CHAPTER 3

METHODOLOGY

3.1 VALUE STREAM MAPPING

Lean production/lean manufacturing/lean is a manufacturing paradigm, minimizing wastes and maximizing the flow, continuously which is the primary goal of the Toyota production system. Lean continuously increases the awareness over the wastes and work for either eliminate or reduce it. This lean tool ensures the sustainable improvements. In the book, the machine that changed the world authored by James Womack and Daniel Roos used the term ‘Lean Production’ during 1990. Value stream management is a technique to plan and link lean initiatives by systematic data capture and analysis. VSM is a management tool, proved that the company to become lean. It encompasses all functional and operational relationships that exists within the value stream.

The value stream management has the following eight steps as the processes, followed sequentially:

1) Commit to lean
2) Choose the value stream
3) Learn about lean
4) Map the current state
5) Determine lean metrics
6) Map the future state
7) Create kaizen plans
8) Implement kaizen pans

The successful implementation of lean manufacturing depends on committeemen from people, understanding customer demands and present working conditions and good communication. The following lean management principles are necessary while proceeding over eight VSM steps: Defining the value stream from customer’s viewpoint, identifying suitable value stream, eliminating seven deadly wastes, making the work flow, pulling the work and pursuing perfection.

3.1.1 Commit to Lean

The first step is to ensure commitment towards the implementation of lean culture in the organization. Management commitment forms the core ingredient for lean implementation. The committed management and committed workforce are required for successful lean implementation.

The manufacturing industries to become as a world class organization needs to work on the following commitments:

- To work on the cost-reduction principles
- Manufacture the products based on the highest quality with zero defects in its business sector
- Maintain the quality, cost and delivery requirements
The identification of value stream manager/champion and core team members. The core team activities being create plans and maps, communicate information/instructions to all levels within the organization, ensure that people are trained and implement the value stream management process.

The champion organize a kick off meeting on VSM project, and explain about VSM process, the expected duration of the project, the expected communication, the resource allocations to attain the objectives, clarify the questions from team members and so on.

The identification of value stream manager/champion and core team members. The core team activities being create plans and maps, communicate information/instructions to all levels within the organization, ensure that people are trained and implement the value stream management process.
The Value Stream Manager/Champion and core implementation team members need to be identified. The attributes of VSM manager should be sense of product ownership, commitment to lean practices, authority to initiate changes. VSM project need to be initiated. The VSM manager should demonstrate the importance of lean practices, select the area and allocate the resources. The team should go to the floor and observe the organizations activities and production activities. The team prepare current state map for the present manufacturing activities; the manager and team should prepare the future state map after analyzing the Current State Map. The manager must demonstrate the benefits of lean implementation. The team will brain storm the each findings in Current State Map and formulate Future State Map. Next the value stream needs to be selected.

3.1.2 Choose the Value Stream

A value stream consists everything including value and non value added activities that makes the transformation of raw materials into finished goods is possible. The survivability of manufacturing industries is due to transformation of materials at their customer’s value. While processing, transforming the material into products, the operations are considered as actions that accomplish those transformations.
There are two reliable methods used for selecting value streams for improvement:

- PQ analysis
- PR analysis

The key decision on the selection of value streams can be done using Product-quantity analysis (PQ) or Product-routing analysis (PR). Appropriate steps in PQ or PR analysis need to be followed.

The following steps are considered while performing PQ analysis:

- Collect three to six months data on production output.
- Enter the products by quantity (from greatest to least) on a PQ analysis list.
- Prepare the Pareto Chart using the data from PQ analysis sheet.
- Analyse the product mix.

The following steps are considered while performing PR analysis:

- Prepare the process sequence for each product type as listed by volume.
- Group the products which are having the same process routes.
- Analyse the mix of process routes.
Some thumb rules commonly followed for value stream selection are:

- Select a value stream that includes not more than one machining operation.
- Select a value stream that includes not more than three raw material suppliers.
- Select a value stream that includes not more than 12 operations or process stations.

This will be followed by learning about lean principles and practices.

3.1.3 Learn about Lean

This step discusses how to get training and review and understanding the lean concepts. The learning about lean and lean implementation processes differs for one organization to other, integrating them suitable in the success of lean implementation. To assess the current state and plan the future state efficiently on the manufacturing system, the lean concepts and tools are used.

The lean concepts include: Cost reduction principle, Seven deadly wastes (Overproduction, Over processing, Waiting, Transportation, Defects, Inventory and Storage), Two pillars of Toyota production system (TPS) (JIT, Autonomation), 5S system (Sort, Set in order, Shine, Standardize, Sustain), Visual Workplace, Three Stages of lean application.
The cost reduction principle

To keep up the highest priority on quality, the management is going on under pressure from customers to reduce manufacturing cost and lead time. In traditional way of working the sales price is fixed by calculating the production cost and adding the margin of profit. But in lean thinking according to the cost reduction principle, the sales price is fixed by calculating the production cost on either eliminating or reducing the wastes from value stream and remain the profit as it is.

Seven deadly wastes

In processes anything that adds cost or time without adding value is called as waste or muda and the lean target would be the total elimination of waste. The commonly identified wastes are in seven types:

1. Over production- manufacture the products more than our requirements.
2. Waiting - The unproductive time i.e. idle time between operations due to want of materials, tools, unbalanced line, etc.,
3. Transport - The unnecessary movement of materials and tools mostly due to poor layout.
4. Over processing - The unnecessary operations/processes are carried over the material to attain the finished product.
(5) Inventory - Stocking the materials in excess than the requirement in the form of raw materials, work-in-process and finished goods.

(6) Motion - During the manufacturing process, excess movement of machine members, tools and operator than the requirement.

(7) Defects - Manufacturing of defective products and wrong handling of materials.

**Two pillars of Toyota Production System (TPS):**

The existence of lean concepts is more in TPS. Toyota Production System has two pillars, one is Just In Time (JIT) production and the other is Jidoka (autonomation). JIT production is the state of continuous flow obtained by replenishing a single part which is pulled by the customer. Its goal is provide highest quality products to the customers on meeting highly specific order and delivery requirements. Jidoka is a method of preventing of malfunctioning and defects by introducing mistake-proof detectors. By this way it ensures Zero defects and never pass a defective product in downstream.

**5S System:**

It used to design any work place or organization becoming standardization. It has five kinds of activities:

Sort – By sorting the contents of an area, remove the unwanted items.
Set in Order – For the sake of easy and efficient access, the items/goods are arranged in order.

Shine – By cleaning everything, the area and equipment is kept in bright and attractive.

Standardize – By preparing the guidelines, keep up the area in organized order and clean. Make the standards in visual and obvious.

Sustain – By educating and communicating every one, guide and ensure that every one to follow the 5 S standards.

**Visual workplace (Visual factory):**

It provides the just-in-time information to the needy, while displaying the information at work place in the form of slogans, pictures and instructions. The goal of visual factory is alert the people to care and control over the work place. It has different levels of controls such as training and standards, building information into the workplace, warnings, physically change the work place and eliminate the causes of problems.

**Three stages of lean application are demand, flow and leveling:**

The lean concepts are grouped as stated; the customer demand stage understands customer’s requirements over the product. At flow stage, ensure that both internal and external customers of the company receiving the right product, at the right time, in the right quantity and maintaining continuous flow in the manufacturing plant. At leveling stage, ensure that the works are
distributed evenly, by volume and variety among the machines in the plant in order to reduce inventory and WIP.

The various tools and concepts for determining and meeting customer demand include Takt time, Pitch, Takt image, Buffer and safety inventories, Finished-goods supermarket.

**Takt time:**

It is the rate at which a company manufactures the goods based on customer demand. It is calculated as the ratio between the available production time and the daily quantity required.

**Pitch :**

It is the amount of time based on takt at upstream to release pack-out quantity of work in process to downstream operation. So it is the product of takt time and the pack-out quantity.

**Takt image:**

It is the vision of an ideal state with value stream to achieve one piece flow based on takt time.

**Buffer inventory:**

Keeping the goods/materials readily available to meet customer demand while customer ordering patterns or takt time varies.
Safety inventory:

Keeping the goods/materials readily available to meet customer demand while internal constraints of inefficiencies disturb the process flow.

Finished-goods Super Market:

It is the system of replacing the goods when they are removed based on customer orders. It ensures the pull system at finished goods super market and the items are replenished by upstream operations.

Lights - out Manufacturing (or) unattended manufacturing:

Manufacturing the goods by automated machines without operator presents to meeting the customer demand.

The tools and concepts necessary to establish the flow are: Continuous flow, Work cells, Line balancing, Standardized work, Quick changeover, Autonomous maintenance, In-process supermarkets, Kanban systems, First-in first-out (FIFO) lanes and Production scheduling.

Continuous flow:

It means that producing or transmitting products as per the three key principles: Only what is needed, just when it is needed and exact amount needed. There are two types of flow systems, pull system and push system. The pull system production is faster than the batch or push production. At pull system, one job is produced at upstream only after the previous one is moved to downstream.
**Work Cells:**

A layout designed to sustain the continuous flow, the equipment and personnel are rearranged according to process sequence necessary to complete a product. The product demand and product mix are considered when designing the cell layout.

**Line Balancing:**

It is the process of even distribution of work elements within a value stream in order to meet takt time. It helps in optimized use of personnel and balances the workloads among machineries so that no one kept idle or work more and ensure the maximum utilization of resources.

**Cycle time (processing time):**

It is also referred as total value adding time. It is the time between beginning of an operation and to its completion.

**Standardized work:**

It is a set of established work procedures and sequences for each manufacturing and assembly process. It gives the base to keep up the consistency on high levels of productivity, quality and safety.

**Quick Changeover:**

It is a methodology of permitting flexibility in tool changes to meet variety of products without disturbing the continuous flow. It is derived from single minute exchange die (SMED) that was developed by Shigeo Shingo at Toyota.
**Autonomous Maintenance:**

It is a technique to prevent equipment related losses by identifying the equipment’s abnormal conditions while on working. This system focuses on keeping up the optimal conditions to prevent such losses: poor lubrication, excessive wears of machine parts, loose or missing bolts, break downs and so on. It reduces break downs and quality problems that disturb continuous flow.

**In-process Super Markets:**

It is a super market established in between two processes to overcome the obstacles arise during the continuous flow and ensure that flow is possible.

**Kanban system:**

It is used in pull system. It means that cards attached to containers with lot sizes. Once the lot in the container is used Kanban card in the empty container indicates that more inventory (asks to fill) is needed. By this way the container is filled with new and exact inventory needed. There are three types of kanbans: production kanban, withdrawal kanban and signal kanban.

**FIFO Lanes:**

This concept can be used where existence of lack of high degree of commonality among the parts and cannot use the in-process super market system. It is a kind of inventory control method permitting the oldest inventory (first-in) to be given as the first priority to work (first-out). FIFO
lanes are used where multiple value streams meet before product customization.

**Production scheduling:**

It is a system of scheduling the production and controlling the inventory based on necessary of downstream operation very close to the customer. The scheduling should ensure the zero down time, no or less change over and personnel flexibility.

The concept and tools used to level the production are: Paced withdrawal, Heijunka, Heijunka box and runner.

**Paced withdrawal:**

It is a system of moving small lots from one operation to other with time intervals equal to pitch. It can be used where there is no product variety in the value stream and all pitch increments are identical.

**Heijunka (Load leveling):**

It is a method of planning and leveling the customer demand in volume and variety for the span of a day or shift. It establishes the true lean pull system.

**Heijunka box (Leveling box):**

It is a technique used to manage leveling the production volume and variety over a specified period of time with a consideration of efficient use of people and equipment. Kanban cards used in this system according to pitch increments of products released to shipping and subsequently replenished.
The Runner:

It is a person who moves over a designated route within the pitch period and picking up kanban cards, tooling, components and delivering them to their appropriate locations. Runners continuously monitor the functioning of line and fulfilling the customer requirements.

Understanding of lean concepts is very essential to determine lean metrics and plan the future state. The core lean implementation team should educate and train the shop people about lean concepts. Then the current state needs to be mapped followed by determining lean metrics.

3.1.4 MAP THE CURRENT STATE

In this step, the current state of production and manufacturing processes need to be mapped. It shows the flow of material and information. For this purpose, accurate and real time data related to the product family or value stream need to be collected. Mapping a process gives a clear picture of the wastes that slow down the flow.

The elimination of wastes leads to reduction of total manufacturing lead time and meet customer demand satisfactorily.

The commonly used VSM Icons as shown in Figure 3.1, for plotting CSM and FSM:
VSM icons

Figure 3.1 VSM Icons

Once the data are collected at shop floor by core team and compiled, plotting of current state map is started.

To create the current state map the following steps are taken into account in general.

- Drawing of various icons representing the customer, supplier and production control
- After drawing a data box below the customer icon, enter the customer requirements in the box.
- Make the entry of shipping and receiving data.

- According to sequence of operations, draw the icons along the bottom of the map such that the most upstream process on the left and the most downstream process on the right.

- Make the entry of process attributes in the data boxes created under the process icons.

- Exhibit the information flow between customers and suppliers in both electronic and manual.

- Draw and make the entry of inventory icons between processes.

- Draw and make the entry in push, pull and FIFO locations.

- After plotting the map, the core team makes a discussion and approves the map to display on VSM story board for everyone to see.

### 3.1.5 Determine Lean Metrics

The identification of metrics will help to achieve the future-state goals. Lean metrics gives direction to achieve continuous improvement and waste elimination. Lean metrics can be defined as metrics with lean perception. Some of basic metrics that most the companies will find useful are: Inventory turns, Days of inventory in hand, Defective parts per million (DPPM) or sigma level, Total Value stream WIP, Total cycle time or Total value adding time (VAT), Total lead time, Uptime, On time delivery, Overall equipment effectiveness, First time through capability, Health and safety record.
Uptime:

It is the ratio between actual operating time and net available production time. It is indicating that how well an operation or a process uses its available time.

On-time Delivery:

It means that honour of shipment compliance.

Total value stream WIP Inventory:

It means that totaling the amount of work-in-process inventory on-hand between each operation.

For identifying lean metrics the following steps are considered:

- Prepare an initial list of metrics after reviewing common metrics and the specific customer targets.
- Discuss with management and get their approval.
- Determine the way how the metrics to be calculated.
- Calculate the baseline measures from the data collected while mapping the current state.

Lean manufacturing assessment is used to identify particular areas to focus improvement efforts, within value state. The assessment started with an effort to quantify the current level of progress related to ten important criteria related with lean manufacturing. The criteria include Team involvement, Training, Workplace organization, Quick change over, TPM, Quality, Visual controls, Order leveling, Material movement and Flow manufacturing. Then the future state needs to be mapped.
3.1.6 Map the Future State

Mapping the future state is the process of identifying the lean tools and the improvement methods that can meet the requirements. The repetition can be done until reaching a more efficient and waste free value stream. The process of mapping the future state has three stages namely Customer demand, Flow and Leveling.

The steps considered for designing the future state map to meet customer demand are:

- Calculate takt time and pitch
- The decision on, whether the customer demand can be met with present available manufacturing methods.
- The decision on the need of buffer and safety inventories.
- The decision on the necessity of finished-goods super market.
- The decision on the improvement methods to be used.

The steps considered for designing future state map to meet continuous flow in manufacturing processes are:

- Do the line balancing
- Do the plan for work cells.
- The decision on controlling the production in upstream.
- The decision on improvement methods to be used.

The steps considered for designing the future state map to leveling the production are:
- The decision on choosing the best method to monitor production against the pace of sales.

- The decision on fixing the route of runner and materials and information flow.

- The decision on improvement methods to be used.

This will be followed by creating and implementing Kaizen plans.

3.1.7 Create Kaizen Plans

In this step core team members prepare the detailed plans that will help the efforts to improve the value stream. In planning, the comprehension can be reached if the core team members have more practical experience in lean manufacturing methods. The most effective and costless planning is the implementation of Kaizen plans.

The following steps are considered in Kaizen planning process:

- Analyse the future state map and prepare a monthly Kaizen plan.

- Decide milestones for each major kaizen activity and prepare a kaizen milestone chart

- Finish the VSM story board

- Get the approval from management for Kaizen plans.

After creating Kaizen plans, actions to be taken on proceeding to implement kaizen plans with very sincerity and earnest efforts.
3.1.8 **Implement Kaizen Plans**

The implementation of kaizen plans are the most effective and cost less by using the appropriate planning sequence. The implementation of kaizen plans should be carried out with enthusiasm and confidence.

The following points are to considered while implementing Kaizen plans to move forward:

- Communicate the information to all and let everyone knows what is happening and why.
- If anyone behave negatively, counsel and resolve during the implementation.
- Acknowledge and resolve immediately if any problem arises.
- Take each kaizen event as an experiment.
- Recognize and honour the people’s efforts.
- Treat the people with honest.

Note that once the implementation begins, the kaizen activities will have an impact on every one linked with target value stream.

### 3.2 FUZZY QFD

The proposed architecture of Fuzzy QFD integrated with VSM is shown in Figure 3.2.
As shown in Figure 3.2, the integrated VSM and Fuzzy QFD is created, after the construction of current state map, the wastes are categorized as over production, over processing, waiting, transportation, defects, inventory, and storage. Then the proposals/improvements identified during brainstorming sessions are designated as design attributes. Then, Fuzzy QFD procedure was used for the construction of correlation matrix and inter-relationship matrix. Then the wastes as well as the improvement proposals are prioritized. This prioritization will help to incorporate the improvement proposals in the future state map.

**Fuzzy Function Matrix**

The waste prioritization and methodology selection was done by constructing and deriving a House of Quality (HOQ) adopted from Quality Function Deployment (QFD).
The detailed structure of HOQ is shown in Figure 3.3. Components of HOQ are:

Requirements: Determine the requirements to be achieved from the house of quality. In our case the requirements are identified wastes to be eliminated.

Technical Descriptors: The technical descriptors are the techniques or methods by which the wastes will be eliminated. In our case, the technical descriptors are proposed methodologies.

Weight: Obtain the weight from group of experts to determine the importance of requirements and technical descriptors.

Relationship Matrix: The relationship matrix is relationship between requirements (wastes to be eliminated) and technical descriptors (proposed methodologies) using the scale.

Correlation Matrix: It is the examination of how each of the technical descriptors impacts each other.

In order to overcome vagueness, linguistics variables are used to build the HOQ, we propose to express importance weights, as well as relationships and correlations, with fuzzy triangular numbers. The relationship matrix $R_{ij}$ ($i = 1,..,n$, $j = 1,......,m$) of the HOQ is a matrix whose generic entry ($i$, $j$) assesses how the $j$-th Proposed Methodology (PM) performs in minimizing the $i$-th Identified Waste (IW). Fuzzy logic was used to deal with the ill-defined nature of human judgements, and the ratings Weak, Medium, and Strong expressing the degree of relationship are translated into fuzzy triangular numbers as shown in Table 3.1(Bottani 2009; Vinodh & Chintha, 2011b).
Table 3.1 Degree of relationship with wastes and identified lean concepts

<table>
<thead>
<tr>
<th>Degree of relationship</th>
<th>Fuzzy number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong (S)</td>
<td>(0.7; 1; 1)</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>(0.3; 0.5; 0.7)</td>
</tr>
<tr>
<td>Weak (W)</td>
<td>(0; 0; 0.3)</td>
</tr>
</tbody>
</table>

Table 3.2 Linguistic variables for importance weight and corresponding fuzzy number

<table>
<thead>
<tr>
<th>Importance weight (Wi)</th>
<th>Fuzzy number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high (VH)</td>
<td>(0.7; 1; 1)</td>
</tr>
<tr>
<td>High (H)</td>
<td>(0.5; 0.7; 1)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>(0; 0.3; 0.5)</td>
</tr>
<tr>
<td>Very low (VL)</td>
<td>(0; 0; 0.3)</td>
</tr>
</tbody>
</table>
Table 3.3  Linguistic variables used for correlation matrix and its corresponding fuzzy numbers

<table>
<thead>
<tr>
<th>Degree of correlation</th>
<th>Fuzzy number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong positive (SP)</td>
<td>(0.3; 0.5; 0.7)</td>
</tr>
<tr>
<td>Positive (P)</td>
<td>(0; 0.3; 0.5)</td>
</tr>
<tr>
<td>Negative (N)</td>
<td>(0.5;0.3; 0)</td>
</tr>
<tr>
<td>Strong negative (SN)</td>
<td>(0.7;0.5;0.3)</td>
</tr>
</tbody>
</table>

Degree of relationship with waste and identified lean concepts as shown in Table 3.1.

Strong- Depicts the strong relationship between identified waste and proposed methodology

Medium- Depicts the medium relationship between identified waste and proposed methodology

Weak- Depicts no or some relation between identified waste and proposed methodology

Linguistic variable for importance weight and corresponding fuzzy numbers as shown in Table 3.2.

Very high- indicates the identified waste has highest priority with respect to other waste

High- indicates the identified waste has priority with respect to other waste

Low- indicates the identified waste has low priority with respect to other waste

Very low- indicates the identified waste no required to consider with respect to other waste
Linguistic variable use for correlation matrix and its corresponding fuzzy numbers as shown in Table 3.3.

Strong positive- indicates proposed methodology i will highly support the proposed methodology j for the output.

Positive- indicates proposed methodology i will support the proposed methodology j for the output.

Negative- indicates proposed methodology i will affect the proposed methodology j for the output.

Strong- negative indicates proposed methodology i will highly affect the proposed methodology j for the output.

Once relationships between PMs and IWs were assessed using Linguistic variables and then transferred into fuzzy numbers as shown in Table 3.2 and the relative importance RIj of the j-th Proposed Methodology can be computed as a fuzzy cumulative value using Equation (3.1) (Bottani 2009; Vinodh & Chintha 2011b).

\[
RI_j = \sum_{i=1}^{n} W_i \otimes R_{ij} \quad j = 1, \ldots, m
\]  

(3.1)

where \( W_i \) is the weighted importance of the \( i^{th} \) Identified Waste and \( R_{ij} \) the fuzzy number expressing the relationship between the \( j^{th} \) Proposed Methodology and the \( i^{th} \) Identified Waste.

\[
Score_j = RI_j \bigoplus \sum_{j' \neq j} T_{ij'} \otimes RL_{j'} \quad j = 1, \ldots, m
\]  

(3.2)

\( T_{ij'} \) of the correlation matrix is assessed using the linguistic variables as shown in Table 3.3 has an incremental change of the degree of attainment of the \( j\)-th attribute when the attainment of the \( j'\)-th one is unitary
increased. So, the final score of the j-th proposed methodology can be computed using Equation (3.2) (Bottani, 2009; Vinodh & Chintha, 2011b).

The resulting score is also a fuzzy number. In order to rank the proposed methodologies, the crisp values are used. The crisp value of a fuzzy triangular number \( a (l, m, u) \), is computed using Equation (3.3) (Bottani 2009; Vinodh & Chintha 2011b).

\[
\text{Crisp Value} = \frac{l + 2m + u}{4} \tag{3.3}
\]

Based on the crisp values, the proposed methodology with the highest crisp value is given more importance. The matrix will be developed as shown in Figure 3.4. After ranking the proposals, the best improvement proposals will be identified.

![Figure 3.4 A typical Fuzzy QFD Matrix](image-url)