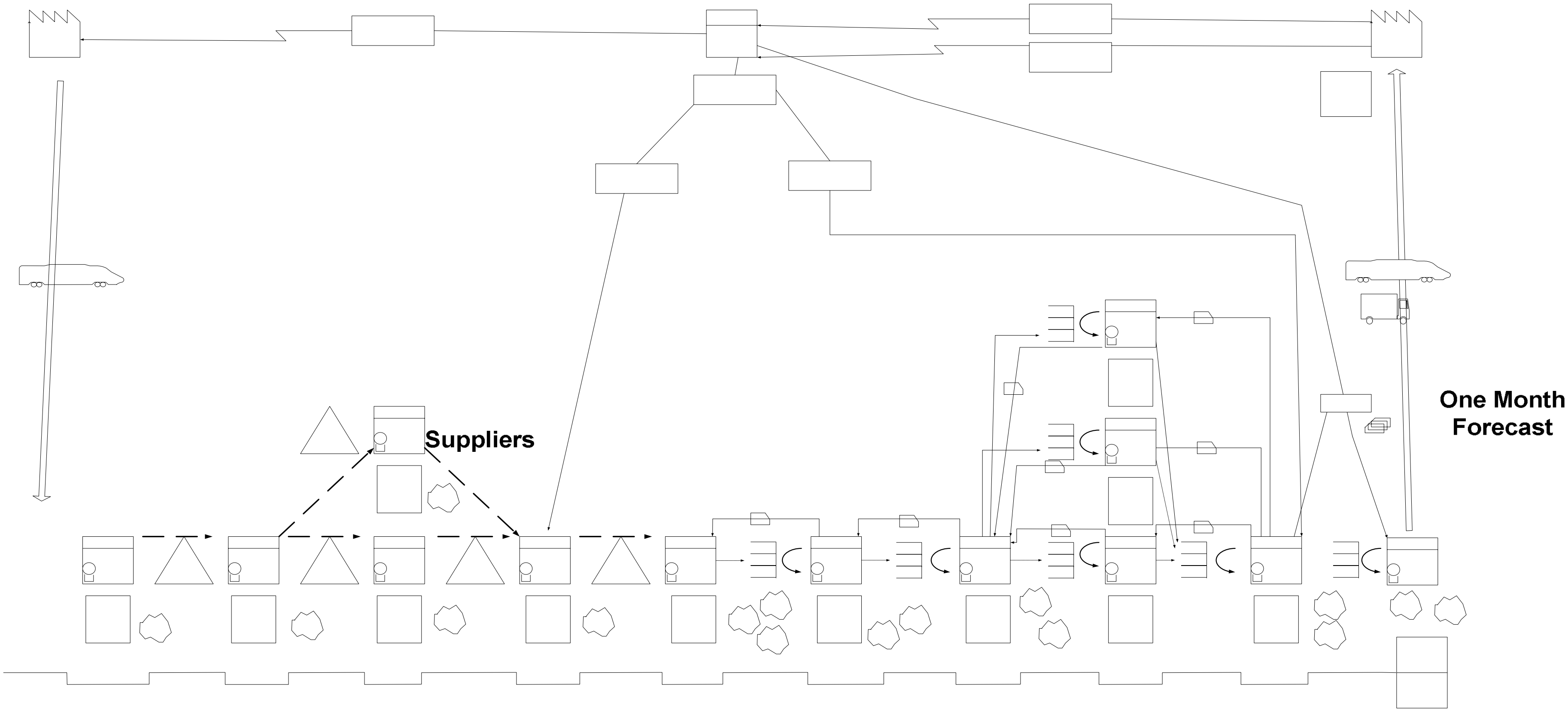



Figure27 Future State Map.

# 8.0 OTHER LEAN TOOLS: 5S AND VISUAL SYSTEMS

There are some lean tools that do not readily lend themselves to be quantified by simulation; two of those tools are 5S and visual systems (VS). 5S and VS are key components to any lean implementation, complementing all the other tools and helping to eliminate waste. They are now seen as widely applicable concepts regardless of industry or size of company. They can be used to tackle problems without requiring additional engineering and expertise and are practical and simple methods to engage employees in organizational improvement. In this chapter we will develop a detailed 5S and VS program for ABS and speculate on the benefits that can be gained by implementing this tool in support of other lean tools that have been proposed earlier.

## 8.1 5S

There are two major areas at ABS that can use 5S and VS, the shipping area and the hot mill tool area. Currently at ABS, there are six docks in the shipping warehouse at ABS. Table 25 explains dock requirements:

Table 25 Dock requirements at shipping warehouse

| Shipping Dock | Product Shipped | Mode of shipping |
|---|---|---|
| Dock 1 | Mix of products | Truck and rails |
| Dock 2 | Mix of products | Truck and rails |

Table 25 (continued)

| | | |
|---|---|---|
| Dock 4 | Mix of products | Truck and rails |
| Dock 5 | Metal tech and FHPKL | Truck and rails |
| Dock 10 | Mix of products | Truck and rails |
| Barge Dock | Mix of products | Barge |

At dock 2 for example the coils arrive from their final process by a C-hook crane. The coil is unloaded at the entrance to the dock where it is wrapped in a protective packaging and banded. The coil is tagged with a bar-coded ticket containing the coil number, gauge, width, weight, length, the mill order item number, customer order number, bay number and the tracking number. The crane then picks up the coil and places it in its designated bay. Each bay is numbered, and coils are placed in their designated bays ready for shipping.

While touring the facility it was observed that the driver of the buggy has to make occasional stops to remove rolls of plastic packaging that were blocking the way. It was also observed that sometimes when the crane operator is ready to pick up the coil from its bay to move it to shipping he finds out that it is not the right coil, a coil without a tag, or a coil with the wrong tag information. Most of the mistakes happen at the beginning of the line when the coil is wrapped and tagged.

At the other end of the facility the current tools and rolls area for the hot mill are completely disorganized. Tools scattered all over the place, outdated rolls occupying space, and a cluttered shop floor distinguish the roll preparation area. Here two things are proposed: first, a 5S program to designate an area for the tools used in the wrapping operation and roll preparation area for the hot mill, and second, developing VS to utilize a kanban post for keeping track of all coils.

First, 5S for the tool and packaging area at the shipping warehouse and hot mill area will be explored. The first element of 5S is Sort. Good housekeeping starts with sorting those items that are important from those that are not relevant to the working areas. At the shipping dock only tools that are needed in the packaging operation should stay there; this includes plastic packing and tools used in the packaging operations. The same thing applies to the hot mill roll area where damaged rolls, broken fixtures, and unnecessary tools should be removed. A good start is to get rid of anything that is not going to be utilized for the next 30 days. A red tag is placed on unneeded items. Each tag must have a number, which department it belongs to, the date, and the reason for tagging. Figure 28 shows an example of a red tag.

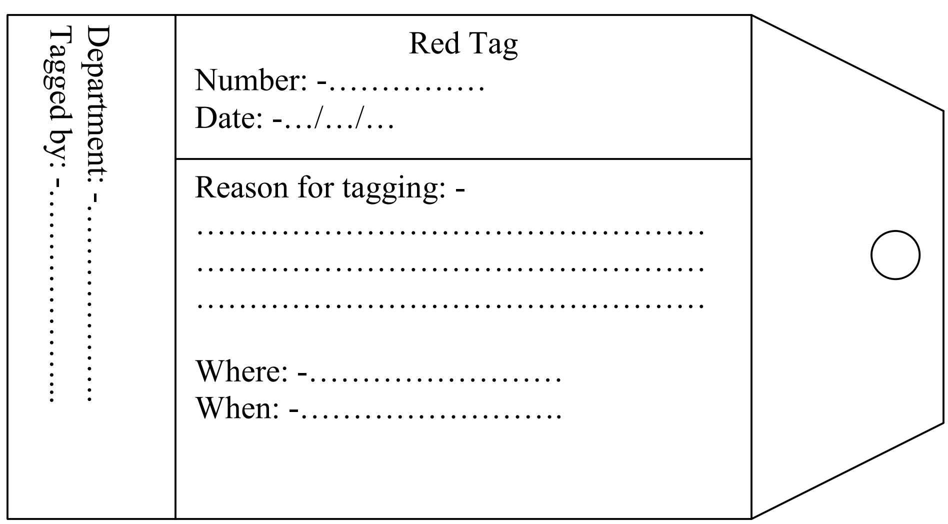



Figure 28 Example of a red tag

If there are doubts as to whether any item is needed or not, a red tag must be placed on it. At the end of the red tagging the workers at the shipping dock or the hot mill must determine whether these items should be removed to another place, taken to the repair shop, or taken to a discharge area. A discharge area must be allocated to those items that must be removed. Thus for example damaged rolls should either go to the discharge area or be sent to the repair shop.

The second element of 5S is Straighten. Straighten involves having order in the workplace and less congestion so every activity can be performed freely with minimum time. After all unwanted items are moved, the next step is to organize the items that are needed in the best way possible. First of all, at the shipping docks tools and packaging materials should all have a well-defined and designated area for placement. This area should be within reach of the workers so that items are available when needed, and it should be outlined clearly by painting a rectangle around it. Items that have a designated storage place must be labeled with the name and a return address on the label so that they can be brought back to the proper place. The same thing applies to the hot mill roll area as well. Rolls must be placed in an area very close to the mill so that they can be transferred quickly whenever a changeover is needed. All rolls and tools must be labeled. Backup and work rolls must be painted and each color must represent the type of roll and other roll criteria such as width and gauge. With respect to the tools, jigs, and fixtures needed for the rolls, these should be placed in an area close to the actual rolls to minimize movement and to expedite work. Color-coded areas must be designated for these items so that after use each can be placed in the proper place.

Once the items and tools, rolls, and fixtures are placed in the proper position, the next step is to clean the work place. Sustain is the third element of 5S. It has to do with cleaning the working environment so as to sustain the improvement. Cleaning include things such as machines, tools, rolls, jigs, fixtures, floors, and walls. Dirt, oil, and stains should be wiped off from machines. Areas where red-tagged items were removed must be cleaned. When touring the ABS hot mill roll area the place looked cluttered and dusty. Dust is one characteristic of the steel industry and since the roll area is located near the mill it is no coincidence that this area is dusty. Big target areas for cleaning are the floor, walls, conveyance equipment, and loading docks. Cleaning should be done on a daily basis. By cleaning jigs and fixtures, sources of malfunctions such as broken covers, or loose nuts can be uncovered, and immediate action can be taken to fix these problems. Cleaning responsibilities should be assigned to different workers to make cleaning a team effort. To prevent dirt from getting into tools, rolls, jigs, and fixtures, simple things such as covering around cords, legs of fixtures and tables can be done to make the removal of dirt easy.

The fourth element of 5S is Systematize. Systematize means continuous work on the previous three 5S pillars. Kaizen efforts in the work place do not end if they have been implemented once or twice. Rather, it is a continuous improvement effort. Procedures should be set up to make sure that employees are working on sort, straighten, and shine. It is easy to perform kaizen activities in the work place once and observe the improvement. However, in order to maintain the improvement it should be done on a consistent basis, otherwise everything will be back to what it was before. How can this be done at ABS? A team of two people can be assigned to the shipping area and the hot mill roll area to conduct weekly audits to see if every 5S initiative is being followed. At the startup of a new initiative, it is always hard to obtain results right away; so it is important to develop a checklist or assessment sheet to follow up on these initiatives. A 5S assessment sheet developed for both areas at ABS is shown in Table 26.

This checklist sheet can be used to evaluate the current status of a 5S program at ABS on a weekly basis and corrective actions and improvement can be taken accordingly.

The last element of 5S is Standardize. Standardize means to sustain and adhere to 5S standards. Managers should set standards and make everyone follow them. People should be held accountable at the shipping area and hot mill roll area for carrying out 5S actions. For example, a group of two people may be responsible for carrying out the checklist, two others are responsible for cleaning and sorting, and two others are responsible for sorting. 5S does not promote adding extra people to the shop floor, but it requires that existing workers at each area carry out these tasks and make practicing 5S tools a habit. Also, in order to see the improvement people at ABS should be encouraged to take before and after photographs that recognize the difference and provide more motivation.

Table 26 5S Audit Checklist (Based on E.J. Sweeny, 2003)

| **Date:** | **Target Area:** | | **Performed by:** |
|---|---|---|---|
| **5S element** | **Initiative** | **Score** | **Notes for next Level improvement** |
| (Sort) | 1) Necessary items are sorted from those that are unnecessary | | |
| | 2) Discharge area is defined. | | |
| | 3) Unwanted items are moved to discharge area. | | |
| (Straighten) | 4) Items are organized to permit easy access to materials and tools. | | |
| | 5) An access system is in place with labels and color code to identify | | |
| | 6) Proper position of tools, materials, and objects. | | |
| | 7) Materials or objects are always in their designated position. | | |
| Scrub | 8) Rolls, tools, jigs and fixtures are well maintained and clean. | | |
| | 9) Walls, floors, shipping docks, conveyance equipment and hallways are shiny and stainless. | | |
| | 10) Actions have been developed to remove sources of wastes. | | |
| Systematize | 11) Procedures are set to work on sort, straighten, and scrub. | | |
| | 12) 5S is run on a daily basis. | | |
| | 13) Working environment is healthy and pleasant. | | |
| Standardize | 14) Standards are set and followed. | | |
| | 15) Goals of 5S have been achieved. | | |
| | **Total Score:** | | **Divided by 15 = Avg. Score:** |

**1= Little or No 5S Apparent (<20%) 3= Meets Several 5S Requirements (60%) 5= 5S Compliant (100%)**

**2= Meets Minimal 5S Requirements (40%) 4= Meets Most 5S Requirements (80%)**

## 8.2 Visual Systems

A visual system is proposed at the shipping area to address the problems of handling the wrong coil, having a coil without a tag or a coil with wrong tag information. Most of the mistakes happen at the beginning of the line when the coil is wrapped and tagged. Here a VS and a kanban system is proposed to eliminate the critical problems mentioned above. Currently, after the coil is tagged the crane operator moves the coil to its designated bay, which is nothing more than a place dedicated to coils that are ready to be shipped.

To eliminate the problem mentioned previously, it is proposed that a number of rows be added to each bay. Each row inside a bay will be number sequentially. Inside each row a specific position for each coil is designated. Figure 29 shows a schematic of the proposed layout. When a coil arrives to the shipping department and goes through packaging, a kanban card is attached to it. This kanban card in nothing but the old tag with new entries for the row number and the position added on. Each coil will have two identical kanban cards, one placed on the coil and the other placed in a kanban post.

Currently, the data on the tag is entered into a computer system to track the coils. The kanban post (see Figure 30) is a box that has holes according to the bay, row, and position combination. When it is time to ship a specific coil, the crane operator pulls the record from the computer system and compares it to the information in the kanban card. If the two agree he goes to the coil position and picks up the coil. The proposed system would eliminate the problem of placing a coil and not being able to locate it, and eliminate the problem of placing the wrong card on a coil because each coil would have a designated position with three records, one in the computer and two in the two kanban cards.

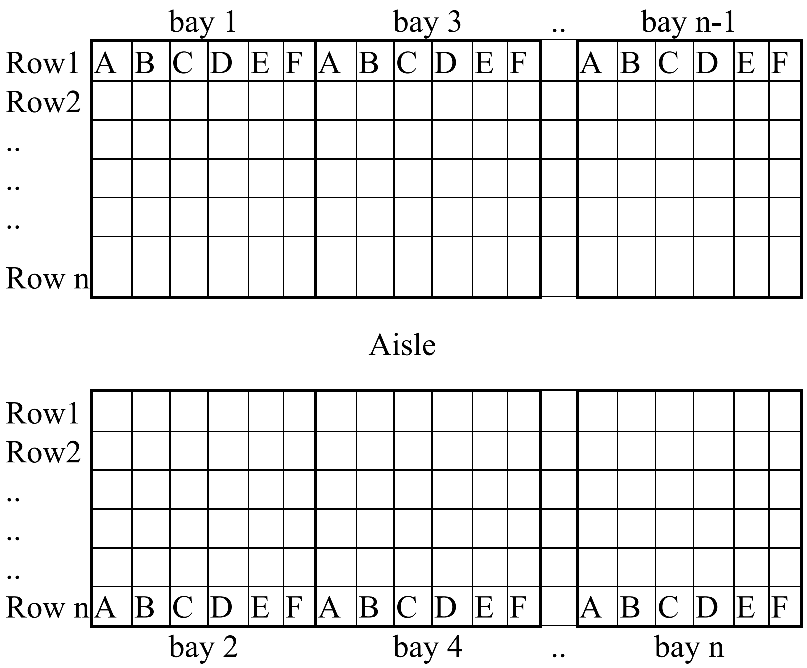



Figure 29 Schematic of the proposed shipping dock layout

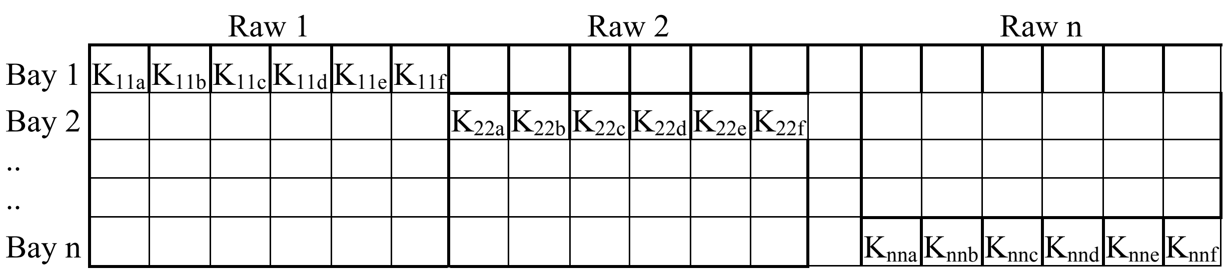



Figure 30 Proposed Kanban post

## 8.3 Summary

5S & VS should be a way of life at ABS. In the steel industry workers seem to accept dirt as part of the normal condition of the workplace, the argument being, "Why should I clean it, it will only get dirty again?" Managers who fail to promote the principles of 5S & VS normally end up with a workforce that is indifferent and lacks discipline. ABS must recognize that people are much more inclined to support what they help create, and are highly likely to resist what is forced upon them.

5S & VS in its implementation sounds basic; in fact, not implementing the tool can have a detrimental effect on the organization. Housekeeping has always been overlooked because it seems too simple. However, it is a powerful way to reduce waste. Removing the unnecessary items can free up space, leading to flexibility at the working area, which in turn avoids congestion. The uniqueness presented by ABS of having long setup times and costly changeover makes it even more necessary to promote 5S & VS. At ABS, having the right jig, tool or fixture in the place needed at a roll area can have a great effect on reducing setup times. Also, tools, jigs and fixtures needed are very large so eliminating the unnecessary materials in the roll area makes it easier to convey these items, which reduces the time needed to do setups. Cleanliness will lead to better identification and problem solving. The communication process can be improved between employees with VS; the proposed kanban post at the shipping area can help in expediting shipping by locating the coil position is a simple manner.

5S & VS are foundations of any lean manufacturing program and could be implemented at the ABS facility very much like in the discrete industry. This provides a good start to implement the future state map in order to help ABS achieve the desired inventory and lead-time reduction. It is strongly believed that ABS will achieve all the above mentioned benefits offered by the 5S & VS initiatives. This is also supported by the benefits that have reportedly been gained by implementing good housekeeping in different manufacturing environments. Cox (2002) reported that Getchell Gold (GG), a gold mine in Neveda implemented 5S and achieved great savings. GG implemented 5S in three areas at their facility. Using 5S audits the team was able to demonstrate results to management within just two days. Sixteen of the 5S events had been completed both on the surface and underground. 5S had helped to eliminate over $53,000 in waste and had offered considerable improvements in work area efficiencies. Sweeney (2003) reported that Labinal, Inc, a division of French-owned global aerospace supplier began a 5S program at their company. They wanted to make the 5S program fun and involve every one, so they developed the Golden Duster Award. This was a trophy presented to the winning team of the month; a lean checklist was developed with the highest winning the award. After one year the 5S program has helped Labinal saved approximately $100,000. While these figures may not necessarily be achieved at ABS, one could certainly expect significant savings with a minimal investment cost.

Here again it should be noted that there might be some barriers to implementing the lean tools described in this section. For example, when considering 5S the union contracts might not allow the workers to do simple things such as sweeping the shop floor. Also, there might be resistance to change from the workers themselves. Workers are accustomed to the way the business is run and in the steel industry dust and dirt are part of the production area, so workers would not care if the place is clean or not. People are always attached to the way that business is run, and it might take some time to change the culture of the company, but the results clearly show that it is worth the effort to do so.

## 9.0 SUMMARY AND CONCLUSIONS

In this chapter, we summarize the key aspects of this research are summarized and conclusions are provided. The contributions of this research are addressed and future directions are offered for the work.

### 9.1 Summary of the Research

In this research the use of lean manufacturing tools and techniques in the process industry are addressed and in particular the steel industry as represented by ABS. First a new taxonomy of the process industry with a view to identifying targets for implementing lean tools was developed. This taxonomy was used to contrast the process industry and characterize it into distinguishable groups according to (a) product characteristics and (b) material flow characteristics. This differs from the current “standard industry group” classification system. Also, in this taxonomy the question of when a product eventually becomes discrete in the process was addressed. The purpose of this taxonomy was to demonstrate that “process industry” is a very general term and that each industry within the process sector has its own distinguishing characteristics. In particular, on the steel industry was focused upon. This industry was characterized as having some flexibility in terms of products taking different routings and a number of similar machines to process coils in parallel. It was also characterized as having its nondiscrete product become discrete at some point during the middle of the manufacturing process, after which the products go through one of several flow line-like systems.

Next, in order to identify opportunities for implementation of lean methods value stream mapping was used as a tool. In particular, at ABS it was used to identify various types of waste in the value stream of the company and to try and take steps to eliminate them. The current state map was developed by mapping all the information and production flow at ABS. All the data for the current state map was gathered on site (at ABS); this included machine cycle times, inventory numbers, setup times, and information flow data such as how often customers placed orders. The map was studied and target areas for improvement were identified to eliminate the waste revealed by the current state map at ABS. Procedures were then developed for adapting lean manufacturing techniques such as kanban pull systems, TPM, setup reduction, and 5S to help in reducing the wastes.

Third, in order to quantify the results obtainable from using lean manufacturing tools at ABS, a simulation model was used to enhance the value stream mapping and to evaluate the future state map. A $2^3$ factorial design was developed to assess the impact of the production system, TPM, and setup reduction on lead-time as well as WIP inventory. The analysis of the results obtained by the simulation concludes that a hybrid push-pull production system along with TPM can significantly reduce lead-time and inventory. Even under the existing push system, implementing TPM alone results in substantial reduction of WIP.

Last, a 5S and visual system (VS) program for ABS was proposed. The 5S program was proposed at the shipping area and hot mill roll area. A VS system was developed for the shipping area to better track coils with the help of a kanban post. We speculate that 5S & VS can generate significant benefits at ABS.

## 9.2 Conclusions

The main goal of this dissertation was to develop a general methodology to implement lean manufacturing tools and techniques in the process industry with a focus on steel as a specific application instance.

The first task of this research was to develop a taxonomy of the process industries to further characterize it into distinguishable groups and study how lean tools can be applied. The taxonomy demonstrated that process industries share characteristics with discrete industries that make it possible to implement lean techniques, but in varying degrees depending on the specific industry. It also showed that certain techniques such as 5S or visual systems could work universally whereas others would be possible in certain sectors but perhaps harder to implement in others. Thus, low-variety high-volume products such as beverages are not good candidates for JIT or small-lot productions but would benefit from techniques such as TPM and TQM. On the other hand, products such as metals that become discrete relatively early in the process would be good candidates for kanban systems and production smoothing. Products such as specialty chemicals and dyes with flexibility and multiple use equipment in their process could be candidates for cellular layouts and would benefit greatly from setup reduction operations such as setup reduction. In general, the taxonomy thus provides a good starting point to start planning for lean implementation in the process sector.

The second task was to develop a survey of the steel industry to examine the current level of lean implementation in the steel sector. From the survey it was found that with steel companies (as with others), the driving force behind implementing lean was cost reduction. Also from the findings of the survey, various companies reported making at least some effort at using a variety of lean tools such as JIT, TQM, TPM, setup reduction, and 5S. However, the survey also showed that most of the companies surveyed were still in the very early stages of lean implementation. It is clear that steel companies now see the need to implement lean to drive their costs down and become more competitive by reduction of cost, increased customer satisfaction, reduction of machine downtime, and having a better and safer work place.

The third task of this research was the use of value stream mapping to map the current and future state for ABS. The current state map for ABS revealed a huge amount of waste represented by excessive inventory and large production lead-time. The link between the current state map and the unveiling of waste was very clear. The procedure demonstrated a universally applicable method to view the value stream and identify areas of large inventories, long lead-time and lack of information coordination. Value stream mapping is a valuable tool in any lean manufacturing effort and can unveil all the wastes in the entire value stream and not just portions of it. For those in the process industry who want to start the lean journey, it is the ideal starting point. As mentioned before, some lean tools are harder to implement than others in the process industry, so instead of starting the lean journey on the fly, value stream mapping can systematically guide the process industries to see the waste in their value streams and identify the lean tools that best fit their environment.

The fourth task of this research was to address how one could eliminate the wastes identified by the current state map and come up with the first version of a future state map. This was done by carrying out two steps. First, a set of structured questions were addressed so as to develop the future state map. Again, these questions could almost all be applied to any continuous environment. Second, a simulation was used to help come up with the ideal future state map. The results of the first step indicate that companies should integrate the customer into their production system according to the customer takt time, and can then try to practice kanban pull systems production leveling, and paced withdrawal wherever possible in order to achieve potential improvement in the value stream.

In general, simulation provides a means for quantifying the potential gains of lean tools proposed by the first step. It was shown that a designed experiment can rigorously assess the effect of specific tools on system performance measures such as WIP inventory and lead-time. For any process industry that is considering implementing lean manufacturing and that is uncertain of what the potential outcomes might be, simulation can estimate implementation the basic performance measures by comparing the present environment to the proposed lean system. Specifically as demonstrated within this research values for the potential reduction in lead-time and WIP inventory with the lean system can be estimated. Thus, the availability of the information provided by the simulation can facilitate and validate the decision to implement lean manufacturing and can also motivate the organization during the actual implementation in order to obtain the desired results.

Finally, for those lean tools whose gains cannot be readily quantified, we developed a detailed methodology to implement them at ABS. Tools like 5S and VS can have significant impact on ABS when implemented, by further helping in elimination of wastes such as excess inventory, long set up times, and missed shipments.

The findings of this research demonstrated potential gains in different areas at ABS. It is worth mentioning that there could also be some limitations and potential barriers to implementing the different lean tools addressed in this research. These vary from issues like union contracts to management changes. For example, when qualitative lean tools such as 5S were discussed, one of the limitations for the 5S program is the union. The union contracts might oppose thing like sweeping the floor or carrying an audit checklist every week. Also, the workers themselves might resist changes to their current work environment; a simple reason for this is the statement “this is the way we always do business.” Another barrier might be in reducing the number of maintenance workers for the proposed TPM program. Again, the union contracts might not allow for getting rid of or reducing the number of maintenance workers. An additional limitation is the assumption made in this research that the coil width and thickness are fixed, i.e., each coil in every supermarket will have the same width and thickness. This assumption had to be made because it was unrealistic to consider every coil width and thickness in the simulation. Finally, one other last barrier to lean could be management support. Although the survey that was carried out showed that most companies reported strong management support, there possibly could be some resistance to lean, in particular from people who advocate the traditional way of running the steel industry.

In conclusion, the primary focus of this research was on the implementation of lean manufacturing in the process industry, with a focus on steel. It was demonstrated that lean manufacturing is a process for all seasons and it is not only limited to a discrete manufacturing environment. It was shown that value stream mapping is an ideal tool to expose the waste in a value stream and to identify tools for improvement. It was also illustrated by the help of the simulation model and qualitatively as well, that lean manufacturing tools can greatly reduce wastes identified by the current state map. The development of the future state map is not the end of a set of value stream activities. It should be stressed that the value stream should be revisited until the future becomes the present. The idea is to keep the cycle going because if sources of waste are reduced during a cycle, other wastes are uncovered in the next cycle. Lean manufacturing can thus be adapted in any manufacturing situation albeit to varying degrees. As demonstrated, in the steel industry most of the lean tools are applicable with the possible exception of cellular manufacturing. Table 27 below summarizes lean tools and their applicability in the steel industry.

Table 27 Assessment of lean tools in the steel industry

| **Lean Tool** | **Applicability to the process industry** |
|---|---|
| Cellular manufacturing | Very difficult |
| Setup Reduction | Universally Applicable |
| 5S | Universally Applicable |
| Value Stream Mapping | Universally Applicable |
| Just-in-time | Partially Applicable |
| Production Leveling | Partially Applicable |
| Total productive maintenance | Universally Applicable |
| Visual Systems | Universally Applicable |

## 9.3 Research Contributions and Future Directions

The major contribution of this research is the development of a systematic methodology to implement lean manufacturing in the process industry. Previous research has addressed the issue of lean manufacturing in discrete manufacturing but little attention has been paid to the use of lean manufacturing in the process industry. The steel industry was chose as a representative of the process industry.

The primary idea of this research is to help the process industry to take new initiatives such as lean manufacturing in order to become more cost-competitive in today's global market. The methodology developed for the steel industry can be readily extended to other application areas within the continuous process industry. Based on the taxonomy developed, industries such as metal, pharmaceutical, and textile will be a good fit to adapt lean tools that were developed for the steel industry. These industries have several similar characteristics as steel. Metals by and large have the same characteristics as steel and lean tools that were applicable in the steel industry can also be applied in the metal industry. The textile industry, where the product become discrete early in the process can take those practices of lean manufacturing such as kanban pull systems that were implemented in the finishing mill of the steel industry and apply them to its plants. For other process industries there are lean tool which could easily be applied to the manufacturing setting, e.g., setup reduction, TPM, 5S, and VS are applicable in any process industry that wants to become lean.

Finally, one of the contributions of this work is the reduction of inventory and lead-time, (which are major concerns in any industry) which was accomplished when implementing lean. The simulation showed that up to 65% and 89% of lead-time and inventory reduction respectively could be accomplished at ABS respectively if lean tools are utilized.

The value stream mapping in this work was conducted by focusing on the annealed product family at ABS. So a natural extension of this work is to map other product families in the value stream. It is speculated that by mapping other product families, ABS can further expose other types of wastes in the value stream. It is also important to investigate how the synchronization of the pull systems for different product families could be best accomplished.

Having mapped a single firm's value stream, another possible extension of this work would be to extend the current state map to integrate the suppliers and major customers. By doing this a full integration of the entire supply chain for ABS could be achieved. Even though ABS owns its own raw materials, there was huge amount of raw material at the facility indicating that if the suppliers are integrated into the mapping activities better coordination can be accomplished. As far as customer integration goes, ABS should focus on one of its major customers and try to include it in the current map. Although, the mapping activities developed in this work are from the customers' perspective, the inclusion of the customers' value stream in the current state map would mean full customer integration. One other extension of this work is to investigate how the reduction of inventory and lead-time would translate into cost benefits for ABS. For example, the reduction of inventory would help avoid relegating a prime product to non-prime product for which there is a significant penalty (dollars per ton).

Finally, another extension of this work is to transform the production system into a pure pull system. In this research we considered a hybrid production system where through the hot end the system is push and at the finishing mill the system is pull. One idea would be to examine integrating both system to further reduce the inventory created by the push system. Future research should focus on the processing of ladles between the blast furnace and the BOP shop. As indicated in this work more than 60% of ladles wait 45 minutes or more ahead of the BOP, so this should be investigated to try to synchronize the release of the ladles from the blast furnace to the BOP Shop.

# APPENDICES

APPENDIX A (SURVEY)

Lean Manufacturing Survey

**Section 1: Demographic**

Survey Date:

Company Name:

Company Address:

Company Phone number

Interviewee:

Title:

Note:

**Section 2: Project Objectives**

**The objectives of this project are:**

- To investigate how widely lean manufacturing techniques are used in the steel industry.
- To investigate the challenges presented when trying to implement lean manufacturing.
- The benefits gained from lean.

Note: **If you are familiar with lean manufacturing and its tools skip to section 3**

**Definition of lean:**

Lean manufacturing focuses on abolishing or reducing waste, and on maximizing or fully utilizing activities that add value from the customer's perspective.

**Lean tools include:**

- ➢ Cellular manufacturing
- ➢ Just in time
- ➢ Value stream mapping
- ➢ Total preventive maintenance
- ➢ Setup reduction
- ➢ Total quality management
- ➢ 5S

**Definition of lean tools as needed:**

- Cellular manufacturing: Organizes the entire process for one particular product or similar products into a group of team members, includes all the necessary machines and equipment and is known as a "Cell". Facilities within cells are arranged to easily facilitate all operations.  Parts are handed off from operation to operation eliminating setups and unnecessary costs between operations.

- Just in time: Is a pull system where a customer initiates the demand, and then the demand is transmitted backward from the final assembly all the way to raw material, "pulling" all requirements or i.e. move backwards.
- Value stream mapping: A value stream is a compilation of all the actions required to bring a product through the main flow to every product or service, from raw material to delivery to the customer. The goal is to identify and eliminate the waste in the process waste being any activity that does not add value to the final product.
- Total preventive maintenance: Workers have to carry out regular equipment maintenance to detect any anomalies as they occur. The common focus is changed from fixing breakdowns to preventing them. Since operators are the closest to the machines, they are included in maintenance and monitoring activities in order to prevent and provide warning of malfunctions.
- Setup reduction: Continuously try to reduce the set up time on a machine.
- Total quality management: A system of continuous improvement employing participative management and centered on the needs of customers. Key components of TQM are employee involvement and training, problem solving teams, statistical methods, long-term goals and thinking, and recognition that inefficiencies are produced by the system, not people.
- 5S: focuses on effective work place organization and standardized work procedures

**Section 3: Questions**

1) Has your company begun to implement lean manufacturing?

2) How far along are you in implementing lean?

a. 0-25%
b. 26-50%
c. 51-75%
d. 76-100%

3) What lean techniques has your company used?

a. Cellular Manufacturing
b. JIT
c. VSM
d. TPM
e. Setup Reduction
f. TQM
g. 5S

4) How effective was the implementation of each tool?

| **Tool** | **Ineffective** | **Effective** | **Extremely effective** | **N/A** |
|---|---|---|---|---|
| Cellular manufacturing | | | | |
| Just in time | | | | |
| Value stream mapping | | | | |
| Total preventive maintenance | | | | |
| Setup reduction | | | | |
| Total quality management | | | | |
| 5S | | | | |

5) Does your company use any other lean tools (i.e., tools which aim to abolish or reduce waste)?

6) What was the driving force behind implementing lean?

7) What did you expect to gain from implementing lean?

8) To date, what benefits have you gained by implementing lean?

9) While implementing lean, have there been any other unexpected changes within your company?

10) To date, what has been the biggest challenge(s) that you have faced when implementing lean?

11)What phrase best reflects your top management support of lean?

a. Very Unsupportive
b. Unsupportive
c. Neutral
d. Supportive
e. Very supportive

11)Where there any unexpected benefits gained by implementing lean?

Thank you for your time.

**Q:** Would you like a copy of the survey results?

- ❑ Yes
- ❑ No

APPENDIX B (SIMULATION MODEL)

## Simulation Model

**Experiment File**

ATTRIBUTES: cut:
Other product Index:
number of_slabs:
weight:
caster not fail:
HBA Index:
Pickle Index:
LMF Time:
volume:
Furnace Index:
CA Index:
Subladel #:
Continuous Casting Time:
Furnaces only Index:
ET Time:
L50 product Index:
north:
caster time:
caster fail:
OCA Index:
BOP Time:
Degasser Time:
A40 product Index:
V10 product Index:
Cutting width period:
Irvin Time:
rail car #;

SCHEDULES:
ColdmillSchedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,85),DATA(0,15),
DATA(1,85),DATA(0,15),DATA(1,85),

DATA(0,15),DATA(1,85),DATA(0,15),DATA(1,85),DATA(0,15),DATA(1,85),DATA(0,15),D
ATA(1,85),DATA(0,15),DATA(1,85),DATA(0,15),

DATA(1,85),DATA(0,15),DATA(1,85),DATA(0,15),DATA(1,85),DATA(0,15),DATA(1,85),DATA(0,15),DATA(1,85),DATA(0,15),DATA(1,85),
DATA(0,15),DATA(1,85),DATA(0,15):

HSMF2Schedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,720),DATA(0,35),
DATA(1,720),DATA(0,35):

HSMF4Schedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,720),DATA(0,35),
DATA(1,720),DATA(0,35):

Tempermillschedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,170),DATA(0,15),DATA(1,170),DATA(0,15),DATA(1,170),

DATA(0,15),DATA(1,170),DATA(0,15),DATA(1,170),DATA(0,15),DATA(1,170),DATA(0,15),DATA(1,170),DATA(0,15),DATA(1,170),
DATA(0,15):
DegasserSchedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,44640),DATA(0,960):

CasternorthSchedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,43200),DATA(0,960):

HSMF1Schedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,720),DATA(0,35),
DATA(1,720),DATA(0,35):

BOPSchedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,43200),DATA(0,960):

HSMF3Schedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,720),DATA(0,35),
DATA(1,720),DATA(0,35):

HSMF5Schedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,720),DATA(0,35),
DATA(1,720),DATA(0,35):

84PickleSchedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,2160),DATA(0,15):

CastersouthSchedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,43200),DATA(0,960):

LMFSchedule,TYPE(Capacity),FACTOR(1.0),UNITS(Minutes),DATA(1,43200),DATA(0,960);

STORAGES: BA storage:
Pickle storage:
Temper mill storage:

Hot mill storage:
Raw coil storage:
GALV3 storage:
OCA storage:
Cold mill storage:
CA storage:
GALV2 storage:
GALV1 storage:
ET slab storage:
Shipping storage;

```
VARIABLES:
  Degasser furnace.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Pickling.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Separate 13.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
          Separate 22.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
          Cold reduction.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Temper mill.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Bop.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Continuous Casting 2.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Galv2.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):

FactorBA(31),CLEAR(System),CATEGORY("UserSpecified"),1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1,1,1,1,1,1,1,
          1:
          Hot strip mill.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Hot strip mill.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
          Dispose 12.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          CA.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          OCA.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
          Blast Furnace Process.VATime,CLEAR(Statistics),CATEGORY("Exclude"):

FactorCA(15),CLEAR(System),CATEGORY("UserSpecified"),1,1,1,1,1,1,1,1,1,1,1,1,1,1,1:
          Separate 9.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
          Cold reduction.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
          Shipping.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Continuous Casting 2.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):

FactorOCA(13),CLEAR(System),CATEGORY("UserSpecified"),1,1,1,1,1,1,1,1,1,1,1,1,1:
          Galv2.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Batch Coils for BA.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          HSMfurnacesprocessonly.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          BA.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Separate 10.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
          CA.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Degasser furnace.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
```

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Galv1.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Batch Coils for OCA.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Blast Furnace Process.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Hot strip mill.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
LMF furnace.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Batch Ladles.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Galv2.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
Raw Materials.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
casterup_time,CLEAR(System),CATEGORY("User Specified-None"),0:
DisposeofCounterEntity.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Continuous Casting 2.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Decide 36.NumberOut False,CLEAR(Statistics),CATEGORY("Exclude"):
Blast Furnace Process.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
Decide 36.NumberOut True,CLEAR(Statistics),CATEGORY("Exclude"):
Continuous Casting 1.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
Continuous Casting 1.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Separate 14.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
Separate 23.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
Batch for PK.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
HSMfurnacesprocessonly.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Temper mill.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
CA.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Temper mill.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
CA.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Degasser furnace.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Hot strip mill.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
LMF furnace.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
Check Period.NumberOut False,CLEAR(Statistics),CATEGORY("Exclude"):
Cold reduction.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Batch Slabs for HSM furnace.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Tundishdown_time,CLEAR(System),CATEGORY("User Specified-None"),0:
Separate 9.NumberOut Dup,CLEAR(Statistics),CATEGORY("Exclude"):
Galv2.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Galv1.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Pickling.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
Cold reduction.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
Separate 14.NumberOut Dup,CLEAR(Statistics),CATEGORY("Exclude"):
Separate.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
HSM furnaces process only.WIP,CLEAR(System),CATEGORY("Exclude Exclude"):
BA.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
HSMfurnacesprocessonly.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Blast Furnace Process.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
LMF furnace.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Pickling.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Bop.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
CA.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
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```
Galv3.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Period,CLEAR(System),CATEGORY("User Specified-None"),0:
Continuous Casting 1.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Continuous Casting 1.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
Blast Furnace Process.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Temper mill.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Cold reduction.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Degasser furnace.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
HSMfurnacesprocessonly.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
BA.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Galv3.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Batchslabstobetransported.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
width1,CLEAR(System),CATEGORY("User Specified-None"):
width2,CLEAR(System),CATEGORY("User Specified-None"):
Separate 10.NumberOut Dup,CLEAR(Statistics),CATEGORY("Exclude"):
width3,CLEAR(System),CATEGORY("User Specified-None"):
width4,CLEAR(System),CATEGORY("User Specified-None"):
Continuous Casting 1.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Separate 15.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
Galv3.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
Galv1.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
Galv3.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
Pickling.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
BA.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Shipping.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
Check Period.NumberOut True,CLEAR(Statistics),CATEGORY("Exclude"):
Continuous Casting 2.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
Separate 12.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
Bop.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
BA.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Galv1.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
Create Counter Entity.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Separate 19.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
Pickling.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
LMF furnace.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
OCA.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Galv2.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
BatchforslabsinNstrand.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
casterdown_time,CLEAR(System),CATEGORY("User Specified-None"),0:
Bop.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
Tundishup_time,CLEAR(System),CATEGORY("User Specified-None"),0:
Bop.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Continuous Casting 2.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"):
OCA.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
FactorPKL(2),CLEAR(System),CATEGORY("User Specified"),1,1:
Shipping.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
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          Galv1.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
          LMF furnace.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Galv3.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
          Shipping.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
          OCA.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Temper mill.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Degasser furnace.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          FactorHSM(4),CLEAR(System),CATEGORY("User Specified"),1,1,1,1:
          OCA.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          BatchforslabsinSstrand.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Hot strip mill.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Shipping.WIP,CLEAR(System),CATEGORY("Exclude-Exclude");

QUEUES:   Galv1.Queue,FIFO,,AUTOSTATS(Yes,,):
          Batch Coils for BA.Queue,FIFO,,AUTOSTATS(Yes,,):
          Galv2.Queue,FIFO,,AUTOSTATS(Yes,,):
          Galv3.Queue,FIFO,,AUTOSTATS(Yes,,):
          Shipping.Queue,FIFO,,AUTOSTATS(Yes,,):
          Batch for slabs in Nstrand.Queue,FIFO,,AUTOSTATS(Yes,,):
          LMF furnace.Queue,FIFO,,AUTOSTATS(Yes,,):
          CA.Queue,FIFO,,AUTOSTATS(Yes,,):
          Degasser furnace.Queue,FIFO,,AUTOSTATS(Yes,,):
          Batch Slabs for HSM furnace.Queue,FIFO,,AUTOSTATS(Yes,,):
          Cold reduction.Queue,FIFO,,AUTOSTATS(Yes,,):
          Batch for PK.Queue,FIFO,,AUTOSTATS(Yes,,):
          Blast Furnace Process.Queue,FIFO,,AUTOSTATS(Yes,,):
          Pickling.Queue,FIFO,,AUTOSTATS(Yes,,):
          Temper mill.Queue,FIFO,,AUTOSTATS(Yes,,):
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          OCA.Queue,FIFO,,AUTOSTATS(Yes,,):
          Batch Coils for OCA.Queue,FIFO,,AUTOSTATS(Yes,,):
          Hot strip mill.Queue,FIFO,,AUTOSTATS(Yes,,):
          Request 6.Queue,FIFO,,AUTOSTATS(Yes,,):
          Bop.Queue,FIFO,,AUTOSTATS(Yes,,):
          Batch slabs to be transported.Queue,FIFO,,AUTOSTATS(Yes,,):
          HSM furnaces process only.Queue,FIFO,,AUTOSTATS(Yes,,):
          Batch Ladles.Queue,FIFO,,AUTOSTATS(Yes,,):
          Continuous Casting 2.Queue,FIFO,,AUTOSTATS(Yes,,):
          Request 7.Queue,FIFO,,AUTOSTATS(Yes,,):
          BA.Queue,FIFO,,AUTOSTATS(Yes,,);

PICTURES: Picture.Airplane:
          Picture.Green Ball:
          Picture.Blue Page:
          picture.L50HRPKL:
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Picture.SlabB:
picture.V10CROCA:
Picture.SlabG:
Picture.SlabR:
picture.L50GALV1:
picture.L50GALV2:
Picture.Telephone:
Picture.A40CROCA:
Picture.Blue Ball:
Picture.Yellow Page:
Picture.EMail:
Picture.A40HR:
Picture.Yellow Ball:
Picture.Bike:
Picture.Report:
Picture.Van:
Picture.Widgets:
Picture.Envelope:
Picture.Fax:
picture.OtherHRPKL:
Picture.Truck:
picture.L50CRBA:
picture.OtherGALV1:
picture.OtherGALV2:
picture.OtherGALV3:
Picture.Letter:
picture.L50CRCA:
Picture.Box:
Picture.Woman:
Picture.Package:
Picture.Man:
picture.OtherCRBA:
Picture.Diskette:
picture.OtherHR:
Picture.A40CRBA:
Picture.Boat:
picture.OtherCROCA:
picture.OtherCRCA:
Picture.A40CRCA:
Picture.Red Page:
Picture.A40HRPKL:
Picture.A40GALV2:
Picture.A40GALV3:
Picture.Green Page:
Picture.Red Ball;

FAILURES:
CastersouthFailure,Time(MinutesToBaseTime(casterup_time),MinutesToBaseTime(casterdown_time),):

BlastFurnace2Failure,Time(MinutesToBaseTime(EXPO(20160)),MinutesToBaseTime(UNIF(120,240)),):

TundishsouthChange,Time(MinutesToBaseTime(Tundishup_time),MinutesToBaseTime(Tundishdown_time),):

BlastFurnace1Failure,Time(MinutesToBaseTime(EXPO(20160)),MinutesToBaseTime(UNIF(120,240)),):

TM roll Failure 1,Time(MinutesToBaseTime(4320),MinutesToBaseTime(90),):

TM roll Failure 2,Time(MinutesToBaseTime(11520),MinutesToBaseTime(90),):
BlastFurnace2Planned,Time(MinutesToBaseTime(87840),MinutesToBaseTime(960),):

TundishnorthChange,Time(MinutesToBaseTime(Tundishup_time),MinutesToBaseTime(Tundishdown_time),):
BlastFurnace1planned,Time(MinutesToBaseTime(86400),MinutesToBaseTime(960),):

64pickleFailure,Time(MinutesToBaseTime(EXPO(20160)),MinutesToBaseTime(UNIF(120,300)),):

HSMFailure,Time(MinutesToBaseTime(EXPO(20160)),MinutesToBaseTime(UNIF(180,480)),):

HSMrollFailure,Time(MinutesToBaseTime(10080),MinutesToBaseTime(120),):

TM Failure,Time(MinutesToBaseTime(EXPO( 17280 )),MinutesToBaseTime(UNIF(120 , 300 )),):
Coldreductionrollfailure,Time(MinutesToBaseTime(8640),MinutesToBaseTime(120),):

ColdmillFailure,Time(MinutesToBaseTime(EXPO(17280)),MinutesToBaseTime(UNIF(120,300)),):

CasternorthFailure,Time(MinutesToBaseTime(casterup_time),MinutesToBaseTime(casterdown_time),):

84pickleFailure,Time(MinutesToBaseTime(EXPO(20160)),MinutesToBaseTime(UNIF(120,300)),):

LMFFailure,Time(MinutesToBaseTime(EXPO(24480)),MinutesToBaseTime(UNIF(1440,2880)),):

DegasserFailure,Time(MinutesToBaseTime(EXPO(24480)),MinutesToBaseTime(UNIF(1440,2880)),);

RESOURCES:

OxygenFurnace,Schedule(BOPSchedule,Wait),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

LMF,Schedule(LMFSchedule,Wait),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(LMF Failure,Ignore),AUTOSTATS(Yes,,):
64 Pickle,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(64 pickle Failure,Ignore),AUTOSTATS(Yes,,):

HBA3,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA4,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA5,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA6,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA7,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA8,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA9,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

Galv2line,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

Furnace1,Schedule(HSMF1Schedule,Ignore),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(HSM roll Failure,Ignore),
FAILURE(HSM Failure,Ignore),AUTOSTATS(Yes,,):

Furnace2,Schedule(HSMF2Schedule,Ignore),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(HSM roll Failure,Ignore), FAILURE(HSM

Furnace3,Schedule(HSMF3Schedule,Ignore),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(HSM roll Failure,Ignore), FAILURE(HSM Failure,Ignore),AUTOSTATS(Yes,,):

Furnace4,Schedule(HSMF4Schedule,Ignore),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(HSM roll Failure,Ignore),
FAILURE(HSM Failure,Ignore),AUTOSTATS(Yes,,):

Furnace5,Schedule(HSMF5Schedule,Ignore),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(HSM roll Failure,Ignore),

FAILURE(HSM Failure,Ignore),AUTOSTATS(Yes,,):
CA10,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA11,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA12,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA13,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA14,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA15,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA13,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA14,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

TemperMillline,Schedule(Tempermillschedule,Ignore),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(TM roll Failure 1,Ignore),
FAILURE(TM roll Failure 2,Ignore),FAILURE(TM Failure,Ignore),AUTOSTATS(Yes,,):
CA1,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA2,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA3,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA4,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA5,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA6,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA7,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA8,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
CA9,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA1,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA2,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA3,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA4,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA5,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA6,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA7,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA8,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA9,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
Blast Furnace1,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(Blast Furnace 1 Failure,Ignore),

FAILURE(Blast Furnace 1 planned,Ignore),AUTOSTATS(Yes,,):
Blast
Furnace2,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(Blast Furnace 2 Failure,Ignore),
FAILURE(Blast Furnace 2 Planned,Ignore),AUTOSTATS(Yes,,):

Galv1line,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

Castersouth,Schedule(CastersouthSchedule,Wait),,,COST(0.0,0.0,0.0),CATEGORY(Resources), FAILURE(Caster south Failure,Ignore),
FAILURE(Tundish south Change,Ignore),AUTOSTATS(Yes,,):

Coldreductionline,Schedule(ColdmillSchedule,Ignore),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(Cold reduction roll failure,Ignore),
FAILURE(Cold mill Failure,Ignore),AUTOSTATS(Yes,,):

HBA1,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA2,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
Degasser,Schedule(Degasser
Schedule,Wait),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(Degasser Failure,Ignore),
AUTOSTATS(Yes,,):

Galv3line,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA10,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA11,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA12,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA15,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA16,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA17,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA18,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA19,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

84pickle,Schedule(84PickleSchedule,Ignore),,,COST(0.0,0.0,0.0),CATEGORY(Resources),FAILURE(84 pickle Failure,Ignore),
AUTOSTATS(Yes,,):

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HBA20,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA21,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA22,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA23,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA24,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA25,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA26,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA27,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA28,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA10,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA29,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA11,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

Shippingline,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA12,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

OCA13,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA30,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

HBA31,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):

Casternorth,Schedule(CasternorthSchedule,Wait),,,COST(0.0,0.0,0.0),CATEGORY(Resources),
FAILURE(Caster north Failure,Ignore),
          FAILURE(Tundish north Change,Ignore),AUTOSTATS(Yes,,);

STATIONS:
  galv1:
          galv2:
          galv3:
          cold red:
          Blast furnace station:
          others caster prepare:
```

V10 Degasser prepare:
slab prepar:
L50 caster prepare:
Bins station:
BA:
CA:
Continuous Casting station:
temper mill:
V10 caster prepare:
Irvin:
Slab station:
Finished from blast furnace:
LMF station:
hotmill:
others Degasser prepare:
Degasser station:
A40 LMF prepare:
BOP station:
others LMF prepare:
A40  caster prepare:
pickling:
shipping:
OCA:
L50 LMF prepare;

DISTANCES:
submarine ladel.Distance,Finished from blast furnace-BOP station-1,BOP station-Finished from blast furnace-1:
rail car.Distance,Slab station-Irvin-7,Irvin-Slab station-7;

TRANSPORTERS:
rail car,149,(rail car.Distance),0.28---,Station(Slab station),AUTOSTATS(Yes,,):
submarine ladel,23,(submarine ladel.Distance),40---,Station(Finished from blast furnace),AUTOSTATS(Yes,,);

SEQUENCES:
Other galv1,hotmill,STEPNAME=Othergalv1 step 1&pickling,STEPNAME=Othergalv1 step 3&cold red,STEPNAME=
Othergalv1 step 5&galv1,STEPNAME=Othergalv1 step 7&shipping,STEPNAME=Othergalv1 step 8:
Other galv2,hotmill,STEPNAME=Othergalv2 step 1&pickling,STEPNAME=Othergalv2 step 3&cold red,STEPNAME=
Othergalv2 step 5&galv2,STEPNAME=Othergalv2 step 7&shipping,STEPNAME=Othergalv2 step 8:
Other galv3,hotmill,STEPNAME=Othergalv3 step 1&pickling,STEPNAME=Othergalv3 step 3&cold red,STEPNAME=

Othergalv3 step 5&galv3,STEPNAME=Othergalv3 step 7&shipping,STEPNAME=Othergalv3 step 8:

L50 CR BA,hotmill,STEPNAME=L50CR BA step 1&pickling,STEPNAME=L50CR BA step 3&cold red,STEPNAME=L50CR BA step 5&BA,

STEPNAME=L50CR BA step 7&temper mill,STEPNAME=L50CR BA step 9&shipping,STEPNAME=L50CR BA step 10:

A40 CR BA,hotmill,STEPNAME=A40CR BA step 1&pickling,STEPNAME=A40CR BA step 3&cold red,STEPNAME=A40CR BA step 5&BA,

STEPNAME=A40CR BA step 7&temper mill,STEPNAME=A40CR BA step 9&shipping,STEPNAME=A40CR BA step 10:

Other hotroll pkl,hotmill,STEPNAME=OtherHRpkl step 1&pickling,STEPNAME=OtherHRpkl step 3&shipping,STEPNAME=

OtherHRpkl step 4:

L50 CR CA,hotmill,STEPNAME=L50CR CA step 1&pickling,STEPNAME=L50CR CA step 3&cold red,STEPNAME=L50CR CA step 5&CA,

STEPNAME=L50CR CA step 7&temper mill,STEPNAME=L50CR CA step 9&shipping,STEPNAME=L50CR CA step 10:

A40 CR CA,hotmill,STEPNAME=A40CR CA step 1&pickling,STEPNAME=A40CR CA step 3&cold red,STEPNAME=A40CR CA step 5&CA,

STEPNAME=A40CR CA step 7&temper mill,STEPNAME=A40CR CA step 9&shipping,STEPNAME=A40CR CA step 10:

A40 hotroll pkl,hotmill,STEPNAME=A40HRpkl step 1&pickling,STEPNAME=A40HRpkl step 3&shipping,STEPNAME=

A40HRpkl step 4:

Other CR OCA,hotmill,STEPNAME=OtherCR OCA step 1&pickling,STEPNAME=OtherCR OCA step 3&cold red,STEPNAME=

OtherCR OCA step 5&OCA,STEPNAME=OtherCR OCA step 7&temper mill,STEPNAME=OtherCR OCA step 8&shipping,STEPNAME=

OtherCR OCA step 10:

L50 hotroll pkl,hotmill,STEPNAME=L50HRpkl step 1&pickling,STEPNAME=L50HRpkl step 3&shipping,STEPNAME=

L50HRpkl step 4:

L50 galv1,hotmill,STEPNAME=L50galv1 step 1&pickling,STEPNAME=L50galv1 step 3&cold red,STEPNAME=L50galv1 step 5&

galv1,STEPNAME=L50galv1 step 7&shipping,STEPNAME=L50galv1 step 8:

L50 galv2,hotmill,STEPNAME=L50galv2 step 1&pickling,STEPNAME=L50galv2 step 3&cold red,STEPNAME=L50galv2 step 5&

galv2,STEPNAME=L50galv2 step 7&shipping,STEPNAME=L50galv2 step 8:

A40 galv2,hotmill,STEPNAME=A40galv2 step 1&pickling,STEPNAME=A40galv2 step 3&cold red,STEPNAME=A40galv2 step 5&

galv2,STEPNAME=A40galv2 step 7&shipping,STEPNAME=A40galv2 step 8:

A40 galv3,hotmill,STEPNAME=A40galv3 step 1&pickling,STEPNAME=A40galv3 step 3&cold red,STEPNAME=A40galv3 step 5&

galv3,STEPNAME=A40galv3 step 7&shipping,STEPNAME=A40galv3 step 8:

A40 hotroll,hotmill,STEPNAME=A40HR step 1&shipping,STEPNAME=A40HR step2:

Other CR BA,hotmill,STEPNAME=OtherCR BA step 1&pickling,STEPNAME=OtherCR BA step 3&cold red,STEPNAME=
OtherCR BA step 5&BA,STEPNAME=OtherCR BA step 7&temper mill,STEPNAME=OtherCR BA step 9&shipping,STEPNAME=
OtherCR BA step 10:
Other hotroll,hotmill,STEPNAME=OtherHR step 1&shipping,STEPNAME=OtherHR step2:
Other CR CA,hotmill,STEPNAME=OtherCR CA step 1&pickling,STEPNAME=OtherCR CA step 3&cold red,STEPNAME=
OtherCR CA step 5&CA,STEPNAME=OtherCR CA step 7&temper mill,STEPNAME=OtherCR CA step 9&shipping,STEPNAME=
OtherCR CA step 10:
V10 CR OCA,hotmill,STEPNAME=V10CR OCA step 1&pickling,STEPNAME=V10CR OCA step 3&cold red,STEPNAME=
V10CR OCA step 5&OCA,STEPNAME=V10CR OCA step 7&temper mill,STEPNAME=V10CR OCA step 9&shipping,STEPNAME=
V10CR OCA step 10;

COUNTERS:
2,batch,,Replicate,"batch.dat":
3,entity1,,Replicate,"entity1.dat":
4,entity1 from BF,,Replicate:
5,afourty,,Replicate:
6,lten,,Replicate:
7,vten,,Replicate:
8,therest,,Replicate:
weightlarge,,,,DATABASE(,"Count","User Specified","weightlarge"):
number of slabs from N,,,,DATABASE(,"Count","User Specified","number of slabs from N"):
number of slabs from S,,,,DATABASE(,"Count","User Specified","number of slabs from S"):
l10 counter,,,,DATABASE(,"Count","User Specified","l10 counter"):
Cout Batched Ladles,,,,DATABASE(,"Count","User Specified","Cout Batched Ladles"):
volumesmall,,,,DATABASE(,"Count","User Specified","volumesmall"):
a40 counter,,,,DATABASE(,"Count","User Specified","a40 counter"):
volumelarge,,,,DATABASE(,"Count","User Specified","volumelarge"):
weightsmall,,,,DATABASE(,"Count","User Specified","weightsmall"):
rest counter,,,,DATABASE(,"Count","User Specified","rest counter"):
entity1 from BFcounter,,,,DATABASE(,"Count","User Specified","entity1 from BFcounter"):
v10 counter,,,,DATABASE(,"Count","User Specified","v10 counter");

TALLIES:

Galv1.VATimePerEntity,,DATABASE(,"VA Time","Process","Galv1"):

BA.TotalTimePerEntity,,DATABASE(,"Total Time","Process","BA"):
LMF furnace.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","LMF furnace"):
NUMBER in storage COLD R,,DATABASE(,"Expression","User Specified","NUMBER in storage COLD R"):
NUMBER in storage HSM,,DATABASE(,"Expression","User Specified","NUMBER in storage HSM"):
Galv2.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Galv2"):
Time spent At ET,,DATABASE(,"Interval","User Specified","Time spent At ET"):
Galv2.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Galv2"):
Blast Furnace Process.VATimePerEntity,,DATABASE(,"VA Time","Process","Blast Furnace Process"):
Degasser furnace.VATimePerEntity,,DATABASE(,"VA Time","Process","Degasser furnace"):
Pickling.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Pickling"):
Record 68,,DATABASE(,"Expression","User Specified","Record 68"):
Cold reduction.VATimePerEntity,,DATABASE(,"VA Time","Process","Cold reduction"):
Cold reduction.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Cold reduction"):
Bop.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Bop"):
NUMBER in storage OCA,,DATABASE(,"Expression","User Specified","NUMBER in storage OCA"):
CA.TotalTimePerEntity,,DATABASE(,"Total Time","Process","CA"):
Degasser furnace.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Degasser furnace"):
Interarrival time for Pickle Inventory,"",DATABASE(,,"User Specified",):
Galv2.VATimePerEntity,,DATABASE(,"VA Time","Process","Galv2"):
Galv1.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Galv1"):
Pickling.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Pickling"):
Temper mill.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Temper mill"):
Galv3.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Galv3"):
Temper mill.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Temper mill"):
OCA.VATimePerEntity,,DATABASE(,"VA Time","Process","OCA"):
Blast Furnace Process.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Blast Furnace Process"):
Shipping.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Shipping"):
NUMBER in storage for GALV1,,DATABASE(,"Expression","User Specified","NUMBER in storage for GALV1"):
NUMBER in storage for GALV2,,DATABASE(,"Expression","User Specified","NUMBER in storage for GALV2"):
CA.VATimePerEntity,,DATABASE(,"VA Time","Process","CA"):
NUMBER in storage for GALV3,,DATABASE(,"Expression","User Specified","NUMBER in storage for GALV3"):
Shipping.VATimePerEntity,,DATABASE(,"VA Time","Process","Shipping"):

Hot strip mill.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Hot strip mill"):
Continuous Casting 2.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Continuous Casting 2"):
Galv3.VATimePerEntity,,DATABASE(,"VA Time","Process","Galv3"):
Avg waiting time for PK inventory,"",DATABASE(,,"User Specified",):
Interarrival time for OCA,,DATABASE(,"Between","User Specified","Interarrival time for OCA"):
NUMBER in storage Temper mill,,DATABASE(,"Expression","User Specified","NUMBER in storage Temper mill"):
Continuous Casting 1.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Continuous Casting 1"):
Time spent At Irvin,"Entity Time.dat",DATABASE(,"Interval","User Specified","Time spent At Irvin"):
OCA.TotalTimePerEntity,,DATABASE(,"Total Time","Process","OCA"):
Cold reduction.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Cold reduction"):
HSM furnaces process only.VATimePerEntity,,DATABASE(,"VA Time","Process","HSM furnaces process only"):
Hot strip mill.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Hot strip mill"):
Continuous Casting 1.VATimePerEntity,,DATABASE(,"VA Time","Process","Continuous Casting 1"):
CA.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","CA"):
NUMBER in storage for PK,,DATABASE(,"Expression","User Specified","NUMBER in storage for PK"):
Degasser furnace.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Degasser furnace"):
NUMBER in storage BA,,DATABASE(,"Expression","User Specified","NUMBER in storage BA"):
Shipping.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Shipping"):
Galv1.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Galv1"):
LMF furnace.TotalTimePerEntity,,DATABASE(,"Total Time","Process","LMF furnace"):
BA.VATimePerEntity,,DATABASE(,"VA Time","Process","BA"):
Continuous Casting 1.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Continuous Casting 1"):
Pickling.VATimePerEntity,,DATABASE(,"VA Time","Process","Pickling"):
NUMBER in storage CA,,DATABASE(,"Expression","User Specified","NUMBER in storage CA"):
Galv3.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Galv3"):
Continuous Casting 2.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","Continuous Casting 2"):
Bop.VATimePerEntity,,DATABASE(,"VA Time","Process","Bop"):
Continuous Casting 2.VATimePerEntity,,DATABASE(,"VA Time","Process","Continuous Casting 2"):

Bop.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Bop"):
HSM furnaces process only.TotalTimePerEntity,,DATABASE(,"Total Time","Process","HSM furnaces process only"):
BA.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","BA"):
OCA.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","OCA"):
Hot strip mill.VATimePerEntity,,DATABASE(,"VA Time","Process","Hot strip mill"):
Temper mill.VATimePerEntity,,DATABASE(,"VA Time","Process","Temper mill"):
HSM furnaces process only.WaitTimePerEntity,,DATABASE(,"Wait Time","Process","HSM furnaces process only"):
Blast Furnace Process.TotalTimePerEntity,,DATABASE(,"Total Time","Process","Blast Furnace Process"):
LMF furnace.VATimePerEntity,,DATABASE(,"VA Time","Process","LMF furnace");

DSTATS:

NSTO(BA storage)+NSTO(CA storage)+NSTO(Cold mill storage)+NSTO(OCA storage)+NSTO(Pickle storage)+NSTO(Temper mill storage)+NSTO(Shipping storage),
Total Inventory in System,"TotalWIP1.dat",DATABASE(,"Time Persistent","User Specified","Total Inventory in System"):
NSTO(Hot mill storage),WIP ahead of HSM,"WIP HSM.dat",DATABASE(,"Time Persistent","User Specified",
"WIP ahead of HSM"):

EntitiesWIP(A40GALV3)+EntitiesWIP(A40CRBA)+EntitiesWIP(A40CRCA)+EntitiesWIP(L50GALV1)+EntitiesWIP(L50GALV2),
Total WIP,"TotalWIP.dat",DATABASE(,"Time Persistent","User Specified","Total WIP");

FREQUENCIES: State(Blast Furnace 1),BF1,"fail.dat",DATABASE(,"Frequency","User Specified","BF1"):
State(Blast Furnace 2),BF2,"",DATABASE(,"Frequency","User Specified","BF2"):
State(Caster south),casters,"",DATABASE(,"Frequency","User Specified","casters"):
State(Caster north),castern,"",DATABASE(,"Frequency","User Specified","castern");

OUTPUTS: Degasser furnace.NumberOut,,Degasser furnace Number Out,DATABASE(,"Number Out","Process","Degasser furnace"):
Pickling.VATime,,Pickling Accum VA Time,DATABASE(,"Accum VA Time","Process","Pickling"):
Cold reduction.NumberIn,,Cold reduction Number In,DATABASE(,"Number In","Process","Cold reduction"):
Temper mill.NumberOut,,Temper mill Number Out,DATABASE(,"Number Out","Process","Temper mill"):
Bop.NumberOut,,Bop Number Out,DATABASE(,"Number Out","Process","Bop"):
Continuous Casting 2.NumberIn,,Continuous Casting 2 Number In,DATABASE(,"Number In","Process",
"Continuous Casting 2"):

Hot strip mill.NumberIn,,Hot strip mill Number In,DATABASE(,"Number In","Process","Hot strip mill"):
CA.VATime,,CA Accum VA Time,DATABASE(,"Accum VA Time","Process","CA"):
OCA.WaitTime,,OCA Accum Wait Time,DATABASE(,"Accum Wait Time","Process","OCA"):
Blast Furnace Process.VATime,,Blast Furnace Process Accum VA Time,DATABASE(,"Accum VA Time","Process",
"Blast Furnace Process"):
Cold reduction.WaitTime,,Cold reduction Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Cold reduction"):
Shipping.VATime,,Shipping Accum VA Time,DATABASE(,"Accum VA Time","Process","Shipping"):
Continuous Casting 2.WaitTime,,Continuous Casting 2 Accum Wait Time,DATABASE(,"Accum Wait Time","Process",
"Continuous Casting 2"):
Galv2.NumberIn,,Galv2 Number In,DATABASE(,"Number In","Process","Galv2"):
HSM furnaces process only.NumberIn,,HSM furnaces process only Number In,DATABASE(,"Number In","Process",
"HSM furnaces process only"):
BA.VATime,,BA Accum VA Time,DATABASE(,"Accum VA Time","Process","BA"):
CA.NumberIn,,CA Number In,DATABASE(,"Number In","Process","CA"):
Degasser furnace.NumberIn,,Degasser furnace Number In,DATABASE(,"Number In","Process","Degasser furnace"):
Galv1.NumberOut,,Galv1 Number Out,DATABASE(,"Number Out","Process","Galv1"):
Blast Furnace Process.NumberOut,,Blast Furnace Process Number Out,DATABASE(,"Number Out","Process",
"Blast Furnace Process"):
Hot strip mill.WaitTime,,Hot strip mill Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Hot strip mill"):
Galv2.VATime,,Galv2 Accum VA Time,DATABASE(,"Accum VA Time","Process","Galv2"):
Continuous Casting 2.NumberOut,,Continuous Casting 2 Number Out,DATABASE(,"Number Out","Process",
"Continuous Casting 2"):
Blast Furnace Process.NumberIn,,Blast Furnace Process Number In,DATABASE(,"Number In","Process",
"Blast Furnace Process"):
Continuous Casting 1.VATime,,Continuous Casting 1 Accum VA Time,DATABASE(,"Accum VA Time","Process",
"Continuous Casting 1"):
HSM furnaces process only.WaitTime,,HSM furnaces process only Accum Wait Time,DATABASE(,"Accum Wait Time",
"Process","HSM furnaces process only"):
Temper mill.NumberIn,,Temper mill Number In,DATABASE(,"Number In","Process","Temper mill"):

CA.WaitTime,,CA Accum Wait Time,DATABASE(,"Accum Wait Time","Process","CA"):
Degasser furnace.WaitTime,,Degasser furnace Accum Wait Time,DATABASE(,"Accum Wait Time","Process",
"Degasser furnace"):
Hot strip mill.NumberOut,,Hot strip mill Number Out,DATABASE(,"Number Out","Process","Hot strip mill"):
LMF furnace.NumberIn,,LMF furnace Number In,DATABASE(,"Number In","Process","LMF furnace"):
Cold reduction.NumberOut,,Cold reduction Number Out,DATABASE(,"Number Out","Process","Cold reduction"):
Galv2.WaitTime,,Galv2 Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Galv2"):
Pickling.NumberIn,,Pickling Number In,DATABASE(,"Number In","Process","Pickling"):
Cold reduction.VATime,,Cold reduction Accum VA Time,DATABASE(,"Accum VA Time","Process","Cold reduction"):
BA.NumberIn,,BA Number In,DATABASE(,"Number In","Process","BA"):
HSM furnaces process only.NumberOut,,HSM furnaces process only Number Out,DATABASE(,"Number Out","Process",
"HSM furnaces process only"):
Blast Furnace Process.WaitTime,,Blast Furnace Process Accum Wait Time,DATABASE(,"Accum Wait Time","Process",
"Blast Furnace Process"):
LMF furnace.WaitTime,,LMF furnace Accum Wait Time,DATABASE(,"Accum Wait Time","Process","LMF furnace"):
Bop.VATime,,Bop Accum VA Time,DATABASE(,"Accum VA Time","Process","Bop"):
CA.NumberOut,,CA Number Out,DATABASE(,"Number Out","Process","CA"):
Galv3.NumberOut,,Galv3 Number Out,DATABASE(,"Number Out","Process","Galv3"):
Continuous Casting 1.NumberOut,,Continuous Casting 1 Number Out,DATABASE(,"Number Out","Process",
"Continuous Casting 1"):
Continuous Casting 1.NumberIn,,Continuous Casting 1 Number In,DATABASE(,"Number In","Process",
"Continuous Casting 1"):
Temper mill.WaitTime,,Temper mill Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Temper mill"):
HSM furnaces process only.VATime,,HSM furnaces process only Accum VA Time,DATABASE(,"Accum VA Time","Process",
"HSM furnaces process only"):
BA.WaitTime,,BA Accum Wait Time,DATABASE(,"Accum Wait Time","Process","BA"):
Continuous Casting 1.WaitTime,,Continuous Casting 1 Accum Wait Time,DATABASE(,"Accum Wait Time","Process",

"Continuous Casting 1"):
Galv3.VATime,,Galv3 Accum VA Time,DATABASE(,"Accum VA Time","Process","Galv3"):
Galv1.NumberIn,,Galv1 Number In,DATABASE(,"Number In","Process","Galv1"):
Galv3.NumberIn,,Galv3 Number In,DATABASE(,"Number In","Process","Galv3"):
Pickling.WaitTime,,Pickling Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Pickling"):
Shipping.NumberIn,,Shipping Number In,DATABASE(,"Number In","Process","Shipping"):
Continuous Casting 2.VATime,,Continuous Casting 2 Accum VA Time,DATABASE(,"Accum VA Time","Process",
"Continuous Casting 2"):
Bop.NumberIn,,Bop Number In,DATABASE(,"Number In","Process","Bop"):
BA.NumberOut,,BA Number Out,DATABASE(,"Number Out","Process","BA"):
Galv1.VATime,,Galv1 Accum VA Time,DATABASE(,"Accum VA Time","Process","Galv1"):
Pickling.NumberOut,,Pickling Number Out,DATABASE(,"Number Out","Process","Pickling"):
LMF furnace.VATime,,LMF furnace Accum VA Time,DATABASE(,"Accum VA Time","Process","LMF furnace"):
Galv2.NumberOut,,Galv2 Number Out,DATABASE(,"Number Out","Process","Galv2"):
Bop.WaitTime,,Bop Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Bop"):
OCA.NumberOut,,OCA Number Out,DATABASE(,"Number Out","Process","OCA"):
Shipping.NumberOut,,Shipping Number Out,DATABASE(,"Number Out","Process","Shipping"):
Galv1.WaitTime,,Galv1 Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Galv1"):
LMF furnace.NumberOut,,LMF furnace Number Out,DATABASE(,"Number Out","Process","LMF furnace"):
Galv3.WaitTime,,Galv3 Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Galv3"):
Shipping.WaitTime,,Shipping Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Shipping"):
OCA.VATime,,OCA Accum VA Time,DATABASE(,"Accum VA Time","Process","OCA"):
Temper mill.VATime,,Temper mill Accum VA Time,DATABASE(,"Accum VA Time","Process","Temper mill"):
Degasser furnace.VATime,,Degasser furnace Accum VA Time,DATABASE(,"Accum VA Time","Process","Degasser furnace"):
TAVG(Time spent At ET)+TAVG(Time spent At Irvin),"totaltime.dat",Total Time in System,DATABASE(,"Output",
"User Specified","Total Time in System"):
OCA.NumberIn,,OCA Number In,DATABASE(,"Number In","Process","OCA"):

```
     Hot strip mill.VATime,,Hot strip mill Accum VA Time,DATABASE(,"Accum VA
Time","Process","Hot strip mill");

REPLICATE,
5,,MinutesToBaseTime(200000),Yes,Yes,MinutesToBaseTime(60000),,,24,Minutes,No,No;

EXPRESSIONS:
  furnace discharge time(2),NORM(179,20.2),NORM(180,19.9):
     Furnaces only Time(5),150,150,150,150,150:
     Galv2 time(1),EXPO(1):
     pickle time(1),NORM(4,1):
     cast_down,UNIF(180,480):
     Tundish_down,UNIF(12,14):
     OCA time(1),UNIF(1200,1440):
     hotmill time(1),NORM(10,1.99):
     Galv1 time(1),EXPO(1):
     cold red time(1),ERLA(0.956,4):
     BA time(1),TRIA(900,1470,2040):
     temper time(1),UNIF(2,7):
     cast_up,EXPO(20160):
     strand,NORM(0.504,0.0569):
     CA time(1),TRIA(10,17.5,25):
     Galv3 time(1),EXPO(1):
     Tundish_up,720;

ENTITIES:   OtherHRPKL,picture.OtherHRPKL,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     V10,Picture.Red Ball,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     OtherGALV1,picture.OtherGALV1,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     OtherGALV2,picture.OtherGALV2,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     OtherGALV3,picture.OtherGALV3,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     L50CRBA,picture.L50CRBA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     others,Picture.Report,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     L50CRCA,picture.L50CRCA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     Counter Entity,Picture.Report,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     slab A40,Picture.SlabG,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     OtherCROCA,picture.OtherCROCA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     A40HRPKL,Picture.A40HRPKL,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     A40HR,Picture.A40HR,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     slab L50,Picture.SlabB,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     OtherHR,picture.OtherHR,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     A40CRBA,Picture.A40CRBA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     A40GALV2,Picture.A40GALV2,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     A40GALV3,Picture.A40GALV3,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     A40,Picture.Green Ball,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     A40CRCA,Picture.A40CRCA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
     L50HRPKL,picture.L50HRPKL,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
```

V10CROCA,picture.V10CROCA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
L50GALV1,picture.L50GALV1,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
L50GALV2,picture.L50GALV2,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
L50,Picture.Blue Ball,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
Entity 1,Picture.Box,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
A40CROCA,Picture.A40CROCA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
OtherCRBA,picture.OtherCRBA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
slab V10,Picture.SlabR,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
OtherCRCA,picture.OtherCRCA,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,);

SETS:
L50 product pictures,picture.L50HRPKL,picture.L50GALV1,picture.L50GALV2,picture.L50CRBA,picture.L50CRCA:
V10 product sequences,V10 CR OCA:
L50 product sequences,L50 hotroll pkl,L50 galv1,L50 galv2,L50 CR BA,L50 CR CA:
HSMFurnaces only,Furnace1,Furnace2,Furnace3,Furnace4,Furnace5:
L50 product types,L50HRPKL,L50GALV1,L50GALV2,L50CRBA,L50CRCA:
A40 product sequences,A40 hotroll,A40 hotroll pkl,A40 galv2,A40 galv3,A40 CR BA,A40 CR CA:
Batch Annealing,HBA1,HBA2,HBA 3,HBA 4,HBA 5,HBA 6,HBA 7,HBA 8,HBA 9,HBA 10,HBA 11,HBA 12,HBA13,HBA14,HBA 15,
HBA 16,HBA 17,HBA 18,HBA 19,HBA 20,HBA 21,HBA 22,HBA 23,HBA 24,HBA 25,HBA 26,HBA 27,HBA 28,HBA 29,HBA 30,HBA 31:
A40 product types,A40HR,A40HRPKL,A40GALV2,A40GALV3,A40CRBA,A40CRCA:
V10 product pictures,picture.V10CROCA:
V10 product types,V10CROCA:
Open Coil Annealing,OCA 1,OCA 2,OCA 3,OCA 4,OCA 5,OCA 6,OCA 7,OCA 8,OCA 9,OCA 10,OCA 11,OCA 12,OCA 13:
Continuous Annealing,CA 1,CA 2,CA 3,CA 4,CA 5,CA 6,CA 7,CA 8,CA 9,CA 10,CA 11,CA 12,CA 13,CA 14,CA 15:
Other product pictures,picture.OtherHR,picture.OtherHRPKL,picture.OtherGALV1,picture.OtherGALV2,
picture.OtherGALV3,picture.OtherCRBA,picture.OtherCRCA,picture.OtherCROCA:
Pickle,84 pickle,64 Pickle:
Other product sequences,Other hotroll,Other hotroll pkl,Other galv1,Other galv2,Other galv3,Other CR BA,
Other CR CA,Other CR OCA:
Blast Furnace,Blast Furnace 1,Blast Furnace 2:
A40 product pictures,Picture.A40HR,Picture.A40HRPKL,Picture.A40GALV2,Picture.A40GALV3,Picture.A40CRBA,
Picture.A40CRCA:

Other product types,OtherHR,OtherHRPKL,OtherGALV1,OtherGALV2,OtherGALV3,OtherCRBA,OtherCRCA,OtherCROCA;

**Model File**

```
14$         STATION,      LMF station;
195$        DELAY:        0.0,,VA:NEXT(3$);


;
;
;    Model statements for module:  Process 27
;
3$          ASSIGN:       LMF furnace.NumberIn=LMF furnace.NumberIn + 1:
                          LMF furnace.WIP=LMF furnace.WIP+1;
225$        STACK,        1:Save:NEXT(199$);

199$        QUEUE,        LMF furnace.Queue;
198$        SEIZE,        2,VA:
                          LMF,1:NEXT(197$);

197$        DELAY:        LMF Time,,VA:NEXT(240$);

240$        ASSIGN:       LMF furnace.WaitTime=LMF furnace.WaitTime + Diff.WaitTime;
204$        TALLY:        LMF furnace.WaitTimePerEntity,Diff.WaitTime,1;
206$        TALLY:        LMF furnace.TotalTimePerEntity,Diff.StartTime,1;
230$        ASSIGN:       LMF furnace.VATime=LMF furnace.VATime + Diff.VATime;
231$        TALLY:        LMF furnace.VATimePerEntity,Diff.VATime,1;
196$        RELEASE:      LMF,1;
245$        STACK,        1:Destroy:NEXT(244$);

244$        ASSIGN:       LMF furnace.NumberOut=LMF furnace.NumberOut + 1:
                          LMF furnace.WIP=LMF furnace.WIP-1:NEXT(5$);


;
;
;    Model statements for module:  Decide 26
```

```
;
5$          BRANCH,       1:
                        If,Entity.Type==A40,7$,Yes:
                        If,Entity.Type==L50,6$,Yes:
                        If,Entity.Type==V10,8$,Yes:
                        Else,81$,Yes;


;
;
;    Model statements for module:  Assign 92
;
81$          ASSIGN:        Entity.Type=others:
                        Picture=Picture.Boat:
                        Continuous Casting Time=NORM(43, 1.96):NEXT(82$);



;
;
;    Model statements for module:  Station 52
;

82$          STATION,       others caster prepare;
251$          DELAY:         0.0,,VA:NEXT(83$);



;
;
;    Model statements for module:  Route 32
;
83$          ROUTE:         POIS(18.4),Continuous Casting station;



;
;
;    Model statements for module:  Assign 64
;
7$          ASSIGN:        Entity.Type=A40:
                        Picture=Picture.Green Ball:
                        Continuous Casting Time=32 + EXPO(5.79):NEXT(18$);



;
;
;    Model statements for module:  Station 43
;
```

```
18$          STATION,      A40  caster prepare;
254$          DELAY:        0.0,,VA:NEXT(19$);


;
;
;    Model statements for module:  Route 26
;
19$          ROUTE:        POIS(15.2),Continuous Casting station;


;
;
;    Model statements for module:  Assign 63
;
6$          ASSIGN:       Entity.Type=L50:
                          Picture=Picture.Blue Ball:
                          Continuous Casting Time=34 + 40 * BETA(0.781, 3.37):NEXT(32$);


;
;
;    Model statements for module:  Station 47
;

32$          STATION,      L50 caster prepare;
257$          DELAY:        0.0,,VA:NEXT(33$);


;
;
;    Model statements for module:  Route 28
;
33$          ROUTE:        7.5 + 16 * BETA(1.89, 2.27),Continuous Casting station;


;
;
;    Model statements for module:  Assign 65
;
8$          ASSIGN:       Entity.Type=V10:
                          Picture=Picture.Red Ball:
                          Continuous Casting Time=NORM(43, 1.96):NEXT(34$);


;
```

```
;
;    Model statements for module:  Station 48
;

34$          STATION,      V10 caster prepare;
260$         DELAY:        0.0,,VA:NEXT(35$);


;
;
;    Model statements for module:  Route 29
;
35$          ROUTE:        POIS(18.4),Continuous Casting station;


;
;
;    Model statements for module:  Station 42
;

17$          STATION,      Degasser station;
263$         DELAY:        0.0,,VA:NEXT(4$);


;
;
;    Model statements for module:  Process 28
;
4$           ASSIGN:       Degasser furnace.NumberIn=Degasser furnace.NumberIn + 1:
                    Degasser furnace.WIP=Degasser furnace.WIP+1;
293$         STACK,        1:Save:NEXT(267$);

267$         QUEUE,        Degasser furnace.Queue;
266$         SEIZE,        2,VA:
                    Degasser,1:NEXT(265$);

265$         DELAY:        Degasser Time,,VA:NEXT(308$);

308$         ASSIGN:       Degasser furnace.WaitTime=Degasser furnace.WaitTime +
Diff.WaitTime;
272$         TALLY:        Degasser furnace.WaitTimePerEntity,Diff.WaitTime,1;
274$         TALLY:        Degasser furnace.TotalTimePerEntity,Diff.StartTime,1;
298$         ASSIGN:       Degasser furnace.VATime=Degasser furnace.VATime +
Diff.VATime;
299$         TALLY:        Degasser furnace.VATimePerEntity,Diff.VATime,1;
264$         RELEASE:      Degasser,1;
```

```
313$        STACK,        1:Destroy:NEXT(312$);

312$        ASSIGN:       Degasser furnace.NumberOut=Degasser furnace.NumberOut + 1:
                      Degasser furnace.WIP=Degasser furnace.WIP-1:NEXT(5$);


;
;
;   Model statements for module:  Station 44
;

20$         STATION,      Continuous Casting station;
317$        DELAY:        0.0,,VA:NEXT(45$);


;
;
;   Model statements for module:  Assign 75
;
45$         ASSIGN:       north=strand:
                      number of_slabs=NORM(20.8, 3.5):
                      caster time=Continuous Casting Time:NEXT(60$);


;
;
;   Model statements for module:  Separate 14
;
60$         DUPLICATE,    100 - 50:
                      1,320$,50:NEXT(319$);

319$        ASSIGN:       Separate 14.NumberOut Orig=Separate 14.NumberOut Orig +
1:NEXT(43$);

320$        ASSIGN:       Separate 14.NumberOut Dup=Separate 14.NumberOut Dup +
1:NEXT(44$);


;
;
;   Model statements for module:  Assign 73
;
43$         ASSIGN:       weight=north:NEXT(61$);


;
```

```
;
;    Model statements for module:  Decide 29
;
61$          BRANCH,        1:
                         If,cutting width period == 1,62$,Yes:
                         If,cutting width period == 2,63$,Yes:
                         If,cutting width period == 3,64$,Yes:
                         Else,71$,Yes;


;
;
;    Model statements for module:  Assign 85
;
71$          ASSIGN:        width4=UNIF(33,42):NEXT(52$);



;
;
;    Model statements for module:  Separate 9
;
52$          DUPLICATE,     100 - 50:
                         ANINT(weight *  number of_slabs)-1,325$,50:NEXT(324$);

324$          ASSIGN:        Separate 9.NumberOut Orig=Separate 9.NumberOut Orig +
1:NEXT(56$);

325$          ASSIGN:        Separate 9.NumberOut Dup=Separate 9.NumberOut Dup +
1:NEXT(56$);



;
;
;    Model statements for module:  Batch 6
;
56$          QUEUE,         Batch for slabs in Nstrand.Queue;
326$          GROUP,         ,Temporary:ANINT(weight * number of_slabs),Last:NEXT(327$);

327$          ASSIGN:        Batch for slabs in Nstrand.NumberOut=Batch for slabs in
Nstrand.NumberOut + 1:NEXT(1$);



;
;
;    Model statements for module:  Process 26
;
1$           ASSIGN:        Continuous Casting 1.NumberIn=Continuous Casting 1.NumberIn + 1:
```

```
                 Continuous Casting 1.WIP=Continuous Casting 1.WIP+1;
357$       STACK,       1:Save:NEXT(331$);

331$       QUEUE,       Continuous Casting 1.Queue;
330$       SEIZE,       2,VA:
                 Caster north,1:NEXT(329$);

329$       DELAY:       caster time,,VA:NEXT(372$);

372$       ASSIGN:      Continuous Casting 1.WaitTime=Continuous Casting 1.WaitTime +
Diff.WaitTime;
336$       TALLY:       Continuous Casting 1.WaitTimePerEntity,Diff.WaitTime,1;
338$       TALLY:       Continuous Casting 1.TotalTimePerEntity,Diff.StartTime,1;
362$       ASSIGN:      Continuous Casting 1.VATime=Continuous Casting 1.VATime +
Diff.VATime;
363$       TALLY:       Continuous Casting 1.VATimePerEntity,Diff.VATime,1;
328$       RELEASE:     Caster north,1;
377$       STACK,       1:Destroy:NEXT(376$);

376$       ASSIGN:      Continuous Casting 1.NumberOut=Continuous Casting 1.NumberOut
+ 1:
                 Continuous Casting 1.WIP=Continuous Casting 1.WIP-1:NEXT(57$);


;
;
;    Model statements for module:  Separate 12
;
57$        SPLIT::NEXT(379$);

379$       ASSIGN:      Separate 12.NumberOut Orig=Separate 12.NumberOut Orig +
1:NEXT(146$);


;
;
;    Model statements for module:  Record 52
;
146$       COUNT:       number of slabs from N,1:NEXT(47$);


;
;
;    Model statements for module:  Decide 28
;
47$        BRANCH,      1:
```

```
                  If,Entity.Type==A40,46$,Yes:
                  If,Entity.Type==L50,48$,Yes:
                  If,Entity.Type==V10,49$,Yes:
                  Else,84$,Yes;

;
;
;    Model statements for module:  Assign 93
;
84$       ASSIGN:      Entity.Type=others:
                  Picture=Picture.Boat:NEXT(100$);


;
;
;    Model statements for module:  Decide 33
;
100$      BRANCH,      1:
                  If,volume<>0,95$,Yes:
                  Else,101$,Yes;

;
;
;    Model statements for module:  Decide 34
;
101$      BRANCH,      1:
                  If,weight>=0.5,96$,Yes:
                  Else,99$,Yes;

;
;
;    Model statements for module:  Record 50
;
99$       COUNT:       weightsmall,1:NEXT(152$);


;
;
;    Model statements for module:  Store 3
;
152$      STORE:       ET slab storage:NEXT(102$);


;
;
;    Model statements for module:  Station 53
```

```
;

102$        STATION,      Slab station;
390$        DELAY:        0.0,,VA:NEXT(107$);


;
;
;    Model statements for module:  Batch 8
;
107$        QUEUE,        Batch slabs to be transported.Queue;
391$        GROUP,        ,Temporary:200,Last:NEXT(392$);

392$        ASSIGN:       Batch slabs to be transported.NumberOut=Batch slabs to be
transported.NumberOut + 1:NEXT(103$);


;
;
;    Model statements for module:  Request 7
;
103$        QUEUE,        Request 7.Queue;
          REQUEST,      1:rail car(CYC,rail car #),60:NEXT(106$);


;
;
;    Model statements for module:  Delay 9
;
106$        DELAY:        5,,Wait:NEXT(191$);


;
;
;    Model statements for module:  Record 90
;
191$        TALLY:        Time spent At ET,INT(ET Time),1:NEXT(105$);


;
;
;    Model statements for module:  Transport 7
;
105$        TRANSPORT:    rail car(rail car #),Irvin;
```

```
;
;
;    Model statements for module:  Record 47
;
96$         COUNT:        weightlarge,1:NEXT(152$);


;
;
;    Model statements for module:  Decide 32
;
95$         BRANCH,       1:
                   If,volume>=0.5,97$,Yes:
                   Else,98$,Yes;


;
;
;    Model statements for module:  Record 49
;
98$         COUNT:        volumesmall,1:NEXT(152$);


;
;
;    Model statements for module:  Record 48
;
97$         COUNT:        volumelarge,1:NEXT(152$);


;
;
;    Model statements for module:  Assign 76
;
46$         ASSIGN:       Entity.Type=slab A40:
                   Picture=Picture.SlabG:NEXT(100$);


;
;
;    Model statements for module:  Assign 77
;
48$         ASSIGN:       Entity.Type=slab L50:
                   Picture=Picture.SlabB:NEXT(100$);


;
```

```
;
;     Model statements for module:  Assign 78
;
49$          ASSIGN:        Entity.Type=slab V10:
                          Picture=Picture.SlabR:NEXT(100$);


;
;
;     Model statements for module:  Assign 79
;
62$          ASSIGN:        width1=UNIF(33,43):NEXT(52$);


;
;
;     Model statements for module:  Assign 80
;
63$          ASSIGN:        width2=UNIF(45,54):NEXT(52$);


;
;
;     Model statements for module:  Assign 81
;
64$          ASSIGN:        width3=UNIF(55,66):NEXT(52$);


;
;
;     Model statements for module:  Assign 74
;
44$          ASSIGN:        volume=1-north:NEXT(72$);


;
;
;     Model statements for module:  Decide 31
;
72$          BRANCH,        1:
                          If,cutting width period == 1,73$,Yes:
                          If,cutting width period == 2,74$,Yes:
                          If,cutting width period == 3,75$,Yes:
                          Else,76$,Yes;

;
```

```
;
;    Model statements for module:  Assign 89
;
76$        ASSIGN:       width4=UNIF(33,42):NEXT(53$);


;
;
;    Model statements for module:  Separate 10
;
53$        DUPLICATE,    100 - 50:
                  ANINT(volume * number of_slabs)-1,400$,50:NEXT(399$);

399$       ASSIGN:       Separate 10.NumberOut Orig=Separate 10.NumberOut Orig +
1:NEXT(58$);

400$       ASSIGN:       Separate 10.NumberOut Dup=Separate 10.NumberOut Dup +
1:NEXT(58$);


;
;
;    Model statements for module:  Batch 7
;
58$        QUEUE,        Batch for slabs in Sstrand.Queue;
401$       GROUP,        ,Temporary:ANINT(volume * number of_slabs),Last:NEXT(402$);

402$       ASSIGN:       Batch for slabs in Sstrand.NumberOut=Batch for slabs in
Sstrand.NumberOut + 1:NEXT(36$);


;
;
;    Model statements for module:  Process 29
;
36$        ASSIGN:       Continuous Casting 2.NumberIn=Continuous Casting 2.NumberIn + 1:
                  Continuous Casting 2.WIP=Continuous Casting 2.WIP+1;
432$       STACK,        1:Save:NEXT(406$);

406$       QUEUE,        Continuous Casting 2.Queue;
405$       SEIZE,        2,VA:
                  Caster south,1:NEXT(404$);

404$       DELAY:        caster time,,VA:NEXT(447$);
```

```
447$        ASSIGN:       Continuous Casting 2.WaitTime=Continuous Casting 2.WaitTime +
Diff.WaitTime;
411$        TALLY:        Continuous Casting 2.WaitTimePerEntity,Diff.WaitTime,1;
413$        TALLY:        Continuous Casting 2.TotalTimePerEntity,Diff.StartTime,1;
437$        ASSIGN:       Continuous Casting 2.VATime=Continuous Casting 2.VATime +
Diff.VATime;
438$        TALLY:        Continuous Casting 2.VATimePerEntity,Diff.VATime,1;
403$        RELEASE:       Caster south,1;
452$        STACK,        1:Destroy:NEXT(451$);

451$        ASSIGN:       Continuous Casting 2.NumberOut=Continuous Casting 2.NumberOut
+ 1:
                   Continuous Casting 2.WIP=Continuous Casting 2.WIP-1:NEXT(59$);


;
;
;    Model statements for module:  Separate 13
;
59$         SPLIT::NEXT(454$);

454$        ASSIGN:       Separate 13.NumberOut Orig=Separate 13.NumberOut Orig +
1:NEXT(147$);


;
;
;    Model statements for module:  Record 53
;
147$        COUNT:        number of slabs from S,1:NEXT(47$);


;
;
;    Model statements for module:  Assign 86
;
73$         ASSIGN:       width1=UNIF(33,42):NEXT(53$);


;
;
;    Model statements for module:  Assign 87
;
74$         ASSIGN:       width2=UNIF(45,54):NEXT(53$);
```

```
;
;
;    Model statements for module:  Assign 88
;
75$          ASSIGN:       width3=UNIF(55,66):NEXT(53$);


;
;
;    Model statements for module:  Create 5
;

457$          CREATE,       2,MinutesToBaseTime(0.0),Entity
1:MinutesToBaseTime(60):NEXT(458$);

458$          ASSIGN:       Raw Materials.NumberOut=Raw Materials.NumberOut +
1:NEXT(37$);


;
;
;    Model statements for module:  Batch 5
;
37$          QUEUE,        Batch Ladles.Queue;
461$          GROUP,        ,Temporary:2,Last:NEXT(462$);

462$          ASSIGN:       Batch Ladles.NumberOut=Batch Ladles.NumberOut + 1:NEXT(54$);

54$          COUNT:        batch,1:NEXT(55$);


;
;
;    Model statements for module:  Record 40
;
55$          COUNT:        Cout Batched Ladles,1:NEXT(42$);


;
;
;    Model statements for module:  Assign 72
;
42$          ASSIGN:       weight=250:
                volume=250:
                casterup_time=cast_up:
                casterdown_time=cast_down:
```

```
                    Tundishup_time=Tundish_up:
                    Tundishdown_time=Tundish_down:NEXT(39$);


;
;
;    Model statements for module:  Station 49
;

39$          STATION,      Bins station;
465$         DELAY:        0.0,,VA:NEXT(40$);


;
;
;    Model statements for module:  Route 30
;
40$          ROUTE:        1,Blast furnace station;


;
;
;    Model statements for module:  Station 50
;

41$          STATION,      Blast furnace station;
468$         DELAY:        0.0,,VA:NEXT(38$);


;
;
;    Model statements for module:  Process 30
;
38$          ASSIGN:       Blast Furnace Process.NumberIn=Blast Furnace Process.NumberIn + 1:
                    Blast Furnace Process.WIP=Blast Furnace Process.WIP+1;
498$         STACK,        1:Save:NEXT(472$);

472$         QUEUE,        Blast Furnace Process.Queue;
471$         SEIZE,        2,VA:
                    SELECT(Blast Furnace,CYC, Furnace Index),1:NEXT(470$);

470$         DELAY:        furnace discharge time(Furnace Index),,VA:NEXT(513$);

513$         ASSIGN:       Blast Furnace Process.WaitTime=Blast Furnace Process.WaitTime +
Diff.WaitTime;
477$         TALLY:        Blast Furnace Process.WaitTimePerEntity,Diff.WaitTime,1;
```

```
479$        TALLY:        Blast Furnace Process.TotalTimePerEntity,Diff.StartTime,1;
503$        ASSIGN:       Blast Furnace Process.VATime=Blast Furnace Process.VATime +
Diff.VATime;
504$        TALLY:        Blast Furnace Process.VATimePerEntity,Diff.VATime,1;
469$        RELEASE:      Blast Furnace(Furnace Index),1;
518$        STACK,        1:Destroy:NEXT(517$);

517$        ASSIGN:       Blast Furnace Process.NumberOut=Blast Furnace Process.NumberOut
+ 1:
                  Blast Furnace Process.WIP=Blast Furnace Process.WIP-1:NEXT(160$);


;
;
;    Model statements for module:  Separate 22
;
160$        SPLIT::NEXT(520$);

520$        ASSIGN:       Separate 22.NumberOut Orig=Separate 22.NumberOut Orig +
1:NEXT(190$);


;
;
;    Model statements for module:  Assign 120
;
190$        ASSIGN:       ET Time=TNOW-179:NEXT(65$);


;
;
;    Model statements for module:  Assign 82
;
65$         ASSIGN:       Cutting width period=period:NEXT(85$);

85$         COUNT:        entity1 from BF,1:NEXT(86$);


;
;
;    Model statements for module:  Record 42
;
86$         COUNT:        entity1 from BFcounter,1:NEXT(2$);


;
```

```
;
;    Model statements for module:  Decide 25
;
2$          BRANCH,       1:
                    With,12.58/100,25$,Yes:
                    With,6.44/100,26$,Yes:
                    With,5.04/100,27$,Yes:
                    Else,77$,Yes;


;
;
;    Model statements for module:  Assign 90
;
77$         ASSIGN:       Entity.Type=others:
                    Picture=Picture.Boat:
                    BOP Time=NORM(65.7, 7.43)-NORM(30,2.99):NEXT(93$);

93$         COUNT:        therest,1:NEXT(94$);



;
;
;    Model statements for module:  Record 46
;
94$         COUNT:        rest counter,1:NEXT(29$);



;
;
;    Model statements for module:  Station 45
;

29$         STATION,      Finished from blast furnace;
527$         DELAY:       0.0,,VA:NEXT(21$);



;
;
;    Model statements for module:  Request 6
;
21$         QUEUE,        Request 6.Queue;
          REQUEST,       1:submarine ladel(CYC,Subladel #),40:NEXT(23$);


;
;
```

```
;    Model statements for module:  Delay 7
;
23$         DELAY:        UNIF( 22 , 25 ),,NVA:NEXT(24$);


;
;
;    Model statements for module:  Transport 6
;
24$         TRANSPORT:    submarine ladel(Subladel #),BOP station,40;


;
;
;    Model statements for module:  Assign 69
;
25$         ASSIGN:       Entity.Type=A40:
                  Picture=Picture.Green Ball:
                  BOP Time=39.5 + GAMM(2.33, 10.4)-NORM(30,2.99):NEXT(88$);

88$         COUNT:        afourty,1:NEXT(87$);


;
;
;    Model statements for module:  Record 43
;
87$         COUNT:        a40 counter,1:NEXT(29$);


;
;
;    Model statements for module:  Assign 70
;
26$         ASSIGN:       Entity.Type=L50:
                  Picture=Picture.Blue Ball:
                  BOP Time=NORM(65.7, 6.48)-NORM(30,2.99):NEXT(89$);

89$         COUNT:        lten,1:NEXT(91$);


;
;
;    Model statements for module:  Record 44
;
91$         COUNT:        l10 counter,1:NEXT(29$);
```

```
;
;
;    Model statements for module:  Assign 71
;
27$          ASSIGN:       Entity.Type=V10:
                           Picture=Picture.Red Ball:
                           BOP Time=NORM(65.7, 7.43)-NORM(30,2.99):NEXT(90$);

90$          COUNT:        vten,1:NEXT(92$);


;
;
;    Model statements for module:  Record 45
;
92$          COUNT:        v10 counter,1:NEXT(29$);


;
;
;    Model statements for module:  Enter 7
;

51$          STATION,      Irvin;
529$          DELAY:       5,,VA:NEXT(531$);

531$          FREE:       rail car(rail car #):NEXT(166$);


;
;
;    Model statements for module:  Record 68
;
166$          TALLY:       Record 68,NE(Irvin),1:NEXT(108$);


;
;
;    Model statements for module:  Separate 15
;
108$          SPLIT::NEXT(540$);

540$          ASSIGN:       Separate 15.NumberOut Orig=Separate 15.NumberOut Orig +
1:NEXT(167$);
```

```
;
;
;    Model statements for module:  Assign 119
;
167$         ASSIGN:       Irvin Time=TNOW:NEXT(109$);


;
;
;    Model statements for module:  Decide 35
;
109$         BRANCH,       1:
                    If,Entity.Type==slab A40,110$,Yes:
                    If,Entity.Type==slab L50,111$,Yes:
                    If,Entity.Type==slab V10,112$,Yes:
                    Else,113$,Yes;


;
;
;    Model statements for module:  Assign 97
;
113$         ASSIGN:       Other product Index=
                    DISC(0.057,1 , 0.065,2 , 0.085,3 , 0.170,4 , 0.539,5 ,0.914,6 ,0.938,7 ,1.000,8):
                    Entity.Sequence=Other product sequences ( Other product Index ):
                    Entity.Type=Other product types ( Other product Index ):
                    Entity.Picture=Other product pictures ( Other product Index ):NEXT(114$);


;
;
;    Model statements for module:  Store 2
;
114$         STORE:        Raw coil storage:NEXT(115$);


;
;
;    Model statements for module:  Station 54
;

115$         STATION,      slab prepar;
547$         DELAY:        0.0,,VA:NEXT(142$);
```

```
;
;
;    Model statements for module:  Route 41
;
142$         ROUTE:        2,SEQ;


;
;
;    Model statements for module:  Assign 94
;
110$         ASSIGN:       A40 product Index=DISC(0.101,1 , 0.115,2 , 0.116,3 , 0.421,4 , 0.855
,5 ,1 ,6):
                   Entity.Sequence=A40 product sequences ( A40 product Index ):
                   Entity.Type=A40 product types ( A40 product Index ):
                   Entity.Picture=A40 product pictures ( A40 product Index ):NEXT(114$);


;
;
;    Model statements for module:  Assign 95
;
111$         ASSIGN:       L50 product Index=DISC(0.013,1 , 0.124,2 , 0.645,3 , 0.653,4 ,
1.000,5):
                   Entity.Sequence=L50 product sequences ( L50 product Index ):
                   Entity.Type=L50 product types ( L50 product Index ):
                   Entity.Picture=L50 product pictures ( L50 product Index ):NEXT(114$);


;
;
;    Model statements for module:  Assign 96
;
112$         ASSIGN:       V10 product Index=DISC(1, 1):
                   Entity.Sequence=V10 product sequences( V10 product Index):
                   Entity.Type=V10 product types( V10 product Index):
                   Entity.Picture=V10 product pictures( V10 product Index):NEXT(114$);


;
;
;    Model statements for module:  Create 6
;

548$         CREATE,       1,MinutesToBaseTime(0.0),Counter
Entity:MinutesToBaseTime(1440):NEXT(549$);
```

```
549$         ASSIGN:       Create Counter Entity.NumberOut=Create Counter Entity.NumberOut
+ 1:NEXT(66$);


;
;
;    Model statements for module:  Assign 83
;
66$          ASSIGN:       Period=0:NEXT(67$);


;
;
;    Model statements for module:  Assign 84
;
67$          ASSIGN:       Period=Period + 1:NEXT(68$);


;
;
;    Model statements for module:  Decide 30
;
68$          BRANCH,       1:
                           If,Period<4,552$,Yes:
                           Else,553$,Yes;
552$         ASSIGN:       Check Period.NumberOut True=Check Period.NumberOut True +
1:NEXT(69$);

553$         ASSIGN:       Check Period.NumberOut False=Check Period.NumberOut False +
1:NEXT(70$);


;
;
;    Model statements for module:  Delay 8
;
69$          DELAY:        360,,Other:NEXT(67$);


;
;
;    Model statements for module:  Dispose 11
;
70$          ASSIGN:       Dispose of Counter Entity.NumberOut=Dispose of Counter
Entity.NumberOut + 1;
```

```
554$        DISPOSE:      No;


;
;
;    Model statements for module:  Station 55
;

116$        STATION,      hotmill;
557$        DELAY:        0.0,,VA:NEXT(170$);

170$        DELAY:        NORM(8.21e+003, 1.35e+003),Hot mill storage,Other:NEXT(171$);


;
;
;    Model statements for module:  Record 79
;
171$        TALLY:        NUMBER in storage HSM,NSTO(Hot mill storage),1:NEXT(163$);


;
;
;    Model statements for module:  Batch 14
;
163$        QUEUE,        Batch Slabs for HSM furnace.Queue;
558$        GROUP,        ,Temporary:100,Last:NEXT(559$);

559$        ASSIGN:       Batch Slabs for HSM furnace.NumberOut=Batch Slabs for HSM
furnace.NumberOut + 1:NEXT(164$);


;
;
;    Model statements for module:  Process 45
;
164$        ASSIGN:       HSM furnaces process only.NumberIn=HSM furnaces process
only.NumberIn + 1:
                  HSM furnaces process only.WIP=HSM furnaces process only.WIP+1;
589$        STACK,        1:Save:NEXT(563$);

563$        QUEUE,        HSM furnaces process only.Queue;
562$        SEIZE,        2,VA:
                  SELECT(HSMFurnaces only,CYC, Furnaces only Index),1:NEXT(561$);

561$        DELAY:        Furnaces only Time (Furnaces only Index),,VA:NEXT(604$);
```

```
604$        ASSIGN:       HSM furnaces process only.WaitTime=HSM furnaces process
only.WaitTime + Diff.WaitTime;
568$        TALLY:        HSM furnaces process only.WaitTimePerEntity,Diff.WaitTime,1;
570$        TALLY:        HSM furnaces process only.TotalTimePerEntity,Diff.StartTime,1;
594$        ASSIGN:       HSM furnaces process only.VATime=HSM furnaces process
only.VATime + Diff.VATime;
595$        TALLY:        HSM furnaces process only.VATimePerEntity,Diff.VATime,1;
560$        RELEASE:      HSMFurnaces only(Furnaces only Index),1;
609$        STACK,        1:Destroy:NEXT(608$);

608$        ASSIGN:       HSM furnaces process only.NumberOut=HSM furnaces process
only.NumberOut + 1:
                  HSM furnaces process only.WIP=HSM furnaces process only.WIP-
1:NEXT(165$);


;
;
;    Model statements for module:  Separate 24
;
165$        SPLIT::NEXT(611$);

611$        ASSIGN:       Separate.NumberOut Orig=Separate.NumberOut Orig +
1:NEXT(50$);


;
;
;    Model statements for module:  Process 31
;
50$        ASSIGN:       Hot strip mill.NumberIn=Hot strip mill.NumberIn + 1:
                  Hot strip mill.WIP=Hot strip mill.WIP+1;
643$        STACK,        1:Save:NEXT(617$);

617$        QUEUE,        Hot strip mill.Queue;
616$        SEIZE,        2,VA:
                  SELECT(HSMFurnaces only,CYC, ),1:NEXT(615$);

615$        DELAY:        Normal(1,0.5),,VA:NEXT(658$);

658$        ASSIGN:       Hot strip mill.WaitTime=Hot strip mill.WaitTime + Diff.WaitTime;
622$        TALLY:        Hot strip mill.WaitTimePerEntity,Diff.WaitTime,1;
624$        TALLY:        Hot strip mill.TotalTimePerEntity,Diff.StartTime,1;
648$        ASSIGN:       Hot strip mill.VATime=Hot strip mill.VATime + Diff.VATime;
649$        TALLY:        Hot strip mill.VATimePerEntity,Diff.VATime,1;
```

```
614$        RELEASE:      SELECT(HSMFurnaces only,LAST),1;
663$        STACK,        1:Destroy:NEXT(662$);

662$        ASSIGN:       Hot strip mill.NumberOut=Hot strip mill.NumberOut + 1:
                  Hot strip mill.WIP=Hot strip mill.WIP-1:NEXT(117$);


;
;
;    Model statements for module:  Route 33
;
117$        ROUTE:        2,SEQ;


;
;
;    Model statements for module:  Station 56
;

119$        STATION,      pickling;
667$        DELAY:        0.0,,VA:NEXT(172$);

172$        DELAY:        TRIA(6.51e+003, 7.32e+003, 1.35e+004),Pickle
storage,Other:NEXT(173$);


;
;
;    Model statements for module:  Record 81
;
173$        TALLY:        NUMBER in storage for PK,NSTO(Pickle storage),1:NEXT(168$);


;
;
;    Model statements for module:  Batch 15
;
168$        QUEUE,        Batch for PK.Queue;
668$        GROUP,        Entity.Type,Permanent:2,Last:NEXT(669$);

669$        ASSIGN:       Batch for PK.NumberOut=Batch for PK.NumberOut +
1:NEXT(118$);


;
;
```

```
;     Model statements for module:  Process 32
;
118$        ASSIGN:       Pickling.NumberIn=Pickling.NumberIn + 1:
                          Pickling.WIP=Pickling.WIP+1;
699$        STACK,        1:Save:NEXT(673$);

673$        QUEUE,        Pickling.Queue;
672$        SEIZE,       2,VA:
                          SELECT(Pickle,CYC, Pickle Index),1:NEXT(671$);

671$        DELAY:        Normal(4,1),,VA:NEXT(714$);

714$        ASSIGN:       Pickling.WaitTime=Pickling.WaitTime + Diff.WaitTime;
678$        TALLY:        Pickling.WaitTimePerEntity,Diff.WaitTime,1;
680$        TALLY:        Pickling.TotalTimePerEntity,Diff.StartTime,1;
704$        ASSIGN:       Pickling.VATime=Pickling.VATime + Diff.VATime;
705$        TALLY:        Pickling.VATimePerEntity,Diff.VATime,1;
670$        RELEASE:        Pickle(Pickle Index),1;
719$        STACK,        1:Destroy:NEXT(718$);

718$        ASSIGN:       Pickling.NumberOut=Pickling.NumberOut + 1:
                          Pickling.WIP=Pickling.WIP-1:NEXT(120$);


;
;
;     Model statements for module:  Route 34
;
120$        ROUTE:        2,SEQ;


;
;
;     Model statements for module:  Station 57
;

122$        STATION,       galv1;
723$        DELAY:        0.0,,VA:NEXT(180$);

180$        DELAY:        NORM(1.46e+004, 3.27e+003),GALV1 storage,Other:NEXT(181$);


;
;
;     Model statements for module:  Record 85
;
```

```
181$        TALLY:        NUMBER in storage for GALV1,NSTO(GALV1
storage),1:NEXT(121$);


;
;
;   Model statements for module:  Process 33
;
121$        ASSIGN:       Galv1.NumberIn=Galv1.NumberIn + 1:
                    Galv1.WIP=Galv1.WIP+1;
753$        STACK,        1:Save:NEXT(727$);

727$        QUEUE,        Galv1.Queue;
726$        SEIZE,       2,VA:
                    Galv1 line,1:NEXT(725$);

725$        DELAY:        EXPO(1),,VA:NEXT(768$);

768$        ASSIGN:       Galv1.WaitTime=Galv1.WaitTime + Diff.WaitTime;
732$        TALLY:        Galv1.WaitTimePerEntity,Diff.WaitTime,1;
734$        TALLY:        Galv1.TotalTimePerEntity,Diff.StartTime,1;
758$        ASSIGN:       Galv1.VATime=Galv1.VATime + Diff.VATime;
759$        TALLY:        Galv1.VATimePerEntity,Diff.VATime,1;
724$        RELEASE:      Galv1 line,1;
773$        STACK,        1:Destroy:NEXT(772$);

772$        ASSIGN:       Galv1.NumberOut=Galv1.NumberOut + 1:
                    Galv1.WIP=Galv1.WIP-1:NEXT(123$);



;
;
;   Model statements for module:  Route 35
;
123$        ROUTE:        2,SEQ;



;
;
;   Model statements for module:  Station 58
;

125$        STATION,      galv2;
777$        DELAY:        0.0,,VA:NEXT(182$);

182$        DELAY:        NORM(1.46e+004, 3.27e+003),GALV2 storage,Other:NEXT(183$);
```

```
;
;
;    Model statements for module:  Record 86
;
183$         TALLY:        NUMBER in storage for GALV2,NSTO(GALV2
storage),1:NEXT(124$);


;
;
;    Model statements for module:  Process 34
;
124$         ASSIGN:       Galv2.NumberIn=Galv2.NumberIn + 1:
                    Galv2.WIP=Galv2.WIP+1;
807$         STACK,        1:Save:NEXT(781$);

781$         QUEUE,        Galv2.Queue;
780$         SEIZE,        2,VA:
                    Galv2 line,1:NEXT(779$);

779$         DELAY:        EXPO(2),,VA:NEXT(822$);

822$         ASSIGN:       Galv2.WaitTime=Galv2.WaitTime + Diff.WaitTime;
786$         TALLY:        Galv2.WaitTimePerEntity,Diff.WaitTime,1;
788$         TALLY:        Galv2.TotalTimePerEntity,Diff.StartTime,1;
812$         ASSIGN:       Galv2.VATime=Galv2.VATime + Diff.VATime;
813$         TALLY:        Galv2.VATimePerEntity,Diff.VATime,1;
778$         RELEASE:      Galv2 line,1;
827$         STACK,        1:Destroy:NEXT(826$);

826$         ASSIGN:       Galv2.NumberOut=Galv2.NumberOut + 1:
                    Galv2.WIP=Galv2.WIP-1:NEXT(126$);


;
;
;    Model statements for module:  Route 36
;
126$         ROUTE:        2,SEQ;


;
;
;    Model statements for module:  Station 59
```

```
;

128$        STATION,      BA;
831$        DELAY:        0.0,,VA:NEXT(176$);

176$        DELAY:        TRIA(4.77e+003, 8.13e+003, 1.79e+004),BA
storage,Other:NEXT(179$);


;
;
;    Model statements for module:  Record 84
;
179$        TALLY:        NUMBER in storage BA,NSTO(BA storage),1:NEXT(157$);


;
;
;    Model statements for module:  Batch 11
;
157$        QUEUE,        Batch Coils for BA.Queue;
832$        GROUP,        ,Temporary:3,Last:NEXT(833$);

833$        ASSIGN:       Batch Coils for BA.NumberOut=Batch Coils for BA.NumberOut +
1:NEXT(127$);


;
;
;    Model statements for module:  Process 35
;
127$        ASSIGN:       BA.NumberIn=BA.NumberIn + 1:
                    BA.WIP=BA.WIP+1;
863$        STACK,        1:Save:NEXT(837$);

837$        QUEUE,        BA.Queue;
836$        SEIZE,        2,VA:
                    SELECT(Batch Annealing,CYC, HBA Index),1:NEXT(835$);

835$        DELAY:        Uniform(900,1500),,VA:NEXT(878$);

878$        ASSIGN:       BA.WaitTime=BA.WaitTime + Diff.WaitTime;
842$        TALLY:        BA.WaitTimePerEntity,Diff.WaitTime,1;
844$        TALLY:        BA.TotalTimePerEntity,Diff.StartTime,1;
868$        ASSIGN:       BA.VATime=BA.VATime + Diff.VATime;
869$        TALLY:        BA.VATimePerEntity,Diff.VATime,1;
```

```
834$        RELEASE:      Batch Annealing(HBA Index),1;
883$        STACK,        1:Destroy:NEXT(882$);

882$        ASSIGN:       BA.NumberOut=BA.NumberOut + 1:
                     BA.WIP=BA.WIP-1:NEXT(158$);


;
;
;    Model statements for module:  Separate 19
;
158$        SPLIT::NEXT(885$);

885$        ASSIGN:       Separate 19.NumberOut Orig=Separate 19.NumberOut Orig +
1:NEXT(129$);


;
;
;    Model statements for module:  Route 37
;
129$        ROUTE:        2,SEQ;


;
;
;    Model statements for module:  Station 60
;

131$        STATION,      galv3;
890$        DELAY:        0.0,,VA:NEXT(184$);

184$        DELAY:        NORM(1.46e+004, 3.27e+003),GALV3 storage,Other:NEXT(185$);


;
;
;    Model statements for module:  Record 87
;
185$        TALLY:        NUMBER in storage for GALV3,NSTO(GALV3
storage),1:NEXT(130$);


;
;
;    Model statements for module:  Process 36
```

```
;
130$        ASSIGN:      Galv3.NumberIn=Galv3.NumberIn + 1:
                 Galv3.WIP=Galv3.WIP+1;
920$        STACK,       1:Save:NEXT(894$);

894$        QUEUE,       Galv3.Queue;
893$        SEIZE,       2,VA:
                 Galv3 line,1:NEXT(892$);

892$        DELAY:       EXPO(1),,VA:NEXT(935$);

935$        ASSIGN:      Galv3.WaitTime=Galv3.WaitTime + Diff.WaitTime;
899$        TALLY:       Galv3.WaitTimePerEntity,Diff.WaitTime,1;
901$        TALLY:       Galv3.TotalTimePerEntity,Diff.StartTime,1;
925$        ASSIGN:      Galv3.VATime=Galv3.VATime + Diff.VATime;
926$        TALLY:       Galv3.VATimePerEntity,Diff.VATime,1;
891$        RELEASE:     Galv3 line,1;
940$        STACK,       1:Destroy:NEXT(939$);

939$        ASSIGN:      Galv3.NumberOut=Galv3.NumberOut + 1:
                 Galv3.WIP=Galv3.WIP-1:NEXT(132$);


;
;
;   Model statements for module:  Route 38
;
132$        ROUTE:       2,SEQ;



;
;
;   Model statements for module:  Station 61
;

134$        STATION,     CA;
944$        DELAY:       0.0,,VA:NEXT(178$);

178$        DELAY:       TRIA(4.77e+003, 8.13e+003, 1.79e+004),CA
storage,Other:NEXT(177$);


;
;
;   Model statements for module:  Record 83
;
```

```
177$        TALLY:       NUMBER in storage CA,NSTO(CA storage),1:NEXT(133$);


;
;
;    Model statements for module:  Process 37
;
133$        ASSIGN:      CA.NumberIn=CA.NumberIn + 1:
                    CA.WIP=CA.WIP+1;
974$        STACK,       1:Save:NEXT(948$);

948$        QUEUE,       CA.Queue;
947$        SEIZE,       2,VA:
                    SELECT(Continuous Annealing,CYC, CA Index),1:NEXT(946$);

946$        DELAY:       Triangular(10,17.5,25),,VA:NEXT(989$);

989$        ASSIGN:      CA.WaitTime=CA.WaitTime + Diff.WaitTime;
953$        TALLY:       CA.WaitTimePerEntity,Diff.WaitTime,1;
955$        TALLY:       CA.TotalTimePerEntity,Diff.StartTime,1;
979$        ASSIGN:      CA.VATime=CA.VATime + Diff.VATime;
980$        TALLY:       CA.VATimePerEntity,Diff.VATime,1;
945$        RELEASE:     Continuous Annealing(CA Index),1;
994$        STACK,       1:Destroy:NEXT(993$);

993$        ASSIGN:      CA.NumberOut=CA.NumberOut + 1:
                    CA.WIP=CA.WIP-1:NEXT(135$);


;
;
;    Model statements for module:  Route 39
;
135$        ROUTE:       2,SEQ;


;
;
;    Model statements for module:  Station 62
;

137$        STATION,     temper mill;
998$        DELAY:       0.0,,VA:NEXT(188$);

188$        DELAY:       NORM(5.05e+003, 601),Temper mill storage,Other:NEXT(189$);
```

```
;
;
;    Model statements for module:  Record 89
;
189$         TALLY:        NUMBER in storage Temper mill,NSTO(Temper mill
storage),1:NEXT(136$);


;
;
;    Model statements for module:  Process 38
;
136$         ASSIGN:       Temper mill.NumberIn=Temper mill.NumberIn + 1:
                    Temper mill.WIP=Temper mill.WIP+1;
1028$        STACK,        1:Save:NEXT(1002$);

1002$        QUEUE,        Temper mill.Queue;
1001$        SEIZE,        2,VA:
                    Temper Mill line,1:NEXT(1000$);

1000$        DELAY:        Uniform(2,7),,VA:NEXT(1043$);

1043$        ASSIGN:       Temper mill.WaitTime=Temper mill.WaitTime + Diff.WaitTime;
1007$        TALLY:        Temper mill.WaitTimePerEntity,Diff.WaitTime,1;
1009$        TALLY:        Temper mill.TotalTimePerEntity,Diff.StartTime,1;
1033$        ASSIGN:       Temper mill.VATime=Temper mill.VATime + Diff.VATime;
1034$        TALLY:        Temper mill.VATimePerEntity,Diff.VATime,1;
999$         RELEASE:      Temper Mill line,1;
1048$        STACK,        1:Destroy:NEXT(1047$);

1047$        ASSIGN:       Temper mill.NumberOut=Temper mill.NumberOut + 1:
                    Temper mill.WIP=Temper mill.WIP-1:NEXT(138$);


;
;
;    Model statements for module:  Route 40
;
138$         ROUTE:        2,SEQ;


;
;
;    Model statements for module:  Station 63
;
```

```
139$         STATION,      shipping;
1052$        DELAY:        0.0,,VA:NEXT(192$);

192$         DELAY:        TRIA(6.51e+003, 7.32e+003, 1.35e+004),Shipping
storage,Other:NEXT(140$);


;
;
;    Model statements for module:  Process 39
;
140$         ASSIGN:       Shipping.NumberIn=Shipping.NumberIn + 1:
                   Shipping.WIP=Shipping.WIP+1;
1082$        STACK,        1:Save:NEXT(1056$);

1056$        QUEUE,        Shipping.Queue;
1055$        SEIZE,        2,VA:
                   Shipping line,1:NEXT(1054$);

1054$        DELAY:        EXPO( 1 ),,VA:NEXT(1097$);

1097$        ASSIGN:       Shipping.WaitTime=Shipping.WaitTime + Diff.WaitTime;
1061$        TALLY:        Shipping.WaitTimePerEntity,Diff.WaitTime,1;
1063$        TALLY:        Shipping.TotalTimePerEntity,Diff.StartTime,1;
1087$        ASSIGN:       Shipping.VATime=Shipping.VATime + Diff.VATime;
1088$        TALLY:        Shipping.VATimePerEntity,Diff.VATime,1;
1053$        RELEASE:      Shipping line,1;
1102$        STACK,        1:Destroy:NEXT(1101$);

1101$        ASSIGN:       Shipping.NumberOut=Shipping.NumberOut + 1:
                   Shipping.WIP=Shipping.WIP-1:NEXT(156$);


;
;
;    Model statements for module:  Record 62
;
156$         TALLY:        Time spent At Irvin,INT(Irvin Time),1:NEXT(141$);


;
;
;    Model statements for module:  Dispose 12
;
141$         ASSIGN:       Dispose 12.NumberOut=Dispose 12.NumberOut + 1;
```

```
1104$        DISPOSE:      Yes;


;
;
;    Model statements for module:  Station 64
;

144$         STATION,      cold red;
1107$        DELAY:        0.0,,VA:NEXT(174$);

174$         DELAY:        NORM(8.21e+003, 1.35e+003),Cold mill storage,Other:NEXT(175$);


;
;
;    Model statements for module:  Record 82
;
175$         TALLY:        NUMBER in storage COLD R,NSTO(Cold mill
storage),1:NEXT(143$);


;
;
;    Model statements for module:  Process 40
;
143$         ASSIGN:       Cold reduction.NumberIn=Cold reduction.NumberIn + 1:
                    Cold reduction.WIP=Cold reduction.WIP+1;
1137$        STACK,        1:Save:NEXT(1111$);

1111$        QUEUE,        Cold reduction.Queue;
1110$        SEIZE,        2,VA:
                    Cold reduction line,1:NEXT(1109$);

1109$        DELAY:        ERLA( 0.956 , 4 ),,VA:NEXT(1152$);

1152$        ASSIGN:       Cold reduction.WaitTime=Cold reduction.WaitTime +
Diff.WaitTime;
1116$        TALLY:        Cold reduction.WaitTimePerEntity,Diff.WaitTime,1;
1118$        TALLY:        Cold reduction.TotalTimePerEntity,Diff.StartTime,1;
1142$        ASSIGN:       Cold reduction.VATime=Cold reduction.VATime + Diff.VATime;
1143$        TALLY:        Cold reduction.VATimePerEntity,Diff.VATime,1;
1108$        RELEASE:      Cold reduction line,1;
1157$        STACK,        1:Destroy:NEXT(1156$);

1156$        ASSIGN:       Cold reduction.NumberOut=Cold reduction.NumberOut + 1:
```

```
                    Cold reduction.WIP=Cold reduction.WIP-1:NEXT(145$);


;
;
;     Model statements for module:  Route 42
;
145$        ROUTE:        2,SEQ;



;
;
;     Model statements for module:  Station 69
;

154$        STATION,      OCA;
1161$       DELAY:        0.0,,VA:NEXT(186$);

186$        DELAY:        TRIA(4.77e+003, 8.13e+003, 1.79e+004),OCA
storage,Other:NEXT(187$);



;
;
;     Model statements for module:  Record 88
;
187$        TALLY:        NUMBER in storage OCA,NSTO(OCA storage),1:NEXT(169$);



;
;
;     Model statements for module:  Record 78
;
169$        TALLY:        Interarrival time for  OCA,BET,1:NEXT(161$);



;
;
;     Model statements for module:  Batch 13
;
161$        QUEUE,        Batch Coils for OCA.Queue;
1162$       GROUP,        ,Temporary:2,Last:NEXT(1163$);

1163$       ASSIGN:       Batch Coils for OCA.NumberOut=Batch Coils for OCA.NumberOut
+ 1:NEXT(153$);
```

```
;
;
;    Model statements for module:  Process 44
;
153$         ASSIGN:      OCA.NumberIn=OCA.NumberIn + 1:
                          OCA.WIP=OCA.WIP+1;
1193$        STACK,       1:Save:NEXT(1167$);

1167$        QUEUE,       OCA.Queue;
1166$        SEIZE,       2,VA:
                          SELECT(Open Coil Annealing,CYC, OCA Index),1:NEXT(1165$);

1165$        DELAY:       Uniform(1080,1200),,VA:NEXT(1208$);

1208$        ASSIGN:      OCA.WaitTime=OCA.WaitTime + Diff.WaitTime;
1172$        TALLY:       OCA.WaitTimePerEntity,Diff.WaitTime,1;
1174$        TALLY:       OCA.TotalTimePerEntity,Diff.StartTime,1;
1198$        ASSIGN:      OCA.VATime=OCA.VATime + Diff.VATime;
1199$        TALLY:       OCA.VATimePerEntity,Diff.VATime,1;
1164$        RELEASE:     Open Coil Annealing(OCA Index),1;
1213$        STACK,       1:Destroy:NEXT(1212$);

1212$        ASSIGN:      OCA.NumberOut=OCA.NumberOut + 1:
                          OCA.WIP=OCA.WIP-1:NEXT(162$);


;
;
;    Model statements for module:  Separate 23
;
162$         SPLIT::NEXT(1215$);

1215$        ASSIGN:      Separate 23.NumberOut Orig=Separate 23.NumberOut Orig +
1:NEXT(155$);


;
;
;    Model statements for module:  Route 46
;
155$         ROUTE:       2,SEQ;


;
;
```

```
;    Model statements for module:  Enter 8
;

159$        STATION,      BOP station;
1218$       DELAY:        2,,VA:NEXT(1220$);

1220$       FREE:         submarine ladel(Subladel #):NEXT(0$);


;
;
;    Model statements for module:  Process 25
;
0$          ASSIGN:       Bop.NumberIn=Bop.NumberIn + 1:
                    Bop.WIP=Bop.WIP+1;
1258$       STACK,        1:Save:NEXT(1232$);

1232$       QUEUE,        Bop.Queue;
1231$       SEIZE,        2,VA:
                    Oxygen Furnace,1:NEXT(1230$);

1230$       DELAY:        BOP Time,,VA:NEXT(1273$);

1273$       ASSIGN:       Bop.WaitTime=Bop.WaitTime + Diff.WaitTime;
1237$       TALLY:        Bop.WaitTimePerEntity,Diff.WaitTime,1;
1239$       TALLY:        Bop.TotalTimePerEntity,Diff.StartTime,1;
1263$       ASSIGN:       Bop.VATime=Bop.VATime + Diff.VATime;
1264$       TALLY:        Bop.VATimePerEntity,Diff.VATime,1;
1229$       RELEASE:      Oxygen Furnace,1;
1278$       STACK,        1:Destroy:NEXT(1277$);

1277$       ASSIGN:       Bop.NumberOut=Bop.NumberOut + 1:
                    Bop.WIP=Bop.WIP-1:NEXT(28$);


;
;
;    Model statements for module:  Decide 27
;
28$         BRANCH,       1:
                    If,Entity.Type==A40,9$,Yes:
                    If,Entity.Type==L50,10$,Yes:
                    If,Entity.Type==V10,11$,Yes:
                    Else,148$,Yes;


;
```

```
;
;    Model statements for module:  Decide 36
;
148$         BRANCH,        1:
                       With,50/100,1282$,Yes:
                       Else,1283$,Yes;
1282$        ASSIGN:       Decide 36.NumberOut True=Decide 36.NumberOut True +
1:NEXT(78$);

1283$        ASSIGN:       Decide 36.NumberOut False=Decide 36.NumberOut False +
1:NEXT(149$);


;
;
;    Model statements for module:  Assign 91
;
78$          ASSIGN:       Entity.Type=others:
                       Picture=Picture.Boat:
                       Degasser Time=22.5 + ERLA(1.81, 4):NEXT(79$);


;
;
;    Model statements for module:  Station 51
;

79$          STATION,      others Degasser prepare;
1286$        DELAY:        0.0,,VA:NEXT(80$);


;
;
;    Model statements for module:  Route 31
;
80$          ROUTE:        7.5 + 69 * BETA(1.5, 2.45),Degasser station;


;
;
;    Model statements for module:  Assign 98
;
149$         ASSIGN:       Entity.Type=others:
                       Picture=Picture.Boat:
                       LMF Time=14.5 + ERLA(4, 4):NEXT(150$);
```

```
;
;
;    Model statements for module:  Station 67
;

150$          STATION,       others LMF prepare;
1289$         DELAY:         0.0,,VA:NEXT(151$);


;
;
;    Model statements for module:  Route 44
;
151$          ROUTE:         9.5 + 87 * BETA(1.4, 2.44),LMF station;


;
;
;    Model statements for module:  Assign 66
;
9$            ASSIGN:        Entity.Type=A40:
                             Picture=Picture.Green Ball:
                             LMF Time=7.5 + ERLA(3.12, 7):NEXT(12$);


;
;
;    Model statements for module:  Station 39
;

12$           STATION,       A40 LMF prepare;
1292$         DELAY:         0.0,,VA:NEXT(13$);


;
;
;    Model statements for module:  Route 24
;
13$           ROUTE:         7 + WEIB(33.9, 1.72),LMF station;


;
;
;    Model statements for module:  Assign 67
;
```

```
10$          ASSIGN:       Entity.Type=L50:
                           Picture=Picture.Blue Ball:
                           LMF Time=14.5 + ERLA(4, 4):NEXT(30$);


;
;
;    Model statements for module:  Station 46
;

30$          STATION,      L50 LMF prepare;
1295$          DELAY:        0.0,,VA:NEXT(31$);


;
;
;    Model statements for module:  Route 27
;
31$          ROUTE:        9.5 + 87 * BETA(1.4, 2.44),LMF station;


;
;
;    Model statements for module:  Assign 68
;
11$          ASSIGN:       Entity.Type=V10:
                           Picture=Picture.Red Ball:
                           Degasser Time=22.5 + ERLA(1.81, 4):NEXT(15$);


;
;
;    Model statements for module:  Station 41
;

15$          STATION,      V10 Degasser prepare;
1298$          DELAY:        0.0,,VA:NEXT(16$);


;
;
;    Model statements for module:  Route 25
16$          ROUTE:        7.5 + 69 * BETA(1.5, 2.45),Degasser station;
```

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