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"Lean Manufacturing"

Dissertation

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MTM/16/02

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CERTIFICATE

This is certified that the work contained in this dissertation entitled **"Study on lean manufacturing"** by **AJAY(MTM/16/02)** in requirement of the partial fulfilment for the award of degree of Master of Technology in Mechanical Engineering at N.C. College of Engineering, Israna (Panipat). This work was completed under my direct supervision.

The work embodied in this dissertation has not been submitted for the award of any degree to the best of our knowledge.

Mr. Sandeep Malik
(Supervisor)

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Ajay

MTM/16/02

ABSTRACT

Lean manufacturing or lean production, is quite simple. Basically lean means a production practice that undertakes the expenditure of any resources for achievement of any goal rather than creation of value for the customer for the end consumer to be wasteful and thus a target can be achieved working from the perpective or considering the needs of consumer value is defined as process that the consumer is ready to pay for the specific goods and services.

Here we have implemented the lean manufacturing technique in an automobile industry (wiring harness) to reduce the waste elements of a production process. Initially, we created a current state map for the complete process. Then the process studied showing various conditions and parameters like cycle time, inventory etc. Then the bottlenecks were identified in the processes which were hampering the complete production process. Time study was done to actually know the time taken to complete the process and that time was compared with the tact time. The time of all the processes was balanced to make the process smooth. Then a future state map was designed showing the process flow after improvements with complete parameters.

The main objective of this study is to remove the wastes from the process which is the main objective of lean manufacturing.

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ACRONYMS & NOTATIONS

CVSM	Current Value Stream Map
FIFO	First In First Out
FVSM	Future Value Stream Map
IMVP	International Motor Vehicle Program
JIT	Just In Time
LMS	Lean Manufacturing System
OEM	Original Equipment Manufacturing
PVC	Poly Vinyl Chloride
TPS	Toyota Production System
VSM	Value Stream Map

I. INTRODUCTION

A. Lean Manufacturing

The main concept Lean production is set of principles and practices that assists in the determination and elimination of waste in various processes. The quality of the product is improved by reduction of waste, time, cost and resources. Lean production also assists in the determination and reduction of non-value-added activities at different stages such as design and production (APICS Dictionary, 12th Edition).

Lean manufacturing is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for. Basically, lean is centered on preserving value with less work.

Lean manufacturing is a practice that undertakes the expense of different resources for the achievement of goal. It is generic process management philosophy come into existence from the Toyota Production System (TPS) and identified as "Lean". It is renowned for its focus on reduction of the original Toyota seven wastes to improve overall customer value, but there are varying perspectives on how this is best achieved. The steady growth of Toyota, from a small company to the world's largest automaker, has focused attention on how it has achieved this.

Lean manufacturing is a variation on the theme of efficiency based on optimizing flow; it is a present-day instance of the recurring theme in human history toward increasing efficiency, decreasing waste, and using empirical methods to decide what matters, rather than uncritically accepting pre-existing ideas. As such, it is a chapter in the larger narrative that also includes such ideas as the time and motion study, the Efficiency Movement, and Fordism. Lean manufacturing is often seen as a more refined version of earlier efficiency efforts, building upon the work of earlier leaders such as Taylor or Ford, and learning from their mistakes.

Lean Manufacturing has increasingly been applied by leading manufacturing companies throughout the world. It has proven to have many positive outcomes, which include such concepts as reduced cycle time, decreased cost, reduction of defects and waste. Lean manufacturing aims to achieve the same output with less input; such as less time, less space, less human effort, less machinery, less material and less cost. To better understand lean manufacturing, one first needs to understand the basic principles that guide it. Some major lean manufacturing principles include: recognizing wastes, having standard processes, having a continuous flow, pull-production, quality at the source and maintaining continuous improvement.

The main objective of lean production is to reduce lead-time, cycle time and resources and to improve the quality and productivity. Many companies hesitate to implement it, because of the belief that productivity will decrease during the implementation stages. But in reality the results are different from their belief. In LMS, continuous improvement is the best feature.

The Lean Enterprise versus Traditional Mass Production		
	Mass Production	Lean Enterprise
Primary Business	A product-centric strategy. Focus is on exploiting economies of scale of stable product designs and non-unique technologies.	A customer-focused strategy. Focus is on identifying and exploiting shifts in competitive advantage.
Organizational Structure	Hierarchical structures along functional lines. Encourages Functional alignments and following orders. Inhibits the flow of vital information that highlights defects, operator errors, equipment abnormalities, and organizational deficiencies.	Flat, flexible structures along lines of value creation. Encourages individual initiative and the flow of information highlighting defects, operator errors, equipment abnormalities, and organizational deficiencies.
Operational Framework	Application of tools along divisions of labor. Following of Orders, and few problem-solving skills.	Application of tools that assume standardized work. Strength in problem identification, hypothesis generation, and experimentation.

Table 1: A comparison of mass production and Lean.

B. Lean History

The characteristics of lean manufacturing where first identified and encapsulated in a 1990 book entitled, *The Machine that has the ability or that can change the world written by james.* P. Womack, Daniel T. Jones, and Daniel Roos. The lean concept is based on an earlier five year study of the automobile industry by the International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology (Womack:1990:4). The book presents a cautionary treatise warning that companies in the United States must adopt "lean" production process and practice policies to compete successfully with Japanese companies.

This concept is further formalised in a subsequent book by Womack and Jones (1996:15) entitled, powerful lean thinking and Banish waste has the ability to create health in your corporation or organisation. As implied by the title, lean is, in its basic form, the manufacture of a product with a minimum of waste. The treatise by Womack and Jones (1996:19) takes a broader view of "waste" than just that of material scrap and unnecessary overhead and proposes that a lean implementation address all aspects of value- creating activities. The concept of lean production represents the natural evolution of "Just in Time" (JIT), a production concept pioneered by Toyota.

C. Lean Principles

In Lean Thinking, Womack and Jones (1996:16) define lean thinking as “a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively.” There are five key principles vital to lean thinking, these are specify value, identify the value stream, make value flow, organize customer pull, and pursue perfection. These principles are expected to be addressed in order, with each one building on the one before it, as shown in Figure . This research will concentrate on the identification of the value stream and the identification of the value adding actions within this framework of lean principles.

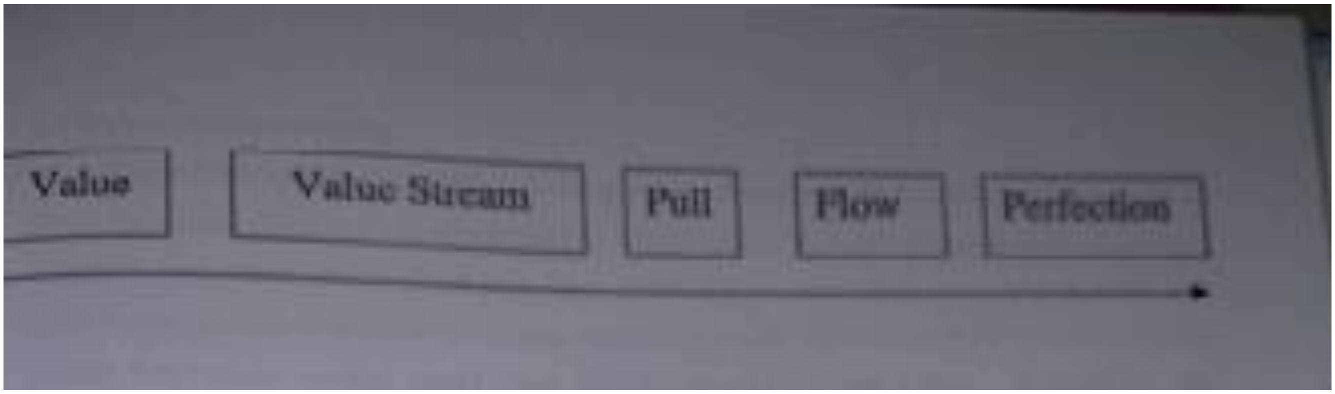


Fig 1:- Steps of lean thinking

- *Specify Value:-* Value is expressed in terms of a specific product or service, delivered at a specific price at a specific time, which meets the needs defined by the customer (Womack & Jones,1996:16).

- *Identify the Value Stream:-* Value stream is a macro view of the entire door-to- door perspective of a production, from raw materials to product delivery. It includes the determination of all actions necessary to produce a product and the separation of those necessary activities from the identified non-value-added steps. This includes not only the physical transformation of the product from raw materials, but also the information system necessary to produce the right quantity at the right time (Womack & Jones,1996:19).

- *Flow:-* Once waste has been eliminated, 'flow' can be accomplished. Flow, the opposite of batch production, requires the movement of products from one value- creating step to the next with no waiting or scrap (Womack & Jones, 1996:21).

- *Pull :-* The production of customer requirements against specified delivery dates. Information travels upstream from the customer, signaling production only when a need is shown desput of pushing or providing product from raw material to consumer.(Womack & Jones,1996:24).

- *Perfection:-* This step is a reminder that reducing waste is never ending. Continuous improvement of a system is vital to perfection, where waste is constantly being eliminated. It is necessary to understand that lean is not a specific control tool, improvement tool, floor layout, or principle. It is the methodology or framework that focuses on the ideas of value, waste, and meeting customer demand. It is clear from this why Value Stream Mapping resulted as a method of determining where the value and waste are located and aiding in the reduction of lead-time to help make the right product at the right (Womack & Jones,1996:25).
-

D. *Value stream mapping*

Value Stream Mapping (VSM) is the process of mapping the material and information flows for components and sub-assemblies in a value chain from raw material to the customer. Womack and Jones define VSM as a tool, which allows identify ways to get material and information to flow without interruption, improve productivity and competitiveness, and help people implement system rather than isolated process improvements. Researchers and practitioners try to identify waste in value streams and, hence, find an appropriate route to removal, or at least diminishing the influence of waste.

According to Seth and Gupta, Value Stream Mapping (VSM) is the process of mapping the material and information flows for components and sub-assemblies in a value chain from raw material to the customer. Womack & Jones, and Rother described value-stream maps as “material and information flow maps”, which are one-page diagrams showing the processes used to make a product. VSM is used to identify the sources of waste in the value stream as basis for implementation plan that helps to see and focus on flow with a vision of and ideal.

VSM is a mapping paradigm used to describe the configuration of value streams and it maps not only material flows but also information flows that signal and control these material flows. Seth and Gupta state that it is necessary to map the value stream of products both within a company and across the supply chain. VSM modeling language includes standard icons, and it is easy to use with its widening dissemi- nation within the manufacturing community, and VSM also includes a step by step approach to transform a current manufacturing state into a Lean Future State, which is the basis of its success in practice.

VSM became a popular implementation method for Lean manufacturing, and it is considered as a classification scheme. VSM with seven mapping tools (namely, process activity mapping, supply-chain response matrix, production variety funnel, quality filter mapping, demand amplification mapping, decision point analysis and physical structure mapping) and their major application areas are very useful.

Mostly, the value-stream maps were applied to manufacturing activities, but nowadays the technique is used to map any service business process, including business-to-business sales, retail sales, e-business, auditing, healthcare, education, and government services.

Value Stream Mapping is an organized approach, used on selected product families, whereby cross-functional project teams walk and map the current material and information flow. They then apply lean thinking to create a future state map, with lean elements such as kanban systems and cellular flow. Kaizen breakthrough event targets are identified.

E. Value stream mapping objectives

Various objectives of using VSM as given by Mike and John (1996) are listed below:

- It helps to visualize more than just the single- process level, i.e. assembly, welding, etc., in production. One can see the flow.
- It helps to see more than the waste. Mapping helps to see the sources of waste in your value stream.
- It can solve the language barrier by giving them common language.
- It makes decisions about the flow apparent, so one can discuss them. Otherwise, many details and decisions on the shop floor just happen by default.
- It ties together lean concepts and techniques, which helps to avoid "cherry picking".
- It creats a link between the information and material flow.
- Provides a company with a "blueprint" for strategic planning to deploy the principles of Lean Thinking for their transformation into a Lean Enterprise.

F. Three types of activity

Manufacturing, especially lean manufacturing strives to reduce waste in human effort, inventory and time to market. Manufacturing space is becoming highly responsive to customer demand, same as the demand to produce the quality products is focused on the efficient and economical manner. Since lean thinking analyzes business processes systematically by identifying and removing wastes, it helps also to distinguish between value added and non-value added processes. Classification of processes is based on the elimination of waste. There are two types of activities classification, see Table 2.

Activities, classified by Monden	Activities, classified by Womack & Jones
Value-added activities	Value-added activities
Necessary but non value-added activities	Type One muda
Non value-added activities	Type Two muda

Table 2: Classification of activities

Value-added activities involve the conversion or processing of raw materials or semi-finished products through the use of manual labor. Examples include activities such as sub- assembling of parts, forging raw materials, and painting bodywork. Thus, value added activities are the machinery working time required to produce a product.

Meanwhile, necessary but non-value added activities or Type One muda may be wasteful but are necessary under the current operating procedures. Examples include such as walking long distances to pick up parts, unpacking deliveries, and transferring a tool from one hand to another. In order to eliminate these types of operation it would be necessary to make major changes to the operating system such as creating a new layout or arranging for suppliers to deliver unpacked goods. Such change may not be possible immediately.

Non-value added activities or Type two muda stands for the pure waste and involves unnecessary actions, which can be eliminated completely. Examples include waiting time, stacking intermediate products, double handling and etc. Typically, 95% of all lead-time is non-value added activities.

G. Wastes

According to Hines, Taylor, Butterworth & Sullivan, understanding wastes within the supply chain is considered as the first stages of VSM. Researchers and practitioners try to identify waste in value streams and, hence, find an appropriate route to removal, or at least diminishing the influence of waste.

Waste takes many forms and can be found at any time and in any place. It may be found hidden in policies, procedures, production process, product designs, and in other operations. Waste consumes resources but does not add any value to the product. Russell and Taylor define waste is defined as something despite of minimum amount, time, efforts and labour that are required to add value of specific product.

According to Shingeo, Bicheno and Taiichi there are seven types of wastes, which are accepted commonly in manufacturing industry:

- Overproduction,
- Waiting,
- Transportation,
- Inappropriate processing,
- Un-necessary inventory,
- Unnecessary movement and
- Defects.

➢ *Waste of overproduction*

The waste of overproduction is considered as the most serious waste as it discourages a smooth flow of goods or services and is likely to inhibit quality and productivity. Such overproduction also tends to lead to excessive lead and storage times. As a result defects may not be detected early, products may deteriorate and artificial pressures on work rate may be generated. In addition, overproduction leads to excessive work-in-progress stocks, which result in the physical dislocation of operations with consequent poorer communication. This state of affairs is often encouraged by bonus systems that encourage the push of unwanted goods .The main concept of pull or kanban system was to employed Toyota to resolve that specific problem.

➢ *Waste of waiting*

The waste of waiting occurs when time is not being used effectively. In a factory, the waste occur whenever products are not moving or being worked on. The waste affects both products and workers, each spending time waiting. The ideal state should be no waiting time with a consequent faster flow of goods. Waiting time for workers may be used for training, maintenance or kaizen (continuous improvement) activities and should not result in overproduction.

➢ *Waste of transportation*

The waste involves goods being moved from one process to the next and adds no value to the products. Taken to an extreme, any movement in the factory could be viewed as waste, and thus, minimization of transportation is usually sought. In addition, double handling and excessive movements are likely to cause damage and deterioration with the distance of communication between processes proportional to the time it takes to feed back reports of poor quality and to take corrective action.

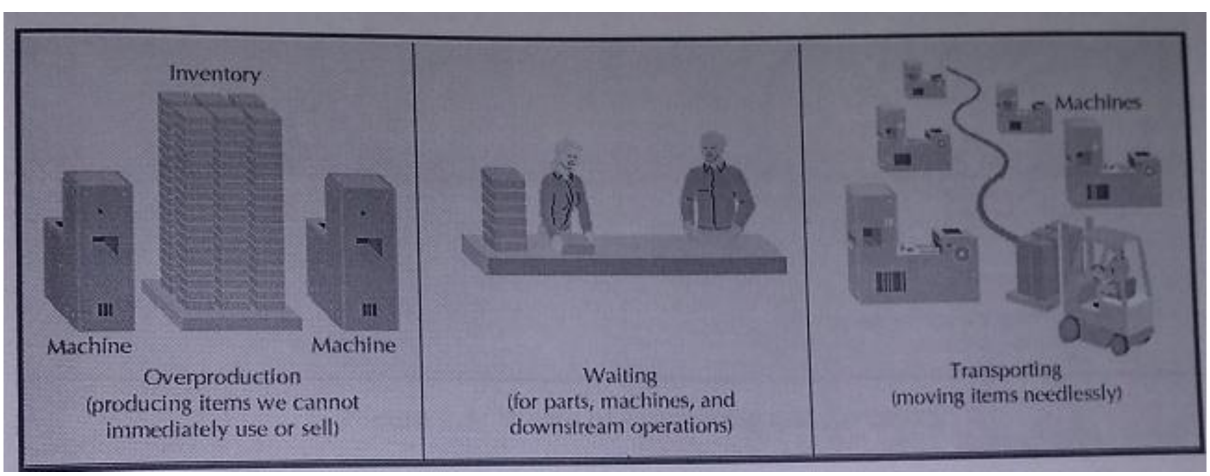


Fig 2:- Waste of overproduction, waiting and transporting

➢ *Waste of inappropriate processing*

The waste of inappropriate processing occurs in situations where overly complex solutions are found to simple procedures such as using a large inflexible machine instead of several small flexible ones. The over-complexity generally discourages ownership and encourages the employees to overproduce to recover the large investment in the complex machines. Such an approach encourages poor layout, leading to excessive transport and poor communication. The ideal, therefore, is to have the smallest possible machine, capable of producing the required quality, located next to preceding and subsequent operations. Inappropriate processing occurs also when machines are used without sufficient safeguards, such as poke-yoke (mistake-proofing technique) or jidoka (stopping a manual line or process when something goes wrong) devices, so that poor quality goods can be made.

➢ *Waste of unnecessary inventory*

The waste of unnecessary inventory is a sign that flow was disrupted, and that there are problems in the process. Unnecessary inventory tends to increase lead time, preventing rapid identification of problems and increasing space, thereby discouraging communication. Thus, problems are hidden by inventory. To correct these problems, they first have to be found. This can be achieved only by reducing inventory. In addition, unnecessary inventories create significant storage costs and, hence, lower the competitiveness of the organization or value stream wherein they exist.

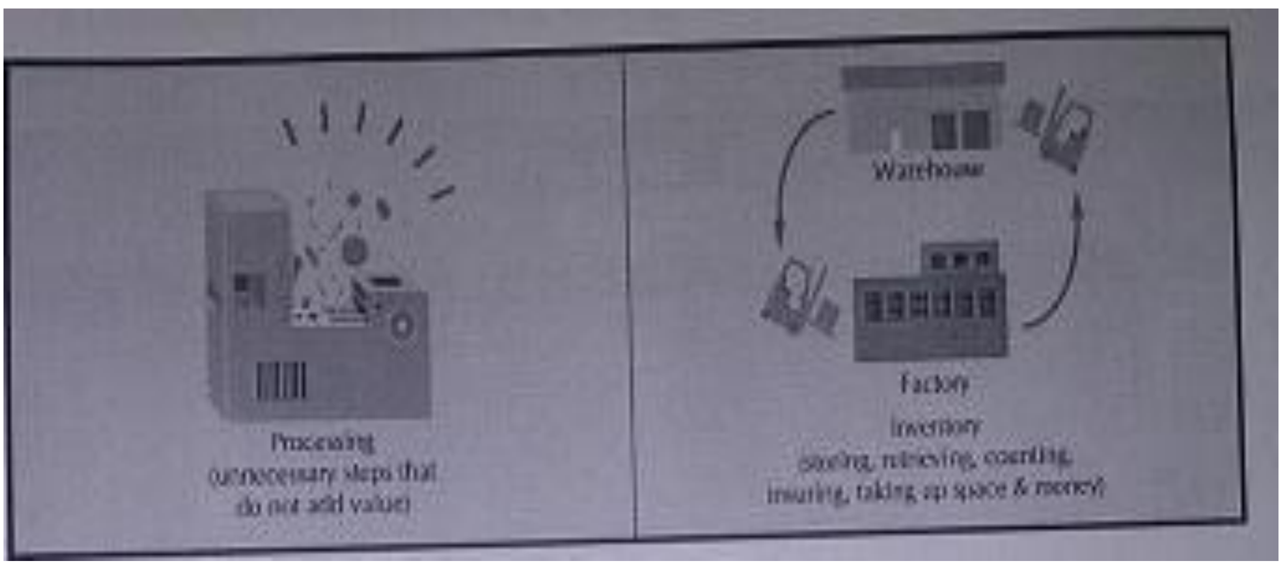


Fig 3:- Waste of Processing and Inventory

➢ *Waste of unnecessary movements*

The waste of unnecessary movements involves the ergonomics of production where operators have to stretch, bend and pick up when these actions could be avoided. Other examples are such as walking between processes, taking a stores requisition for signature or emptying parts from one container into another. Such waste is tiring for the employees and is likely to lead to poor productivity and, often, to quality problems.

➢ *Waste of defects*

The waste of defects implies that producing defects costs time and money. Thus, the bottom-line of waste are direct costs. The Toyota philosophy tells that defects should be regarded as opportunities to improve rather than something to be traded off against what is ultimately poor management. Thus defects are seized on for immediate kaizen activity (continuous improvement concept).

It was shown that it was easy to identify waste and propose ways to reduce or eliminate it. However, it was found that there were actually more than seven wastes in the real life of organizations. Furthermore, the seven wastes "lacked an ability to take on a more exact costing of existing wastes and hence the potential for improvement, and they did not easily represent the human interaction stages of the value stream". Five more wastes were added to cover the lacked functions. They are the following:

- Power and Energy,
- Human Potential,
- Environmental Pollution,
- Unnecessary Overhead (including training), and

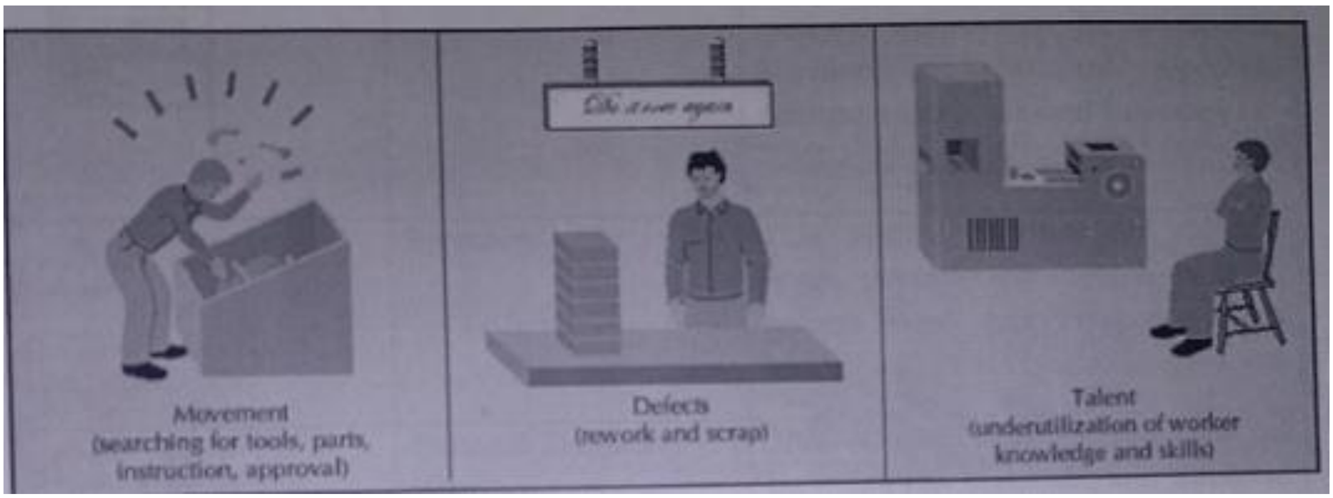


Fig 4:- Waste of Movement, Defects and Talent

H. Nomenclature of Vsm

In order to use VSM to effectively "map" the production of a specific product, it is essential to understand all of the symbols that can be used to represent products, processes, and information flows.

Symbol	Title	Definition
	Dedicated Process	This symbol denotes a process, machine, or department through which materials flows.
	Shared Process	This symbol denotes a process, machine, or department that multiple value stream products share
	Customer or Supplier	This symbol denotes either a customer of the product, or a raw material supplier.

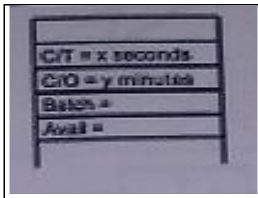
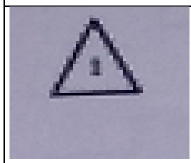
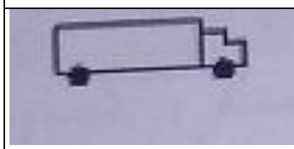
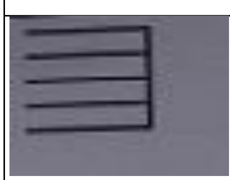
	Data Box	This symbol that is used is to provide relevant information , machine and batch size and frequency to the required consumer.
	Inventory	This symbol denotes raw material levels, the inventory build-up between process steps, and finished product levels.
	External Shipment (Receiving or Shipping)	This symbol denotes shipment of incoming raw materials, and shipment of finished goods out of the plant.
	Push Arrow	This symbol denotes movement of material that is produced and then sent (pushed) to the next process step.
	Shipment (Receiving or Shipping)	This symbol denotes movement of incoming raw materials, and movement of finished goods out of the plant.
	FIFO Lane	This symbol denotes a First- In-First-Out inventory that limits flow between processes.
	Material Pull	This symbol denotes the withdrawal (pull) of materials from a supermarket inventory for downstream processing.
	Supermarket	This symbol denotes an inventory of parts used to reduce overall inventory levels that are essential for downstream processing.

Table 3: Material Flow Symbols

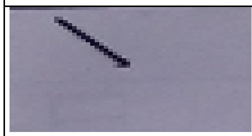
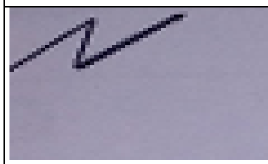
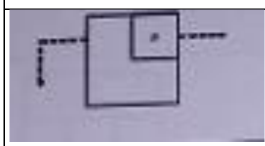
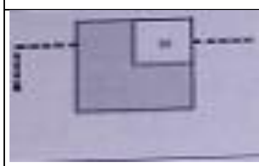
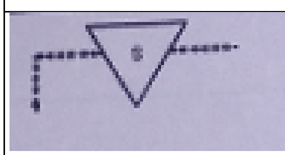
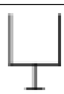
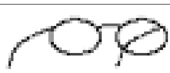
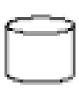
Symbol	Title	Definition
	Manual Information	This symbol denotes manual flow of information (hardcopies, memos, notes).
	Electronic Information	This symbol denotes electronic flow of information (email, fax, phone, computerized data transmission).
	Production Kanban	This symbol denotes the production of a specific number of parts.
	Withdrawal kanban	This symbol denotes the transfer of parts out of a supermarket inventory to a specific process.
	Signal Kanban	This symbol denotes a material pull, but when inventory levels have dropped to a minimum level.
	Load Leveling	This symbol denotes the adjusting of kanbans to level production of parts over time.
	Kanban Post	This symbol denotes the location where kanban cards are collected.
	Go See Scheduling	This symbol denotes scheduling production based on visually inspecting inventory levels.
	Verbal Information	This symbol denotes the flow of verbal information.
	MRP/ ERP	This symbol denotes the use of central production scheduling, such as MRP or ERP.

Table 4: Information Flow Symbols

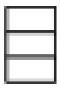
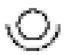
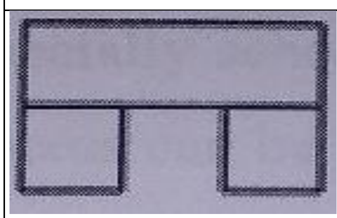
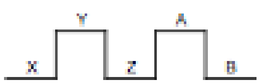
Symbol	Title	Definition
	Kaizen Burst	This symbol denotes a potential process change that can be used to improve the Current State.
	Safety Stock	This symbol an inventory that is used in case of downtime to protect the production system from disruption.
	Human Operator	This symbol denotes a human operator at a specific workstation. The number of operators should be noted.
	Work Cell	This symbol denotes a work cell where several processes are integrated.
	Time Line	This symbol denotes value- added times (lower) and non- value-added times (upper) for each stage in the production process.

Table 5: General Symbols

I. *Procedure for VSM*

Using the symbols discussed above, the procedure associated with VSM construction is relatively straightforward, and consists of three basic steps.

- Draw a Current-State Map of the production system
- Decide how best to improve the current system
- Draw a Future-State Map for the production system incorporating these changes

The real goal of VSM is to produce the future-state map, which essentially plots an optimized production system. This is ultimately realized when lean is implemented on the actual factory floor. To achieve the future state, however, the current state must first be understood. A system's current state can only be defined after thoroughly examining the production floor, and analyzing the complete path a product takes through the plant, not necessarily according to the physical plant layout, but by major processing steps, wherever material or information flows occur. For each process, it is important to note the Cycle Time (CT), and Changeover (i.e., Setup) Time required. Other pertinent information includes production (batch) size, number of operators' required, effective working time, and scrap rate as shown in figure 1.Product flows must be defined as either push or pull, depending on the production process. After all processes and material flows are delineated, it is imperative that all information flows, both electronic as well as manual, be placed on the map as well, especially scheduling information. Finally, a timeline must be added, so that the production process can be analyzed quantitatively. The lead-time for each process should be denoted on the top position of the timeline, while the processing time should be provided on the bottom position. This allows a total Production Lead Time, as well as a total Processing Time, to be calculated for the entire production line.

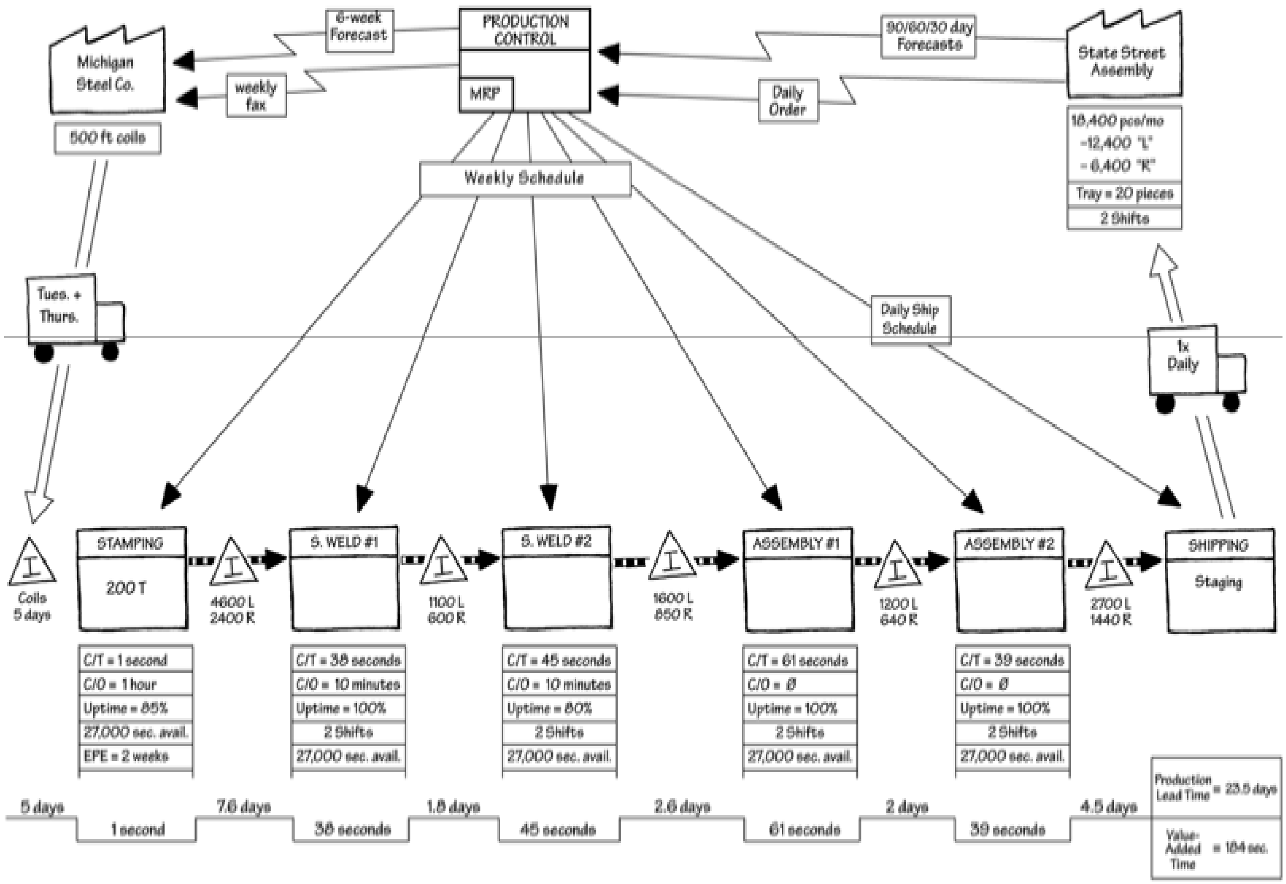


Fig 5:- An Example of CVSM of XYZ industry

➢ *Conversion of CVSM into FVSM*

After the current state has been mapped, the production process must be examined and analyzed so that it can be improved, and thus the future state map can be drawn. One of the primary reasons to examine the current state map is to quantify overproduction of items and wasted time, where inventory sits idle, waiting to be used by the next process. The map should be examined for areas where the concepts of lean manufacturing can be utilized to reduce or eliminate wasted time, and by so doing minimize lead times, and thus streamline each process. Eliminating processing steps, adjusting specific processes, incorporating continuous flow or pull systems, and levelling production are some of the techniques that can be used as shown in figure 6.

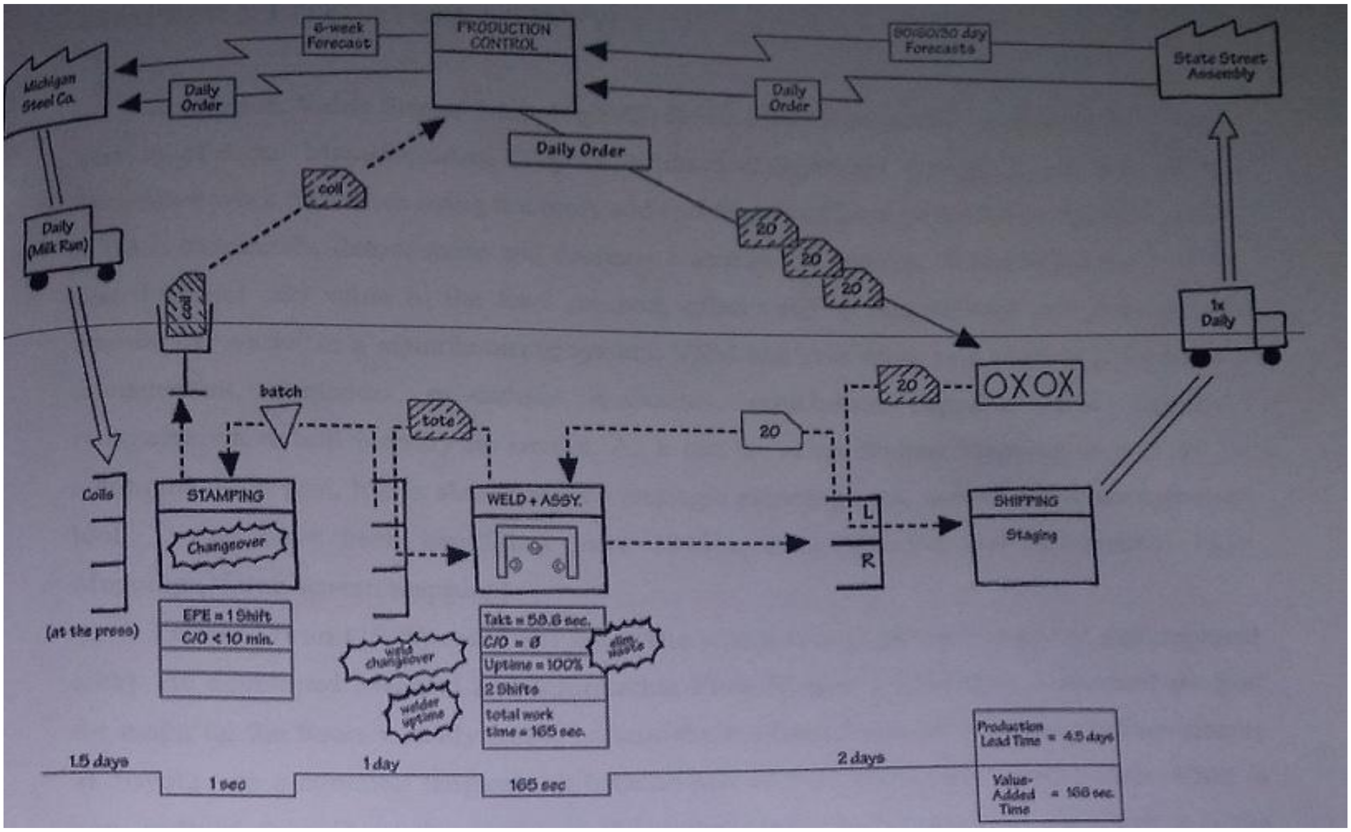


Fig 6:- An Example of FVSM of XYZ industry

II. LITERATURE SURVEY

In essence, Value Stream Mapping (VSM) is a visualization tool oriented to the Toyota version of Lean Manufacturing (Toyota Production System). It helps to understand and streamline work processes using the tools and techniques of Lean Manufacturing. The goal of VSM is to identify, demonstrate and decrease waste in the process. Waste being any activity that does not add value to the final product, often used to demonstrate and decrease the amount of 'waste' in a manufacturing system. VSM can thus serve as a starting point to help management, engineers, production associates, schedulers, suppliers, and customers recognize waste and identify its causes. As a result, Value Stream Mapping is primarily a communication tool, but is also used as a strategic planning tool, and a change management tool. Toyota have been benefiting since 1940's, from Material and Information Flow Mapping (Value stream mapping).

Taiichi Ohno (1988) could not see waste at a glance (especially across a geographical area). He developed Material and Information Flow Mapping (VSM) as a standard method for mapping the flows visually and it became the standard basis for designing improvements at Toyota - as a common language. It became one of their business planning tools. VSM is now utilized throughout the world, in many businesses to strategically plan and it is the starting point to any lean transformation and implementation.

Shingo (1989) has discussed the strategies for the effective implementation of Value Stream Mapping in a wood industry. He also opines that loops can be formed to identify the similar processes and these loops will be helpful in identifying the non value activities in a systematic manner. He has suggested the ways to eliminate non value added activity and proposed measures to increase the Value added ratio.

New (1993), and Jones et.al (1997) and other researchers developed individual tools to understand the value stream. VSM extends guidance for improvements in the process, identifies the need to improve workflow and finally shows avenues to reduce waste.

(Womack and Jones, 1994) Lean manufacturing requires that not only should technical questions be fully understood, but existing relationships between manufacturing and the other areas of the firm should also be examined in depth, as should other factors external to the firm.

Heragu (1997) suggests another key area of lean manufacturing is *layout* which determines the arrangement of facilities in a factory. A poor layout may have several deteriorating effects such as high material handling costs, excessive work-in-process inventories, and low or unbalanced equipment utilization Layouts that cause inventory accumulation and interrupt process flow should be eliminated. On the other hand, lean manufacturing needs flexible layouts that reduce movements of both materials and people, minimize material handling losses, and avoid inventories between stations.

In order to attain noteworthy improvements the Zayko, et.al (1997) have decided to use value stream mapping to visualize the entire flow and select lean tools that yielded maximum benefits.

Hines and Rich (1997) has opined that, the value stream is "the specific activities within a supply chain required to design order and provide a specific product or value".

Liker (1997) reported that the benefits of lean manufacturing generally are lower costs, higher quality, and shorter lead times. The term lean manufacturing is created to represent less human effort in the company, less manufacturing space, less investment in tools, less inventory in progress, and less engineering hours to develop a new product in less time. *Shingo* (1997) developed the concept of single minute exchange of dies (SMED) to reduce set up times; for instance, setup times in large punch presses could be reduced from hours to less than ten minutes. This has a big effect on reducing lot sizes. Another way to reduce inventory is by trying to minimize machine downtime. This can be done by preventive maintenance. It is clear that when inventory is reduced other sources of waste are reduced too. For example, space that was used to keep inventory can be utilized for other things such as to increase facility capacity. Also, reduction in setup times as a means to reduce inventory simultaneously saves time, thus reduces time as a source of waste

Womack and Jones (1998) and Moore (2006) have stated that, the organizations of many types are implementing lean manufacturing, or lean production, practices to respond to competitive challenges. They have mentioned that lean initiatives can be taken up in the fields of automotive sector, aerospace, and consumer goods industries around the world. Moore has discussed various implementation tools of Lean Manufacturing, which can be incorporated in the industries.

Rother and Shook (1999) have discussed that Value Stream Mapping (VSM) is used to define and analyze the current state for a product value stream and design a future state focused on reducing waste, improving lead-time, and improving workflow. The use of VSM appears to be increasing, particularly since the publication of “learning to see” by Rother and Shook (1999). One of the unique characteristics of VSM in comparison with other process analysis techniques is that one map depicts both material and information flow that controls the material flow. The focus of VSM is on a product “value stream” (all actions required to transform raw materials into a finished product) for a given “product family” -- products that follow the same overall production steps.

Abbett and Payne (1999) have discussed the application of value stream mapping in an aircraft-manufacturing unit. Thus value stream mapping was extended in the field of aircraft manufacturing also. They have created the current and future state in such a proper and effective manner to reduce the time of the consumers.

Doolen et al (2002) have extended the applications of lean production techniques in the electronics manufacturing perspectives. Hyer (2002) has implemented Lean manufacturing in the office service and administrative processes.

Yang-Hua and Valandeghem (2002) describe, Value stream mapping as a mapping tool that is used to describe supply chain networks. It maps not only material flows but also information flows that signal and control the material flows. The material flow path of the product is traced back from the final operation in its routing to the storage location for raw material. This visual representation facilitates the process of lean implementation by helping to identify the value-added steps in a value stream, and eliminating the non-value added steps / waste (muda).

Pavnaskar et al (2003) proposed scheme of classification for lean manufacturing tools and allied detailing. This scheme of classification is structured around seven levels: system, object, operation, activity, resource, characteristic and application. Each level is linked systematically so that lean manufacturing tools and metrics. or manufacturing waste problems, are classified in a meaningful and logical way.

Simchi-Levi et al (2004) are of the opinion that the customers are always concerned with their order status, and sometimes they value the order status more than a reduced lead time. But, McDonald et.al (2002) point out that the VSM creates a common language for production process, thus facilitating more thoughtful decisions to improve the value stream. This will effectively reduce the wastes and improves the productivity. 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. McDonald et.al (2002) have used simulation techniques for the high-performance motion control products manufacturing system to demonstrate that, simulation can be a very crucial tool in assessing different future state maps. They demonstrate that simulation can provide and examine different scenarios to complement those obtained from future state mapping.

Doolen and Hacker (2005); Shah and Ward (2007). Relationship with *customers* is also crucial in lean manufacturing Customers decide what to buy, and when and how they are going to purchase a product. Since the customers determine value, it is essential to develop a good relationship with them. Setting up good relationships with customers will enable an organization to understand and meet their needs and predict their demands accurately, as it is important to attain a perfect match between market demands and production flows (Panizzolo, 1998).

Badrinarayana and Sharma (2007) discusses that the interdependent components form the value stream and Value Stream is the set of all *specific actions* required to bring out a specific product. Wong et al. (2009) As an integrative concept, the adoption of lean manufacturing can be characterized by a collective set of key areas or factors. These key areas encompass a broad array of practices that are believed to be critical for its implementation. They are, scheduling, inventory, material handling, equipment, work processes, quality, employees, layout, suppliers, customers, safety and ergonomics, product design, management and culture, and tools and techniques.

V. Ramesh, K.V. Sreenivasa Prasad, T.R. Srinivas (2008) has observed that, due to enormous potential in the lean manufacturing tools, value stream mapping study was carried out in a medium scale industry for the manufacture of machining center. It was observed from CVSM that the value added time was less. Hence, the study was carried out in the manufacture of Base, Column, Cross Slide, Milling Head and Table and various parameters like cycle time, set up time, WIP were recorded. By carrying out interviews with the managers, engineers and workers, the authors have proposed measures to reduce cycle time and improve the process of manufacture. A CVSM was drawn for all the processes as it was one of the main objectives of this study and identified the reasons for increase in cycle & set up time. The authors have suggested FVSM for improving the value added time by reducing the cycle time and the set up time. Finally, the reductions in the cycle time after the implementation is estimated and proposed.

Yu Cheng Wong, Kuan Yew Wong, Anwar Ali (2009) has provided important insights into the current status of lean manufacturing implementation in the electrical and electronics industry in Malaysia, as well as highlighted some associated issues. Firstly, the respondent companies' general backgrounds (e.g. their size, their involvement in lean manufacturing, etc) have been discussed. The companies are found to have a good understanding of lean manufacturing, and since its implementation, they have gained many benefits such as reduced cost and improved productivity. It is also apparent that the companies have implemented various tools and techniques to support lean manufacturing, and they do not adopt a single tool in isolation. In order to assess the extent to which they have implemented lean manufacturing, developing and producing 14 key areas and factor which efficiently judge the discipline they have can be checked.

Bhim Singh & Suresh K. Garg & Surrender K. Sharma (2010) highlight some of critical issues relevant to value stream mapping. The available literature is categorized as, conceptual work, empirical/modeling work, case studies, survey articles. Vast literature on value stream mapping and its growing adaptation in developed and developing countries indicate the interest shown in this area by researchers and practitioners. Results of the case study conducted in XYZ Indian Industry shows that VSM is a very effective technique for identification and reduction of various types of wastes. The reduction in work in process inventory by 80.09%, finished goods inventory by 50%, product lead time by 82.12%, station cycle time by 3.75%, change over time by 6.75% and manpower required by 16.66%.

Based upon the literature reviewed in this paper on VSM, few areas need further scrutiny.

- There is a need to discuss cost–benefit analysis of proposed changes made in future state map while applying value stream mapping technique for any specific application.
- Little work has been done with the help of this technique in the area of vendor management.
- Effect of changes done in current state during VSM implementation has not seen yet on human factor.

Ma Ga (Mark), Yang Paul Hong, Sachin B. Modi (2011) This paper explores relationships between lean manufacturing practices, environmental management (e.g., environmental management practices and environmental performance) and business performance outcomes (e.g., market and financial performance). The hypothesized relationships of this model are tested with data collected from 309 international manufacturing firms (IMSS IV) by using AMOS. The findings suggest that prior lean manufacturing experiences are positively related to environmental management practices. Environmental management practices alone are negatively related to market and financial performance. The paper provides empirical evidences with large sample size that environmental management practices become an important mediating variable to resolve the conflicts between lean manufacturing and environmental performance.

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III. CASE STUDY

To implement the technique of Lean manufacturing, firstly we required to select an industry where it could be best applied.

So, we selected Delphi Automotive Systems as our study area. Delphi is basically a wiring harness manufacturing company which supplies wiring harness to automobile OEM companies like General Motors, Mahindra and Mahindra etc.

Wire harness is a product which supplies power from the power source (Battery) to different parts of an automobile.

Types of wire harness in a vehicle:

- Engine harness
- Engine compartment harness
- Instrumental panel harness
- Floor or chassis harness
- Lead wires or small harness (Tail lamp, tail gate, dome lamp etc)

Components of wire harness:

- Wires
- Terminals
- Connectors
- Tape
- PVC tube or Corrugated tube

All the above parts are assembled together to make a complete harness.

The manufacturing of a harness consists of two processes in the manufacturing unit.

- Lead preparation: In the lead preparation cell the wires are cut as per the lengths they are required in the harness. Then crimping process is done in which the terminals are connected with the wires. After that these crimped wires are delivered to the assembly area for further processing.
- Harness assembly: In the assembly area the wires are fitted in connectors and other components like tape, grommet, and corrugated tubes. All these components combine to form a wire harness.

The processes in the assembly of wire harness are:

- Sub-assembly: The wires are assembled in small assemblies or sub-assemblies so as if all are combined constitute the circuit of a complete harness.
- Mounting or Routing: In this process, all the sub-assemblies are combined and laid on the building boards where they are routed as per the fixtures and drawing requirement.
- Taping: In the taping process as the name suggests taping is done on the wires routed on the boards. Some other components like corrugated tubes, PVC tubes, clamps and grommet can also be applied as per the harness requirement. After taping the harness is complete in shape and is processed for checking of defects.

Below is the time study of the processes required in the manufacturing of a wire harness.

PROCESS	ATTIRIBUTE	
SUB-ASSEMBLY	CYCLE TIME	300 sec
	NO. OF SHIFTS	2
	NO. OF OPERATORS	1
ROUTING	CYCLE TIME	304 sec
	NO. OF SHIFTS	2
	NO. OF OPERATORS	1
TAPING	CYCLE TIME	305 sec
	NO. OF SHIFTS	2
	NO. OF OPERATORS	1
CIRCUIT TESTING	CYCLE TIME	350 sec
	NO. OF SHIFTS	2
	NO. OF OPERATORS	2
VISUAL INSPECTION	CYCLE TIME	300 sec
	NO. OF SHIFTS	2
	NO. OF OPERATORS	1
PACKING	CYCLE TIME	300 sec
	NO. OF SHIFTS	2
	NO. OF OPERATORS	1

Table 6: Data of time study

From the above data, we can see that the cycle time at circuit inspection station is not in accordance (350 sec) with the tact time.

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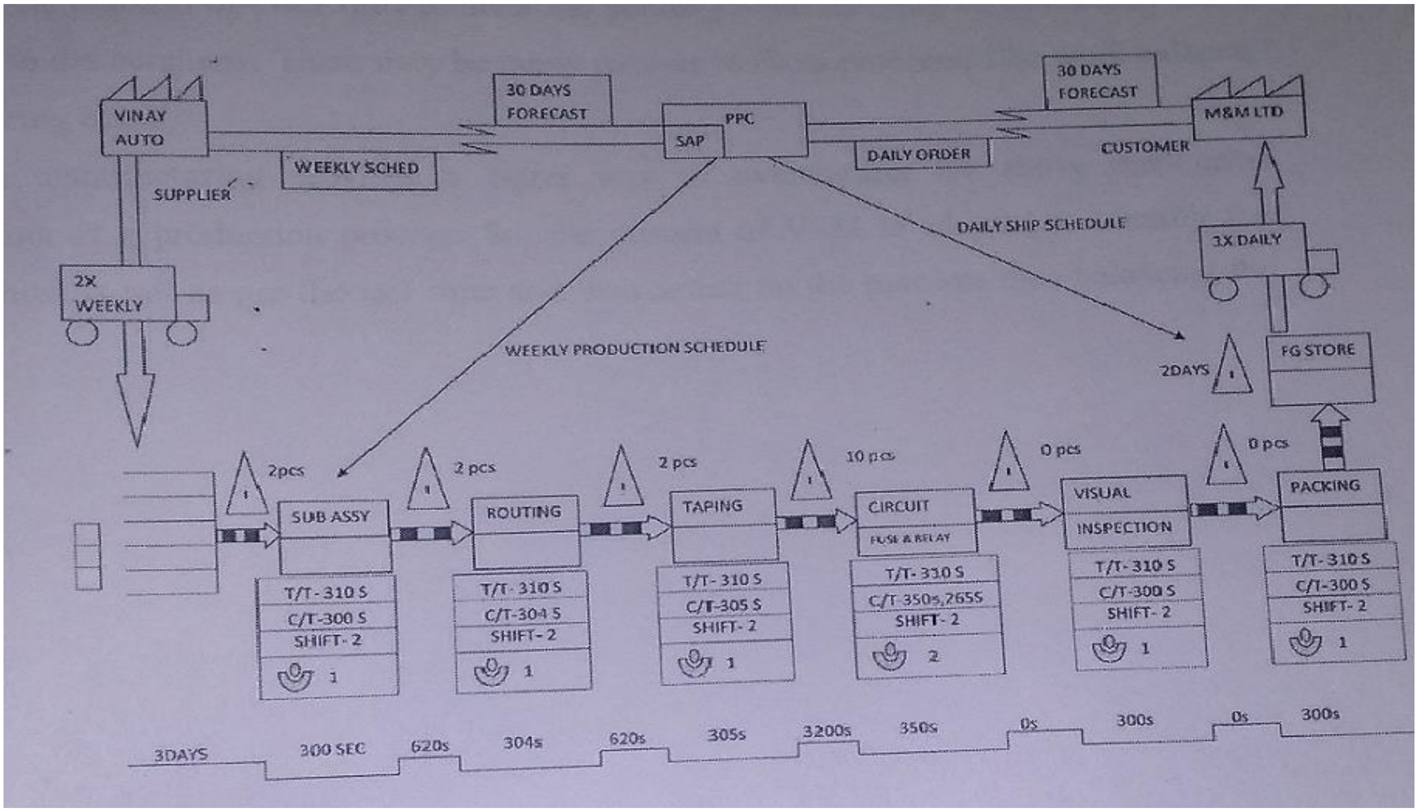

Fig 7:- The CVSM

IV. OBJECTIVE

As discussed earlier, a wire harness consists of many steps in its manufacturing. The major problem faced in the assembly area of excess inventory at a station leading to waiting time for the next process. Excess inventory and waiting time both are losses to the company.

In an industry the main focus is laid on reducing non value adding wastes thus reducing manufacturing costs.

In this study also, the main problems incurred were of accumulating of harness at a station and waiting time at the next station leading to line imbalance. Also, operators were required to be planned on over time to clear the pending material lying on line which was a direct loss to the company. There may be many reasons to these problems like work balance, time balancing etc.

Lean manufacturing provides a better way of overcoming the above mentioned shortcomings of a production process. So, the process of VSM is adopted to identify the process which is not as per the tact time and then acting on the problem thus balancing the process.

V. METHODOLOGY

To implement the process of lean manufacturing by applying the technique of Value Stream Mapping it is necessary to create a current state Value Stream Map (CVSM).

Step1: Firstly, a CVSM was plotted using various symbols and notations showing parameters like cycle time, inventory etc. at various processes. All the assembly processes were shown using standard symbols also representing inventory, cycle time at various stations.

Step 2: After preparing the current value stream map (CVSM), the process was studied for unbalanced/abnormal situations like heavy inventory; unusual cycle time etc. In the above figure the abnormal situation is encircled red.

Step 3: In the next step, time study of the work was done to verify the actual process. After the time study the work was balanced considering the cycle time of both the operators on the circuit testing station. After work distribution time study was again performed to check whether the cycle time is in accordance to the tact time or not.

Step 4: In the last step, the Future State Value Stream Map is made in which the shortcomings of the CVSM are eliminated. In the FVSM all the processes are balanced and there is smooth flow of material without any inventory. Also the cycle time of the processes is in accordance to the tact time.

VI. RESULT AND DISCUSSION

From the study of different aspects we get to know that VSM is a strong technique of lean manufacturing which aims at identifying wastes in a process and giving various measures to eradicate those wastes.

What is the Takt Time?

The Takt time is the demand rate and consequently the time between completions of each product off of the production line. It is first necessary to find the available capacity of the production line.
Takt time can be first determined with the formula:

{T= Ta/Td}

Where :

T = Takt time, e.g. [minutes of work / unit produced]

T_a = Net time available to work, e.g. [minutes of work / day]

T_d = Time demand (customer demand), e.g. [units required / day]

Net available time is the amount of time available for work to be done. This excludes break times and any expected stoppage time (for example scheduled maintenance, team briefings, etc.).

Example :- If there is a total of 8 and half hours (or 510 minutes) in a shift (gross time) less 30 minutes lunch, 15 minutes for breaks, then the net Available Time to Work = 510 - 30 - 15 = 465 minutes. If customer demand was, say, 180 units a day and one shift was being run, then the line would be required to spend a maximum of 155sec to make a part in order to fulfil the need of the consumer.

Takt Time

- Customer requirement = 4650 products/month.
- No. Of working days = 26
- No. Of shifts= 2
- Time available in each shift = 8 and half hrs. = 30600 sec.
- Time for breaks or non-working time per shift = 45 mins = 2700 sec.
- Net available working time per shift = 30600 – 2700 = 27900 sec.

Therefore, Tact Time = 27900 sec ÷ 90 units per shift = 310 sec.

What this tact number means is that to meet customer demand within its available work time, we need to produce a wire harness in every 310 seconds.

Work time	26 days in a month.
	2-shift operation in all production departments.
	Eight and half hours every shift.
	45 mins break during each shift.
	Manual processes stop during breaks.
Production control department	Receives a 1-month forecast from the Customer.
	Loads forecast in SAP.
	Issues 1 month forecast to Supplier.
	Generates weekly department schedules through SAP.
	Issues weekly production schedule to production dept.
	Issues daily shipping schedules to FG/Shipping
FG/Shipping	Remove parts from finished goods warehouse and stages them for truck shipment to customer.

Table 7: General Data of Production control

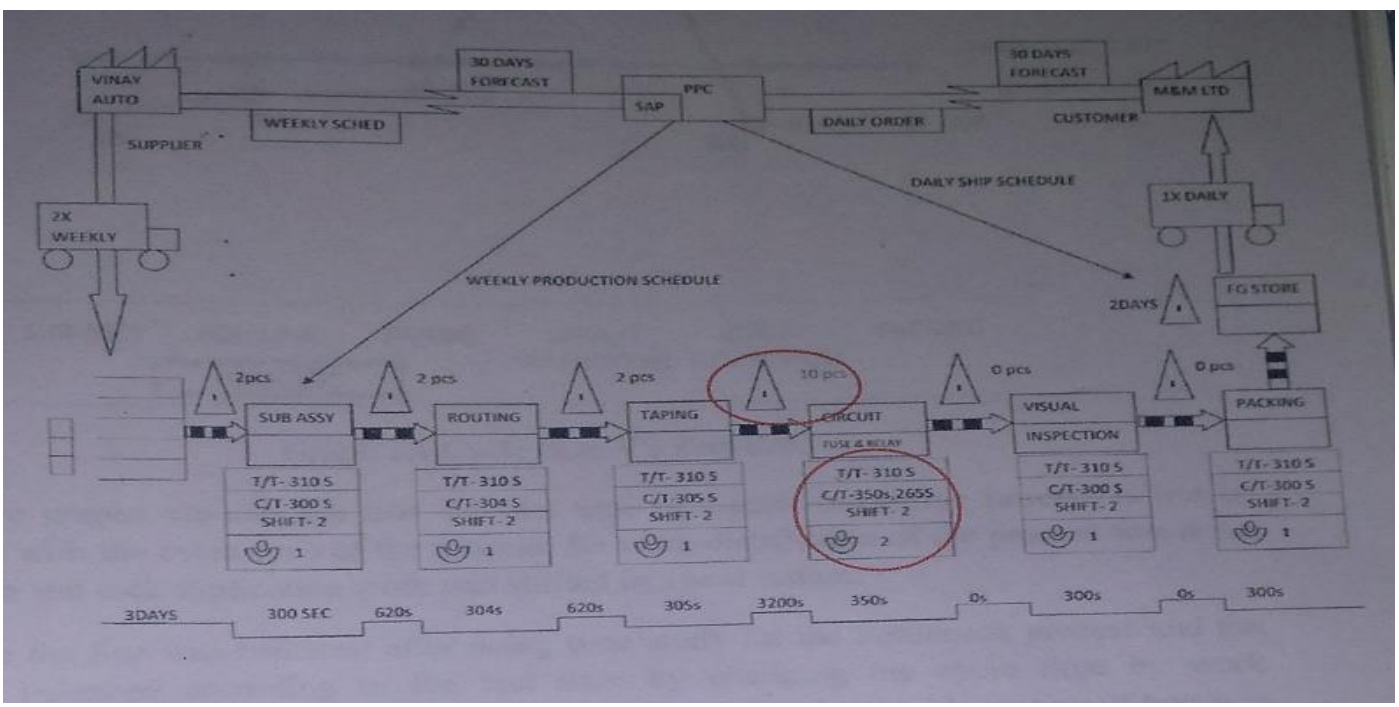

Fig 8:- A CVSM

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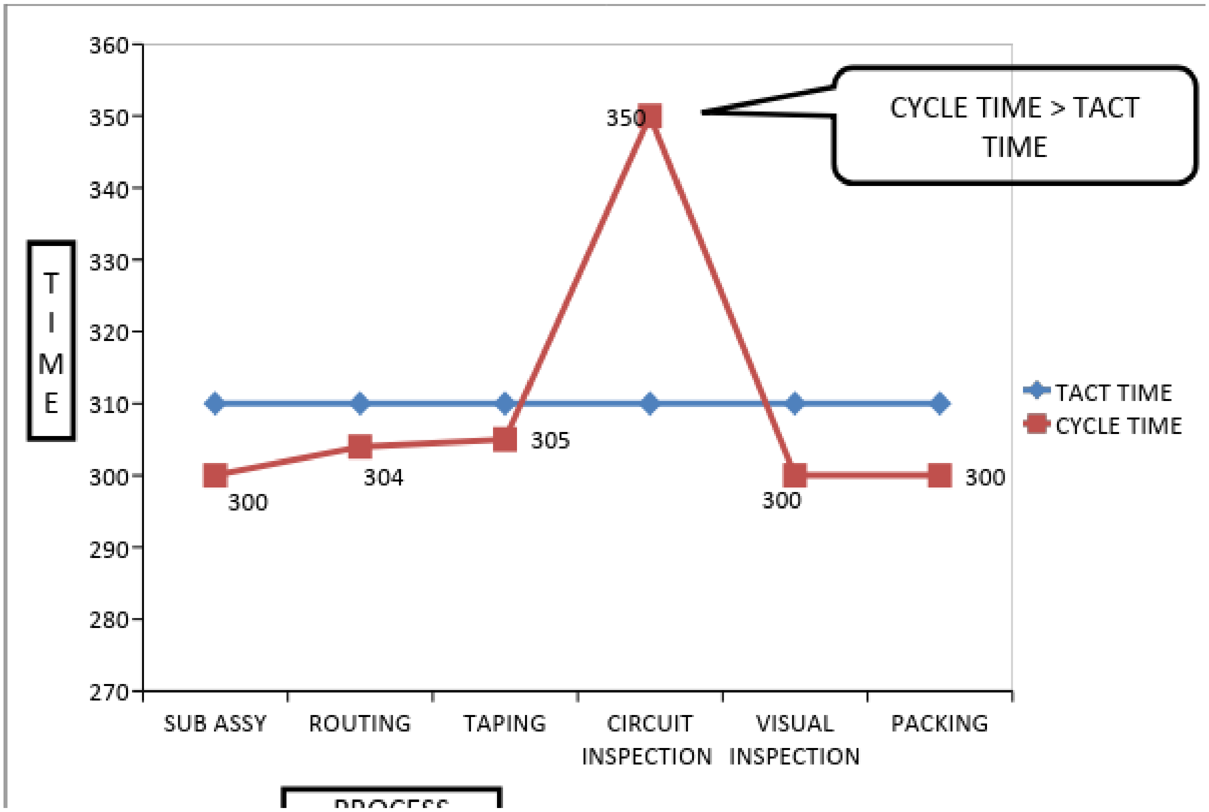


Graph 1: Cycle time VS Tact time

From above graphs we can consider that the tact time of circuit inspection process is not in accordance with the cycle time of the process. So work distribution of the process was done and the fuse and lock application work was shifted to a new station.

In this case the line was balanced after doing time study for the bottleneck process and the work was balanced according to the tact time by changing the cycle time by work distribution. To balance the process a new station for applying fuse and loosening of bolt was added in which some task of the circuit checking station was distributed so as to balance the cycle time of the station.

After changing the work we got the following FVSM

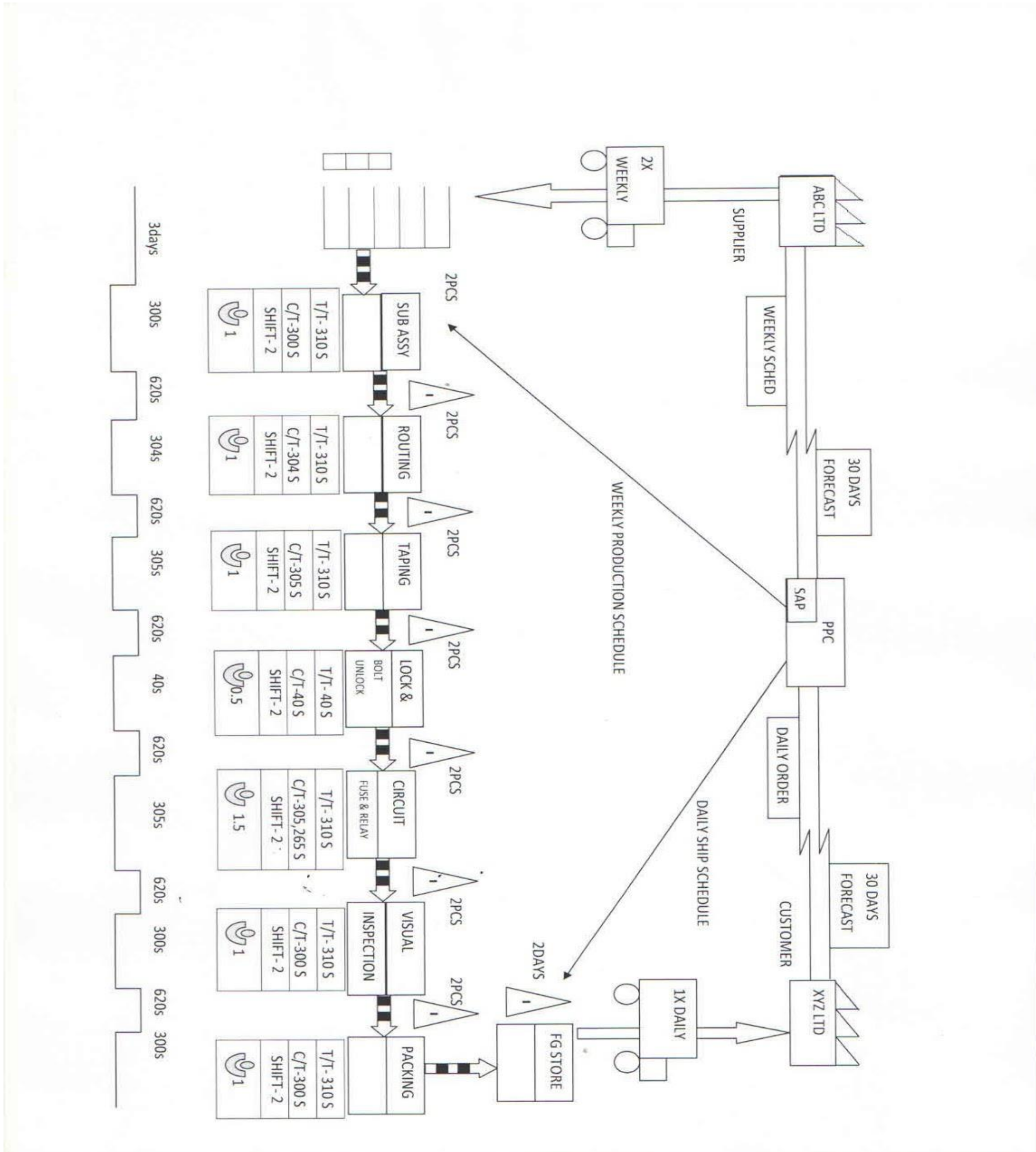
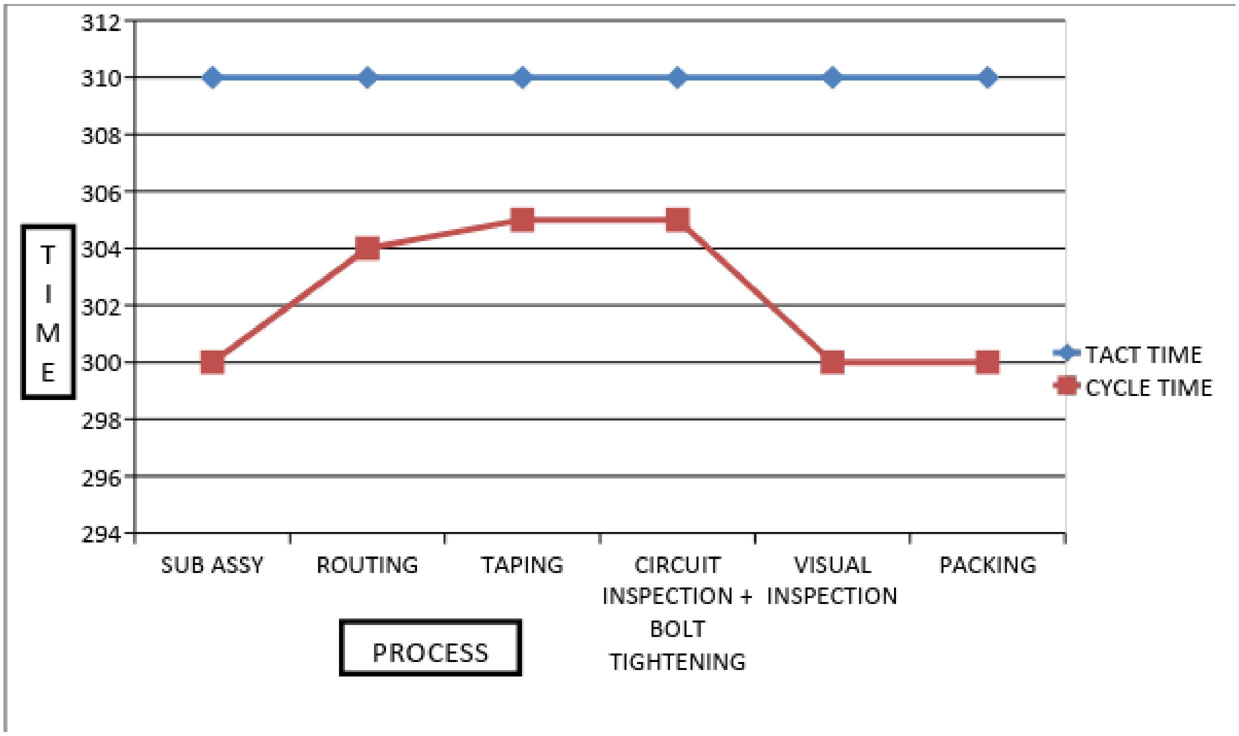


Fig 9:- The FVSM



Graph 2: Cycle Time VS Tact time

In the above graph we can see that the tact time of all the processes are in accordance with the cycle time.

By applying the technique of lean manufacturing we got the following benefits:

- The waiting time for the visual inspection operator was eliminated resulting in waste of waiting.
- The inventory which was being accumulated on the circuit inspection process was also reduced resulting in elimination of waste of excess inventory.
- To clear the pending material 1 extra operator was to be deployed for 4 hours which was a direct loss of money. So it also resulted in terms of money saving.

Total cost of 1 operator for 4 hrs in overtime = 200 Rs (overtime double of original salary)

Cost of 1 operator working for 4 hrs in 26 days (1 month) = 200 x 26 Rs

=5200 Rs

Total cost for 12 months =5200 x 12

= Rs 62400

So, we made a direct saving of Rs 62400 per year.

VII. CONCLUSIONS AND FUTURE WORK

From the analysis and study done in balancing the process by applying the value stream mapping process, it was concluded that Lean manufacturing is an effective technique of improving the process. Here, we improved the production process and reduced wastes like of inventory and waiting.

Lean manufacturing is an effective technique in removing wastes which hampers the process. Main method of Lean is not the tools, but the reduction of three types of waste: muda ("non-value-adding work"), muri ("overburden"), and mura ("unevenness"), to expose problems systematically and to use the tools where the ideal cannot be achieved. Lean implementation is therefore focused on getting the right things to the right place at the right time in the right quantity to achieve perfect work flow, while minimizing waste and being flexible and able to change. The main aims of lean to make the work simple enough to understand, do and manage.

The core of lean is founded on the concept of continuous product and process improvement and the elimination of non-value added activities. "The Value adding activities are simply only those things the customer is willing to pay for, everything else is waste, and should be eliminated, simplified, reduced, or integrated". Improving the flow of material through new ideal system layouts at the customer's required rate would reduce waste in material movement and inventory. A continuous improvement mindset is essential to reach the company's goals. The term "continuous improvement" means incremental improvement of products, processes, or services over time, with the goal of reducing waste to improve workplace functionality, customer service, or product performance.

"For improvement to flourish it must be carefully cultivated in a rich soil bed (a receptive organization), given constant attention (sustained leadership), assured the right amounts of light (training and support) and water (measurement and data) and protected from damaging."

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