LEAN IMPLEMENTATION IN DISCREET AND CONTINUOUS PROCESS INDUSTRIES – A COMPARISON

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By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled “Lean implementation in discreet and continuous process industries – a comparison”, in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Production and Industrial Engineering, submitted in the Department of Mechanical Engineering, Delhi College of Engineering, Delhi is an authentic record of my own work carried out for a period of one year under the supervision of Prof. A. K. Madan, Professor of Mechanical Engineering Department, Delhi College of Engineering, Delhi.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Roma Bhatkoti

This is to certify that the above statement made by the candidate is true to the best of my knowledge.

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Yes, a start leads to an end; initially I never thought that life would be as easy as now. That was in old days where everything was strange but thanks to the God and the institute community for their will and cooperation to feel the comfort I am feeling now. Here, I wish to express my heartily and sincere gratitude and indebtedness to Prof. A.K. Madan, Professor of Mechanical Engineering Department, Delhi College of Engineering, Delhi for his valuable guidance and wholehearted cooperation.
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My credit also goes to all my friends and classmates for their humor, innocence, too much sincerity and cooperation, openness and the like which flourishes my stay here.

Finally, I have shortage of words to express my love and thanks to my Father, to whom I owe my knowledge and personality, who has always inspired and encouraged me to excel in whichever field I may choose.

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EXECUTIVE SUMMARY

As the competition is getting fierce and profit margins getting wafer thin day by day companies can no longer afford to waste their resources instead there is a need to judicially optimize their use. So, there is a trend to go lean.

Lean – A concept that originated in Toyota. And patronized by other Japanese companies has become the need of the hour. One of the key benefits of lean is that its scope is wide enough to include the entire supply chain of any product. The aim of lean is to eliminate any kind of waste (or MUDA in Japanese) and to give the enterprise better reflexes so that it can react immediately to the changing customer needs.

Lean (also known as JIT) started with Toyota which has one piece flow but with times LEAN has evolved and adapted to different kinds of manufacturing environment whether its discreet manufacturing (e.g. Auto-Component industry) or continuous process manufacturing (Pharmaceuticals, Steel, Plastics, etc.). Although, the process and discrete industry share several common characteristics, there are areas where they are very different. Since lean basically stared in car manufacturing industry so most of its tools are suitable for that environment only and cant be adopted without significant changes. Hence, there is a need to tailor them to according to the product type, mix and size of an industry.

The objective of this research is compare Lean Manufacturing implementation in discreet and continuous process industries and to develop a model for the successful implementation of the same. This research has been carried out in real time industrial environment. The names of the companies have been kept confidential to protect their identity. These companies have been assigned arbitrary names henceforth.

INTRODUCTION

Many manufacturers are now critically evaluating their processes to determine their effectiveness in bringing maximum value to customers. Factory management techniques of yesterday are being replaced by more efficient methods that greatly minimize delays, reduce costs, and improve quality.

Lean manufacturing is a whole-systems approach that creates a culture in which everyone in the organization continuously improves processes and production. It is a system focused on and driven by customers, both internal and external. Lean manufacturing isn't just the latest industry buzzword or quick-fix alternative. Increasing competition demands a continuous focus on minimal costs, maximum customer options, fast delivery, and high-quality products and services. Today's manufacturers must be innovative while focusing on waste reduction, improved lead-time, maximized flexibility, and upgraded quality. Lean manufacturing concepts are proven strategies to help manufacturers obtain these attributes. Converting to a lean production system is a process that requires every level of an organization to develop a complete understanding to the basic tents of the concept and its execution. Companies that have fully implemented lean systems are rare, but the list of manufacturers trying to become lean is growing fast.

Lean Manufacturing can be defined as:

“Lean Manufacturing is a series of proven techniques that cause work tasks in a process to be performed with a minimum of waste resulting in greatly reduced wait time, queue time, and other delays. It involves identifying and eliminating non-value adding activities in design, production, supply chain management, and dealing with customers.”

TRADITIONAL VS LEAN MANUFACTURING

For years manufacturers have created products in anticipation of having a market for them. Operations have traditionally been driven by sales forecasts and firms tended to stockpile inventories in case they were needed. A key difference in Lean Manufacturing is that it is based on the concept that production can and should be driven by real customer demand.

Instead of producing what you hope to sell, Lean Manufacturing can produce what your customer wants...with shorter lead times. Instead of pushing product to market, it's pulled there through a system that's set up to quickly respond to customer demand.

Lean organizations are capable of producing high-quality products economically in lower volumes and bringing them to market faster than mass producers. A lean organization can make twice as much product with twice the quality and half the time and space, at half the cost, with a fraction of the normal work-in-process inventory. Lean management is about operating the most efficient and effective organization possible, with the least cost and zero waste.

"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. [3]

SOME BASIC ELEMENTS OF LEAN MANUFACTURING

- Elimination of waste
- Equipment reliability
- Process capability
- Continuous flow
- Material flows one part at a time
- Less inventory required throughout the production process, raw material, WIP, and finished goods
- Defect reduction
- Lead time reduction
- Error proofing
- Stop the Line quality system
- Kanban systems
- Standard work
- Visual management
- In station process control

- Level production
- Takt Time
- Quick Changeover
- Teamwork
- Point of use storage

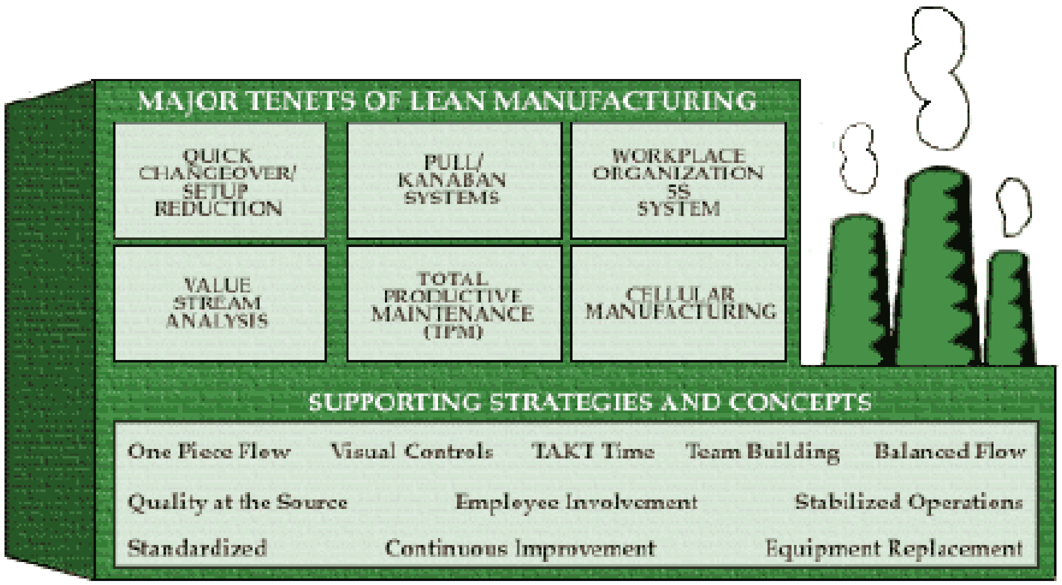


Figure-1 Major tenets of lean manufacturing

THE TRUE COSTS OF INVENTORY

Reducing inventory is an important goal of the lean organization. Carrying inventory has many costs associated with it. Obvious costs include: capital tied up in inventory and the associated loss of interest on that capita., loss due to material handling damage, increased labor costs for material handling, and increased space and storage requirement. A cost from excess inventory that is not so obvious is quality. In fact, many companies have seen quality improvements resulting from inventory reductions while not focusing on quality. The reasoning is that if an upstream process is producing parts on a machine and defects occur halfway through the batch, in an organization with low levels of inventory the next downstream process will discover the defects sooner. An organization with low inventory levels can stop the process when the defect is discovered, throw out the defective inventory, and request the previous process to start another batch. The organization with lower inventory levels will also be more effective at determining what caused the defect because the batch that the defect occurred in is fresh in the minds of both production and maintenance.

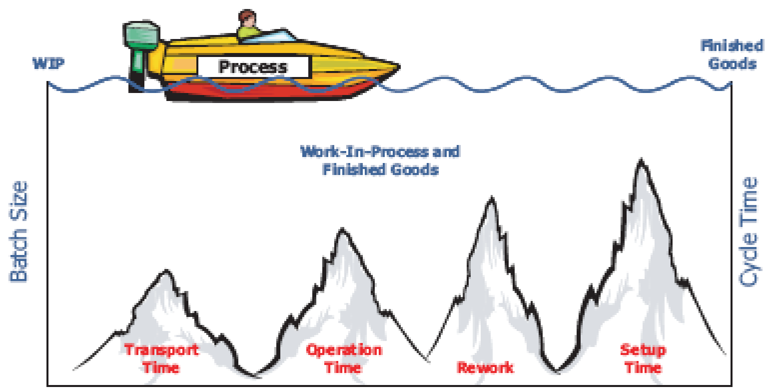


Figure 1: Low Velocity Supply Chain.

Excessively large batch sizes cause WIP and finished goods to clog the Supply Chain.

Figure-2 Boat and rock model of inventory[26]

BENEFITS OF LEAN

- Reduced scrap and waste
- Reduced inventory costs
- Cross-trained employees
- Reduced cycle time
- Reduced obsolescence
- Lower space/facility requirements
- High quality & reliability
- Lower overall costs
- Self-directed work teams
- Lead time reduction
- Fast market response
- Longer machine life

- Improved customer communication
- Lower inventories
- Improved vendor support and quality
- Higher labor efficiency and quality
- Improved flexibility in reacting to changes
- Allows more strategic management focus
- Increased shipping and billing frequencies

HISTORY OF LEAN MANUFACTURING

While tracing the history of Lean Manufacturing I will concentrate on Automobile industry only because the seeds of Lean manufacturing lie there only. In Peter Drucker's words "Automobile Industry is an industry of industries". Twice in the century it has changed our most fundamental ideas of how we make things. And how we make things dictates not only how we work but how we buy, how we think, and the way we live.

After World War I, Henery Ford and General Motors Alfred Sloan moved world manufacture from centuries of crafts production – led by European firms – into the age of mass production. Largely as a result, the United States soon dominated the global economy.

After World War II, Eiji Toyoda and Taiichi Ohno at the Toyota Motor Company in Japan pioneered the concept of Lean Manufacturing. The rise of Japan to its current economic preeminence quickly followed, as other Japanese companies and industries copied this remarkable system.

We will examine each system one by one to see the disadvantages in each and how it gave way to lean.

CRAFTS PRODUCTION SYSTEM

- It started in 1890's and its main hub was Europe and the volume per year was very low about several hundred a year. Much of the work, though including design and engineering, took place in individual workshops scattered through Paris. Different contractors using slightly different gauging systems made the parts, these parts were eventually filed by skilled fitters and made them fit together. Standard gauging system was lacking.
- Workforce was highly skilled in design, machine operating and fitting. Most workers progressed through an apprenticeship to full set of crafts skills. Many hoped to run their own machine shops and to become sub-contractors to the assembler firm.
- Organizations were extremely decentralized, although concentrating within the single city. The system was coordinated/owned by an owner who was in direct contact with everyone.
- General-purpose machine tools were used.

- There was no monopoly.
- Every single car was a prototype and thus consistancy and reliabiliy were elusive.
- Increase in volume didn't drop the cost.
- New technologies could not develop because individual craftsmen did not have enough resources to produce fundamental innovation.
- All these shortcomings led to the era of Mass Production

MASS PRODUCTION SYSTEM

- It started in the beginning of the 20^{th} century and can be credited to Henery Ford. Key to mass production is not the moving continuous assembly line but the complete and consistent interchangeability of parts and the simplicity of attaching them. The cycle time reduced 514 minutes to 1.19 minutes.
- Workforce was de-motivated since the work methods were boring, routine and monotonous and he had no career path. The workmen were not supposed to think and the new professional who did this thinking work was an "Industrial Engineer" who was born in the era of mass production. This newly emerging professional engineer had a direct climb up the career ladder.
- The organization had total vertical integration (that is making everything connected with cars from basic raw material on up)
- This production churned out standardized product at high volume.
- It was very costly and time consuming to change over from one model to another.
- There were dedicated dies, lined, and even entire plants for a particular model thus flexibility was very low.
- Quality of outgoing cars were poor and 20% of the plants area was dedicated to rework and 25% of the production time was dedicated to rework.
- Goal was just to good enough.
- There was a " Pass The Metal Mentality " which emerged due to the pressure on the engineer to produce according to the companies specified " yield " (yield is the ration of the number of cars actually produced to the number that is required to be produced). So they ignored the quality and focussed more on yield that resulted in

defected parts being rolled-down the assembly line that in turn multiplied the defects and ate up precious time and resource for rework.

LEAN PRODUCTION SYSTEM

The Lean Production System is also known as Toyota Production System because it started From Toyota Motor Company. But the journey of Lean wasn't as smooth as expected by some. Toyota Motor Company started in the year 1937. But its sales collapsed in the year 1949 so Eiji Toyota visited Rogue Complex to find out the solution to the problems being faced by Toyota. But when he reached Rogue in Detroit he found various flaws. So he decided not to follow the system as it was but to tailor it according to the workforce, customer, economy, market and culture of Japan.

OBSERVATION

Eiji observed that Rogue had dedicated presses for many stamping operations because die-changing operation was done by specialists and took an entire day to align them. Even a slight miss alignment would result into melting of stamped pats that could only be fixed by expensive and time-consuming repairs.

Eiji decided to buy some used American presses and perfected the die changing operation. The die change over could now be done in only three minutes (earlier it took 24 hours) and could be done by the operator instead of a specialist.

In this process he made an unexpected discovery that changed the way people thought at that times. He discovered that it actually cost less per part to make small batches of stampings than to run off enormous lots.

There were two reasons of this phenomenon:-

1) Making small batches eliminated inventory carrying cost of huge inventory of finished parts that mass production required.
2) Even more importantly, making only a few parts before assembling them into a car caused stamping mistakes to show up almost immidiately.

The consequence of this discovery was that it eliminated the waste of large number of defective parts that had to be repaired at a great expense or even discarded.

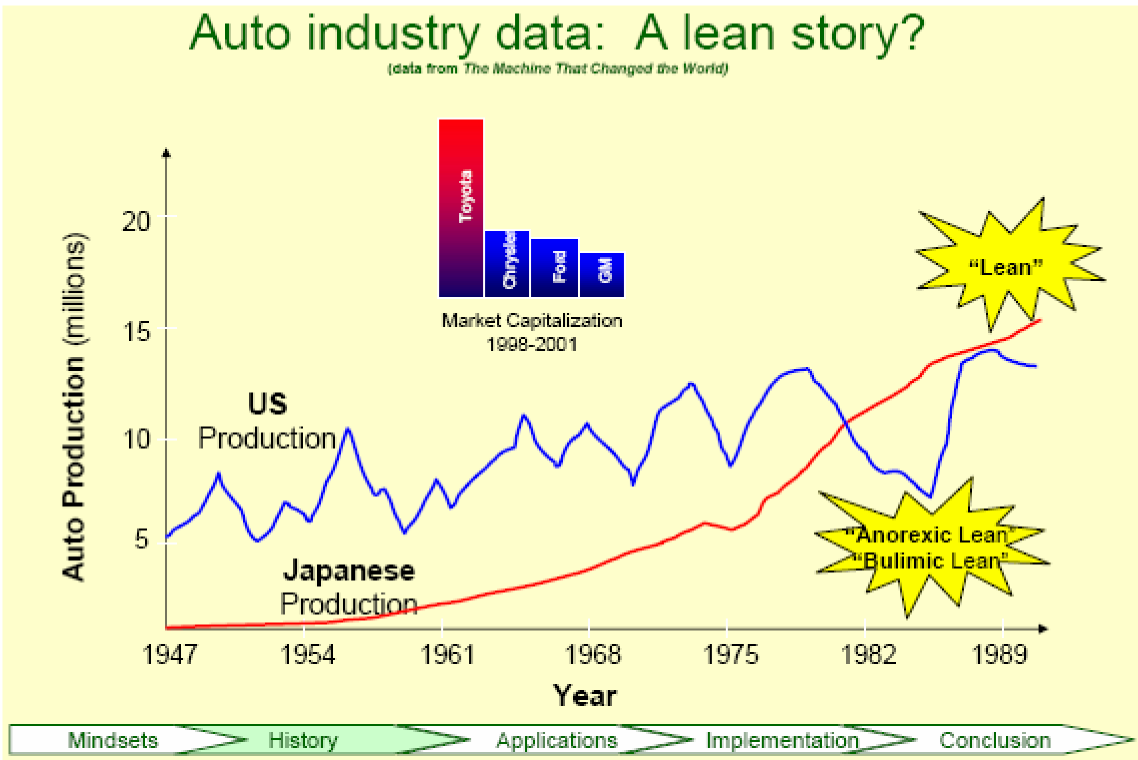
Company as community: workers were given seniority-based wages. Workers were grouped into teams with effective and influential team leaders unlike in mass production system where a team leader was mere a coordinator. Workers were given power to stop the line. Today at Toyota every operator has the power to stop the line but the line practically never stops and the yield is almost 100%. That's how mass production practice of passing on errors to keep the line running, which caused the errors to multiply, was challenged and proved wrong by Toyota.
Ohno instituted a system a system of problem solving called the 5Why's. Production workers were taught to trace systematically every error back to its ultimate cause.

Product Development and Engineering: Product development teams were set up with strong team leaders who had all the expertise. Career paths were structured so that rewards went to strong team players rather than to individual performers.

Supply Chain: Auto component manufacturers were grouped into functional tiers and made into associations so that there is horizontal flow of knowledge, particularly on advanced manufacturing techniques. This was very opposite to mass production suppliers where there was no horizontal flow of information between the suppliers because they were competing with each others and tried to hold back information.
Toyota gave its suppliers enough freedom to innovate. They were free to experiment with material or technique while maintaining specification unlike is west where the assembles used to give out drawings of the product and asked the suppliers to bis. The contract usually went to the one quoting the lowest price.

Changing Customer demand: Toyota built the dealer into the Production System and customer into Product Development Process. A build to order system was developed where the dealer was the first step in the *kanban* system, sending orders for the presold cars to the factory for delivery to specific customer in two-three days.
Toyota focussed relentlessly on repeat buyers.
The success of Lean Manufacturing is very evident from this following graph that shows a comparison between Japanese and American car production over the last 50 years. The

growth of American car industry has been uneven and unpredictable whereas Japanese car production has shown wonderful and steady growth.[1]



Figure–3 Growth of Auto industry data in US and Japan [36]

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.

APPLICATION OF LEAN IN DISCRETE INDUSTRY

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. The lean manufacturing concept is now being widely used in component assembly operations in a variety of industries, e.g., automotive, electronics, and cameras . 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. In a recent study done by Industry week in 2001 the results 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 technique). 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. JIT practices have also been implemented in industries like electronic/electric, transportation equipment, health and medical components, and machinery.[18]

CONTINUOUS PROCESS INDUSTRY AND 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 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. 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. 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). 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. The results were promising: 96% reduction in WIP, working capital decline of $2 million, and product quality improvement of 10% (Billesbach, 1994). In the process industry, JIT principles can focus more on the non production activities such as material movement, distribution and storage.

Process industries have normally been lumped together on the basis of the fact that they are designed to produce non discrete 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 non discrete 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, non discrete 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 non discrete 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 necessarily utilize process flow production techniques.

The different types of the process are classified according to:-

(a) The product characteristics

(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.

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. Almost all the process industries obtain their primary raw materials from mining, agricultural, or other process industries. 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. An 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. On the other hand, there are segments in the process industry that use a relatively low variety of raw materials as input. 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.[21]

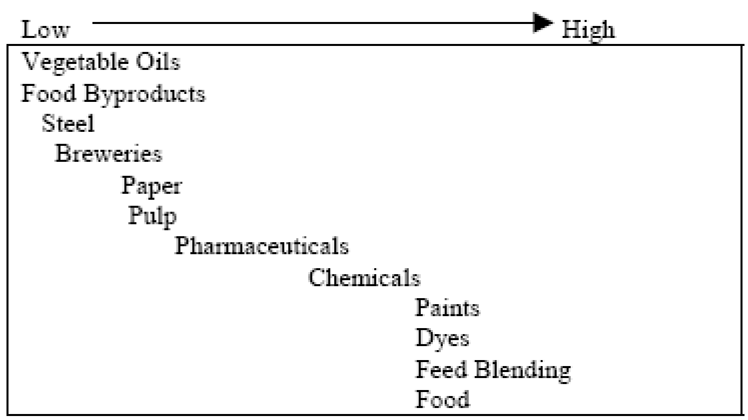


Figure-4 Classification of the process industry based on raw material variety[4]

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.

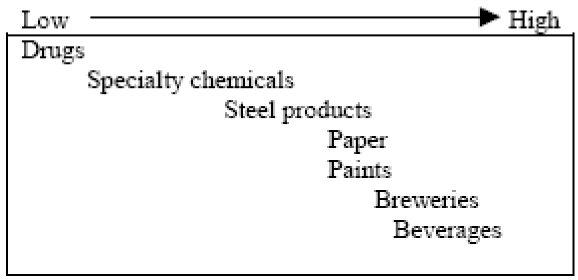


Figure-5 Classification of the process industries based on product volume[4]

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.[5]

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). 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. 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 nondedicated 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). 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.

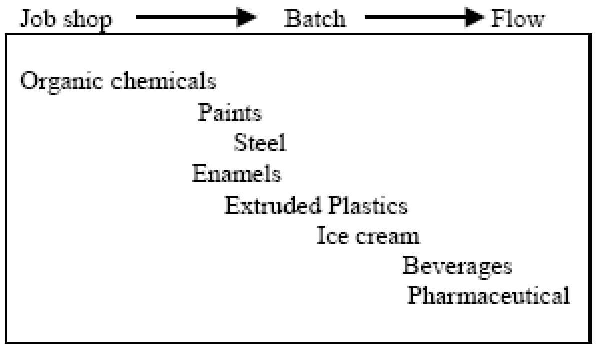


Figure-6 Classification of the process industries with respect to equipment arrangement and flexibility.

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. 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. 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). 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.

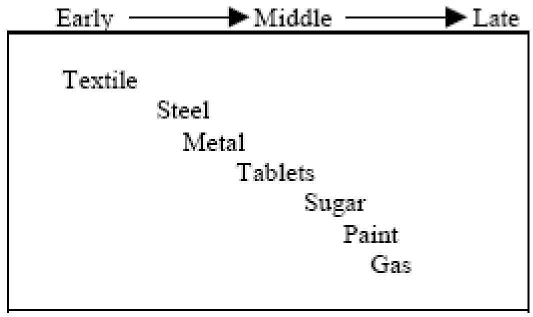


Figure-7 Classification of process industries based upon transformation into discrete units.

OPPORTUNITIES FOR LEAN

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. 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.

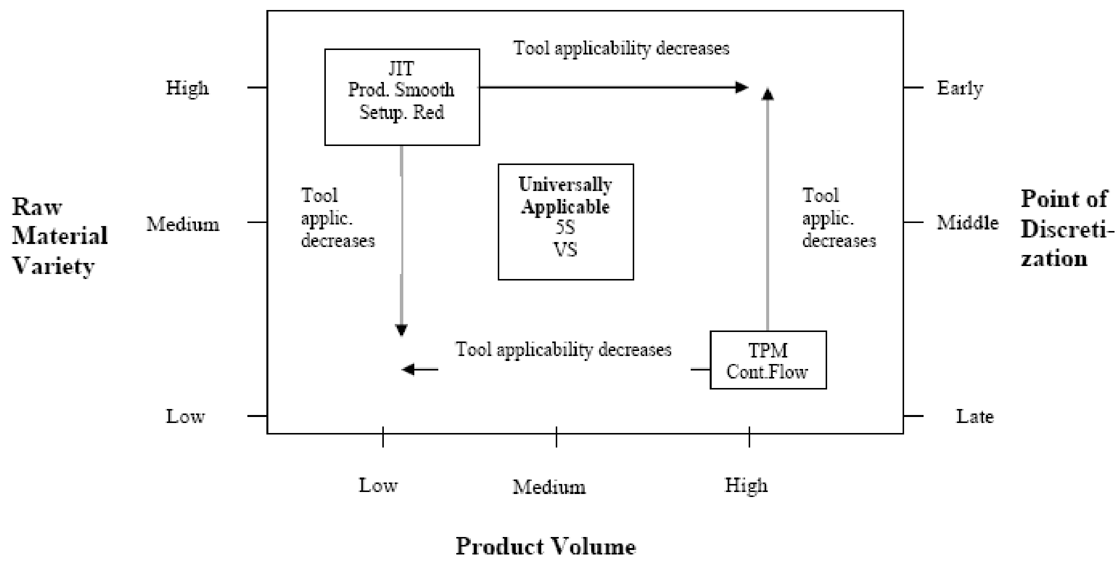


Figure-8 General guidelines for applying lean tools in the process industry: product characteristics

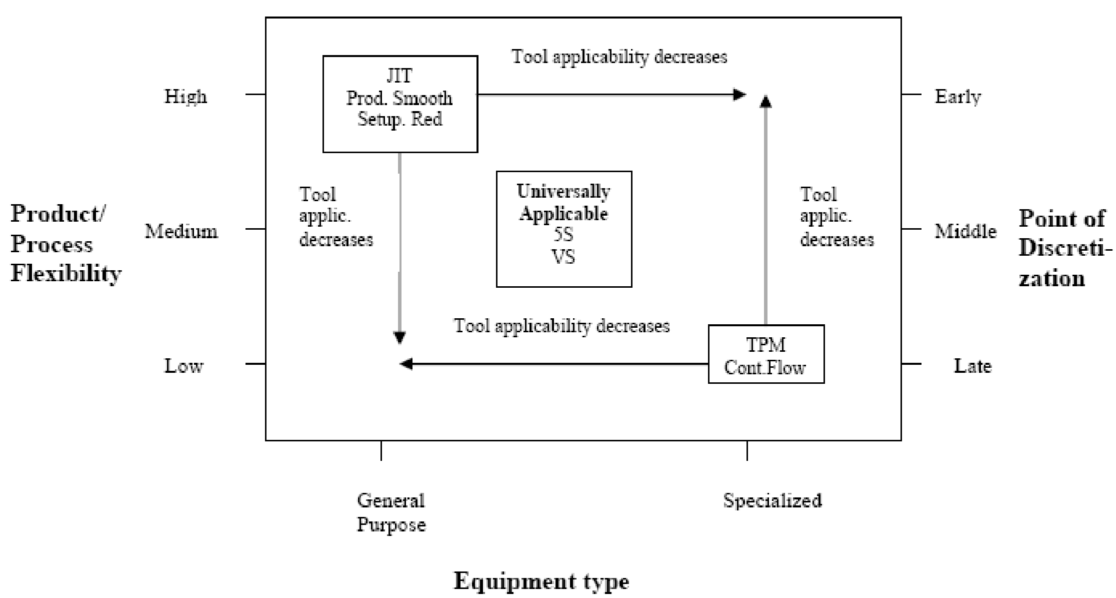


Figure-9 General guidelines for applying lean tools in the process industry: material flow characteristics.

LEAN MANUFACTURING TOOLS AND TECHNIQUES

Once companies pinpoint the major sources of waste, tools such as continuous improvement, just-in-time production, production smoothening, 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.

CELLULAR MANUFACTURING

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. 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[7]

CONTINUOUS IMPROVEMENT/KAIZEN

A system of continuous improvement in quality, technology, processes, company culture, productivity, safety and leadership. Kaizen is focused on making small improvements on a continuous basis. Kaizen is a system that involves every employee - from upper management to the cleaning crew. Everyone is encouraged to come up with small improvement suggestions on a regular basis. This is not a once a year, or monthly activity. It is continuous.

Suggestions are not limited to a specific area such as production or marketing. Kaizen is based on making changes anywhere that improvements can be made. The Kaizen philosophy is to "do it better, make it better, improve it even if it ain't broke, because if we don't, we can't compete with those who do."

Western philosophy can be summarized as, "if it ain't broke, don't fix it." The Kaizen philosophy is that everything, even it it ain't broke, can be improved.

Kaizen involves setting standards and then continually improving those standards. To support the higher standards Kaizen also involves providing the training, materials and supervision that is needed for employees. [8]

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. 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. 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.[8]

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. 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. 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.

Production Kanban	
Model Name	
CT-100 THIN	
Size	
STD	
Inventory in Shop	
Minimum	Maximum
2	**6**
Supplier Process	
Rail Coiling	
Customer Process	
Rail Cut Off	
No. of Coils	No. of Rings
8	**8000**

Figure-10 Example of a Kanban[29]

Just-In-Time Distribution. 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. 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.

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. 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. 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.

Just-In-Time Purchasing. Just-in-time purchasing (JITP) is defined 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.

JIDOKA

It means "automation with human intelligence" (*Autonomation*). Jidoka also refers to the practice of stopping a manual line or process when something goes amiss. Jidoka in one form, Jidoka uses limit switches or devices that shut down a process when:

1. The required number of pieces have been made
2. A part is defective
3. The mechanism jams.

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. 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.

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. Takt time is calculated based on the following formula:

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

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.[20]

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. 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 pokayoke. 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.

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. 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 coordinates 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.

OVERVIEW OF SUPPLY CHAIN MANAGEMENT

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.

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. 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. Basically, customers are always looking for better product quality, lower prices, value-added services, more flexibility, and shorter lead time.

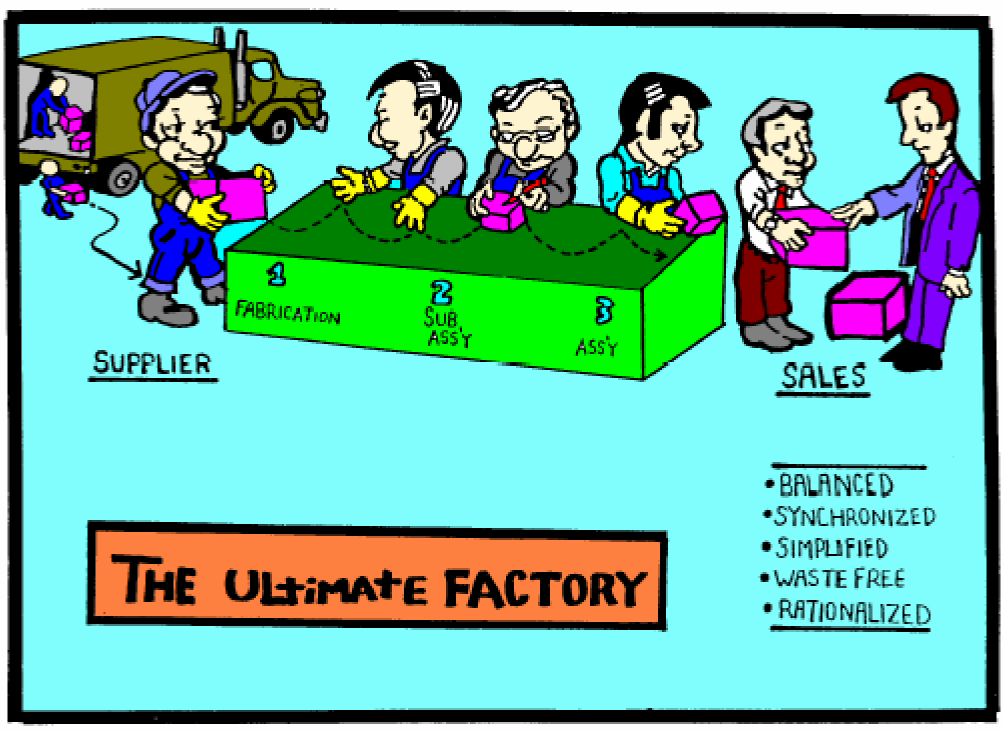
SUPPLIER INTEGRATION

Supplier integration was introduced first in the automotive industry and one of the pioneers in this was Toyota. 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.[11]

MANUFACTURER INTEGRATION

The connecting link between the supplier and the customer in the supply chain is the manufacturer. 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.

Figure-11 The Continuous Factory[37]



LEAN APPROACH TO PROCESS CAPABILITY

Pharmaceutical quality is dominated by specifications. Raw material and product compositions, process operating conditions, development targets, sterility assurance levels, biological monitoring and many other quality aspects are specified. Quality is related to on-spec (perfect) or off-spec (disastrous). The Lean Thinking approach is different: "Specifications are not enough!"

Specifications are an initial benchmark, whereas the traditional approach is to use them as a target to attempt to reach. The aim should be to design systems that will meet specifications from the start, and then carry on improving from there. The target is to develop a system that generates the minimum acceptable variation from the optimum. Attempting to define acceptable standards of quality in terms of specifications leads towards illogicalities and impracticalities – yet this is the way industry have judged quality for decades. This relationship between the deviation from optimum conditions, or process variation, and the resulting loss is described by the Taguchi Loss Function.

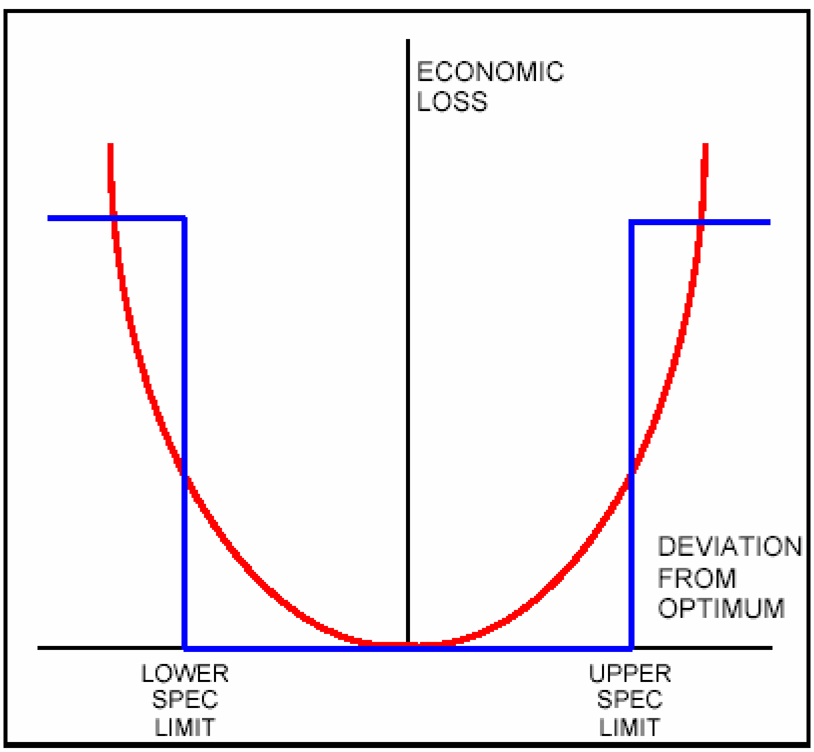


Figure-12 The Taguchi Loss Function[5]

The X-axis forms the quality characteristic being measured; the Y-axis represents the loss attributable to the value of the quality characteristic. The traditional approach of setting specifications is shown in blue and this illustrates the digital GOOD-BAD thinking:

- Between the specification limits, there is no loss and the product is perfect.
- Outside the limits the loss is large and the product quality is unacceptable.

The Taguchi Loss Function is shown in red and it illustrates the two observations made earlier:

- Small deviations from optimum produce small losses.
- As the quality characteristic strays further from the optimum, the resulting loss increases exponentially.

Given the reality of the Taguchi Loss Function, the limitations of the conformance-to-specification approach to quality are apparent. The benefits of using the Taguchi Loss Function include:

- It inimiz the attention on the need for continuous improvement.
- Even rough assessments of the loss function give highly useful information for prioritizing improvement effort.
- Use of the loss function provides a basis for quantifying values of improvement efforts, and for raising awareness of the costs of current poor practices.

DESIGN OF EXPERIMENTS AND PROCESS CAPABILITY

Design of experiment (DoE) is a statistical-based tool for designing experiments to assess the impact of making changes to the results of the experiment. A typical application is reaction optimization, where a range of experiments are carried out and a number of variables e.g. temperature, concentration, residence time etc, are adjusted step-wise, creating a multi-dimensional matrix of experiments. The DoE system calculates the loss function for all of the individual process variables, highlighting:

- The optimum conditions, the X-Y intercept on the Loss Function curve, at which to run the reactor, and
- The resulting loss from moving away from this optimum, the shape of the curve, representing the sensitivity of the reaction to changing the input variables.

This quantification of the Loss Function makes the DoE system an extremely useful and powerful tool that forms the theoretical basis of multivariate analysis systems used for process design, optimization and monitoring.

The Taguchi Loss Function is more than a philosophical representation of the *Lean* approach to quality; it has a rigorous mathematical basis behind it that can be used to measure the capability of a process or system.

The capability of a system is defined as:

$$\frac{\text{Difference between Upper and Lower Specification Limits}}{\text{Difference between the Upper and Lower Natural Process Limits}}$$

where the natural process limits are +/- 3 standard deviation from the process mean.

The capability of a process defines the ability of that process to produce acceptable product. In Western manufacturing, the normal thinking is that a capability of 1.33 is extremely satisfactory. The *Lean* approach is to continuously improve capability with values of 3 to 5 being the norm. The achieved benefits are:

- The overall quality loss is inimized – e.g. a doubling of capability reduces the quality loss by a factor of four.
- Increased capability makes the process less vulnerable to drifts and swings from the optimum e.g. variations in process conditions, raw material inputs, process upsets etc.

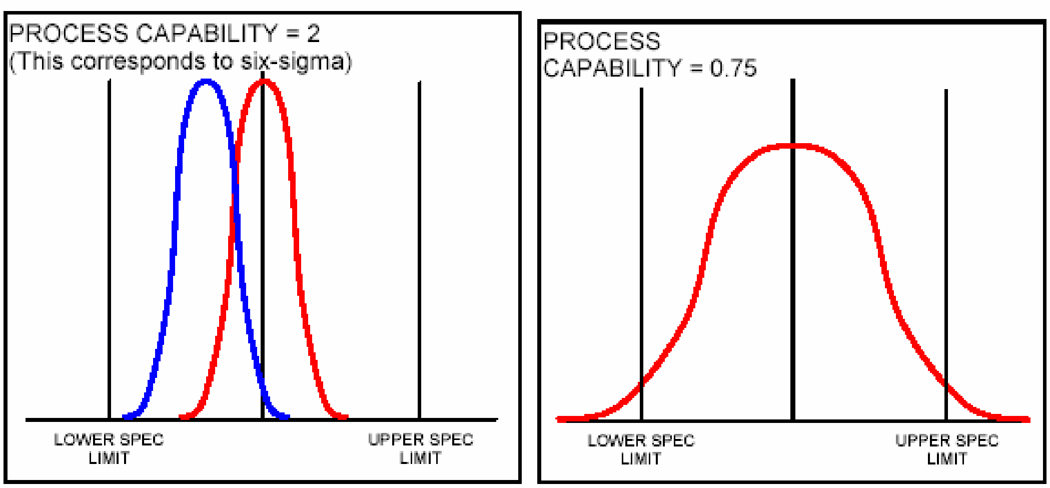
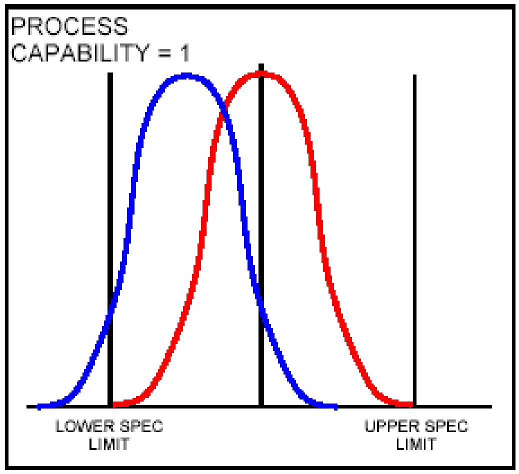


Figure-13 Different process capabilities



As these show, at a capability of 1, the process will produce defects at the rate of 1 in 400. However the smallest drift from optimum conditions will start to rapidly increase the number of defects generated. Improving the capability to 2 means that not only is the steady state loss reduced but the loss produced when the process drifts from optimum is also reduced. When the process capability is less than 1, significant numbers of defects are generated (high loss). The resulting loss when the process drifts is also significantly higher than for a process with a higher capability.

1. Data taken from (Doug and Bruttin, 2001)
2. Calculated from assuming a normal distribution.
3. Data taken from and based on the cost to achieve acceptable quality as a percentage of the overall manufacturing cost.

	Capability	Sigma (+/-)	Taguchi Loss	PPM Defects (1)	Theoretical Yield (2)	Cost of Quality (3)
	½	1.5	400		86.6	20-25%
PHARMA	¾	2.25	178		97.55	17-22%
	1	3	100	2700	99.73	12-18%
AUTOMOTIVE	$1\frac{1}{3}$	4	56	63	99.9937	4-8%
	$1\frac{2}{3}$	5	36	0.002	99.9999998	1-3%
SEMICON	2	6	11			<1%
	5	15	4			

Figure-14 Comparison of The Capability of Different Manufacturing Sectors

Given this data, it may appear strange that anyone would strive to increase the capability of their process beyond say 11/2, given the apparent negligible amount of defects generated at this capability. It should be remembered however that the defects have been calculated on a normal distribution that is centered on the optimum. As previously stated, the additional capability minimises the overall Taguchi Loss during optimum operation and also minimises the resulting loss and probability of defects during process drifts and upsets. In the pharma industry however, many processes are not even capable when operating at optimum operating conditions. In addition, this poor capability generates further large losses when variation is introduced to the process and the conditions move away from the optimum. Reasons for poor capability are a combination of equipment limitations, and poor process understanding gained during development. The limitations of current pharmaceutical manufacturing equipment have been well documented, and the list below gives a brief summary of the main issues. These should be read bearing in mind the lesson from the above section that variation away from the optimum generates significant loss, even if the process is fundamentally capable. This section has introduced the *Lean* concept of process capability, and shown continuous plants can be designed to give far greater capability than batch plants. (Huw Thomas, 2003)[13]

DIFFERENT TYPES OF WASTES AND TECHNIQUES TO REDUCE THEM

Operating large batch plants in long campaigns is a total anathema to *Lean* manufacturing, and their use severely restricts the ability to implement *Lean Thinking* in the manufacturing process. In *Lean Thinking*, waste has a broad definition:

"Waste is the opposite of value"

And waste is broken down into three different types:

- Process wastes (such as QC testing, planning, plant changeovers and in process sampling) do not add customer value but are currently necessary for the process. These should be targeted for reduction then elimination.
- Business wastes are the operations that benefit managers, employees, suppliers, but do not directly benefit the customer. These should also be made as efficient as possible or eliminated.
- Pure waste that needs to be eliminated as quickly as possible.

Taiichi Ohno(5), creator of the Toyota Production System, originally described seven sources of waste, and four additional wastes have been added to his original list. The following sections introduce each source of waste and identify how and where each type of waste exists in process industry taking example of pharma industry. [12]

THE WASTE OF OVERPRODUCTION

Overproduction is making too much, too early. The production rate should be defined by the customer demands – making just what is needed, just when it is needed and with perfect quality. In addition to the direct cost of increased work in progress, overproduction has more serious impact on product quality. Excessive lead and storage times mean defects are not detected early, products deteriorate, and the physical and time separation between manufacturer and customer leads to lack of communication and arms length relationships.

The typical batch-staged campaign system inherently leads to overproduction. If the production cycle is six months long, the first stage must make six months' worth of the first intermediate. The raw material has been bought and processed, but there will be no return on that purchase for six months until the final product is produced.

Any quality problem jeopardizes a significant quantity of material and maximizes the risk to the supply of that product. By overproducing, the plant cannot rapidly compensate for changes in demand for a product because it is set up to manufacture set quantities in a set campaign cycle. This complete lack of flexibility ensures that the only way to guarantee supply is to hold enormous stocks of inventory, both as WIP and as FGI in the supply chain. Once the plant is at full capacity, the only way to increase capacity is to build another plant. This inflexibility generates enormous wastes and inertia in the supply chain.

By comparison, a world-class *Lean* manufacturing system such as that used at Toyota, considers overproduction to have occurred if the daily schedule is exceeded. This daily schedule is of course driven by the exact customer demand of cars ordered in the last few weeks – there is very little inventory in the supply chain that is not already destined for a customer. This comparison is all the more dramatic when it is remembered that very few of the cars that are made to order are identical, given the multitude of options available to the average car buyer. Despite this, the custom product is still delivered with a short lead time, at low cost, and with a minimal need to hold inventory.

The only way to eliminate the waste of overproduction in continuous manufacturing is to dramatically reduce the manufacturing lead time. This can be done in two ways:

- Build a batch plant that moves from raw material to finished product in one campaign. Whilst this is technically feasible and can be achieved using small batch processes, it is not economically feasible to install multiple reaction, crystallization, and filter-dryer trains, with the associated control and utility systems.
- Develop the process and build a plant that operates continuously. The goal of *Lean* manufacturing is ‘one-piece flow’. For discrete item production e.g. cars, washing machines, TVs etc, one piece flow means a single item – each car moving down the assembly line is specifically assembled to match a specific order, and the parts for that car are made for that car only. Given that car body panels and television tubes cannot be made to flow through pipes, achieving this high degree of flow for such a multitude of components and product variants is an incredible achievement.

Conversely for continuous process plants, continuous metering is both simple and accurate.

THE WASTE OF WAITING

Whenever time is not being used effectively, the waste of waiting occurs. How important is the waste of waiting? Time has been identified as an important element of competitiveness and quality.

Competitiveness – Customers will not appreciate being kept waiting e.g. checkout response teams at supermarkets, but may be prepared to pay a premium to be dealt with faster e.g. next day courier services.

Quality – Product quality decreases with time e.g. product shelf life, and the impact of product quality feedback is at least inversely proportional to the time between manufacturing and receiving the feedback. This relationship is at least inversely squared – issues identified and dealt with at the production line are far more powerful than issues arising from, say, a customer complaint from product packed up to three years ago.[25]

THE WASTE OF TRANSPORTING

There is a famous nursery rhyme has the following words:

"The Grand Old Duke of York,
He had 10,000 men.
He marched them up to the top of the hill,
And he marched them down again."

To which she replies "That was a waste." Of effort, time, quality and money. In a typical multi-storey plant, operating on a multi-stage, batch-campaign system, how many times does material get taken 'up to the top of the hill', to an upper storey for charging into vessels below, and then percolate through the plant to drying and pack-off "at the bottom of the hill", on the ground floor? Adding in transportation to and from the warehouse and the scale of the waste of transportation becomes apparent.

Transportation is pure waste – moving products around is not what customers are prepared to pay for. Whilst eliminating transportation is impossible, given that it is pure waste, it should be reduced to a minimum.

Long transportation is associated with the following losses:

- The likelihood of damage and/or deterioration increase with increasing transportation.
- Double handling is simply doubling the waste.
- As transportation distances become greater, communication suffers, with the common result both in manufacturing and service industries of poorer quality.

How can transportation distances in pharmaceutical manufacturing be minimized?

- Minimal material handling – no intermediate isolation, storage, returning to the plant.
- Solids handling is limited to raw materials in and finished product out – all other material handling involves liquids and gases.
- The plant is shrunk in size by a factor of ten, minimizing the transportation distance between adjacent processing stages.
- Online analytical systems reduce the transportation distance between the process and the process product, hence further improving the product quality.

THE WASTE OF INAPPROPRIATE PROCESSING

A common expression that describes this waste is 'using a sledgehammer to crack a nut' –not only is the sledgehammer' process far too large for the operation, it is also not quality-capable. Not quality-capable indicates that the possible variation in how the process is operated (strength and coordination of user leads to enormous variation in the quality of the product (broken shell to pulverized nut). In what other ways is this waste represented?

- Thinking in terms of one large plant or plant item. This can lead to pressure to run the plant as often as possible, to maximize utilization, whether there is the demand or not.
- Large multi-purpose plant items may not be the ideal machine for the process, but the drive for high utilization of that expensive item leads to processes being adapted to fit, with sub-optimal results.
- A multi-purpose plant will never be as efficient as a dedicated plant. The current trend for higher potency actives requiring smaller production volumes means that the economics of batch production favor the inherently compromised solution of multi-purpose plants. Instead of resigning ourselves to this compromise based on the batch production economic model, is it not better to look for a new production model that eliminates this compromise?

- Building a multi-purpose plant with a wide-ranging design specification to cover all eventualities. For example designing the process vessels and the heating-cooling system to cover a temperature range between -80oC to 300oC – when in reality a temperature range of –40oC to 150oC will cover 99% of processes. To what degree does the expensive multi-purpose functionality actually get utilized?
- A single large plant or plant item becomes a bottleneck, and can lead to poor layout or process flow, which as the above sections identify, leads to extra transportation and its resultant communication and quality losses.

Lean Thinking considers that the ideal is to have plant items and plant whose available capacity is exactly matched to demand. The only way to economically move nearer to this *Lean* in process industry is to move towards continuous processing where appropriate. I have added the caveat of ’where appropriate’ to cover the fact that there will be processes that are simply not suitable for continuous processing. Attempting to convert these to continuous operation will in fact be another form of the waste of inappropriate processing. Continuous processing addresses the problems of this waste in a number of ways:

- The plant can be economically dedicated at low production throughputs.
- Where this is not possible, the plant can be rapidly configured to run different products either by conventional cleaning or by swapping out the small product contact process equipment.
- Multiple dedicated process lines can be economically assembled within the space envelope of an existing batch plant; and each one only needs to be designed to meet the requirements of a specific process, eliminated over specifying the plant.
- Each process line can be designed to cover a range of throughputs, so the capacity of each line can be changed to meet the demand.

THE WASTE OF UNNECESSARY INVENTORY

Inventory is endemic to batch campaign manufacturing – but what is the cost of this inventory?

It is not widely acknowledged in non-*Lean Thinking* that the cost of inventory far exceeds the cost of the investment tied up in it. Inventory is the enemy of productivity and quality. The zeal with which *Lean* manufacturers drive to reduce inventory is driven by this fundamental understanding of how inventory hinders economic performance. Inventory:

- increases lead-time
- prevents rapid identification of problems
- increase plant size
- increases transportation and communication distances
- hides quality problems because there is always sufficient material to cover for the defective batch of material

The quantity of inventory tied up in batch manufacturing is enormous. Lead times for material to be processed from raw materials to final product can range from weeks to several years, depending on the process and the campaign schedule. This long lead time means that the plant warehouse will keep the whole campaigns-worth of material, with the subsequent cost and risk of holding that material.

The ‘product flow’ philosophy of *Lean Thinking* is perfectly epitomized by continuous manufacturing, where raw materials are transformed directly into finished, saleable product in a single process train, with an absolute minimum of process inventory.

THE WASTE OF UNNECESSARY MOTIONS

Quality and productivity are improved by good ergonomics. In current Health and Safety thinking, it is undisputed that application of good ergonomics is both ethically and economically sound.

Given the toxicity of many of the materials used in the pharma industry, it is not surprising that the containment of the operator process interfaces is the subject of significant investment in design effort and capital. Large batch production means large volumes, with the inherent risk this brings. Increasingly potent products are a double-edged sword – the volumes may be smaller but this makes them harder to automate hence more likely to be manipulated manually.

ELIMINATE Continuous processing can eliminate the risk by removing the need for intermediate pack-off by converting the raw material directly to finished product, hence giving a single manual interaction stage.

REDUCE Given the low volume throughput; the individual quantities packed off from the final drying stage will be significantly smaller, hence reducing the inherent risk. The smooth, steady state operation of a continuous plant is in contrast with the peaky, intermittent demands of a batch plant. This steady state operation allows inherently better ergonomics and working patterns to be adopted.

THE WASTE OF DEFECTS

This was the last of Taichi Ohno's wastes, and perhaps the most immediately obvious. The cost of defects in the pharma industry is enormous and can be found internally, in the form of scrap, rework, quality incident reporting, and externally, in the form of complaints, mix-ups, recalls and in extreme cases suspension of operations.

Given that the majority of pharmaceutical company failures are due to quality failures, and the Cost of [Poor] Quality is significantly higher than in other manufacturing industries.

One of the perceived benefits of batch over continuous manufacturing is that ‘there is more opportunity to recover a situation if something goes wrong’, and ’material can be segregated for reprocessing in the future’.

The *Lean Thinking* ‘science-based approach’ , enables this built in waste to be eliminated during process design and development. It is widely recognized that 90% of the cost of a process is locked in at the design stage. This includes the inherent waste of operating a non-capable process. Continuous processing offers one option to escape the limited design options that can create so much ‘Waste of Defects’ in a low capability batch process.

THE WASTE OF UNTAPPED HUMAN POTENTIAL

The real aim of *Lean Thinking* is not to transform manufacturing, but rather it is to create ’thinking people’ who carry out and maintain the transformation. Without the continuous improvement created by thinking people, a plant will suffer in the productivity race. Many automotive manufacturers in the 1980s looked towards automated plants and warehouses as a cure for the productivity gap between them and the new *Lean* manufacturers (mostly Japanese), and discovered that you cannot buy productivity and bolt it into an inherently inefficient production system. The customers do not care whether the excess inventory was placed in the warehouse by a human or a robot; all they care about is the adverse impact on the cost and quality of the excess inventory being there.

Human potential is untapped is during process development, where the free thinking of the development chemists and process engineers is constrained by the equipment limitations of typical batch equipment. By opening up alternative processing routes to the conventional multi-stage batch operation, it becomes possible for people to discover and develop new avenues of chemistry, processing and technology. As with implementing any of the aspects of *Lean Thinking*, untapping new areas of potential requires high level,

long-term commitment and support, resisting the urge for quick wins and losing heart when they do not materialize immediately. *Lean Thinking* is about total transformation, and this cannot be bought in and bolted on for an instant fix.[31]

THE WASTE OF INAPPROPRIATE SYSTEMS

These wastes are generated by systems that act against the basic principles of *Lean Thinking*. As these wastes are identified, it is often discovered that it is not the operation that consumes the time and money, but rather the procedures and the systems. This is shrugged off as the price to pay for operating in a heavily regulated industry. The reality is that much of the waste can be eliminated, as has been demonstrated in other highly regulated industries, such as the food industry, that have lower margin products and hence have a driver to eliminate inappropriate system.

- In batch campaign processing, sampling and analysis are required for the different stages of production. As well as the physical operation, this generates data that needs procedural controls. Integrating the process to a single stage will minimize the amount of sampling required by eliminating multiple process stages.
- Batch plants have enormous variation in utility demands due to the cyclic nature of the process. The utility generation and distribution system are designed to supply a design peak load based on a specified diversity e.g. 50% of users calling for heating. For a multi-purpose batch plant, this limits the ultimate flexibility of the plant. In addition, the installed system will rarely run at 100% of its rated load due to the rapid demand fluctuations of batch processing.
- Operation in a continuous plant has no peak loads to design for, and the base load is significantly lower. This leads to very economic utility systems. Figure 6 gives the calculated utility requirements for a batch and continuous plant with the same duty. Utility systems for continuous plants are designed for 100% diversity and are still up to 40 times smaller than for a similar batch plant.

WASTED ENERGY AND WATER

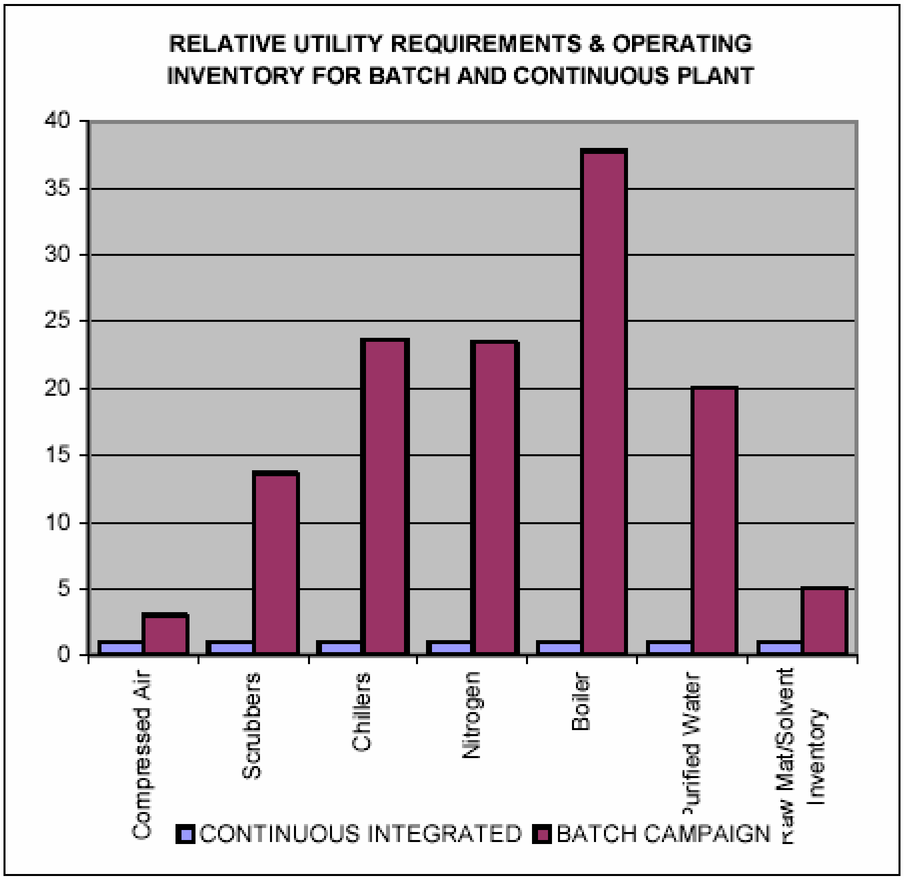


Figure-15 Relative utility requirements & operating inventory for batch and continuous plant[35]

As the above graph indicates continuous plants are much more efficient users of energy and other utilities as the following examples explain.

- Batch reaction cycles typically involve temperature cycling, where not only the reactor contents need to be heated/cooled but also the vessel, the jacket and its contents. One batch reaction for example required a cooling capacity of 80kW whilst the same reaction carried out continuously required only 200W.
- The steam duty is for HVAC heating only – all process heating is done through electrical heating; the largest individual load is less than 3kW.
- The nitrogen requirement is cut by 95% through the use of continuously flooded equipment, small vessel sizes, no line blowing and minimal purging.

- Scrubber duty is reduced by a factor of 14. Continuous equipment is fully flooded; batch fill-empty operation displaces large volumes of solvent-laden gas to the scrubber.

POLLUTION WASTE

In *Lean Thinking*, like zero inventory, zero emissions should be the ultimate goal. Regardless of whether either is realistically achievable, it remains the goal. Like quality requirements, environmental demands will only get tougher.

Regardless of where the batch process falls on the scale of environmental impact, for the same chemistry, an integrated continuous operation will have a number of advantages over the batch process:

- Reduced effluent from integrated process i.e. no intermediate isolation gives a single filtrate and dryer condensate load to waste, not one for each intermediate isolation.
- Reactor heat transfer coefficient can be tuned to give minimum excess solvent requirement, typically needed in batch reactor to minimize temperature rise from reaction exotherm.
- Single crystallization minimizes anti-solvent and filter cake wash liquor consumption.
- Fully contained liquid process reduces emissions to scrubber.
- Greatly reduced scrubber load gives large reduction in scrubber liquor waste.
- Energy input to plant is greatly reduced.
- A ten-fold reduction in plant footprint and move away from multi-storey construction gives far lower building impact.
- Reduction in peak demand for solvents may remove requirement for tank farm, – reduced inventory.

Continuous processing has been identified as a powerful means of reducing the environmental impact of a plant and process. [17]

MODEL FOR IMPLEMENTATION OF LEAN IN CONTINUOUS PROCESS INDUSTRY

Application of lean is studied in steel industry. The 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 steel company studied will be called ABS to maintain confidentiality.

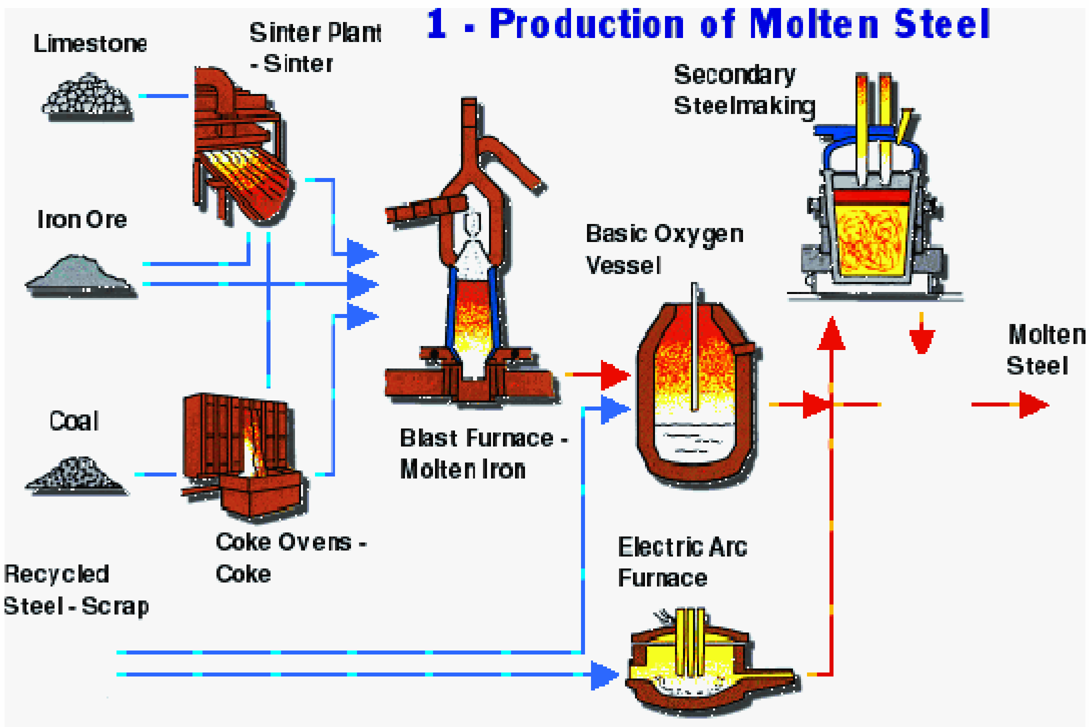
VALUE STREAM MAPPING AT ABS

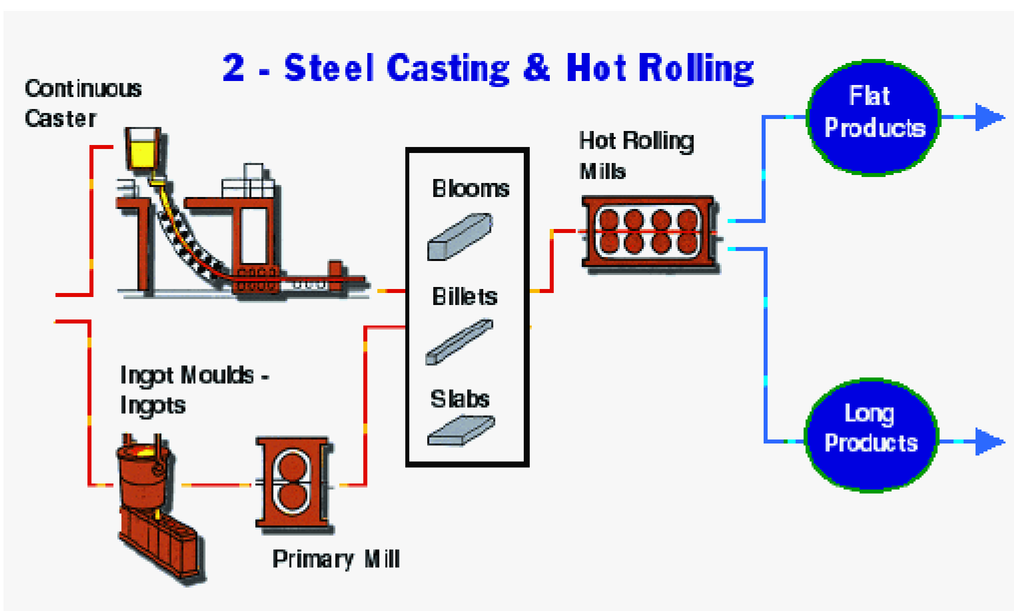
Choosing a product family: ABS produces several products that are used primarily in appliance manufacturing. The focus of this value stream mapping (VSM) is on one product family, the annealed product type.

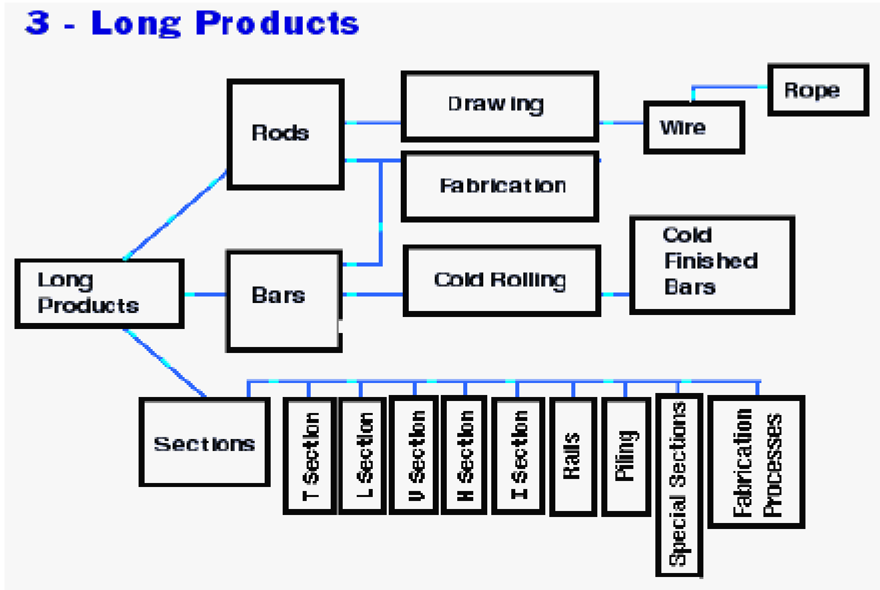
ABS produces three types of the annealed product:

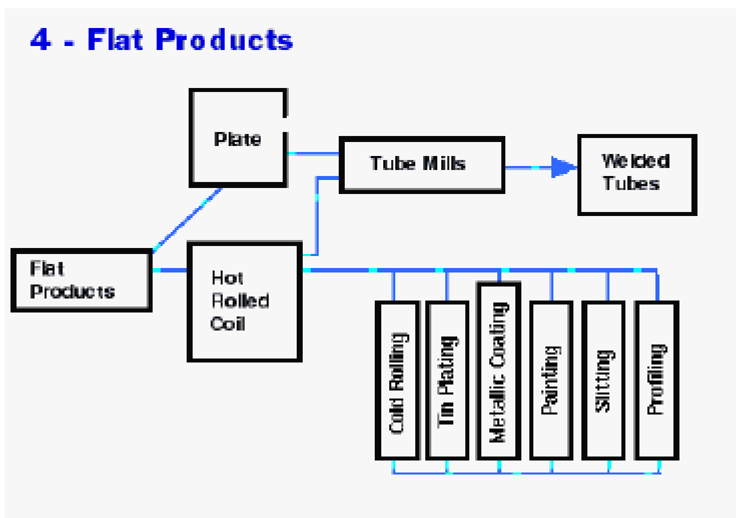
- Open coil annealed
- Hydrogen batch annealed
- Continuous annealed

ABS's processes for this product family start with a blast furnace where on a daily basis raw material including 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° F 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 sand 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 below shows the coil movement at ABS through the manufacturing process at the finishing mill.[17]


1 - Production of Molten Steel
Limestone
Sinter Plant - Sinter
Iron Ore
Coal
Coke Ovens - Coke
Recycled Steel - Scrap
Blast Furnace - Molten Iron
Basic Oxygen Vessel
Secondary Steelmaking
Molten Steel
Electric Arc Furnace


2 - Steel Casting & Hot Rolling
Continuous Caster
Ingot Moulds - Ingots
Primary Mill
Blooms
Billets
Slabs
Hot Rolling Mills
Flat Products
Long Products


3 - Long Products
Rods
Drawing
Wire
Rope
Fabrication
Long Products
Bars
Cold Rolling
Cold Finished Bars
Sections
T Section
L Section
U Section
H Section
I Section
Rails
Piling
Special Sections
Fabrication Processes


4 - Flat Products
Plate
Tube Mills
Welded Tubes
Flat Products
Hot Rolled Coil
Cold Rolling
Tin Plating
Metallic Coating
Painting
Slitting
Profiling

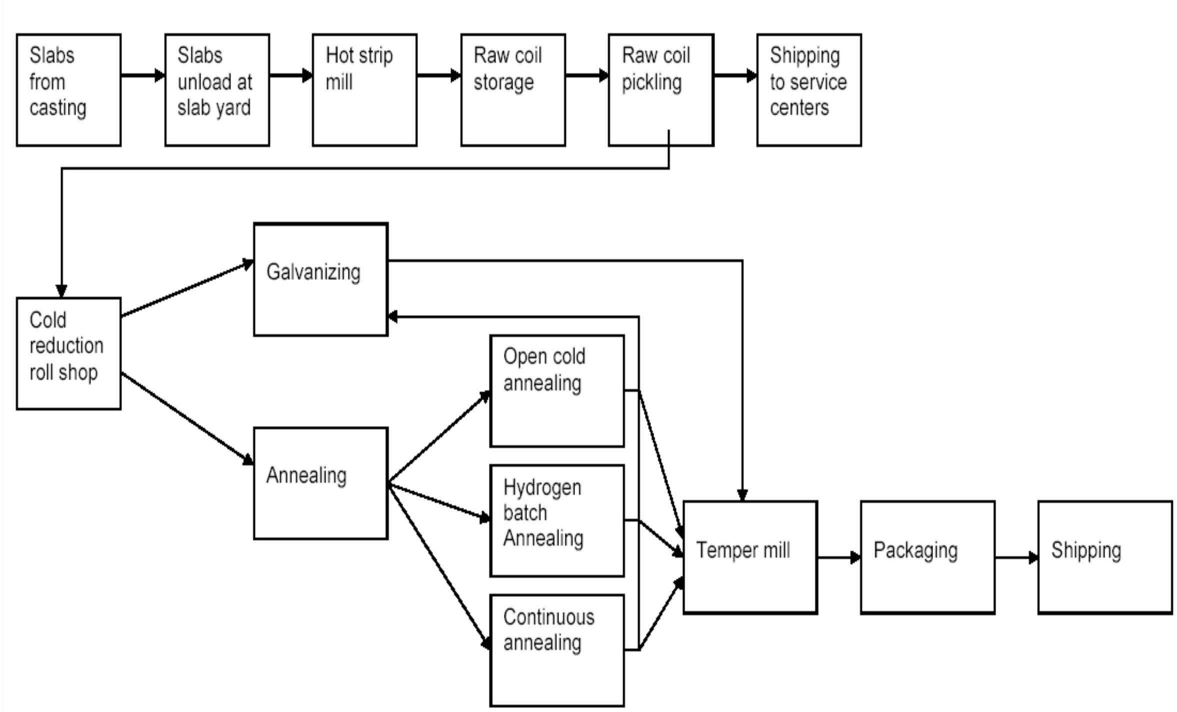


Figure-16 Coil movement through the manufacturing process at the finishing mill.

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

Total demand = 76,500 tons per month

Daily demand = 2,550 tons (one month equals 30 days)

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.

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. 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 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.

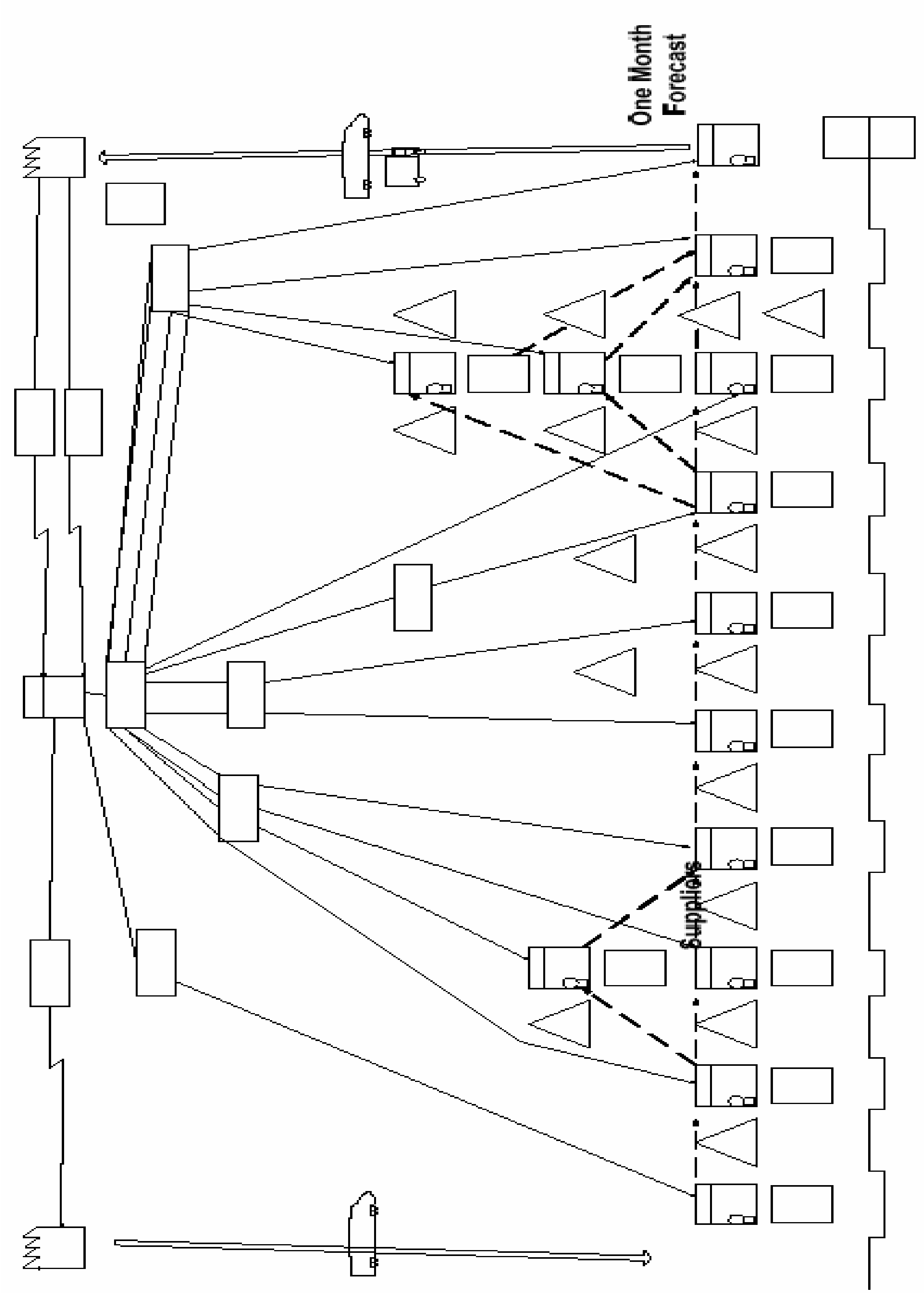
The finishing mill, which starts with the hot strip mill and extends all the way through shipping (as indicated in the current state map) is the other part of the material flow. Here again the product is pushed through different processes until it is ready for shipping, which is the last process shown 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 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 owns 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%.

Table-1 Data collection for drawing current state map

Process	Cycle Time (Sec)	Machine Reliability (%)	Changeover Time (min)	Observed Inventory (tons)	Observed Inventory (days)
Blast Furnace	8,100	99.5	-	91,000	-
BOP Shop	2,700	99	-	1,384	0.54
LMF	2,400	100	-	250	0.098
Degasser	2,400	100	-	250	0.098
Continuous Caster	2,700	99	8 to 12	750	0.29
Hot Mill	9,000	99.5	120(backup rolls)35 (work rolls)	36,345	10.33
Pickling	240	100	15	32200	12.62
Continuous Annealing	600-1500	100	-	2,600	1
Cold Reduction	420	88	120 (backup rolls)9 (work rolls)	4241	1.6
Open coil Annealing	64800-72000	96	-	4,459	1.75
Hydrogen batch annealing	54000-90000	99	-	16000	6.27
Temper Mill	420	97	90 (backup rolls) 7 (work rolls)	8,904	3.49

CURRENT STATE MAP



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.

STEP 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:

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

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.[9]

STEP2: FINISHED GOODS SUPERMARKET

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 Step 7.[9]

STEP 3: PULL SYSTEM SUPERMARKET

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 (Womack, 2003). The customer here is the pickling and the supplier is the hot strip mill. A pull signal from the temper mill (addressed in Step 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 the Future State Map 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.

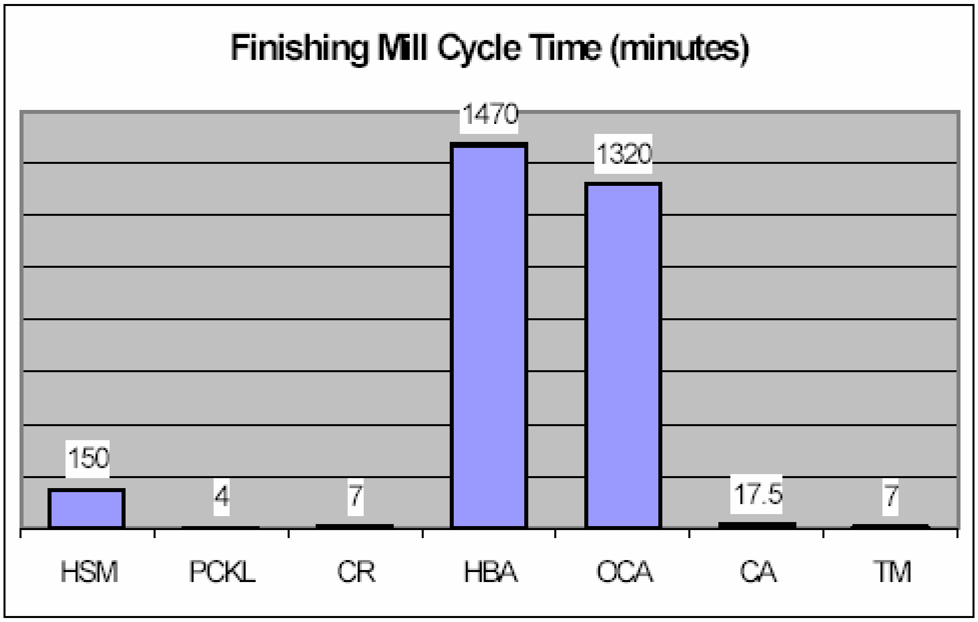
Requiring every coil in a supermarket to be in a cradle puts an upper limit on the amount of inventory in the supermarket and in turn, lead-time will go down. If inventory is limited to a predefined number of coils (*kanbans*), the space between coils will be increased and thus handling damage, which 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 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. [9]

STEP 4: CONTINUOUS FLOW

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-17 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. [10]

STEP 5:THE PACEMAKER

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 (Womack, 2001).

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 (Womack, 2001) 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. [10]

STEP 6: PRODUCTION LEVELING

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:

dij = (j*0.5)*(T/Di)

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-HBAHBA- CA- OCA)…etc. This schedule is the optimal sequence to smooth the production.

Table-2 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
OBA	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		

STEP 7: THE PITCH

What increment of work (the "pitch") will be consistently released to the pacemaker process? Depending on the sequence determined by the last step, 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. [10]

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. The *heijunka* box (load leveling box) 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. 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.

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 Table7. 2. This signals the production of these three products to be pulled from the production process.
2. 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.
3. The process begins to pull the two coils representing HCA, OCA, and CA from the temper mill supermarket.
4. 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.
5. The same sequence explained in Step 5 is followed all the way through the pickle line if needed.
6. Repeat all the above steps for the whole day.

STEP 8: PROCESS IMPROVEMENT

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.

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 below 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 below 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-3 Maintenance time for hot end at ABS

Process	Maintenance uptime (min)	Maintenance Downtime (min)
BF1	86,400	960
BF2	86,840	960
BOP	43,200	960
LMF	43,200	960
Degasser	44,640	960

Table-4 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.

JIT

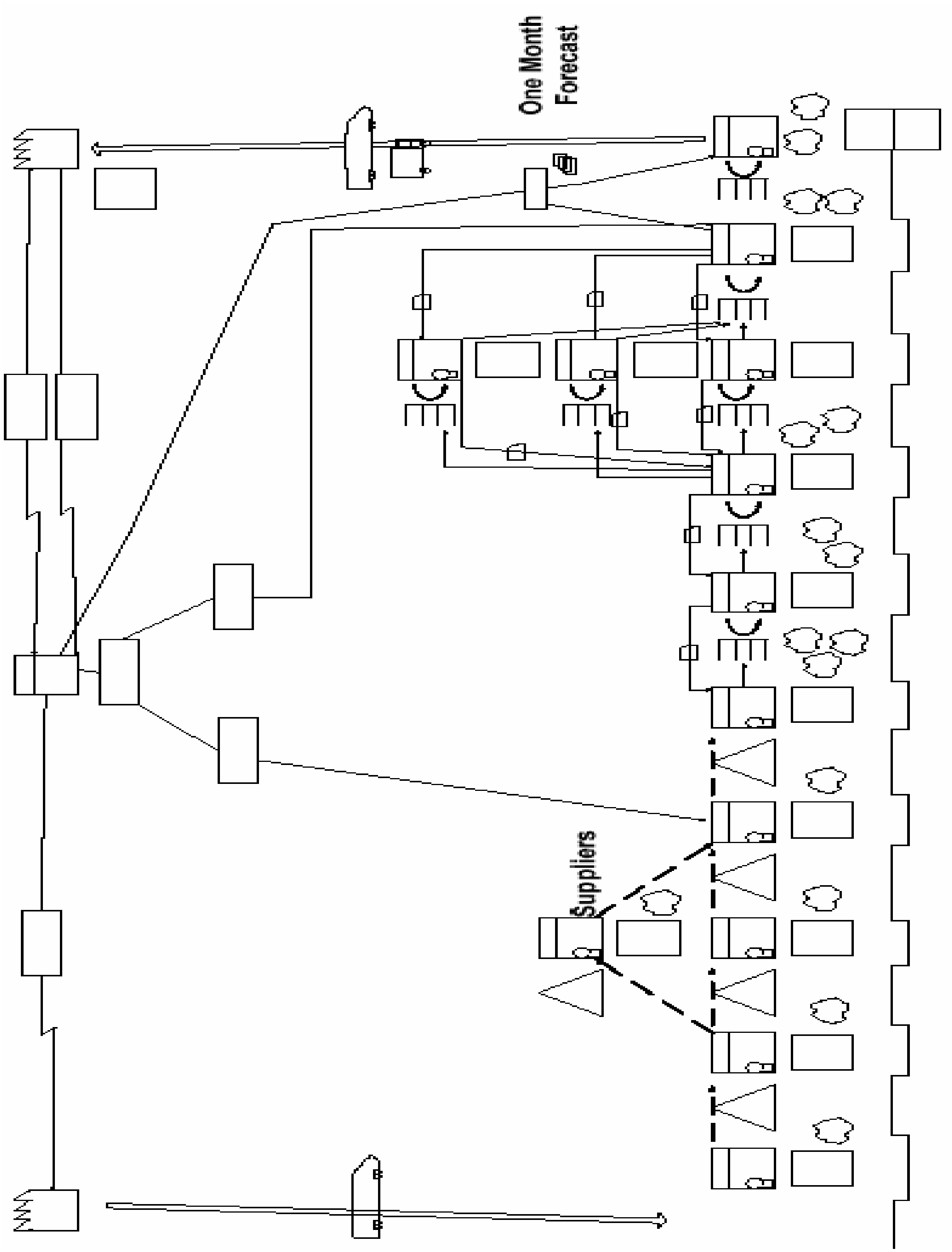
In order to achieve the full benefits of the supermarket *kanban* system ABS should utilize the just-in-time pull system. The *kanban* system explained in Question 3 is based on utilizing a pull system for the annealed products. The procedures necessary to implement the *kanban* pull system are simple 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.

FUTURE STATE MAP



RESULTS

PRODUCTION SYSTEM

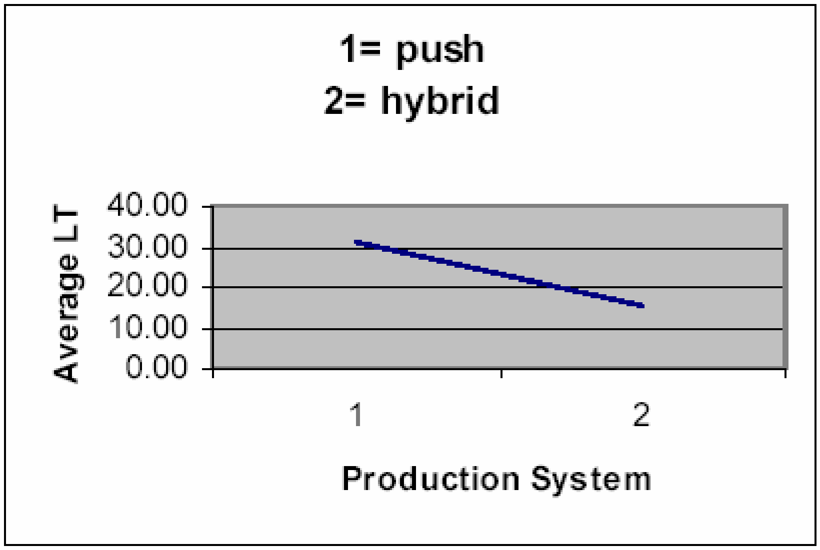
The reason for selecting these two measures became apparent when looking at the current state map, where lead-time compared to value added time is huge and WIP inventory is also very large. By reducing lead-time and WIP inventory considerable savings and quality improvement will be automatically gained. Lead-time is also correlated with WIP inventory; in general, the larger the WIP the longer the lead-time, and vice versa.

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 Step 4 in the development of the future state map, 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 Step 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.

TPM

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 Step 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.

Figure-17 Main effects on Average lead-time



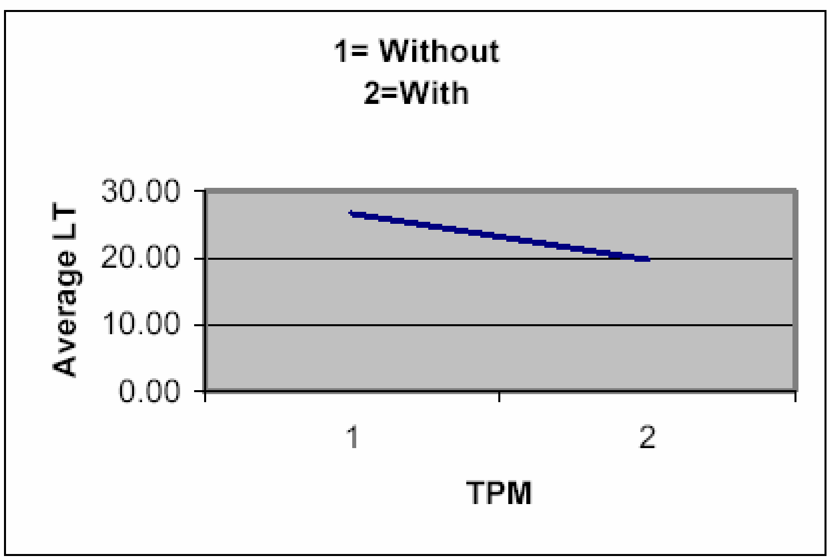
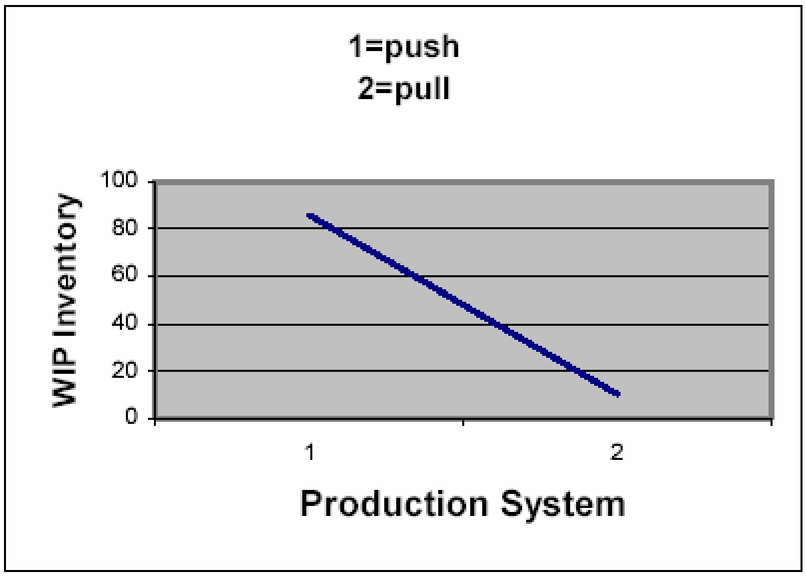
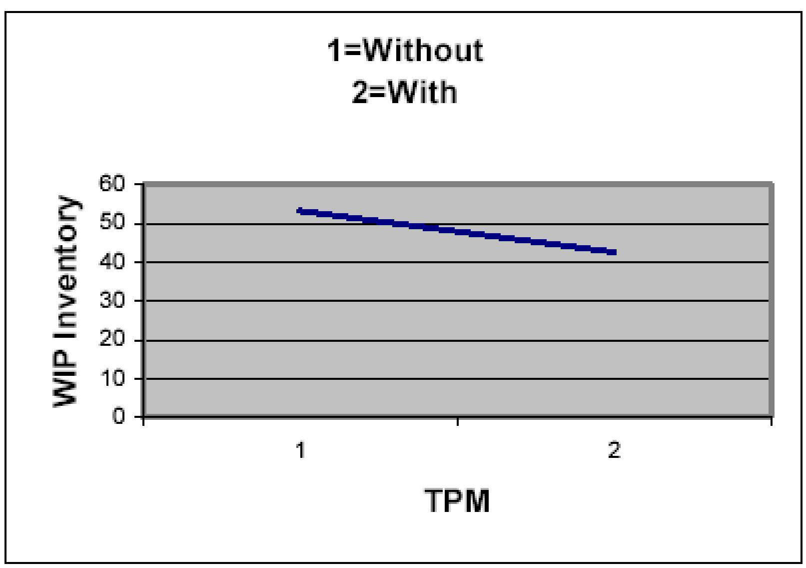


Figure-18 Main effects on Average WIP





MODEL FOR IMPLEMENTATION OF LEAN IN DISCREET MANUFACTURING AND RESULTS

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. 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.

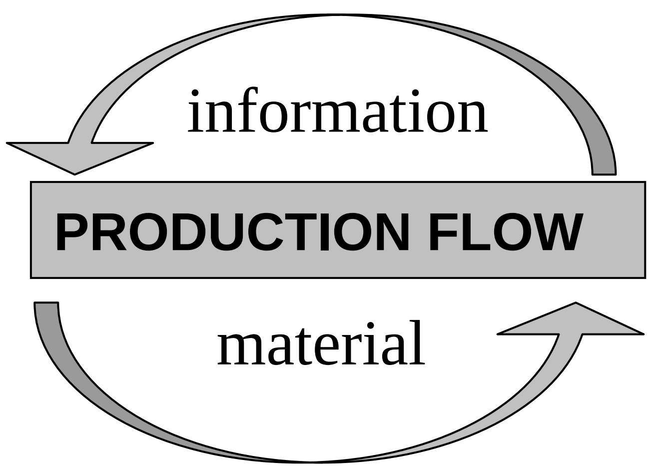


Figure-19 Flow in factory [8]

Selecting a product family

Before starting there is a need to focus on one product family. Since company ABC has a huge product mix (around 150 different models) so it is not possible to map each and every product. The next logical step is to decide on a product family.

A product family is a group of products that passes through similar processing steps and common equipment in your downstream process. We then chart a PP (product-process chart) to see the percentage similarity and if the overlap is 70%or more then we consider those products one product family.

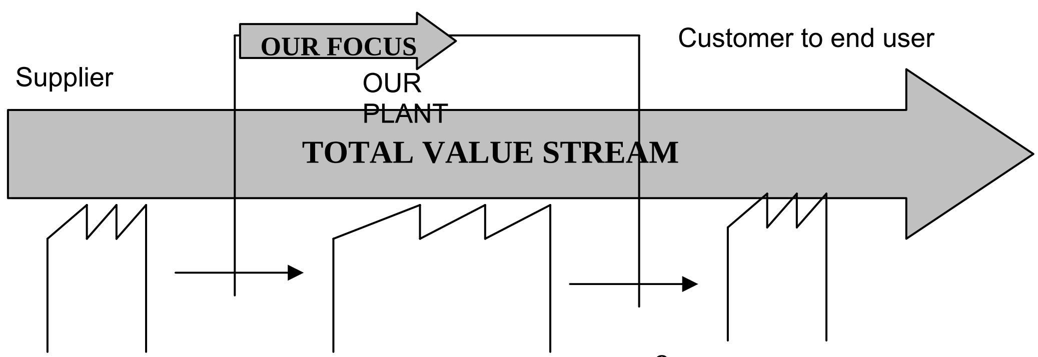


Figure-20 Scope of VSM [9]

Result: After making the PP matrix we came to a conclusion that there are mainly three product families:

- Rail (ring)
- Spacer (ring)

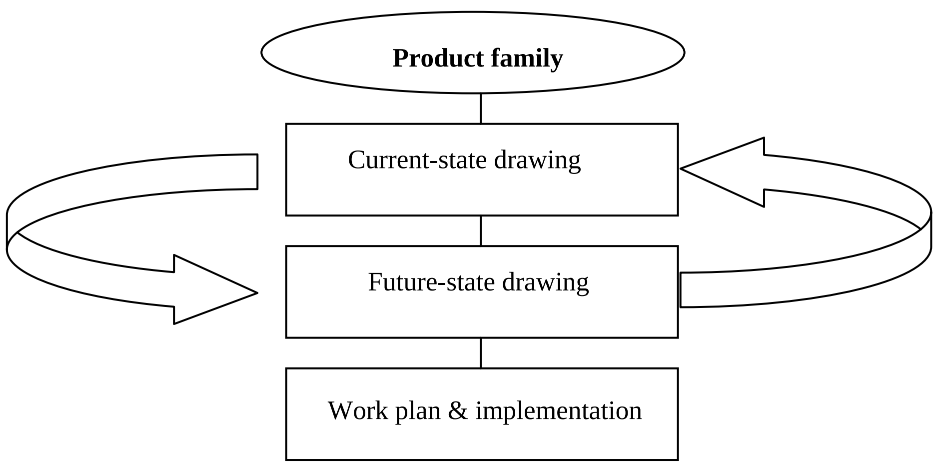
Mapping the value stream: any production engineer who is the member of the lean team is appointed as the value stream manager. His responsibility is to map the value stream of each and every one of these product families. One important thing to notice here is that the mapping task should be done by one person only.

Current State Map: The map that we draw at this time is called Current State Map, which is actually the Benchmark condition of the plant.

The information that the current state map provides:

- Lead Time
- Work in process inventory
- Finished goods inventory
- Flow of the. Product
- Flow of information

The current state map should start with the raw material procurement and end with the delivery of the finished product to the customer. At ABC industry the raw material is in form of steel wire which is imported from Japan. The end product is different kinds of piston rings and these rings are supplied to different manufactures scattered all over the world.



Initial Value stream Mapping Steps

Figure-21 Value stream mapping [10]

Existing Ring Production System

- 100% PUSH production system
- Process base layout.
- Each process operates as an isolated process disconnected from any sort of down stream customer.
- Each process has its own schedule

- High WIP everywhere
- High finished good inventory
- Customer observation due to mix up
- High rework due to rusting
- Production volume not leveled, creating peaks & valleys causing extra burden on man & m/c

STEPS TOWARDS BECOMING LEAN

1. **Produce to your takt time**

   Pace of production with the pace of sales at the pacemaker process.

$$\text{takt time} = \frac{\text{available work time per shift}}{\text{customer demand rate per shift}}$$

$$= 27{,}000 \text{ seconds.} / 455\text{pcs} = 59 \text{ sec}$$

OR

   How much work can be done at the bottleneck process in a "takt" of say 10 minutes.

   Break your orders up into unit of takt time

2. **Develop Continuous flow**

   Every step in process must be:-

   Capable – right every time (TQM)

   Available – always able to run when needed (TPM)

   Adequate – with capability to avoid bottlenecks & over capitalization (Right size tool)

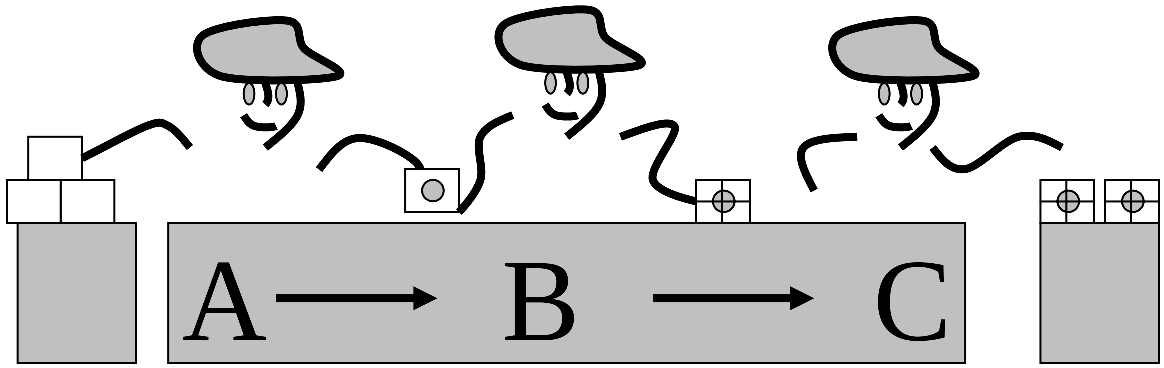


Figure-13 Continuous flow

3. **Use Supermarket**

Use supermarkets to control production where continuous flow does not extend upstream e.g. when processes are:-

- Very fast/slow process
- Need to change over to serve multiple product families. (Cam turning, Cam coiling operations)
- Ancillarised process.
- Process having too much lead time / Unreliable process
- Avoid independent scheduling for such processes (schedule is a guess). Use supermarket based pull system
- Use FIFO Downstream of Pacemaker Process

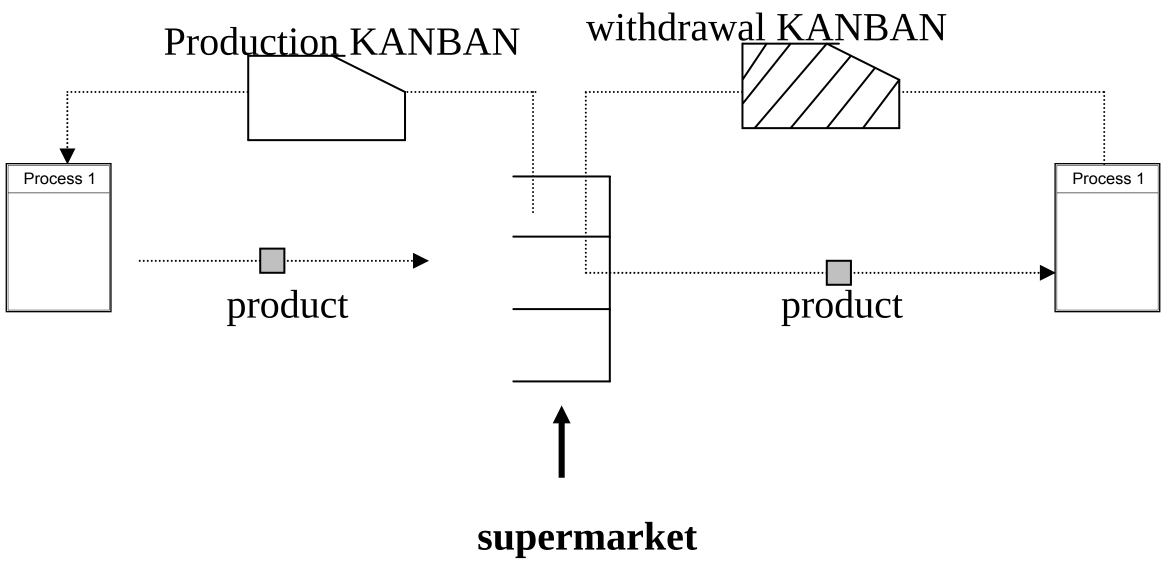


Figure-14 Supermarket System

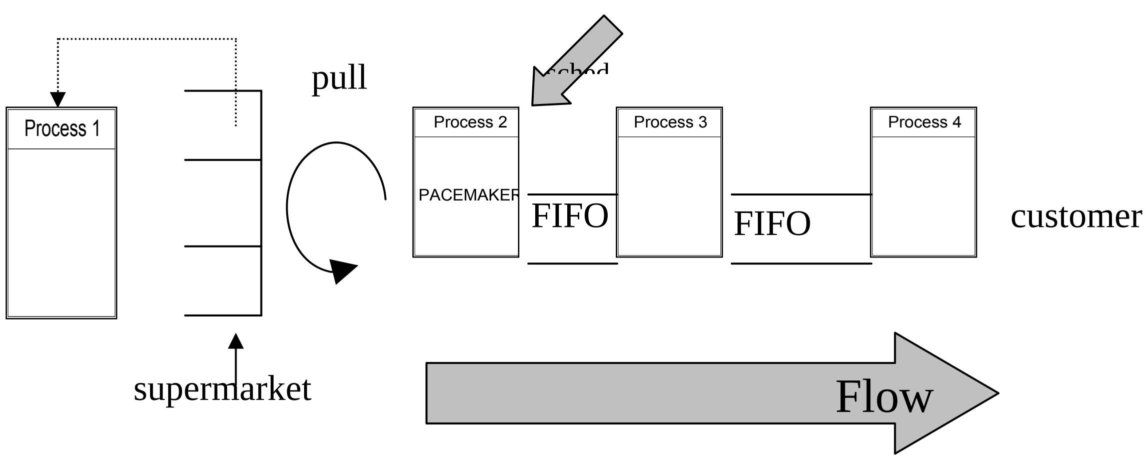


Figure-15 Supermarket flow

4. Identify Pacemaker

"The process which is scheduled as per customer requirement" condition for pacemaker process.

- No supermarket downstream of the pacemaker process
- Mostly Downstream process

5. Level the Product mix at Pacemaker process

- Grouping the same product & Producing them all at once makes it difficult to serve customer who want something different from the batch being produced.
- Leveling product mix means distributing the production of different products evenly over a period of time.
- Leveling product mix requires pain in reducing changeover time.

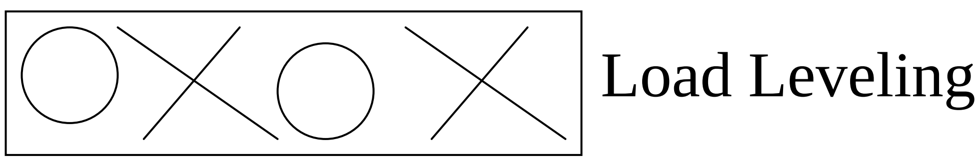


Figure-16 Load leveling

7. Level the production volume (Hiejunka)

If the production volume is not leveled

- Peaks & Valleys causes extra burden on M/c & People.
- It is difficult to monitor " are we behind or Ahead.
- Responding to changes in customer requirement becomes very complicated..

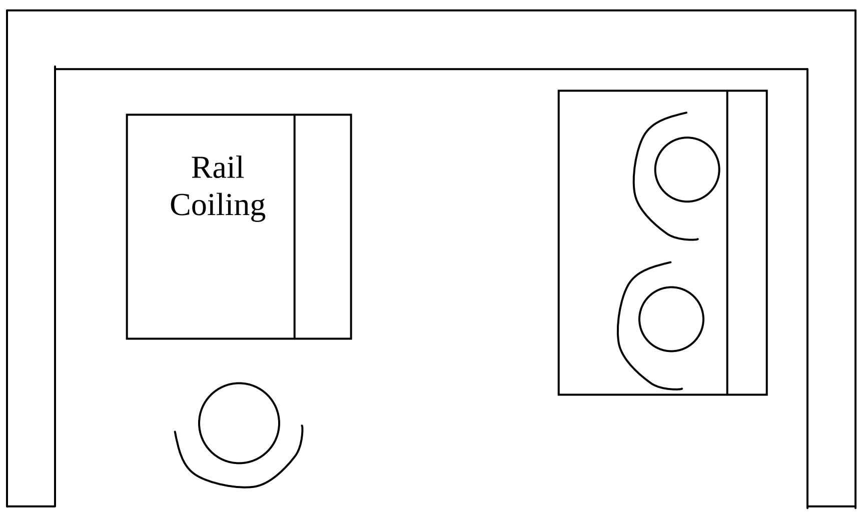
DEVELOPING FUTURE STATE MAP FOR RAIL

1. **Developing continuous flow**

   (Club operations to make manufacturing CELLS)

   - No Inventory (Zero Waiting Time) in between operations
   - Better utilization of operator

Figure-17 Clubbing of operation



3 SUCH CELLS ARE FORMED

2. **Supermarket concept (Type of PULL system)**

Table-5 Types of PULL Systems [9]

OPTIONS	Pros.	Cons.	Company Situation	Company Decision
Replenishment Pull System - **Hold Finish Goods Inventory**	**Ready to ship all items on short**	**Requires Inventory for each part**	**Finished good store & shipping unable to hold**	**Not Practical due to Large Number of Models.**

of all products and make all to stock.	**notice.**	**number and much space.**	**all models.**	
***Sequential Pull System* –** **Hold No Finish Goods Inventory and make all products to order**	**Less inventory and associated waste**	**Requires High process stability and short Lead time to produce**	**- Longer production Lead time due to batch production system** **- Availability / Capability of processes is not guaranteed**	**Not practical with current Lead Time**
***Mixed Pull System* –Hold only strangers in inventory & make Runners & Repeaters to order daily**	**Less Inventory**	**Requires mixed production control and daily stability**	**Daily stability a concern**	**Possible second step for future.**
***Mixed Pull System* –Hold Runners & Repeaters from semi finish Supermarket & make strangers to order.**	**Moderate inventory**	**Requires mixed production control and visibility on strangers**	**Most applicable to current situation**	**Best Fit for today**

3. What to keep in Supermarket

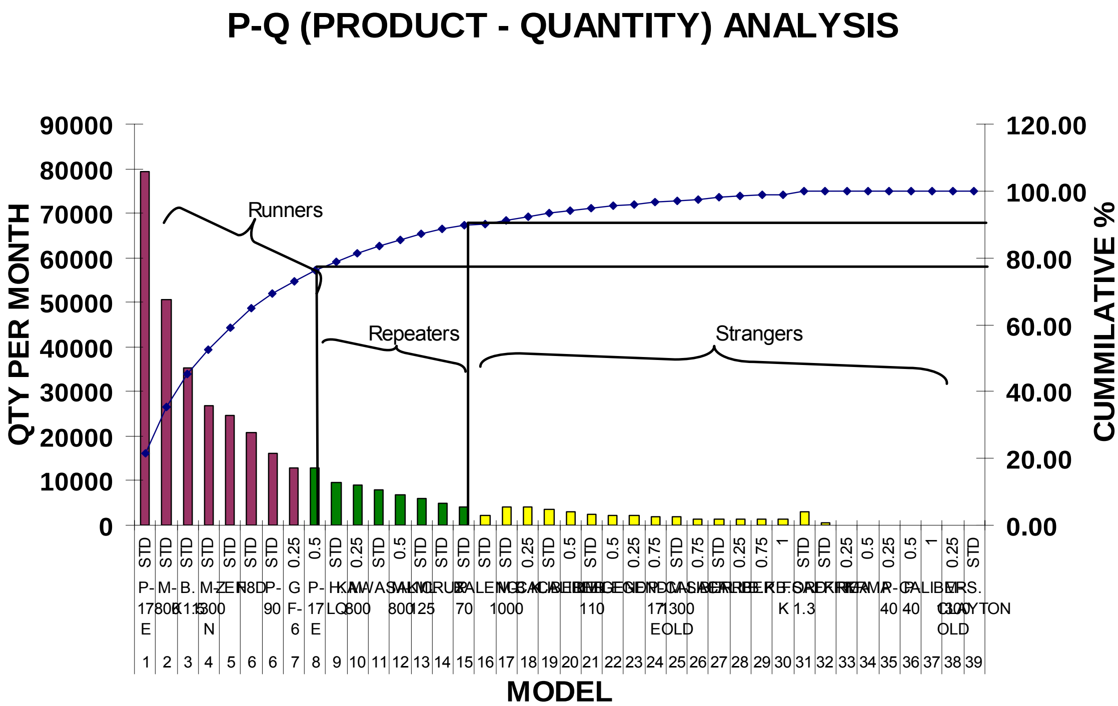


Figure-18 P.Q. Analysis

4. Pacemaker & First In First Out (FIFO

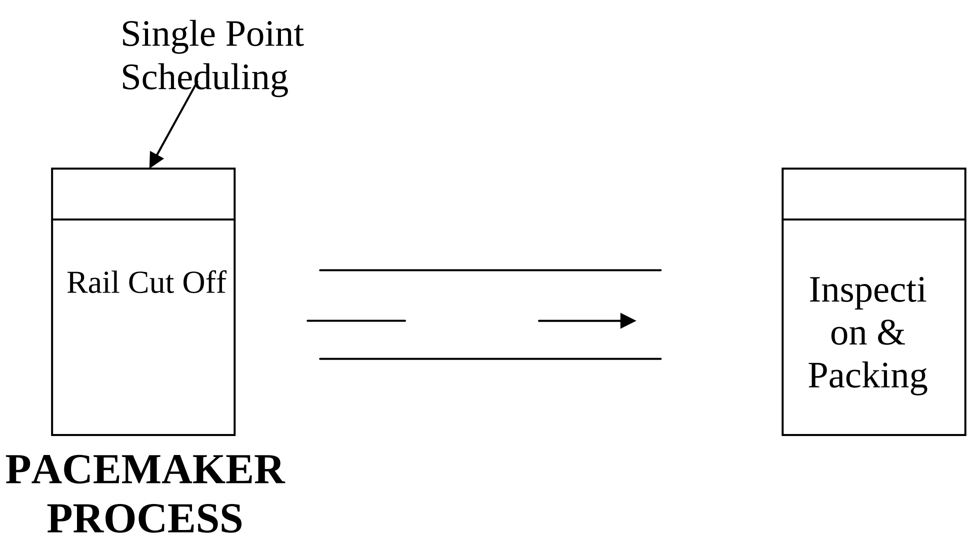


Figure-19 FIFO Lane

5. Pulling parts

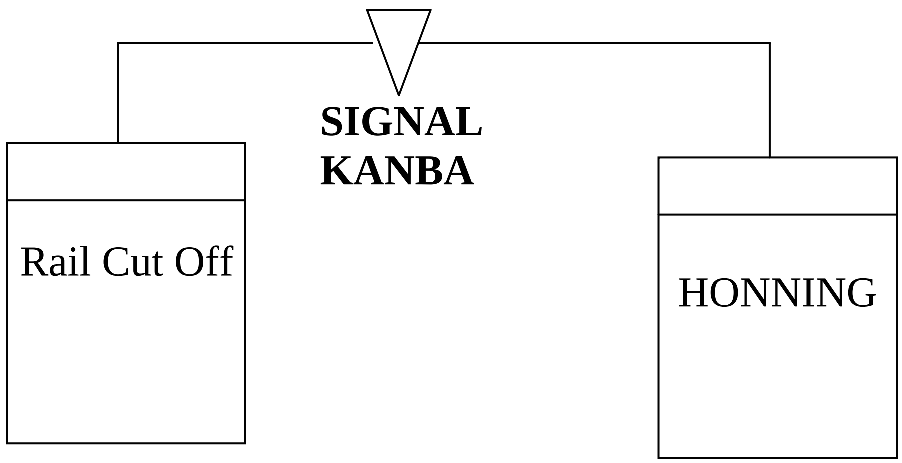


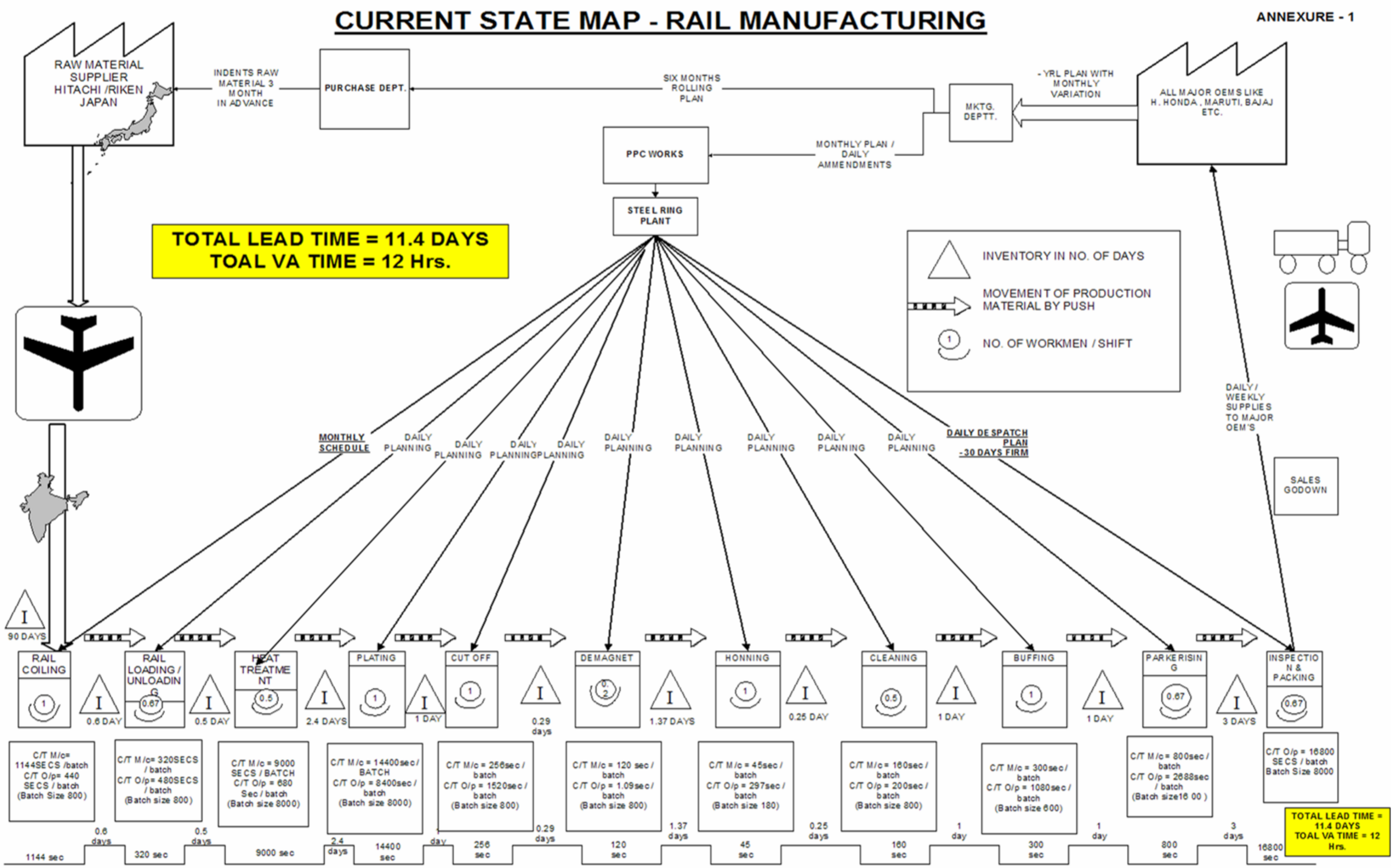
Figure-20 Signal Kanban

CALCULATING NO. OF KANBANS

		# Days/Month	25.0
		Available Minutes per shift	430
		# Shifts/Day	3.0
28 Ton Machine Quantity =	3		
		# of minutes available/month per machine=	32,250
Machine set-up minutes =	90	Total # of Mach min. avail/month =	96,750
Total # of set-ups/month =	17	Machine run time minutes/month =	435,040
Total Set-up minutes/month =	1,538	Number of minutes left available/month =	-340,548
Total Set-up People Needed =	1.2	Total Machine Utilization =	4.50
PM Minutes/Machine =	240		
PM/Breakdown/Month =	720	# Days of Wait =	3

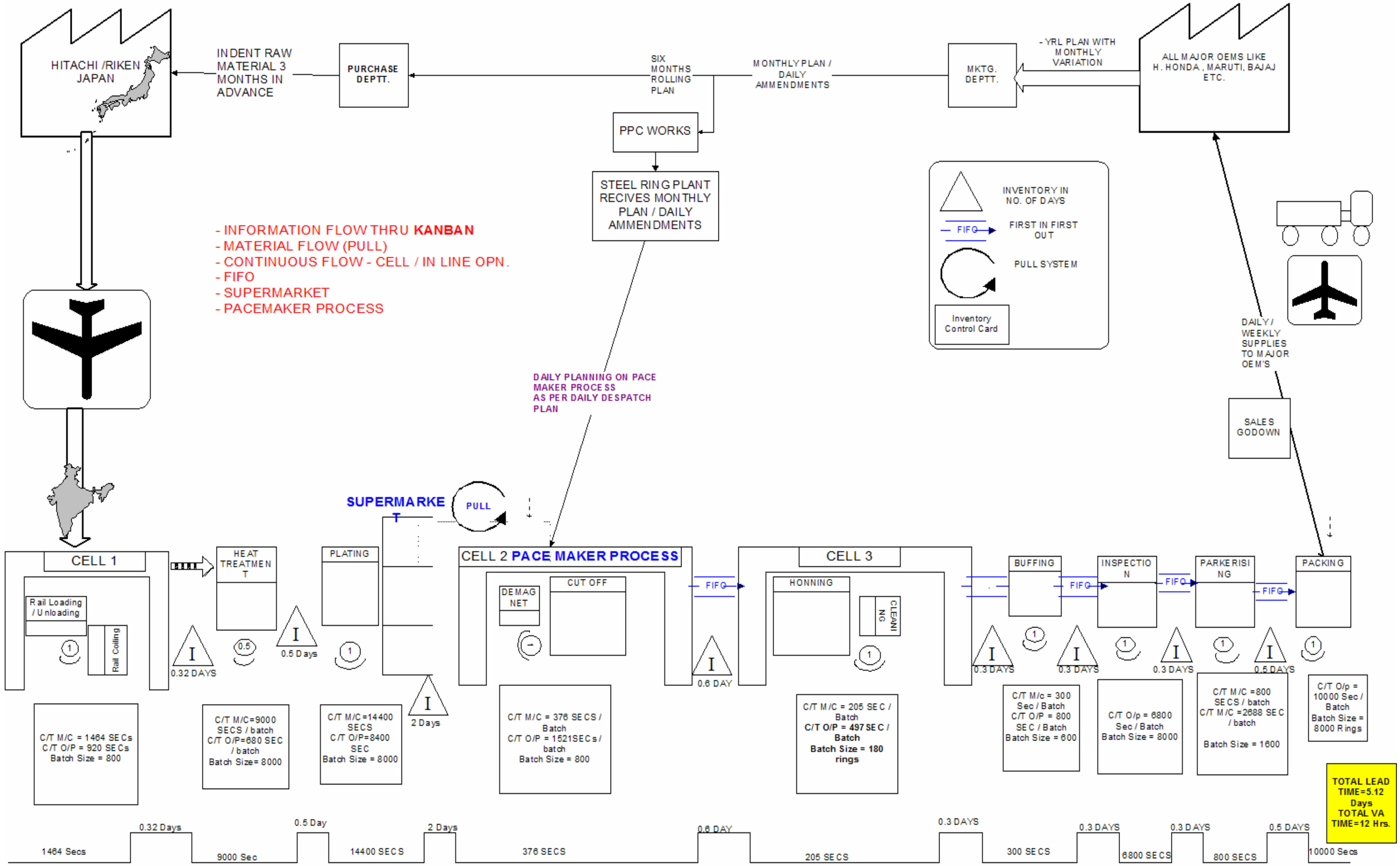
Part Number	Daily Rate	# Days of Kanban	Build Quantity	Mach C/T per piece	Total Minutes	Total Shifts RT	# Set-ups month	# Parts Container	Number of Cards
TATA GOLD	3,000	10	39,000	1.29	50,310	39.0	1.9	150	260
P-17 EURO	2,000	10	26,000	1.29	33,540	26.0	1.9	200	130
FORD 1.7L	2,000	15	36,000	1.18	42,480	32.9	1.4	200	180
P-90	2,000	15	36,000	1.24	44,640	34.6	1.4	100	360
K 1.5	2,000	15	36,000	1.24	44,640	34.6	1.4	200	180
ESTEEM NEW	2,000	10	26,000	1.24	32,240	25.0	1.9	100	260
CP GOLD	4,000	10	52,000	1.28	66,560	51.6	1.9	400	130
AVENGER	2,000	10	26,000	1.34	34,840	27.0	1.9	200	130
JHONDEER	200	10	2,600	1.15	2,990	2.3	1.9	20	130
FORD NEW	4,000	15	72,000	1.15	82,800	64.2	1.4	400	180
Totals					435,040	337.2	17		

Figure-21 Calculatinf the numbers of Kanban


CURRENT STATE MAP - RAIL MANUFACTURING
ANNEXURE - 1
RAW MATERIAL SUPPLIER HITACHI /RIKEN JAPAN
INDENTS RAW MATERIAL 3 MONTH IN ADVANCE
PURCHASE DEPT.
SIX MONTHS ROLLING PLAN
MKTG. DEPTT.
- YRL PLAN WITH MONTHLY VARIATION
ALL MAJOR OEMS LIKE H. HONDA, MARUTI, BAJAJ ETC.
PPC WORKS
MONTHLY PLAN / DAILY AMMENDMENTS
STEEL RING PLANT
TOTAL LEAD TIME = 11.4 DAYS
TOAL VA TIME = 12 Hrs.
INVENTORY IN NO. OF DAYS
MOVEMENT OF PRODUCTION MATERIAL BY PUSH
NO. OF WORKMEN / SHIFT
DAILY / WEEKLY SUPPLIES TO MAJOR OEM'S
SALES GODOWN
MONTHLY SCHEDULE
DAILY PLANNING
DAILY PLANNING
DAILY PLANNING
DAILY PLANNING
DAILY PLANNING
DAILY PLANNING
DAILY PLANNING
DAILY PLANNING
DAILY PLANNING
DAILY DESPATCH PLAN -30 DAYS FIRM
90 DAYS
RAIL COILING
0.6 DAY
RAIL LOADING / UNLOADIN G
0.5 DAY
HEAT TREATME NT
2.4 DAYS
PLATING
1 DAY
CUT OFF
0.29 days
DEMAGNET
1.37 DAYS
HONNING
0.25 DAY
CLEANING
1 DAY
BUFFING
1 DAY
PARKERISIN G
3 DAYS
INSPECTIO N & PACKING
C/T M/c= 1144SECS /batch C/T O/p= 440 SECS / batch (Batch Size 800)
C/T M/c= 320SECS / batch C/T O/p= 480SECS / batch (Batch size 800)
C/T M/c = 9000 SECS / BATCH C/T O/p = 680 Sec / batch (Batch size 8000)
C/T M/c = 14400sec / BATCH C/T O/p = 8400sec / batch (Batch size 8000)
C/T M/c = 256sec / batch C/T O/p = 1520sec / batch (Batch size 800)
C/T M/c = 120 sec / batch C/T O/p = 1.09sec / batch (Batch size 800)
C/T M/c = 45sec / batch C/T O/p = 297sec / batch (Batch size 180)
C/T M/c= 160sec / batch C/T O/p = 200sec / batch (Batch size 800)
C/T M/c = 300sec / batch C/T O/p = 1080sec / batch (Batch size 600)
C/T M/c = 800sec / batch C/T O/p = 2688sec / batch (Batch size16 00)
C/T O/p = 16800 SECS / batch Batch Size 8000
1144 sec
0.6 days
320 sec
0.5 days
9000 sec
2.4 days
14400 sec
1 day
256 sec
0.29 days
120 sec
1.37 days
45 sec
0.25 days
160 sec
1 day
300 sec
1 day
800 sec
3 days
16800 sec
TOTAL LEAD TIME = 11.4 DAYS TOAL VA TIME = 12 Hrs.

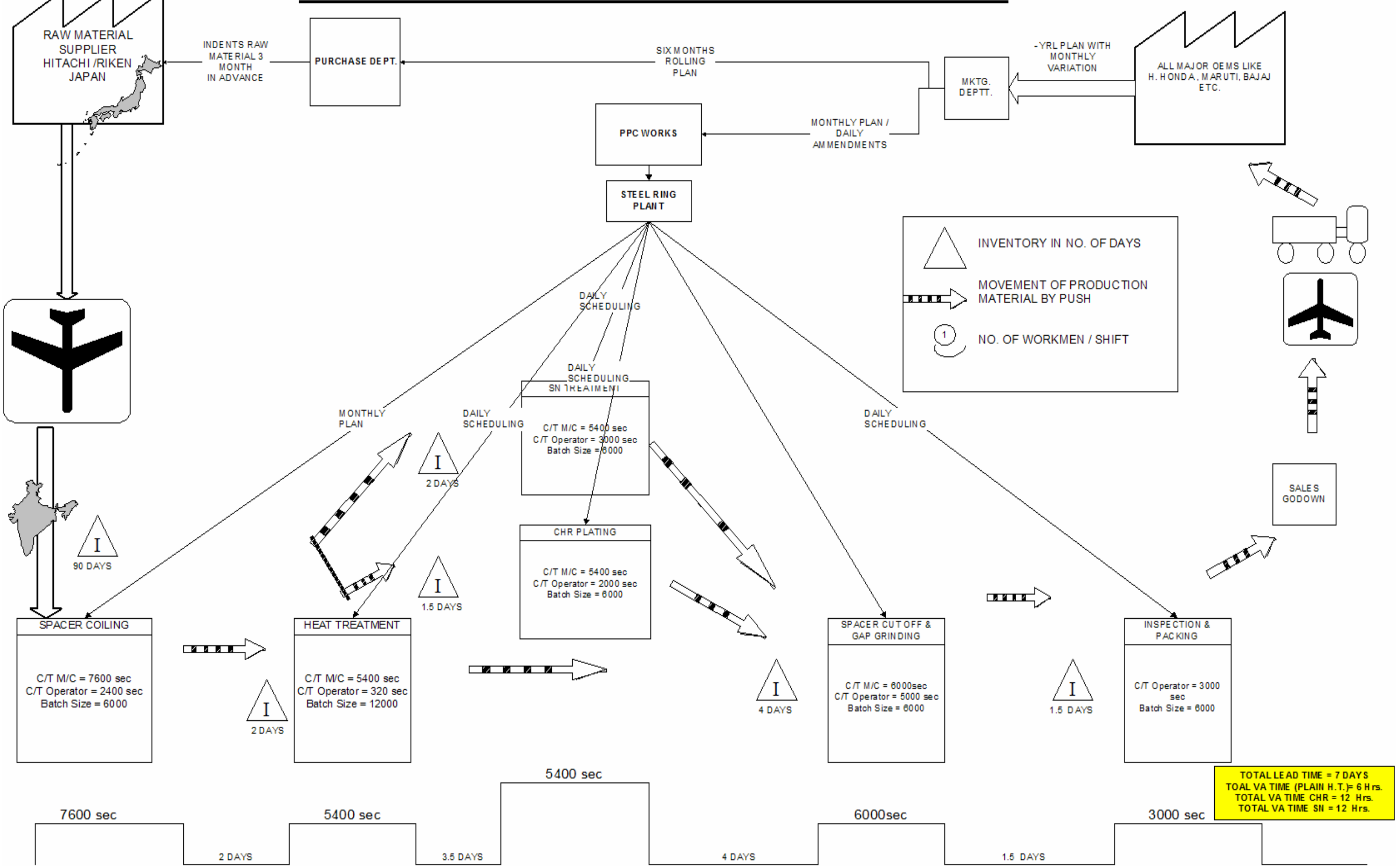
ANNEXURE - 2

FUTURE STATE MAP 1 - RAIL MANUFACTURING



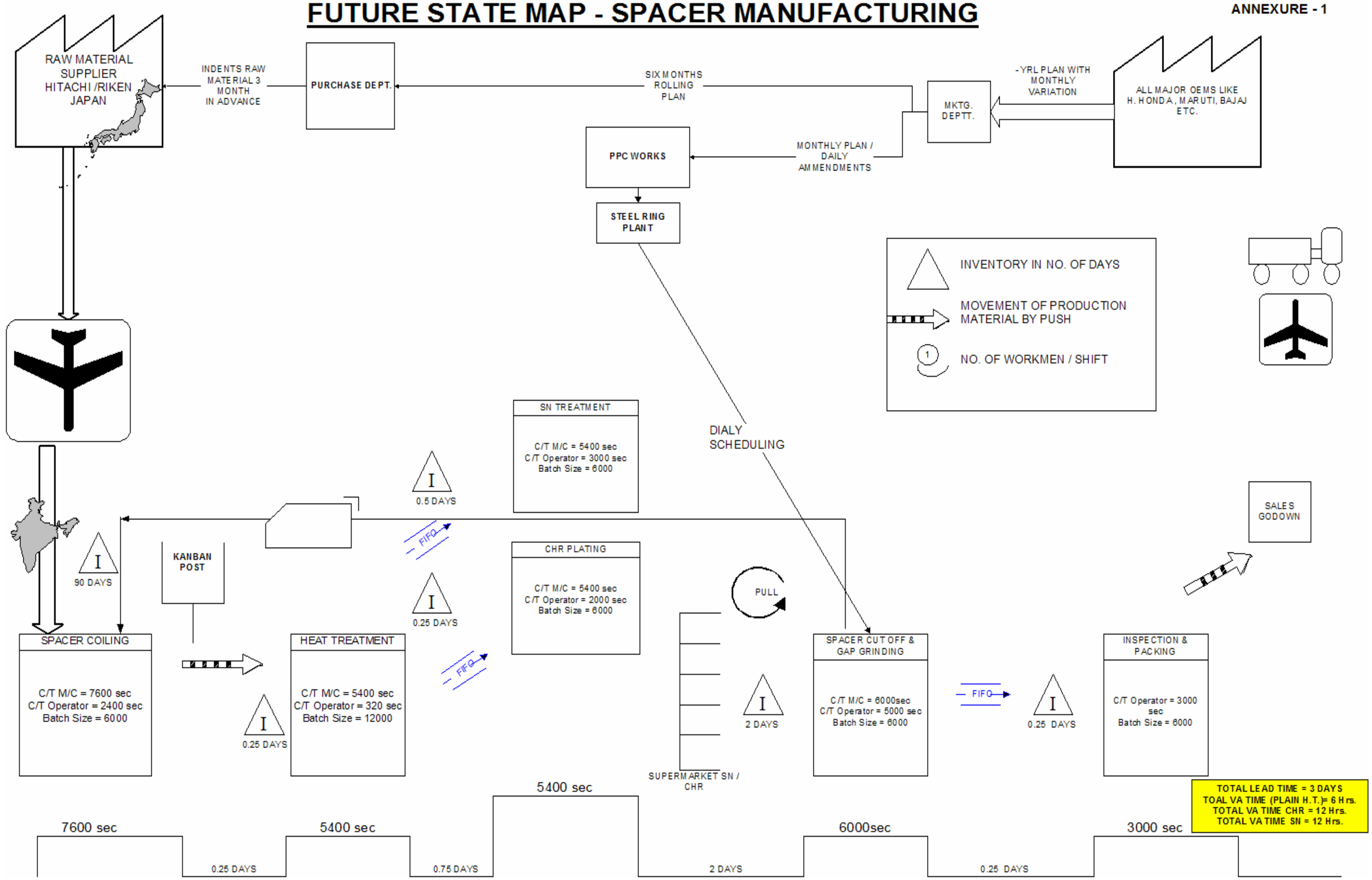
ANNEXURE - 1

CURRENT STATE MAP - SPACER MANUFACTURING



ANNEXURE - 1

FUTURE STATE MAP - SPACER MANUFACTURING



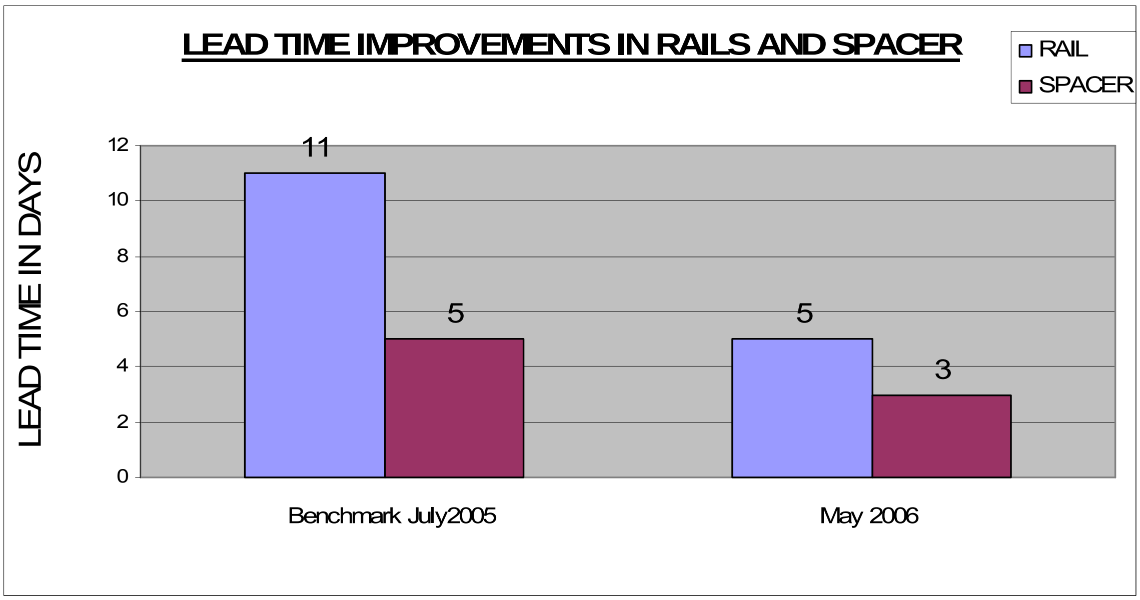
RESULTS

1) LEAD TIME REDUCTION

Lead time reduction in spacers = (11-5) = 6 days

Lead time reduction in rail = (7-3) = 4 days

Figure-22 Improvement in Lead Time



Rail Coiling	Rail Loading`	Heat Treatment	Plating	Cut off	Demagnet	Honning	Cleaning	Buffing	Parkerising	Inspection & Packing	**TOTAL**
Raw Material	0.6 Days	0.5 Days	2.4 Days	1 day	0.29 Days	1.37 Days	0.25 Days	1 Day	1 Day	3 Days	**11.4 Days**
Raw Material	**0 Days**	0.32Days	0.5 Days	2 Days	**0 Days**	0.6 Days	**0 Days**	0.3 Days	0.3 Days	0.8 Days	**5.2 Days**

2) WIP REDUCTION

Figure-23 Improvement in FGI and WIP for spacer

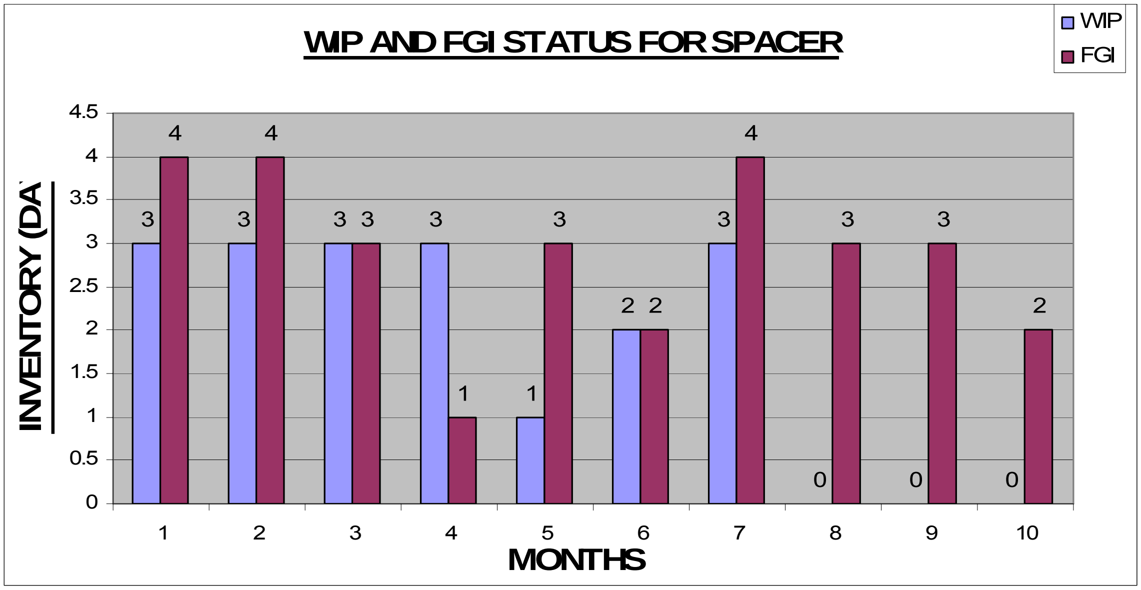


Figure-24 Improvement in FGI and WIP for rails

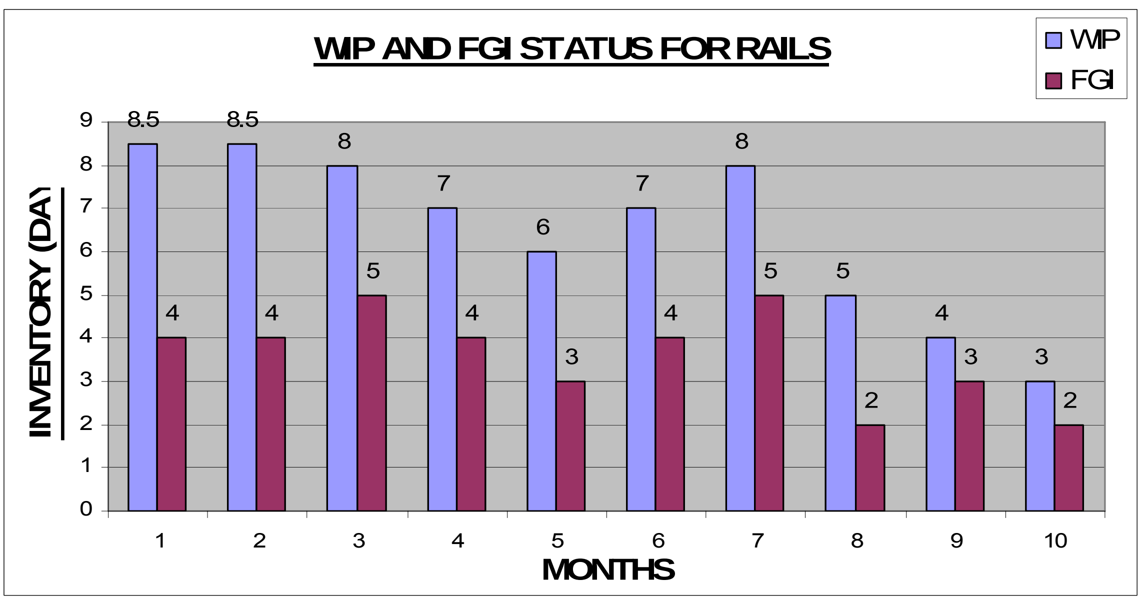
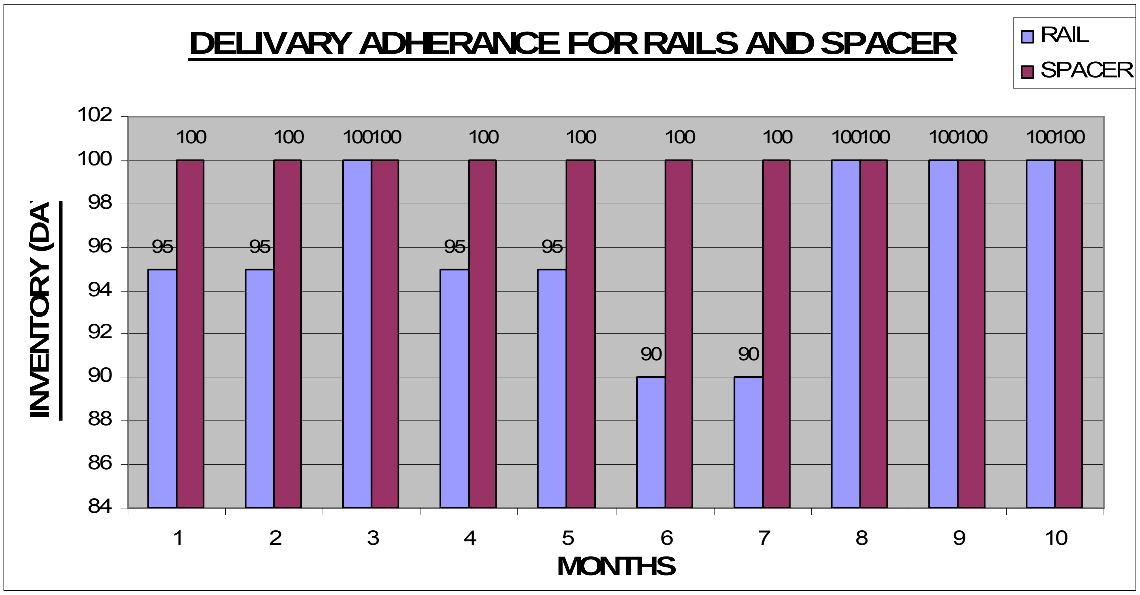
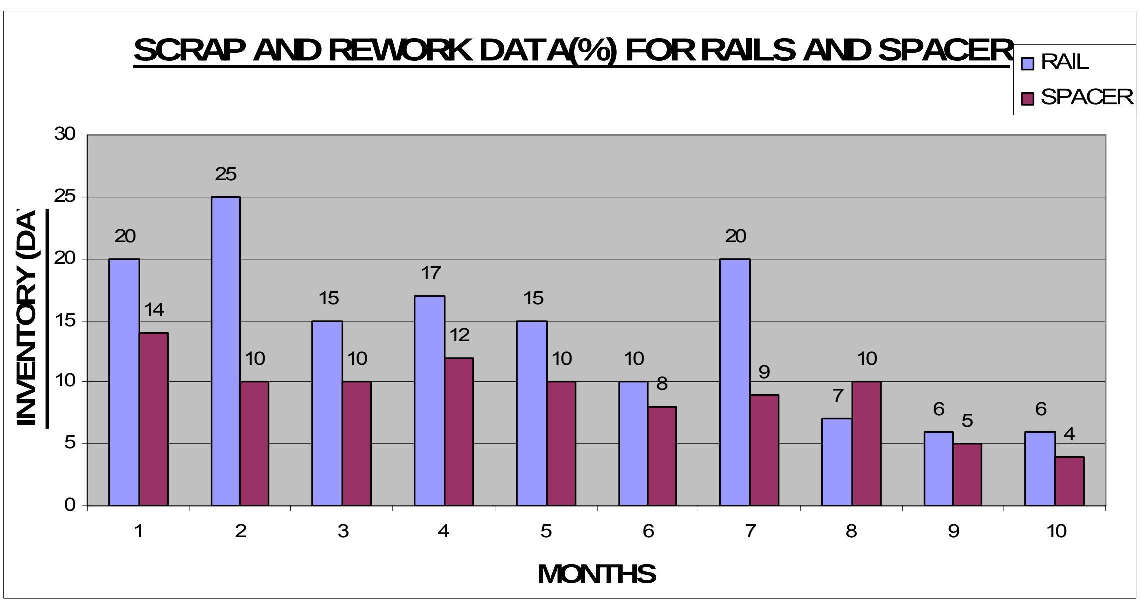


Figure-25 Improvement in delivary adherence for spacer



3) REDUCTION IN REWORK

Figure-26 Scrap and rework data



4) SPACE SAVING

Space Saved = 58 Sq. Ft. (Space occupied by Trollies)

5) PULL BASED PRODUCTION SYSTEM

Evolution of New System based on PULL resulting following additional benefits:-

- Elimination of Go See Scheduling
- Process are linked to each other
- Helps producing what is required.
- Reduces Supervisor’s time for Planning.
- Helps improving operators multiskilling

MODEL FOR ASSESSMENT OF LEAN EFFORTS

I have developed a model to assess the lean efforts of any enterprise. This model has been made by giving weights to various lean principals being applied and followed in different parts of an industry. It also takes into account human involvement and is not merely a parameter based criteria. It also takes into account management initiatives and responsiveness. It judges the enterprise in a wider scope and helps setting benchmarks which is one of the first steps in developing lean steps.

It has also been applied in real time environment and has helped to assess the progress and find out the loop holes. It captures an ideal state and then compares the initial state with the ideal state and captures the weak areas. These areas become apparent in the result window of this model which is self explanatory. It clearly indicated the loop holes and alerts the management that something is going wrong and steps need to be taken in this situation.

It can be a very useful tool in industry as a benchmarking tool if the input to this model is authentic and sincere.

It takes into account:-

1. Inventory

2. Teams

3. Process

4. Maintenance

5. Layout

6. Supplier

7. Set up

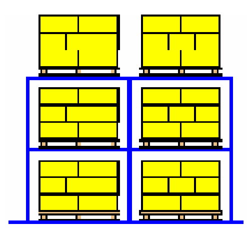
8. Quality

9. Scheduling

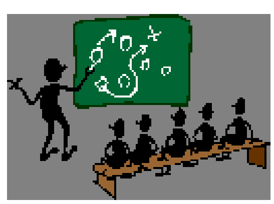
The model has been shown and is has been applied to the Ring manufacturing company where I carried out experiments. The results have also been give along with the areas of improvement.

Figure-27 Model for assessment of lean efforts by an organization

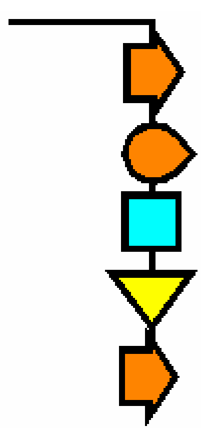
1.0	Inventory	Response	X
1.1	For the categories of Finished Goods, Work-In-Process (WIP) and Purchased/Raw Materials, what portion of middle and upper managers can state from memory the current turnover and the purpose of each type?	0%-6%	
		7%-55%	
		56%-80%	
		81%-93%	
		94%-100%	X
1.2	What is the overall inventory turnover, including Finished Goods, WIP and Purchased/Raw material?	0-3	
		4-6	
		7-12	
		13-24	X
		25+	
1.3	What is the ratio of Inventory Turnover to the industry average?	<=1.0	
		1.1-2.0	
		2.1-4.0	X
		4.1-8.0	
		8.1+	



2.0	The Team Approach	Response	X
2.1	What is the organization type?	Exploitive	
		Bureaucratic	
		Consultive	X
		Participative	
		Highly Participative	
2.2	How are workers on the factory floor compensated?	Individual Incentive	
		Hourly Wage	
		Group Incentive	
		Salary	
		Salary+Annual Bonus	X
2.3	To what extent do people have job security?	Layoffs Every Year	
		Transfers & Retraining Reduce Layoffs	X
		Layoffs Are Rare	
2.4	What is the annual personnel turnover	31%+	
		14%-30%	
		7%-11%	X
		3%-6%	
		0%-2%	
2.5	What percentage of personnel (ALL Personnel) have received at least eight hours of teambuilding training?	<5%	
		6%-10%	
		11%-30%	X
		31%-90%	
		91%-100%	
2.6	What percentage of personnel are active members of formal work teams, quality teams, or problem-solving teams?	<5%	
		6%-10%	
		11%-30%	X
		31%-90%	
		91%-100%	

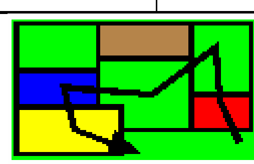


3.0	Processes	Response	X
3.1	How many large-scale machines or single-process areas are in the plant through which 50% or more of different products must pass?	4+	X
		3	
		2	
		1	
		0	
3.2	How would you rate the overall bias of the plant's process selection with respect to scale?	Large Scale	
		Medium/Mixed	X
		Small Scale	
3.3	How easy is it to shift output when the product mix changes?	Very Difficult	
		Moderately Difficult	X
		Easy	
3.4	How easy is it to alter the total production rate by +/-15%?	Very Difficult	
		Moderately Difficult	X
		Easy	
3.5	What is management's target operating capacity for individual departments or machines?	96%-100%	
		91%-95%	
		86%-90%	
		76%-85%	X
		50%-75%	
3.6	How would you rate the overall bias of the plant's process selection with respect to technology level?	Complex Technologies	
		Moderate/Mixed	X
		Simple Technologies	

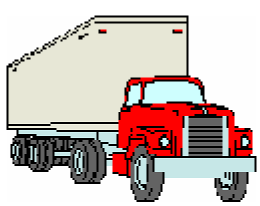


4.0	Maintenance	Response	X
4.1	Describe equipment records and data. Include records of uptime, repair history, and spare parts. Include repair and parts manuals.	Non-Existent	
		Substantially Complete	X
		Complete & Accurate	
4.2	Excluding new installations and construction projects, what percentage of maintenance hours is unplanned, unexpected, or emergency?	71%-90%	
		51%-70%	
		26%-50%	X
		11%-25%	
		0%-10%	
4.3	Does maintenance have and follow a defined preventive schedule?	No PM	
		1%-10% Coverage	
		11%-30% Coverage	
		31%-90% Coverage	X
		91%+ Coverage	
4.4	Do equipment breakdowns limit or interrupt production?	Frequently	
		Occasionally	X
		Rarely	
4.5	What is the overall average availability of plant equipment?	Unknown	
		0%-75%	
		76%-90%	X
		91%-95%	
		96%-100%	

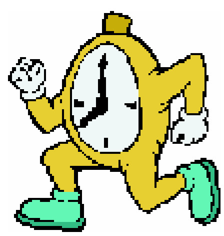
5.0	Layout & Handling	Response	X
5.1	What portion of total space is used for storage and material handling?	71%-100%	
		46%70%	
		30%-45%	
		16%-30%	X
		0%-15%	
5.2	What portion of the plant space is organized by function or process type?	71%-100%	
		46%70%	
		30%-45%	X
		16%-30%	
		0%-15%	
5.3	How would you characterize material movement?	Pallet-size (or larger) loads, long distances (>100'),complex flow patterns, confusion, & lost material	
		Mostly tote-size loads, bus-route transport, & intermediate distances	X
		Tote-size or smaller loads, short distances (<25'), simple & direct flow pattern	
5.4	How would you rate overall housekeeping and appearance of the plant?	Messy, Filthy, Confused	
		Some dirt, Occasional Mess	
		Spotless , Neat, & Tidy	X
5.5	How well could a stranger walking through your plant identify the processes and their sequence?	Impossible to see any logic or flow sequence.	
		Most processes are apparent with some study. Most sequences are visible.	X
		Processes and their sequences are immediately visible.	



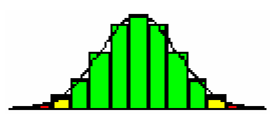
6.0	Suppliers	Response	X
6.1	What is the average number of suppliers for each raw material or purchased item?	2.5+	
		1.6-2.4	
		1.3-1.7	
		1.2-1.4	
		1.0-1.1	X
6.2	On average, how often, in months, are items put up for re-sourcing?	1-11	X
		12-17	
		18-23	
		24-36	
		36+	
6.3	What portion of raw material & purchased parts comes from qualified suppliers with no need for incoming inspection?	0%	
		1%-10%	
		11%-30%	
		31%-70%	X
		70%-100%	
6.4	What portion of raw material and purchased items is delivered directly to the point of use without incoming inspection or storage?	0%	
		1%-10%	X
		11%-30%	
		31%-70%	
		70%-100%	
6.5	What portion of raw materials and purchased parts is delivered more than once per week?	0%	
		1%-10%	X
		11%-30%	
		31%-70%	
		70%-100%	



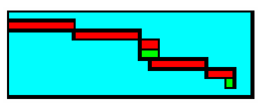
7.0	Setups	Response	X
7.1	What is the average overall setup time (in minutes) for major equipment?	61+	
		29-60	X
		16-30	
		10-15	
		0-9	
7.2	What portion of machine operators have had formal training in Rapid Setup techniques?	0%	
		1%-6%	
		7%-18%	X
		19%-42%	
		43%-100%	
7.3	To what extent are managers and workers measured and judged on setup performance?	Not at All	
		Informal Tracking & Review	
		Setups Tracked, Performance In Job Description	X

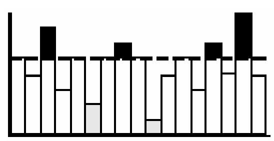


8.0	Quality	Response	X
8.1	What portion of total employees have had basic SPC training?	0%-6%	
		7%-55%	
		56%-80%	
		81%-93%	X
		94%-100%	
8.2	What portion of operations are controlled with Statistical Process Control (SPC)	0%	
		1%-10%	
		11%-30%	
		31%-70%	
		71%-100%	X
8.3	What portion of the SPC that is done is accomplished by operators as opposed to Quality or Engineering specialists?	0%	
		1%-10%	
		11%-30%	X
		31%-70%	
		71%-100%	
8.4	What is the overall defect rate?	0%	
		1%-10%	X
		11%-30%	
		31%-70%	
		71%-100%	



9.0	Scheduling/Control	Response	X
9.1	What portion of work-in-process flows directly from one operation to the next without intermediate storage?	0%	
		1%-10%	
		11%-35%	X
		36%-85%	
		86%-100%	
9.2	What portion of work-in-process is under Kanban or Broadcast control	0%	
		1%-10%	
		11%-35%	
		36%-85%	X
		86%-100%	
9.3	What is the on-time delivery performance?	0%-50%	
		51%-70%	
		71%-80%	
		81%-95%	
		95%-100%	X

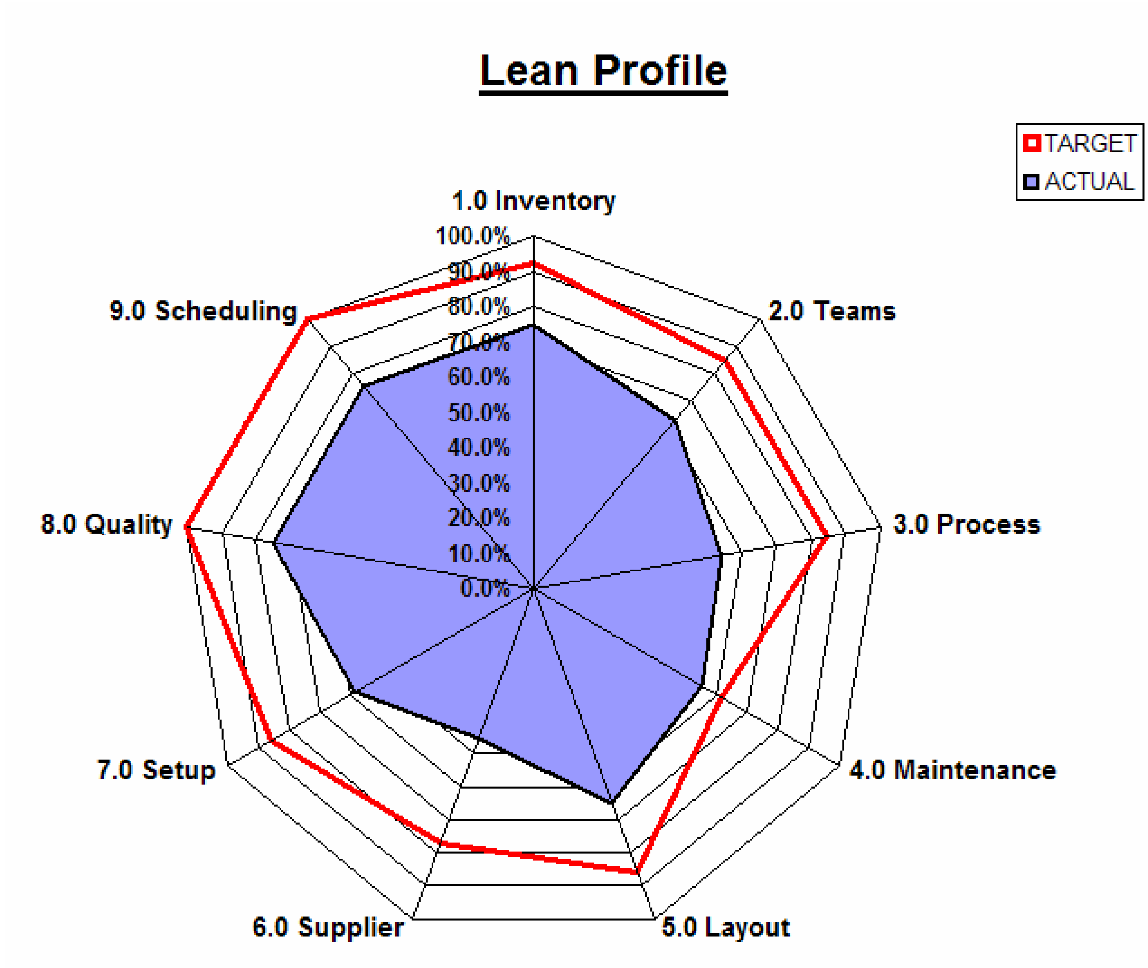




HOW TO SCORE

For each question, place an "X" in box next to the most appropriate answer. If the information is unavailable, use the topmost box of that question for your answer.

Figure-28 Assessment of Lean Efforts of current industry



GAPS

The analysis of the results shows that there are few areas which need immediate attention. This industry is very particular about quality and delivery adherence because these are the parameters on which the customers judge any of their suppliers and thus give them further business.

1. But there are areas where monitoring is lacking. Supplier discipline and process instability is one of them is one of them.
2. Due to unpredictable absenteeism there are lots of problems faced which can be removed by motivating the workers and giving them healthy environment to work. Time to time new employee remuneration schemes should be brought up by the management.
3. Quality circles should be formed and proper training should be given to workers.
4. Management focus must change from asset utilization & organization to Value Stream Improvement.
5. Commitment & Motivation of Workmen
6. Unpredictable Absenteeism should be controlled.

SOFTWARE SUPPOET TO LEAN EFFORTS

Five key areas where Lean-centric software could support Lean manufacturing initiatives. They are:

1. Analysis and Mapping Tools
2. Lean Scheduling
3. Supplier Management
4. Demand Smoothing
5. Lean Accounting

The order represents the sequence of tasks that are taken for most Lean initiatives. In our review of analysis and mapping tools, we found some capabilities among currently available software solutions, but such capabilities were limited, thus unlikely to provide much value to the user. The next phase of establishing and supporting Lean scheduling to enable the pull manufacturing model that Lean advocates is much better supported in today's software offerings. We also found that the extension of such support out in to the supply chain was also, for the most part, well-supported. Surprisingly, we found very weak support for demand smoothing and Lean accounting principles despite the fact that most ERP systems, in principle, could easily support such concepts.[14]

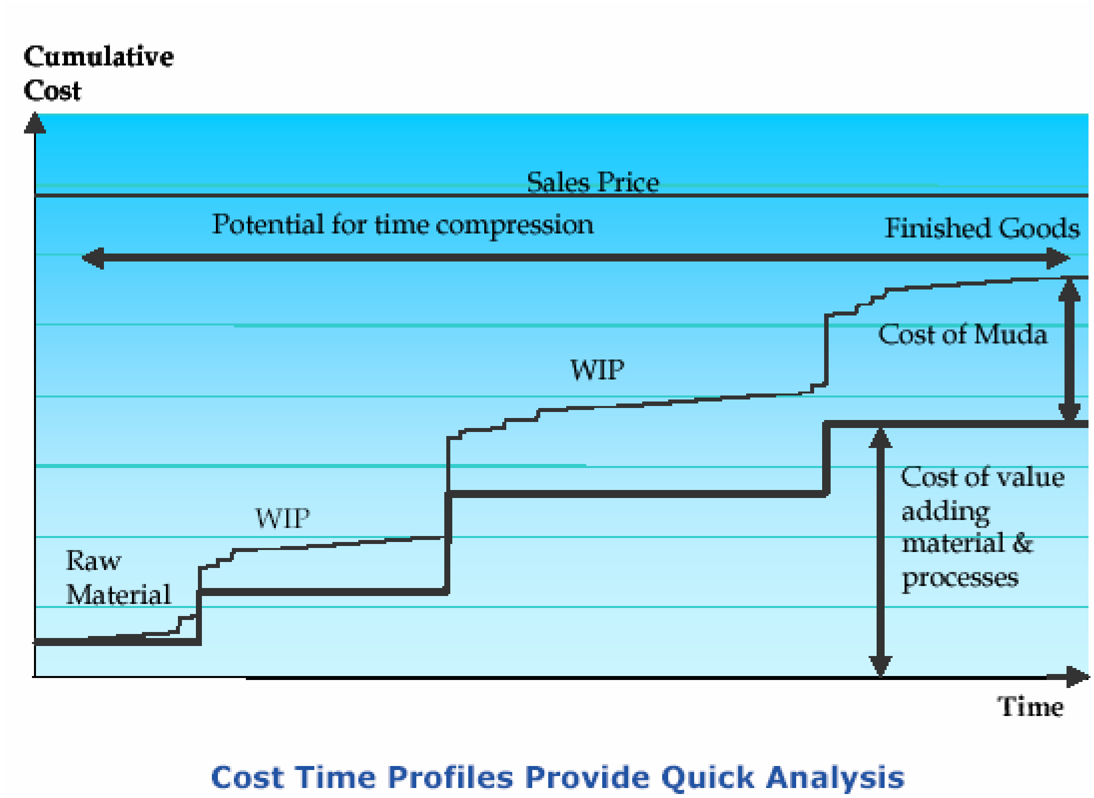
Analysis and Mapping Tools

Most Lean initiatives start with an analysis phase that identifies the mainproblems in production and seeking quick wins that improve performance. For runners, repeaters, and strangers analysis, most systems support basic part quantity analysis by volume, value and contribution, as well paretotype classifications. Capturing such information at least enables managers to demonstrate that improvements have happened. Analysis of current practices is key to Lean manufacturing, since much of Lean practice focuses on creating a smooth production flow through the supply chain. If traceability is switched on, then in principle the time and the batch number of all material, work in progress (WIP), and finished goods movements are known. Consequently, it should be possible, and useful, to produce reports that provide value to production supervisors.

Cost-Time Profile

Developed by Westinghouse, the technique contributed to their Baldridge award winning performance. Westinghouse built charts for each sub process or product, which they combined into a profile for a complete plant. Often senior managers will find the presentation of such charts something of a shock for the information they reveal is often quite different then the assumptions by which they currently run their operations.

Figure-29 Cost time profile[43]



finished good sold (FGS) sits around doing nothing, then the graph plateaus. The area under the graph indicates how much working capital is tied up and for how long. With such a graphical representation, managers can quickly identify which processes to improve for greatest payback. More sophisticated profiles show the difference between value adding and non-value adding activities. The thin line shows cost of value added, plus additional muda costs, e.g. inspections, transports, rework, and clerical activities. The thicker line shows value adding activities only, such as painting, pressing or machining. However, the graph is just a useful start. Even within supposedly value adding activities, muda may lurk such as unnecessary movements or poor ergonomics. [17]

Lead Time Analysis

Most solutions offer some support for lead time analysis, such as which suppliers deliver late, and metrics on production schedule adherence. This analysis focuses on small improvements, missing the big picture. It fails to answer key questions, e.g., how come it takes 90 days to make a product when staff only work on it for perhaps 8 hours in total, so at what point is WIP, sub-assemblies etc., sitting around waiting for the next operation.

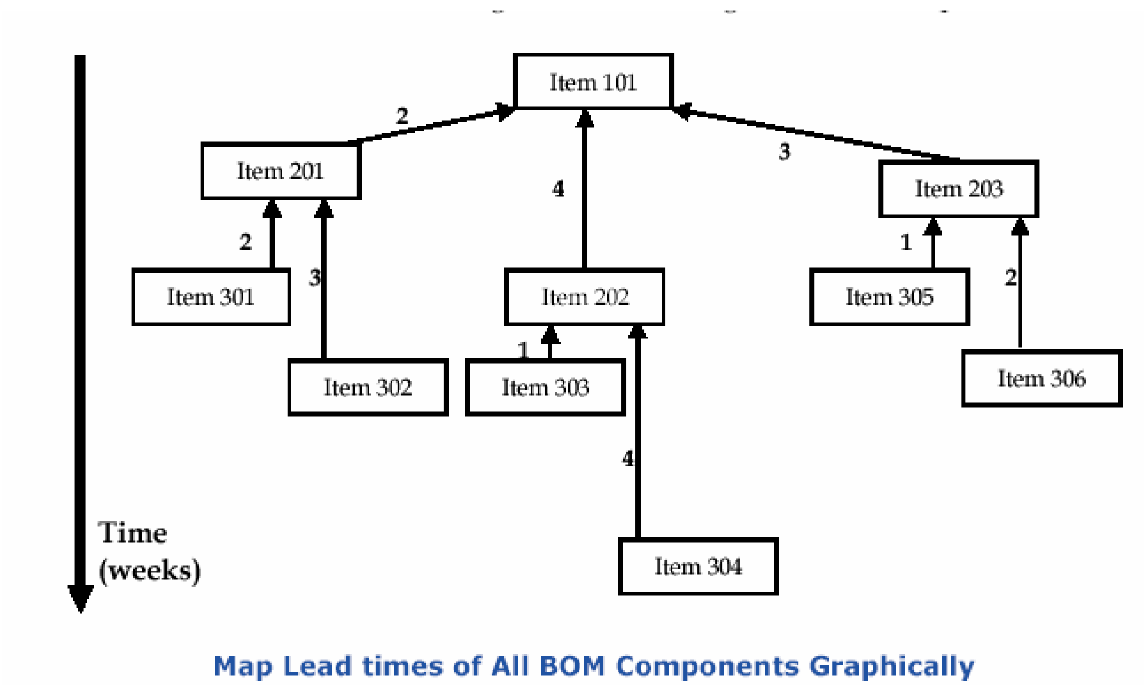


Figure-30 Lead Time analysis [36]

ERP systems tend to enshrine planning lead times during implementation, such that planning lead times are longer than actual lead times. In some implementations, as routing are transferred from the legacy to the new system, planning lead times are deliberately increased, just "to be safe". Unsurprisingly, inventory balloons, and few managers understand why. The simple chart shown shows how long it takes for the BOM to come together, with planned and/or actual lead times between each assembly, offers invaluable clues as to which manufacturing process to attack first. Again, we have not found any ERP or best-of- breed system that generates such a report as standard. [19]

Operating Equipment Effectiveness

Operating Equipment Effectiveness (OEE) is a useful, but underused metric that addresses overall asset/equipment effectiveness by multiplying the percentages of a plants' production rate, yield and utilization. Developed in Japan in the 1960's it has only recently seen wider global adoption. Good performance varies by industry. CPG industries can achieve 80%, Automotive between 40% and 60%, and electronics, since it makes to demand, often achieves 20% to 40%. Software suppliers' standard implementation is 12 to 16 weeks, and they expect to achieve payback within that period.

The bulk of the implementation effort is training supervisors to analyze the results.

OEE= Rate(%)*Yield(%)*Utilization(%)

Where:

Rate = Pieces Produced/(Ideal Rate * Operating Time)

Yield = Good Pieces/Pieces Produced

Utilization = Operating Time/Planned Production Time

Figure-31 OEE

Not every Lean purist recommends this metric; since when misused, it encourages the big batch, make for stock mentality. On the other hand it identifies wastes, and often the small frequent downtimes that are too insignificant to record in a transactional system. Whatever the academic debate, it works, but not when applied to single pieces of equipment, but entire production lines or plants. Of the major ERP suppliers, only SAP has the capability to display OEE in its plant manager's portal. MVI in the UK and Informance are two best of breed suppliers, although this metric is supported by many other automation and CPM suppliers. These solutions don't actually improve a process,

but do highlight opportunities for improvement. ROI, therefore depends on taking advantage of these opportunities. Consequently, when selecting a supplier, pay particular attention to the supplier's ability to train production supervisors to analyze the data, and their approach to institutionalizing a continuous improvement culture. [21]

Supply Chain Measures

The Supply Chain Council's supply chain operations reference model (SCOR) and metrics associated with it are viewed by some practitioners as "Lean measures". The SCOR metrics are widely supported by ERP and SCM suppliers including SAP, Oracle, Intentia, IBS, PeopleSoft as well as i2 and Manugistics. However, theory of constraints metrics are only supported by PeopleSoft as a standard report. Such metrics are, arguably, key to getting managers to focus on enhancing the flow of materials through production. To enhance flow, managers need to consider not only value, but also time. Good metrics include throughput dollar days, and inventory dollar days. Throughput dollar days measures the value of each late shipment multiplied by the number of days it was late –e.g. a one million dollar order that is five days late becomes five million dollar days. Inventory dollar days measure the value of inventory multiplied by the number of days it has been in stock.

Business Process Maps

Increasingly, Lean thinking is being applied to administrative and business processes outside the plant floor. Essentially, this re-brands business process re-engineering, although perhaps with more focus on removing tasks. Best of breed supplier Pelion has a particular strength in its support for value stream mapping, which it links to its Lean scheduling and Kanban management system. The ERP suppliers offer work flow capabilities, with some ability to extract maps of what the current business process should be. [22]

Lean Scheduling

Many Lean initiatives initially convert parts of the production line to pull, using visual Kanban cards. Performance dramatically improves, but after a couple of years, performance improvements plateau, and in some cases decline. The most common problems include Kanban card management, inconsistent demand, and extending Lean to one's supply base.

Kanban Card Management

Manual Kanbans cause problems for a number of reasons. Up to 1% get lost every day, they are labor intensive to distribute, and traceability becomes time-consuming. Sending printed Kanbans by fax to suppliers is inefficient. As production processes become more complex, a greater variety of Kanbans are required to handle special situations such an promotional peaks, 1-off's, and long lead-time supplies. Besides standard Kanban card management, most software solutions support the following capabilities, all of which are difficult to implement in a manual card-based system:

One-time Kanbans: These are used once and no replenished. Useful for manufacturing strangers – items that are rarely sold. Sometimes they are used for promotional demand, and also to signal maintenance operations, since they allow other manufacturing activities to continue.

Consignment Kanbans: Where the supplier owns the inventory until the manufacturer consumes it. Usually the supplier is paid automatically when the back flush occurs.

Dynamic Kanbans: Using standard 2 bin Kanbans, the second bin is a different size to the first Kanban. Typically used where forecast demand is variable, so, e.g., the first bin is a normal sized Kanban, and the second is smaller, since demand is expected to decline.

Summarized Kanban: If a supplier provides multiple products, then it maybe more efficient to send a single Kanban every, say 4 hours, summarizing all Kanban signals during the previous period.

Sequenced Kanbans: Often required in the automotive industry, where each vehicle in final assembly is a unique combination of features, options and color. Suppliers are required to deliver parts in final assembly sequence.

Multi-loop Kanbans: Kanbans may be sized for daily replenishment, but some suppliers may be, for instance, too distant to replenish daily. So if the supplier can only replenish every 10 days, then this batch is stored at goods inwards, and split into 10 lots. After 10 Kanbans from line side, a Kanban is issued to the supplier.

Back-flushing: In some plants, the replenishment signal for a bin is generated from a back-flush, since this saves the waste of creating Kanban cards[22]

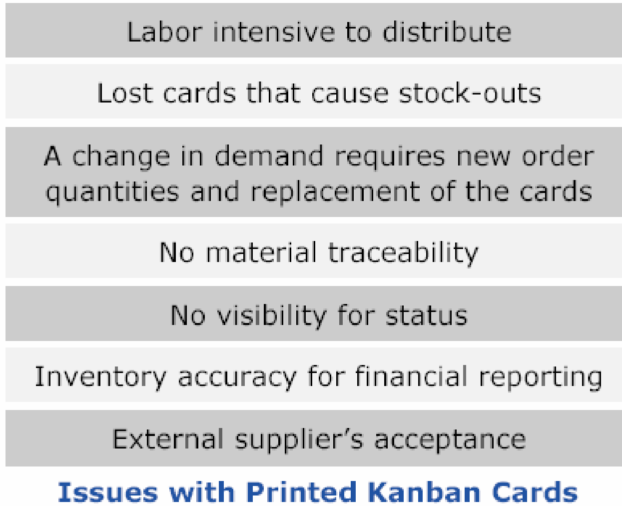


Figure-32 Issues with printed Kanbans

and scanning them. However, the back-flush point maybe, say 10 cells, upstream from the bin at the first production cell. Consequently, the cell 10 re-order point for cell 1 needs to be set at 10 units, because when the backflush occurs at cell 10, the bin at cell 1 will be empty. In addition, the backflush might need to support multi-loop Kanbans.

Kanban sizing: If done manually, Kanban sizing is difficult, and rarely performed. System support enables companies to more frequently resize their Kanbans, to start with relatively large Kanbans, and as problems emerge and are solved, slowly reduce the size thus reducing WIP. Good software systems monitor how long it takes to empty a bin, and the typical frequency of replenishment signals. Consequently, if, by mistake, an empty bin is scanned twice within a short period the system flags an error, since it is unlikely that bin has been replenished and emptied within such a short time period. Suppliers' portals, which are also widely supported, should inform suppliers what is currently on hand, Kanbans issued, and daily min-max levels. Good systems also e-mail Kanbans to the right person in the organization, and monitor that the recipient acknowledges the Kanban.

Inconsistent Demand

Theoretically, Lean proposes a sell one, make one, demand driven approach. This is possible if demand is stable. In the real world, demand is inconsistent, the product mix variable, and production capacity is essentially fixed in the short term. The solution to demand inconsistencies is a judicious mix of line redesign and balancing, combined with what is essentially,building for stock. Good tools to handle variable demand and product mix are: •

Graphical tools to design the line, its feeder lines, and run simulations to check no cell breaks the Takt time, whatever the product mix. However, experienced users will probably find tabular tools quicker to use. If demand is variable from quarter to quarter, then such tools are just key if the production line is to efficiently ramp up or ramp down to meet the new level of demand. However, not all software suppliers have developed good line design and balancing tools. It is at this point that more sophisticated Kanban management and Lean scheduling techniques are required, techniques that are generally well supported by the ERP and specialist software suppliers.

Supplier Management

Suppliers are often the weakest link in Lean supply chains. What's required is the ability to create flexible contracts with appropriately sized calloffs that are sized to match each supplier's economic delivery quantities. Within the plant, multi-loop Kanbans support is required. A typical structure was implemented by Datamax, a DemandStream user. The company placed contracts with suppliers for six months consumption, guaranteeing to purchae that volume within nine months. In addition, DataMax updated its forecast consumption every four months. SSA-Global's customer, Invensys' Safetran is doing something very similar with its suppliers by providing suppliers with six month forecasts and guaranteeing purchase of three months inventory. Nevertheless, there is far more to managing suppliers than e-Kanbans. Datamax devoted considerable effort persuading suppliers to deliver at set times, with consistently sized containers. Supplier portals are common, typically showing Kanban status – full, empty or in transit, and allow suppliers to acknowledge receipt of call-offs. Other requirements include price effectivities, that limit the prices suppliers charge.

Demand Smoothing

A key idea within Lean thinking is that variability causes waste. Hence manufacturers should proactively stabilize demand, to match the production rate against the rate of sales. For manufacturers this is a new concept, as in general marketing runs promotions during periods of peak sales, without thought or concern of the impact on production. Toyota, on the other hand, is reputed to run promotions during periods of slack demand,

to stabilize demand to an even level. The best of breed suppliers offer little support for smoothing demand, and the ERP suppliers are not much better. They argue that collaborative forecasting and promotions management play a role, if the business process
includes input from production and available production capabilities. The ideal would be to smooth demand through dynamic pricing, e.g. if demand exceeds production capabilities, then raise prices to dampen demand. The yield management techniques pioneered by airlines, hotels and car rental companies employ such mechanisms enabling them to rapidly modify pricing, i.e., for a flight at a particular time and day, on a daily basis. Neither the ERP nor the best of breed providers have begun to develop dynamic
pricing processes. Not even simple processes that offer discounts to customers prepared to wait for delivery until a period of slack demand. Manugistics, leads in the development of such dynamic pricing techniques, and their integration with production planning. However, Manugistics has also found that such thinking is somewhat ahead of its time.

Lean Accounting

Most Lean pundits would argue that traditional management accounting methods are at best unhelpful, and at worst can actively sabotage Lean initiatives. Yet in our research we found few Lean practitioners who are willing to tackle this issue and modify accounting practices to actively support their Lean initiatives. A key contributor to this is the apparent perception that there is too much inertia to fight within accounting to realize such a change. While understandable, we find this puzzling in light of the fact that the data required by Lean accounting concepts does reside within an ERP system, it is only a matter of presenting such information in an appropriate manner. But compounding the problem is the lack of such Lean-centric accounting templates within any of the major ERP Lean solutions that we reviewed. This may simply be a function of ERP suppliers not seeing a compelling demand for such reporting templates by their customers, though we strongly believe that it would not be too difficult for these suppliers to create such reporting tools, and if offered, would find a ready market of early adopters among leading Lean enterprises. Consequently, Lean improvements show cost increases, because of the way standard costings apply labor and overhead costs. Manufacturing is traditionally measured on efficiencies, utilizations and variances. This drives a big batch mentality, where supervisors cherry pick production jobs tomaximize earned hours, and procurement buys in alleged economic order quantities. Worse still, as the Lean initiative eats up WIP, deferred labor and overhead moves from the asset side of the balance sheet, to the expense section of the income statement. Some of the ideas behind Lean accounting include:

- Elimination of tracking and reporting of labor-hours, job-step tracking and especially variance reporting.
- Use of back-flushing to reduce the number of transactions.
- Use of direct costs, preferably by value stream and certainly not by department.
- Recording of inventory valuations in terms of raw material only.
- Focus on costs where there is a bottleneck resource: i.e., contribution

per constraint minute lost, accurate valuations of scrapped items at cells that are before or after the bottleneck constraint. Activity Based Costing can be part of a Lean initiative, which is supported by most ERP systems. It can yield more accurate costs than standard costing methods, but is complex, and requires considerable judgment. Generally, Activity Based Costing is a useful exercise if conducted periodically, since it identifies cost drivers. It tends to be less useful when used continuously to monitor and measure managers. [36]

BRIEF SUPPLIER PROFILES

The market for Lean manufacturing software solutions remains a small developing market. No software supplier has yet achieved over $10 million in annual revenues from their Lean manufacturing solution. For many of the ERP suppliers, Lean manufacturing is a relatively new development, and their long term commitment will depend on market acceptance. However, all suppliers do have references and their solutions are delivering good results to those that have implemented them.

Demand Stream/SoftBrands

Demand Stream heritage was Fourth Shift's 1992 acquisition of JIT enterprises, which became Fourth Shift's repetitive manufacturing module. Launched as an independent product early this century, it is the only bestof –breed supplier with a worldwide support network. The FourthShift partnership with SAP, which provides manufacturing functionality for Business One, also includes DemandStream. Major clients include Visteon in China, Alfmeier and DataMax.

eBots

Founded in 1999, with 75 customers that include Invensys and Emerson. eBots Lean Execution System comprises two main modules: Collaborative Electronic Kanban, and the newer Demand Driven Scheduling. Their key strength is supplier management, and in total their customers manage 1,000suppliers with kanbans. Prior to 1999, the founders created an e-business application development infrastructure, which is a layered architecture, separating applications and data, with workflow, a rules engine and appli- cation integration. This application and architecture provided the foundation for eBots development in 1999, and enables strong ERP integration. For analysis and mapping, eBots partners with Orlando Software Group, who produce a $499 value stream mapping tool.

IFS

IFS matches other ERP supplier's Lean manufacturing functionality: business process mapping tools, Takt time scheduling, Kanban and supplier management, but also offers a Kaizen costing system supporting continual cost reduction initiatives. Much functionality within their solutions has been inspired by the automotive industry. IFS is particularly successful in the UK automotive industry, but beware that the automotive industry is not a focus for IFS in every country in which it operates. [34]

Oracle

Oracle was the first major ERP supplier to offer flow manufacturing functionality, launching the solution back in 1998. Oracle claims over 100 companies use its flow manufacturing model, and three or four times that number use its Kanban functionality. Marquee customers include Pella Windows and Ingersoll Rand in Ireland. Oracle's Flow manufacturing model was derived from a partnership with JCIT, and over the years has developed to include good graphical line design and balancing tools, and a well thought-out implementation methodology. Oracle has the best vision of how to apply Lean thinking to enterprise processes. Its recent acquisition of Collaxa enhances its support of BPEL,(business process engineering language). In principle this will better support

integration of data, applications, business processes and people that run on both Oracle and non-Oracle applications. For Lean initiatives, it willsupport better process design and monitoring, so that delays in process execution become visible. Combined with RFID, it may be possible to track raw materials through production and supply chain, and revealing excess queuing waiting and transport movements.

PeopleSoft

PeopleSoft's ambition is to become the thought leader in manufacturing, with its Demand Driven Manufacturing solution suite. In 2003 PeopleSoft acquired JCIT's Flow Manufacturing solution, and is the only ERP supplier to develop a close relationship with Eli Goldratt, who created the theory of constraints ideas and techniques. To date PeopleSoft has around 13 customers implementing this new solution suite including Cascade Designs and FW Murphy. [34]

Pelion

Pelion is a well-funded start up with a heritage as an EAI systems solution supplier. Uniquely, Pelion combines value stream mapping tools, that are now integrated into line design and balancing tools, with their Kanban execution system. This approach enables users to work on four time horizons within a single tool: - *Annually* to design an appropriate plant layout; *Quarterly* to recalculate Kanban sizes, Takt time, and new product introductions; *Monthly* to create work plans; and *Daily* to manage demand and work output. Lighthouse customers include Brookes Automation, Husqvarna Turf Care, and Nissan Forklift. [43]

SAP

SAP has had a flow manufacturing offering for several years. With the recent announcement of its plant manager's portal, SAP is increasingly focusing on the plant floor. There is wide support for Kanban management, supplier management, for flexing production lines, as well as clustering and blocking rules to sequence production. A xApps partnership with Vendavo provides some ability to smooth demand. Many of SAP's Lean manufacturing successes are in Aerospace and Defense, with companies such as Rockwell Collins, Lockheed Martin, and B.F. Goodrich. [34]

SSA-Global

SSA-Global is somewhat of a late entrant to Lean manufacturing with its "Leanware" execution solution, an add-on for its recently released ERP-LN solution. Safetran is an early adopter and has been live since April. The solution currently comprises a production leveling board, production cellleader board, supplier portals, and a sophisticated Kanban execution sys- tem. In addition, there is also a set of lead-time analysis tools. Future plans include extended support for configurable items. [34]

Conclusions

Don’t look to your ERP or specialist breed of supplier for support if you are just commencing your Lean initiative. Better by far to understand the principles, gain credibility with early wins, and with that experience understand what sort of functionality you require. Typically after some early success, the rate of improvement will plateau. It is at this point that software solution offer rapid ROI, and can take your plant to the next level of performance.

- Best of breed systems are best employed across a heterogeneous ERP landscape, or here ERP solutions are dated and not going to be upgraded.
- Current Lean offerings from major ERP suppliers offer good support. With their business process, workflow, and customer management, there is some support for including other functional departments across the enterprise within the Lean initiative. However, the extent to which software supports Lean are limited to particular areas. Major techniques such as customer value analysis, identifying waste, and 5S are clearly beyond the scope of software.

Overall, my opinion of current software systems’ support for Lean is:

- Good support for Lean scheduling, electronic Kanbans, and Lean supplier management processes.
- Poor support, for the Lean Analysis and mapping techniques widely used by Lean practitioners. Nevertheless, great support for OEE analysis is available.
- Basic support for mechanisms to smooth demand.
- A dangerous and for the Lean initiative, potentially fatal, lack of support for Lean accounting concepts. [19]

CONCLUSION

I have shown very vividly in my research that lean manufacturing can be applied in continuous and discrete process industry as effectively as it has been applied in car manufacturing industries all over the world. Though it presents many challenges as I have discovered during the course of my research but they can be over come. There is an urgent need today to adapt lean manufacturing to the changing environment. I have tried to develop models to suite the environment, product mix and character, complexity and customer base of the industries where I have carried my research.

We have seen how we can design lean system for high variety low volume industry and what changes are needed to make it work as planned and how to bridge the gap. I also observed that lack of supervision and relax attitude or management can even drive the system to a near collapse and since in a lean system there is less scope to do mistakes this can prove to be disastrous. It could lead the system again back to its parent state and in some cases even in worse condition. We faced such a phenomenon in the month of February when the system deteriorated to a bad state due to lack of monitoring. This was very de-motivating and taught us an important lesson of always being alert and attentive. It also taught us to catch signs for system deterioration. This was one of the reason why I came up with a model to assess lean implementation. Lean system failure can be fatal since the system is already lean. It’s also true that chances of a lean system failing is a rare phenomenon because we had already eliminated most of the chances of failure.

Some models hve also been developed for calculating number of *kanbans*. These models can also be successfully used in all kinds of industries with minor adjustments and keeping the concept behind it intact.

I have tried to show the models for implementing lean continuous process industries. These industries are already over strained due to very tight specification and very long lean times. In such situations lean can be a real savior as I have already shown in the research and through the examples that I have quoted. I have also shown which tool to use in which kind of process industry (which is very critical since applying lean in its original form may lean to unnecessary burden and will not give results as expected. So, it becomes very important to know the character of your industry and then to apply the most suitable tools be it JIT, TPM, production smoothening, reduced set up time, etc. in many industries these days many efforts are wasted due to wrong choice of lean tool. I have tried to divide process industries into various categories depending on various parameters like, nature and volume of raw material, mature and volume of finished goods, kind of equipments used processes, etc.

With the advent of ERP, lean is also interfaced with these software. These software solutions can aid in implementing lean tool for e.g. we can have electronic kanban system instead of physical kanbans that are being used mostly in various ancillary industry.

To conclude lean manufacturing is an great emerging trend where we can improve efficiency of an industry by making it lean i.e devoid of waste.

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