JOURNAL OF NORTHEASTERN UNIVERSITY
Volume 25 Issue 04, 2022 ISSN: 1005-3026 https://dbdxxb.cn/ Original Research Paper

INVESTIGATIONS OF THE IMPROVEMENT IN PRODUCTIVITY BY APPLYING EFFECTIVE MAPPING FRAME WORK IN MECHANICAL INDUSTRIES WITH THE HELP OF FUZZY QFD

Ramesh Kumar Rawal[1]; Pallavi Maheshwarkar[2]
[1]Research Scholar; [2]Associate Professor
Department of Mechanical Engineering, Oriental University, Indore (M.P.) India
Email id: rameshrawal1970@gmail.com

Abstract: Present research paper is based on the improvements in productivity using value stream mapping (VSM) and fuzzy QFD techniques in two mechanical industries. For this purpose, first of all process related parameters were investigated for the firms, which was followed by the constructions of value stream maps as well as house of quality for the purpose of improvements in productivity.
Keywords: Productivity, Value stream mapping (VSM), Fuzzy quality function deployment (FQFD), paper.

1. Introduction

Today's global economy, the survival of companies depends on their ability to rapidly innovate and continues improvement. As result they are leader in market and they are increasingly searching new methods and processes that drive improvements in quality of product, reduce the cost of manufacturing and increasing productivity. In today's fast changing market place, customer segment, customer requirement are steady & improvements in manufacturing operations will guarantee of the profitability or survival in market. Companies must improvement at a faster rate than their competitors so they are to become leaders in production. Productivity is an indicator of how well an organization is utilizing its resources. Virtually productivity is measured as ratio of output units and input units. To increase productivity, organizations need to make this ratio as large as practical. Productivity improvement is considered as one of the prominent requirements of industries, and one of the most discussed topics, since its inceptions, and even today, many researchers and industrialists work continuously in this field. Considering these aspects, the present research work is based on the investigations on the enhancement of productivity of a system using value stream mapping and quality function deployment. The technique of value stream mapping is used to maximize value and minimize waste in a number of different ways, whereas quality function of deployment is used to convert customer requirements to the product specifications. For this purpose, two mechanical industries have been targeted.

Following are the objectives of the present research work:

a) Development of integrated VSM-Fuzzy QFD framework for an existing firm

With the help of integrated VSM-QFD framework, the existing performance of the firm shall be investigated on different parameters.

b) Investigations on the rankings of different parameters for the firm

Submitted: 29/11/2022 **Accepted**: 20/12/2022

With the help of this objective, ranking of different parameters, like logistic system improvement, 5S, Kanban, Kaizan, etc shall be investigated.

c) Investigations on important parameters for the firm

With the help of this objective, investigations on the importance parameters for the firm shall be made.

2. Review of Literature

Present section deals with different aspects of the research work and presents the contributions of researchers in the field of proposed work, and gaps in the research, as presented below.

2.1 Contributions of Researchers in the Field of Proposed Work

Following are the details of contributions of researchers in the field of productivity improvement, value stream mapping and fuzzy QFD.

- **Qin and Liu (2022)**

This study provides a systematic methodology to understand, evaluate, and improve the entire e-commerce supply chain process utilizing VSM. It was demonstrated that the methodology could improve supply chain management efficiency, customer satisfaction, and cost reduction.

- **Liu and Zhang (2022)**

The purpose of this paper is to review and analyze the VSM literature to identify the advances and hotspots of VSM literature.

- **Nascimento et al. (2022)**

This work aims to show how Industry 4.0 (I4.0) can be combined with Lean Management (LM) to achieve the goals of the Circular Economy (CE).

- **Silva et al. (2021)**

In this work researcher presented a model using fuzzy logic, applied in a small metallurgical industry.

- **Wang et al. (2020)**

This study aims to investigate how value stream mapping (VSM), as a lean tool, can be applied to help improve operation training performances through an immersive virtual reality (VR)-based personalized training program.

- **Ferreira et al. (2022)**

This study indicates that VSM combined with HS can assist Industry 4.0 roadmap development and help companies understand changes in materials, equipment, processes, and information flows associated with Industry 4.0 application scenarios.

- **Murali et al. (2020)**

The objective of the study is to improve productivity of a furniture manufacturing company. Demand forecasts play a crucial role in productivity, improvement and production planning analysing the problems associated with it and there by tackling over production and shortage.

- **Yu-Che et al. (2019)**

This study uses the teaching curriculum to introduce QFD (quality function development) so that the theory of Merchandise Presentation can be truly understood and applied. With QFD listening to the characteristics of customers and professional voices, the demand for Merchandise Presentation of mass merchandisers is listened to, so that the theory can be more realistic.

- **Hamja et al. (2019)**

This article contributes to this debate by reviewing the present knowledge about the effect of lean on productivity and OHS in the RMG industry.

- **Talapatra and Shefa (2019)**

This paper is focused on application of value stream mapping in a production floor of a furniture industry with a view to enhance its performance.

- **Hatsey & Sileyew (2019)**

This paper discusses the importance of Quality Function Deployment (QFD) and strategies to guide the implementation of QFD in the context of Ethiopian industrial sector.

- **Chowdhury et al. (2018)**

The objective of this research is to identify the supply-side barriers and the corresponding mitigation strategies in the context of the apparel industry in Bangladesh by applying an analytical hierarchy process and quality function deployment method.

- **Kapuria & Karmaker (2018)**

The paper shows how customer requirements can be identified and used them to prioritize the design requirements for improving quality of jute yarn. Here, AHP is integrated into house of quality (HOQ) that can be guide for overcoming the pitfalls of traditional QFD.

- **Kapuria Rahman (2018)**

The purpose of this paper is to present a fuzzy quality function deployment (FQFD) model to identify customer requirements and design the production process and improve the quality of the T-shirts according to the requirements.

- **Dorota Klimecka-Tatar (2017)**

In the research work, the method of the production process improvement with the use of lean production tools has been presented.

- **Liao et al. (2017)**

Customers of the Credit Department of Farmers' Association in Taiwan were the object of study with a view to explore the gap between service quality expected and that actually perceived by customers of the farmers' association.

- **Ashrafuzzaman et al. (2016)**

In this research the researcher used Value Stream Mapping (VSM) as key lean tools to address the said issues at ABC Ltd, India on Men's trouser production layout.

- **Oleghe and Salonitis (2016)**

In this work researcher described the lean index is the sum of weighted scores of performance variables that describe the lean manufacturing characteristics of a system

- **Mayatra et al. (2016)**

In this paper study of the bearing industry at Ahmadabad, Gujarat, for reduction of product lead- time and fulfil the customer demand

- **Almomani et al. (2014)**

The researchers proposed integrated model of lean assessment and analytical hierarchy process for a dynamic road map of lean implementation and concluded that implementation of lean can vary according to the situation of the enterprise.

- **Yildiz & Guner (2013)**

In this study, flow of value, waste and waste sources in the value stream was tried to clarify by using value stream mapping. The current state was analyzed and ideas for improving system performance were proposed. Value stream mapping should be repeated periodically in order to achieve better system performance with continuous improvement

- **Kumar & Sampath (2012)**

This is paper based on the two folded objective of investigation of Value stream mapping in existing production line and to alter the same with new cellular based layout.

- **Chowdhury et al. (2012)**

This study aims at identifying sustainability requirements of buyers in apparel industry and corresponding design requirements by applying fuzzy-QFD approach.

2.1 Gaps in the Research

On the basis of the survey of available literature it was found that there is very less research papers available which focus on the investigations on productivity enhancement using quality function deployment value stream mapping technique, which lead the foundation of the research work.

On the basis of gaps in the research title & objectives of the research work have been finalized.

3. Solution Methodology

Present section focuses on the different techniques used to solve the research problem, the details of which are presented in upcoming sub-sections.

3.1 Techniques used to solve the Research Problem

Figure 3.1 presents the flow chart of research methodology used to solve the research problem.

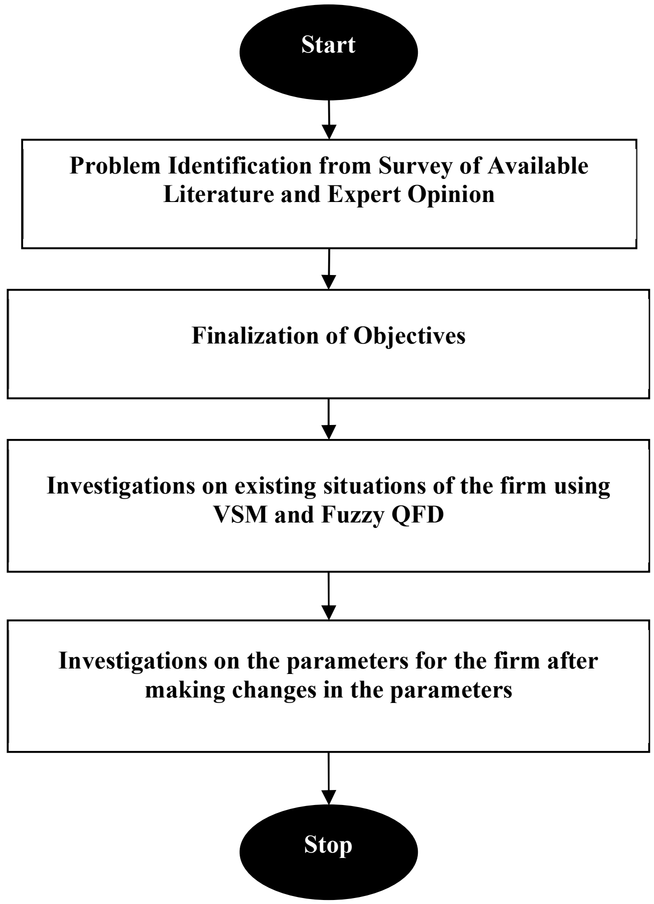


Figure 3.1: Research Methodology used to solve the Research Problem

Details of different techniques used in solving the research problem are presented as follows:

3.1.1 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a tool which is used for analyzing the material flow, information flow necessary in delivering a product to the customer. The advantage of using this method allows anybody to “see” both process flow and communications flow within the process or value stream (Nash and Poling , 2008). Due to the ability of collecting, analyzing and presenting information in a small period of time, this method as gained popularity in continuous improvement. The important objective of Value Stream Mapping method is to identify opportunities for improvement in a future period of time. VSM is defined as a powerful tool that not only highlights process inefficiencies, transactional and communication mismatches but also guides about the improvement (Rother and Shook, 1999). Since VSM is

an analytical method, and it is based on the level of details available, VSM can address only to a process, or to the production lines, or to entire factory.
VSM includes five basic steps:

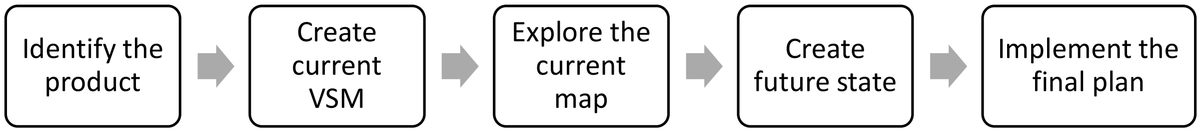


Figure 3.2

Value stream map is mainly divided into three sections:

a) Material flow
The team must identify the start and end points of the product, process description, material movements, and operators' details for drawing value stream.

b) Information or communication flow
Communication throughout the process must be proper and simple such that it can be understood by employees, suppliers, customers and management. Communication signifies informational flow between all the materials involved into the process and more then that into the entire company.

c) Time line
The time line represents the time needed for product to move through production process. The top line indicates the lead time and the bottom line indicates total cycle time.

Figure 3.3 shows different VSM symbols.

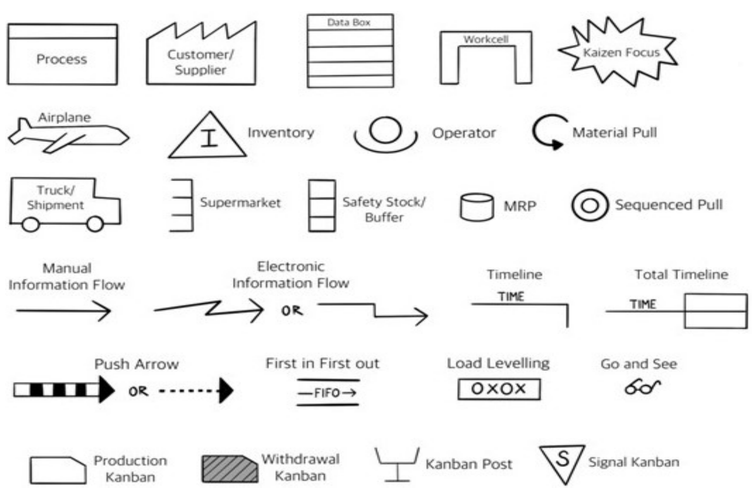


Figure 3.3: Different VSM Symbols (www.sixsigmadsi.com.com)

3.1.2 Fuzzy Quality Function Deployment (F-QFD)

This sub-section describes first describes Quality function deployment (QFD), and then Fuzzy-Quality function deployment (FQFD), as follows.

According to Abu-Assab (2012), Quality Function Deployment (QFD) was developed in Japan in 1966 as a result of extensive efforts to reach product. The method was introduced as part of the total quality control (TQC) concept, as a method for new product development There is no single or unique definition for QFD, but a general basic concept of this method tells that QFD is a system with the aim of translating and planning the voice of the customer into the quality characteristics of products, processes and services in order to reach customer satisfaction. Details of stages of QFD procedure are as follows (Kioumars et al. 2010):

Stage 1: Determine the Customer Demands:

The initial and most critical step of the QFD process is the identification of what customers want and expect from a consumer product. In this step, customers‟ demands, expectations, and complaints are determined.

Stage 2: Customer competitive evaluations

Customer competitive evaluation prepares a competitive or strategic assessment of the business. This plan brings out the firm's competitive weaknesses, strength and identifying areas needing quality improvement.

Stage 3: Determine the Technical Requirements

In this stage, determined customer demands were translated into technical requirements. The objective is to translate each customer voice into one or more technical requirements. Each technical requirement should be measurable and global in nature and should satisfy the voice of the customer (Gonzalez et al.2010).

Stage 4: Interrelationship between technical requirements

The roof of the house is designed to cross correlate the "hows" against each other so that design conflict and complementary characteristics can be identified. Many technical requirements are interrelated. Working to improve one requirement may help another related requirement and affect it in the positive way.

Stage 5: Relationship matrix between Hows and Whats

After establishing the whats and hows, construction of house of quality continues with establishing the relationships between the customer voices and the technical requirements (Gonzalez et al.2010).

Stage 6: Column weights

Weights were calculated for each technical requirement that represent a combination of both the customers‟ level of importance and the strength of the relationships. This is accomplished by multiplying the relationship strength and the importance.

Stage 7: Quality plan

After calculating column weights, it can be seen which particular technical requirements are important to improve first, so that effort could be concentrated on them for quality improvement study.

According to the principle of incompatibility (Zadeh, 1973), when facing a complex decision, human beings have difficulty in making a precise decision. As an effect, the data of human subjective judgment are usually fuzzy and imprecise in nature (Lin et al., 2006). Fuzzy data can be expressed using linguistic terms or in fuzzy numbers (Chen et al., 1992). Thus, the value of fuzzy measures as a linguistic value and then linguistic terms need to be converted to fuzzy numbers (Shyamal and Pal, 2007). Uncertainty can be classified into two types – probabilistic uncertainty and fuzzy uncertainty, though people were not aware of fuzzy uncertainty before mathematical formulation of fuzziness by Zadeh (1965). Fuzziness can be represented in different ways. One of the most useful representations is a membership function (Shyamal and Pal, 2007). There are many forms of fuzzy numbers to represent vague cases. The various types of fuzzy numbers are trapezoidal and triangular (Liou and Wang, 1992). The various operations in fuzzy logic are addition, subtraction and multiplication. These operations are explained as follows:

Fuzzy-number addition: $(a_1, a_2, a_3) \oplus (b_1, b_2, b_3) = (a_1+b_1, a_2+b_2, a_3+b_3)$;

Fuzzy-number subtraction: $(a_1, a_2, a_3) \ominus (b_1, b_2, b_3) = (a_1-b_1, a_2-b_2, a_3-b_3)$;

Fuzzy-number multiplication: $(a_1, a_2, a_3) \otimes (b_1, b_2, b_3) = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3)$ (Klir and Yuan, 1995; Bowles and Pelaez, 1995; Lin et al., 2006).

4. Case Studies

In present research work, two case firms, namely fabricated product firm and automobile part making firm are targeted, the details of which are presented in upcoming sub-sections.

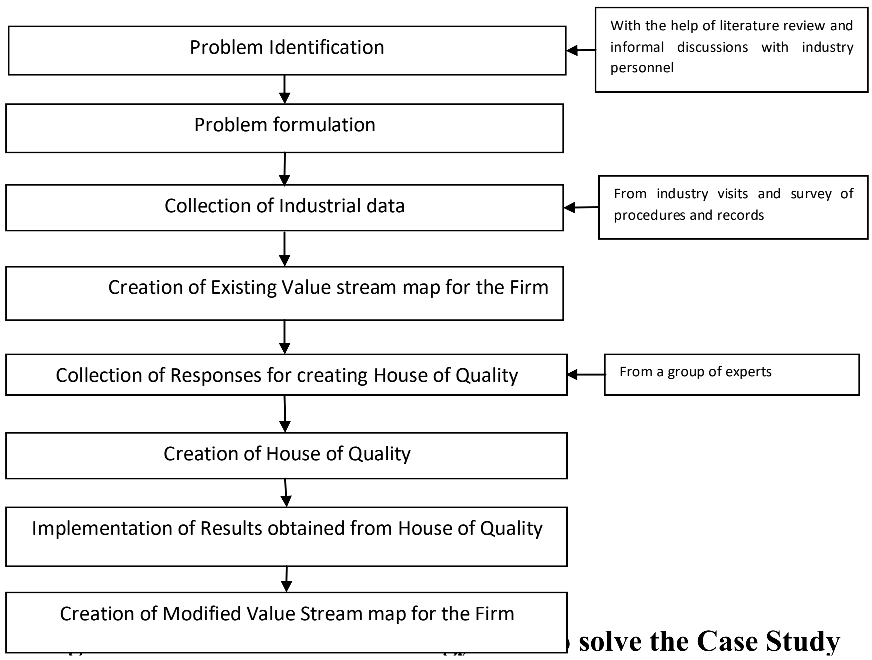
4.1 Case Study-I: Fabricated Product Industry

4.1.1 About the Company

The case study was conducted at Malwa Agro and Fabrication Industry Pvt. Ltd. This Company was established in 2000 in Dhar industrial area. It is a best quality manufacturing and suppliers of fabricated products, fabricated assemblies, water tank ,high rise pole ,water tanker with trolley ,large sign board, wild animal cage trolley, bus stop waiting structure ,death body trolley for village purpose and leg operated hand sanitizer and wild animal cage trolley. The case study has been carried out for water tank mounted on tractor trolley.

4.1.2 Details of Case Study

Researcher have surveyed the above stated industry and studied about the various production steps and held various discussion with shop floor managers, supervisors and workers about of the various points for improvements than manager finally permitted for the case study in organization to identify the wastes in process through various tools and techniques and the elimination the wastes with the help of Value Stream Mapping . In this context, the researcher discussed the case with the managers of the organization to conduct the study. In the case study following main constraints are used for case study, work in process cycle time, change over time, takt time, existing inventory calculation, line balancing, types of product flow, down time and then drawing of the existing state map based on current production process. Following solution methodology was used to solve the case study.



solve the Case Study

After problem identification and problem formulation, industrial data was collected by the candidate.

Cell – I (Channel operations) Shearing parameters

Cycle time	=	60 sec / (Channel)
Change over time	=	300 sec
Availability	=	28800 sec
Up time	=	98.9 %
Operator	=	2
WIP	=	100 units between Shearing and pressing I

Time between pressing -I and shipping 5 days

Cell – I (Channel operations) Pressing I parameters

Cycle time	=	180 sec (channel)
Change over time	=	350 sec
Availability	=	28800 sec
Up time	=	98.7%
Operator	=	2
WIP	=	200 units between Pressing I and Pressing II

Time between pressing II and shipping 10 days

Cell – I (Channel operations) Pressing II parameters

Cycle time	=	150 sec (channel)
Change over time	=	100
Availability	=	28800 sec
Up time	=	98.7%
Operator	=	0
WIP	=	150 units between Pressing II and Deburring

Time between Deburring and Shipping 8 days

Cell – I (Channel operations) Deburring parameters

Cycle time	=	90 sec (channel)
Change over time	=	30sec
Availability	=	28800 sec
Up time	=	98.9%
Operator	=	1
WIP	=	150 units between Deburring and welding

Time between welding and shipping 8 days

Cell – I (Channel operations) Welding parameters

Cycle time	=	300 sec (channel)
Change over time	=	500 sec
Availability	=	28800 sec
Up time	=	98.2%
Operator	=	2

WIP = 200 units between pressing welding and shipping

Time between Deburring and shipping 10 days

Total value stream WIP Inventory Cell I (channel)

To calculate total stream WIP, by totalling the amount of WIP inventory on hand between each operation.

Raw material prior to shearing	=	300 sheets
Between shearing and pressing - I	=	100 sheets
Between pressing - I and pressing - II	=	200 sheets
Between pressing – II and Deburring	=	150 sheets
Between Deburring and welding	=	150 sheets
Between welding and shipping	=	200 sheets
Total inventory	=	1100 units

WIP in terms of days on hand:

100 units (20 units per day = 5 days in hand) between Shearing and pressing I

200 units (20 units per day = 10 days in hand) between pressing I and pressing II

150 units (20 units per day = 8 days in hand) between pressing II and Deburring

150 units (20 units per day = 8 days in hand) between Deburring and welding

200 units (20 units per day = 10 days in hand) between pressing welding and shipping

Total inventory (in days) = 5+10+8+8+10 = 41 days on hand that means total lead time is 41 days

The total product cycle time is also considered as total value adding time, the cycle time for each operator is listed as below:

- Shearing 60 sec
- Bending I 180 sec
- Bending II 150 sec
- Deburring 90 sec
- Welding 300 sec

The total cycle time of the product of all operations as below: 60 sec + 180 sec + 150 sec 90 sec +300 sec = 780 sec

Current state map data collection sheet for water tanker of the axle shaft is as follows which consists of Customer demand or requirement:

- Monthly average demand 300 units means 10 units per day
- Every month supply ; 10 days

- Units supply per trip : 30
- per day ready : 10

Cell I

- Cycle time = 780 s (For Operation)
- Changeover time Cell (1) Step 1 (300s), Step 2 (350s), Step 3 (100s), Step 4 (300s) Step 5 (500S).
- Uptime cell (1) = Step 1(28500), Step 2 (28450s), Step 3 (28700s), Step 4 (28500) Step 5 (28300s)
- Number of operators Step 1 (2), Step 2 (1), Step 3 (0), Step 4 (1), &Step 5 (2) .Total 06 Nos. Operator required

In next step, current state map was created with the help of Table 4.1, presented below.

Table 4.1 Current State map Data (cycle time 780 s) and change over time (1550s) of the Cell – I (Channel Manufacturing)

Type of Operation	SH	BD	BD	DB	WEL	Remark
Step No.	Step 1	Step 2	Step 3	Step 4	Step 5	05
Cycle time in (s)	60s	180s	150s	90s	300s	780s
Changeover time (s)	300	350	100	300	500	1550s
No. of operators	2	1	0	1	2	06
Availability in time (s)	28800	28800	28800	28800	28800	
Uptime in %	98.90%	98.70%	99.60%	98.90%	98.20%	

On the basis of above information, current state map process chart was developed.

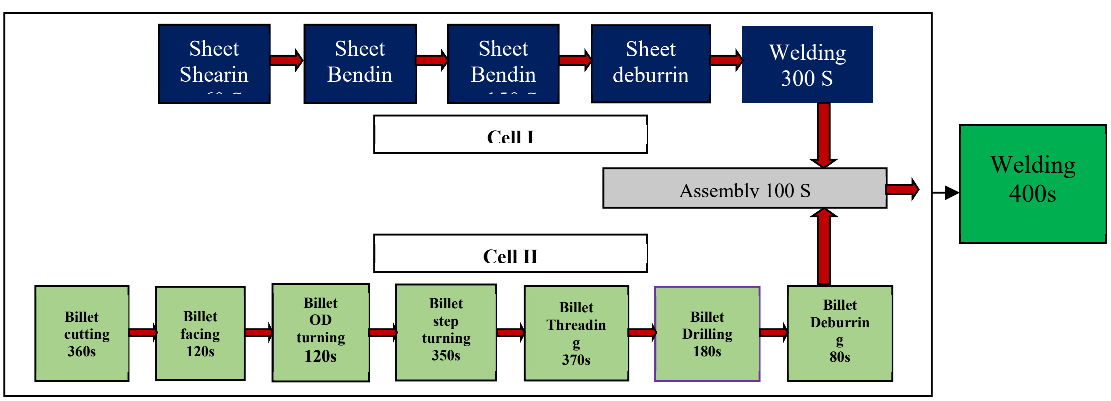
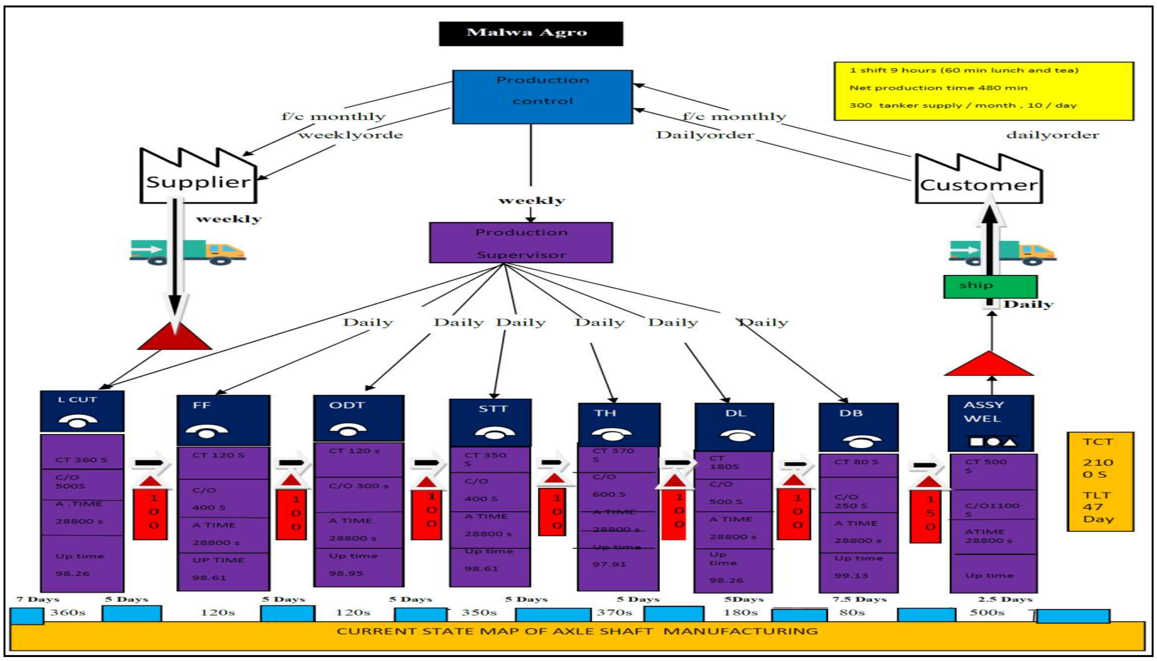


Fig 4.2: Current State Map Process Chart of the Axle shaft L - 2035 mm (14 operations) Cell I & Cell II

On the basis of above information, current state map was prepared, the details of which are presented as follows.



4.3: Current State Map

In next step, following changes were made in the exiting layout.

Some specific changes have been made in Cell I & Cell II to overcome the various issues identified in the current state mapping which are as follows:

- Improvement in the maintenance programme of the industry and proper scheduled maintenance and autonomous maintenance is done as required of machine , tools and equipment
- Work distribute of the cell I is reorganized and total seven different operation haven done by 4 operators. Total cycle time is 590 seconds.

Total cycle time	=	590sec
Change over time	=	800 s
Takt time	=	2880 sec
Number of operators	=	04

- Work distribute of the cell II is reorganized and total nine different operation haven done by 4 operators. total cycle time are 1250 seconds

  Total cycle time = 1250sec

  Change over time = 1500 sec

  Takt time = 2880 sec

  Number of operators = 04

- Minor Set up change according operations allotted to operators.
- Minimize the change over time during machining operations

On the basis of above information, Table 4.2 and Table 4.3 were drawn, as shown as follows.

Table 4.2: Proposed New Data for Future State Map of the Cell I

Sr. No.	Particular	Existing data of current state map	Proposed data for Future state map
1	Cycle time	780s	590s
2	Change over time	1550s	800s
3	Number of operator required	07	04
4	Production steps	05	03

Table 4.3: Proposed New Data for Future State Map of the Cell II

Sr. No.	Particular	Existing data of current state map	Proposed data for Future state map
1	Cycle time	2100 s	1250 s
2	Change over time	4050 s	1500 s
3	Number of operator required	07	04
4	Production steps	09	04

On the basis of above information, future proposed process chart was developed.

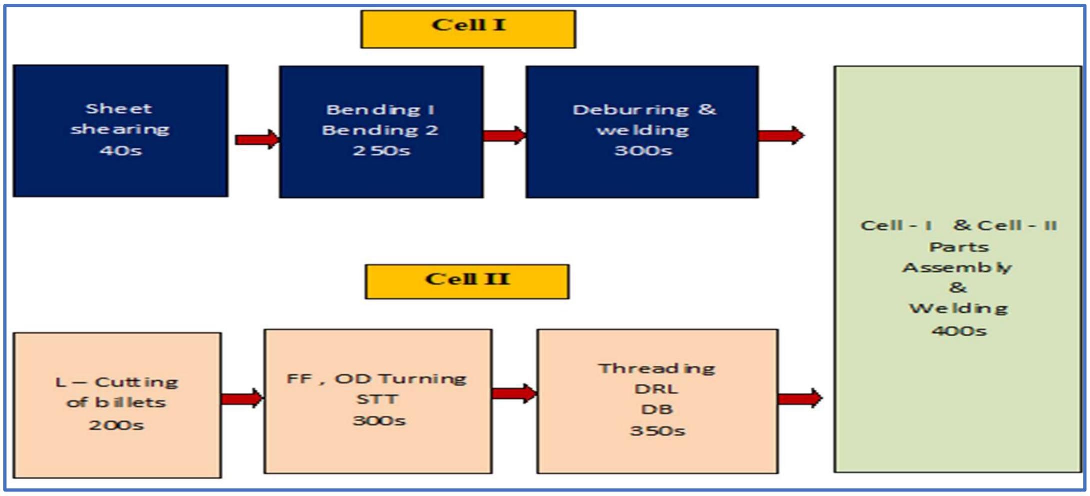


Figure 4.4: Future Proposed Process Chart of the Axle shaft 2035 mm (14 operations) Cell I & II

In this case study the following wastes have been identified in the industries through Quick Change Over, Jidoka, 5S, Kanban (Bin Used), Kaizen, Single Piece Flow, Poka- Yoke, WC, VW ,SPF Just in Time, Autonomous maintenance, which are as follows:

- Over Production In Industry At Shop Floor
- More Inventory In Various Steps
- Re Work Of The Components
- Defects After Measurement
- Transport And Motion Un Necessary
- Un Trained Workers
- Not Used Jig And Fixture
- More Waiting In Processing
- Over Processing Of The Component
- Stores Tools And Equipment Centralized
- Poor Communication Between Management And Workers
- Not Proper Planning for Every Day So That Sudden Change In Process
- Advance Tools And Technique Not Used
- No Automation In Industry
- Maintenance Problem
- Waiting
- Non utilized talent
- Transportation

The symbols used for describe to relationship are as follows strc● ( ), medium (O), and weak (▽).

In the next step, the House of Quality (HOQ) was constructed. HOQ is a design between required improvements and used of identified lean tools. The mostly preference technique s included

- QCO
- 5 S
- WORK CELL
- KANBAN
- KAIZEN
- TPM
- POKA-YOKE
- VW

The main objective of HOQ is to preference the lean tools that provided opportunities for achieving the expected outcomes. Developed and referred to as WHATs and find out tools are referred to as HOWs. When the recognition of suitable lean tools for the expected out comes is done by on the basis of the human knowledge, FUZZY logic has been used as an effective method. In order to overcome the ambiguity are associated with linguistic judgement in building of HOQ and relative importance relationship and correlation have expressed with triangular FUZZY members.

The important weights (Wi) is a fuzzy vector representing the relative importance of expected improvement on a linguistic fuzzy scale. The importance weights and corresponding fuzzy number for rating expected outcomes they are shown in table 4.4.

Table 4.4: Linguistic variables used for correlation matrix and its corresponding fuzzy numbers

Degree of correlation	Symbol	Fuzzy number
Strong positive (SP)	●	(0.3;0.5;0.7)
Positive(P)	+	(0;0.3;0.5)
Negative(N)	-	(0.5;0.3;0)
Strong negative(SN)	- -	(0.7;0.5;0.3)

Table 4.5 show linguistic variables for importance weight and corresponding fuzzy numbers for the rating.

Table 4.5 Linguistic variables for importance weight and corresponding fuzzy numbers for rating

Importance weight (Wi)	Fuzzy Numbers
Very high (VH)	(0.7; 1;1)
High (H)	(0.5;0.7;1)
Low (L)	(0;0.3;0.5)
Very low (VL)	(0;0;0.3)

Table 4.6 shows the relationship with wastes and identified lean concepts.

Table 4.6 Degree of Relationship with Wastes and identified Lean Concepts

Degree of relationship	Symbol	Fuzzy number
Strong(S)	●	(0.7; 1;1)
Medium(M)	O	(0.3;0.5; 0.7)
Weak (W)	▽	(0;0;0.3)

Table 4.7 shows the relationship with wastes and identified lean concepts.

Table 4.7: Waste identified and improvement proposals with relationship (i)

	Weights	5S	QCO	TPM	V W	W C	POKA YOKE	KAIZEN	KANBAN
Work place cleanness	H	S	M	S	M	M	M	M	M
Reduction in work in Process	L	M	S	M	M	S	M	S	M
Reduction in change over time	H	M	M	M	M	S	S	M	M
Reduction	H	M	M	M	M	S	M	M	M

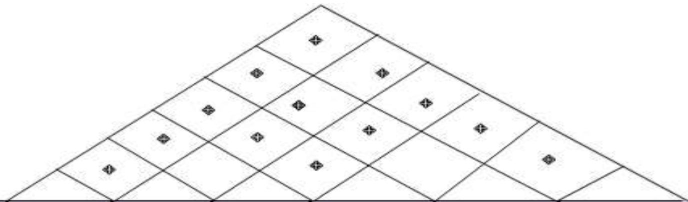
in man power									
Reduction in inventory	H	M	W	M	M	M	W	M	S
Reduction in Transport	H	W	M	M	M	M	W	M	M

Table 4.8 shows the wastes identified and improvement proposals with relationship.

Table 4.8: Waste identified and improvement Proposals with Relationship

INDEX	(0.8, 1.9,3 .75)	(0.7 5,2.0 5,4.0)	(0.95, 2.5,4. 15)	(.075, 1.90,3 .85)	(0.80, 2.4,3. 6)	(0.65, 1.55,2 .05)	(.075, 2.05,4 .0)	(0.75,1. 90,3.85)
SCORE	(0.8 0,3.2 65, 7.82 5)	(0.7 5, 2.77, 5.80)	(095,3 .115,6 .15)	(0.75, 1.90,3 .85)	(0.80, 3.56,7 .48)	(0.65, 1.55,2 .05	(0.75, 2.62,5 .93)	(0.75,2. 62,5.65)
CRISP VALUE	3.78 8	3.02 3	3.33	3.332	3.85	1.325	2.98	2.91
RANK	2	5	4	3	1	8	6	7

Figure 4.5 the shows house of quality.



Weight Chart	Functional Requirements / Identified Wastes	5S	QCO	TPM	WORK CEL	KAIZEN	KANBAN
H	Work place cleanness	•	○	•	○	○	○
H	Reduction In change over time	○	○	○	•	○	○
H	Reduction in man power	○	○	○	•	○	○
H	Reduction in inventory	○	▽	○	○	○	•
H	Reduction in transportation	▽	•	○	○	○	•
	Index	(0.80,1.75,3.4)	(0.60,1.4,3.1)	(0.95,2.11,3.8)	(1.15,2.45,4.10)	(0.75,1.75,3.5)	(1.15.2.45,4.10)
	Score	(0.80,3.28,14.78)	(0.60,3.93,10.65)	(0.95,4.64,11.35)	(1.15,4.76,11.30)	(0.75,4.1,10.7)	(1.15,5.23,13.05)
	Crisp Value	5.78	4.79	5.42	5.51	4.91	6.21
	Rank	2	6	4	3	5	1

Fig 4.5: House of Quality

Figure 4.6 shows the future state map.

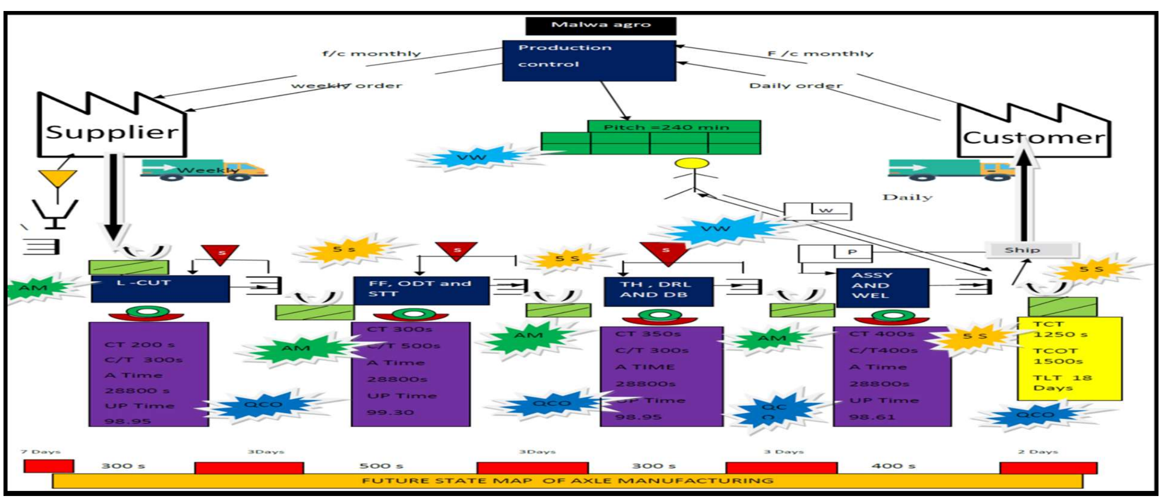


Figure 4.6: Future State Map

4.2 Case Study-II: Metal Forming Industry

4.2.1 About the Company

Hi –Tech Metal Forming Pvt. Ltd Indore established in 1996 situated at Indore (M.P). This industry is known for the best quality of the product manufacturing and leading suppliers to automobile company of the sheet metal parts, fabricated assemblies, air reservoirs, mechanical jack and fire extinguishers.

4.2.2 Details of Case Study

Following solution methodology was used to solve the case study.

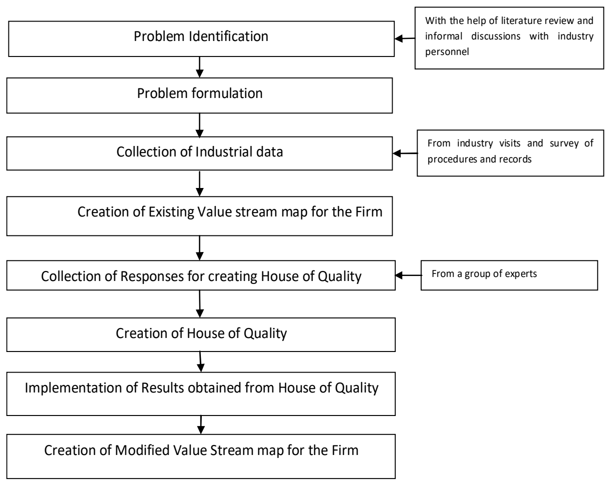


Figure 4.7: Solution Methodology used to solve the Case Study

In the next step, the current production operations were investigated as follows:

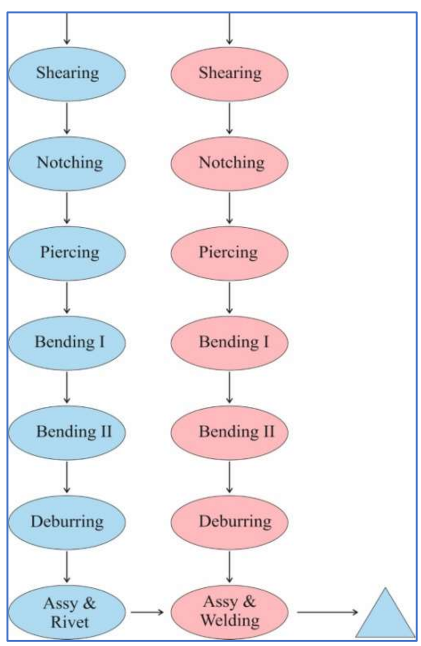


Figure 4.8: Current Production Operation Steps of the Chassis Cross Member

With the help of received data (similar to case study I), in the next step the current state map was constructed, as shown below.

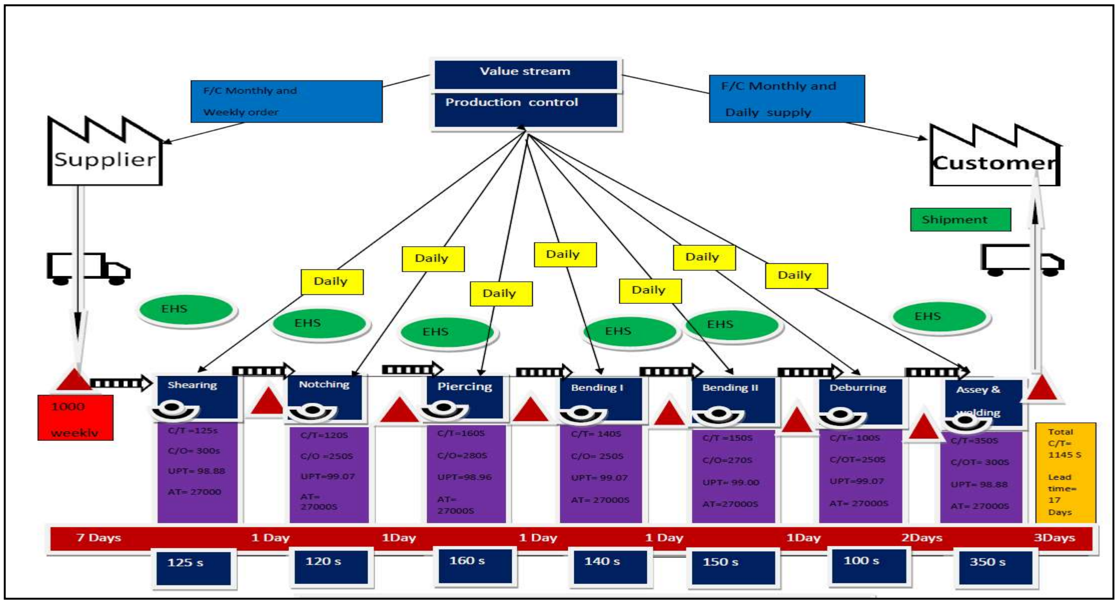
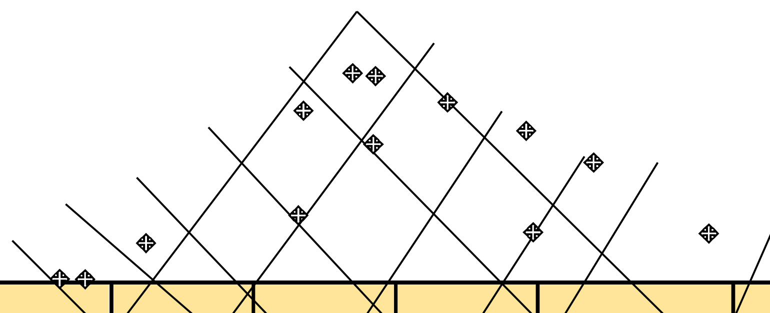


Figure 4.9: Current State Map

Proceeding in the similar manner as mentioned in case study I, the house of quality was drawn.



Weight Chart	Functional Requirements / Identified Wastes	kanban	QCO	AM	WORK CEL	KAIZEN	5 S
H	Work place cleanness	○	○	●	○	○	●
L	Reduction	●	●	○		○	○

	In defects				●		
H	Reduction in man power	○	○	○	●	○	○
H	Reduction in inventory	●	∇	○	●	○	○
L	Reduction in change over time	○	●	○	●	○●	○
	Index	(0.65, 1.85, 3.25)	(0.30, 1.30, 2.70)	(0.65, 1.70, 3.10)	(0.85, 2.35 ,3.70)	(0.45, 1.50, 2.95)	(0.65, 1.70, 3.10)
	Score	(0.935 ,3.97, 10.32)	(0.30, 2.97 ,7.60)	(0.65, 2.63, 5.93)	(0.85, 3.75, 9.10)	(0.45, 3.15, 7.78)	(0.845 ,3.60 ,9.13)
	Crisp Value	4.798	3.46	2.958	4.361	3..633	4.31
	Rank	1	5	6	2	4	3

Figure 4.10: House of Quality

In the next step, from the house of quality Figure 4.11 shows the future state map chart of the production step.

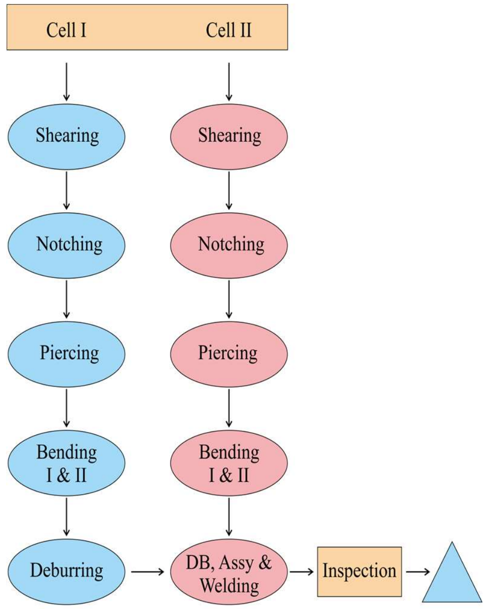


Figure 4.11: Future State Map Chart of the Production Step

In the next step, the future the future state map was created as follows.

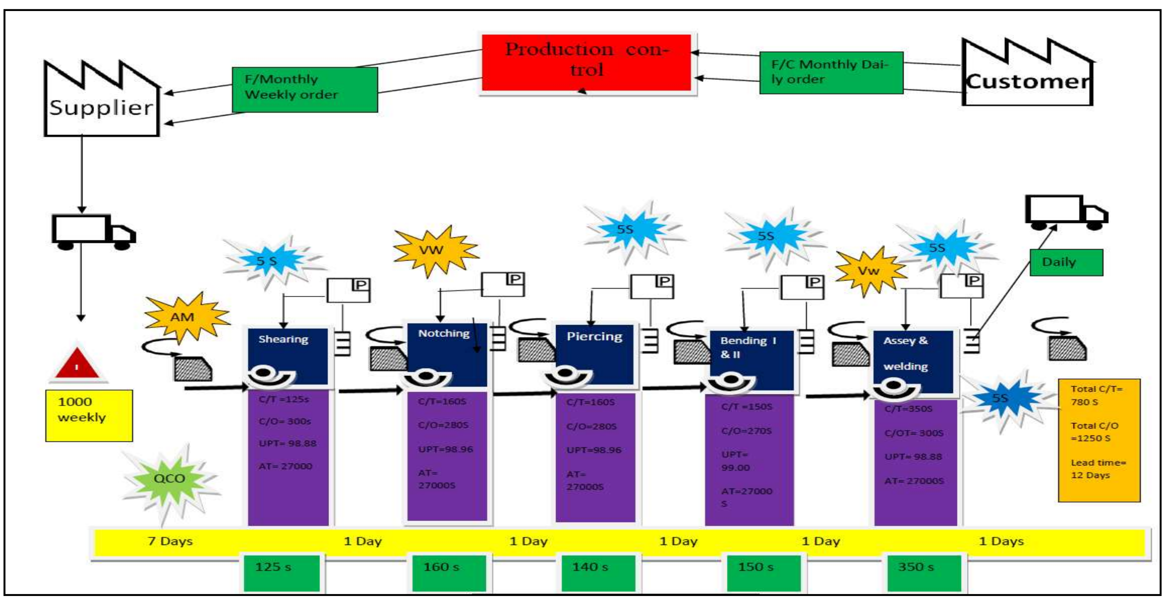


Figure 4.12: Future State Map Chart

5. Results and Discussion

Present section tells about the discussion and obtainment of results, the details of which are presented in upcoming sub-sections.

5.1 Result and Discussion Frome Case Study I

The integration of QFD in VSM framework enables the systematic identification of waste and techniques for eliminating them. The prioritized waste in our study include

- Inventory
- Waiting
- Defects and Transport

The prioritized techniques for waste elimination include

- Kanban
- Single Piece Flow
- Quick Change over
- Kaizen

The improvement techniques are being subjected to implementation in the case organization. In order to minimize the raw material and work in progress inventory, Kanban system is under design stage to ensure streamlining of process.

In the chapter 4 ranking of different quality indicators were obtained, which showed the direction in which changes in the existing system should be made. For this purpose, each main station in the system was deeply analyzed and corrections were made, as per the ranking of different indicators. In this series, first of all, flow process chart for preparation operations was created, as shown in figure as below.

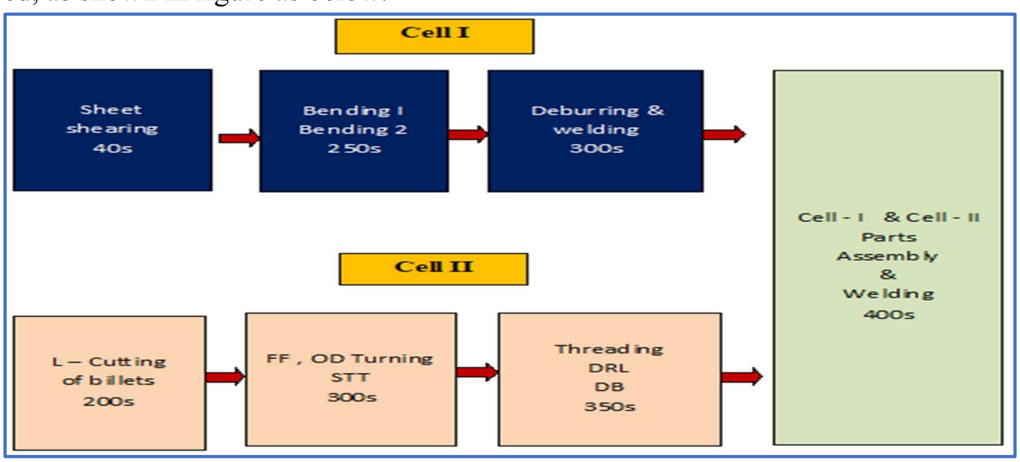


Figure 5.1: FSM Flow Process Chart

The objective to carry out this case study is to identify the potential advantage from implementing of lean and to design and develop a better future state map. The researcher focused on lean manufacturing techniques such as productions levelling through minimizing process WIP, improvement of Takt time and minimizing handling to eliminate or at least reduce changeover/handling time, Continuous improvement through kaizen, Heijunka level production, JIT, single piece flow, Poka Yoke, detecting defect through automation (Jidoka).The integration of QFD in VSM framework enables the systematic identification of wastes and techniques for eliminating them. The prioritized wastes in this case study includes: Inventory, excess processing, waiting, over production, motion, defects (impact time, money resources and customer satisfaction), transport and non utilized talent. Many improvement techniques are used and implemented in this case study. In order to minimize the raw material and work in process inventory, Kanban system is used to ensure streamlining of processes. The main techniques used for waste elimination have been described which are as follows:

5.1.1 Single Piece Flow

At the shop floor redesigned the plan for the work force for the goal of achieving one-piece flow, in the future-state map should include the tools and techniques that will improve flow. Some improvements are necessary for achieving targets are identified. The list of the improvement methods will be compulsory for creating continuous flow in the process.

1. 5S, Pull system, autonomous maintenance, quick changeover at L- cutting in cell II
2.5S, Single piece flow, Pull system, autonomous Maintenance and quick changeover at face facing, OD turning and Step turning in cell II.
3. Quick changeover 5S, Single piece flow, pull system and autonomous maintenance at threading, drilling and de burring in cell II.
4. 5S, Single piece flow at assembly and welding during in cell II and Shipping.

5.1.2 Preference on Levelling of the Production

Levelling is the manufacturing steps in this even work distribution for required to fulfillof the customer demand in a every shift or every day. If do not leveling the production system , than some cells will fall behind in production system And this causing idle time of the downstream while at other work station may be waiting for the work. Study and reviews the following facts, mostly which are determination early in the production steps for creating the future state map.

- The Kanban system to create the necessary for the industry for the improvement.
- The customer has requested to supply of items 3units/ day at right time.It means that every 144 min the 3 units must be completion to packing and ready to shipping.

5.1.3 Kanban

It will be decided that the value stream mapping requires the following types of Kanbans at the following locations:

1. Withdrawal Kanbans it is also kwon as move cards it indicate the material handler how many units to be pulled from the finished-goods.and where they are needed
2. Production Kanbans indicate operators in the L- Cutting, Face Facing, OD turning, Step Turning, Threading, drilling and deburring cell how many quantity must be manufacturing to fill up again those pulled from the finished-goods supermarket.
3. Signal Kanbans at the in-process supermarket between L- Cutting, face facing, OD turning, step turning cell and threading /drilling/deburring cell that the how much qty machining by operator that units have beenpulled from the supermarket.
4. Signal Kanbans just upstream of manufacturing indicate the supplier how many qty have been pulled from raw material inventory.

5.1.4 Mapping of Material and Information Flow

1. An operator from the turning/drilling / debarring - cell will be for pulling required parts from the supermarket between that cell and facing & flange facing - cell. This is shown on the map by drawing a supermarket parts icon and a manual material pull icon between the supermarket icon and the turning/drilling/debarring – cell.
2. When the turning/drilling/debarring cell operator pulls machined parts from the in-process supermarket, the operator will also pull a signal Kanban from the container and place it in a special holder on the side of the supermarket flow rack. The facing & flange - cell operator will retrieve signal Kanbans when he delivers machined parts to the supermarket flow rack. To mark this activity draws a manual communication arrow and a signal Kanban icon from supermarket icon to turning/drilling/debarring – cell icon. It draws a material push arrow running from the turning/drilling/debarring – cell icon to the in process supermarket icon before facing & flange facing –cell.
3. The facing &flange facing –cell operator will also be responsible for pulling signal Kanbans from raw material containers and placing the signal Kanbans on a special Kanban post. The raw materials supplier truck driver will be responsible for collecting the signal Kanban and taking them back to the supplier's plant. To illustrate this part of the plan, draw a Kanban post icon between the supermarket icon and the supplier truck icon. A manual communication arrow and a signal Kanban icon are drawn running from the Kanban post icon to the supplier icon.

5.1.5 Kaizen

Kaizen decided to use visual controls, or visual workplace, at the OD turning, Step turning, threading, drilling, debarring cell and the heijunka box. Kaizen added the icons to the map along with lead times and total cycle time.

(i) Kaizen Plan creating: When preceding the kaizen planning process, than the necessary to implementation of these following steps:

1. Reviewing the future state map and creating the monthly kaizen planning.
2 Find out the milestones for each major kaizen activity and draw the kaizen milestone chart.
3. Completed the value stream mapping management storyboard.
4. After Permission of the management approval for kaizen plans through catch ball.

(ii) Implementation of the Kaizen Planning: Decide the all planning and preparation done to allow proceeding to the implementation phase with excitement and confidence. It is remember that the implementation begins in seriously, kaizen activities will have an impact on virtually everyone person connected to the target of thevalue stream mapping.

5.1.6 Improvement in measures of Lean performance

The lean performance measured of lean practices includes productivity, quality, cost, delivery and flexibility and safety. The improved lean performance measures are gathered from the managers of the case of the industry using a Likert's scale of range 1-10 (1 indicates least improvement, 5 indicates medium improvement and 10 indicates significant improvement) and the average values are presented in Table 5.1.

Table 5.1: Lean performance measures Improvement chart

Performance measures	Level before the conducting of the study	Level after the conduct of the study
Productivity	7.2	8.8
Quality	7.4	8.5
Cost	6.3	8.7
Delivery	6.7	8.2
Flexibility	6.5	8.5

The improvements in the industry at various production steps have been done and the various performance measures as a result of the case study are shown as under**:**

5. Total cycle time reduced of the various production steps in cell I from 780 seconds to 590 seconds as shown in Figure 5.2.

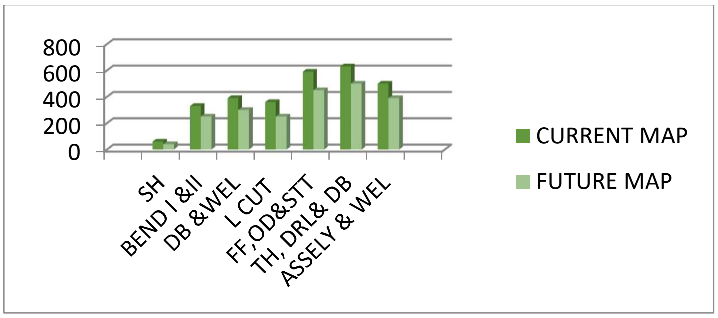


Figure 5.2: CSP and FSP comparison Cycle time reduction chart cell I

6. Total cycle time reduced of the various production steps in cell II from 2100 seconds to 1450seconds. Total change over time reduced of the various production steps in cell I from 1550 sec to 900 sec and also total change over time reduced of the various production steps in cell II from 4050 sec to 2300 sec as shown in Figure 5.3.

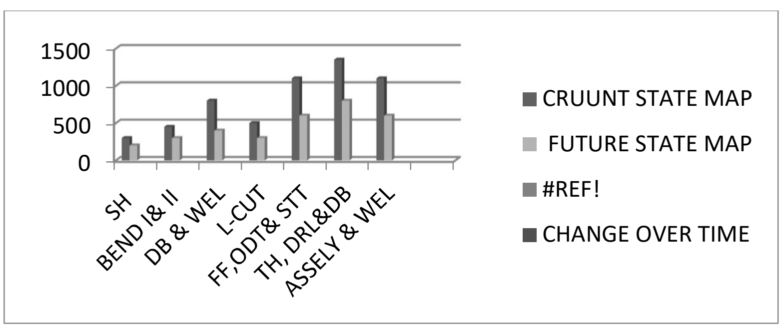


Figure 5.3: Change over time CSM and FSM reduction chart Cell I 1550 sec to 800 sec & Cell II 4050 sec to 2300 sec.

7. Total reduction in man power of the cell I & II from total number of 15 to 9 as shown in Figure 5.4.

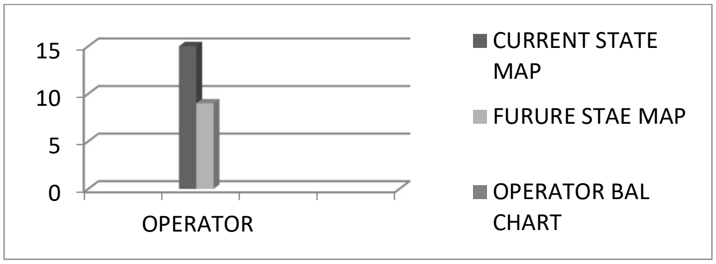


Figure 5.4: Man power reduction chart of the Cell I & II

8. Total inventory reduced of the various production steps in cell I &II from1100 units to 950 units as shown in Figure 5.5.

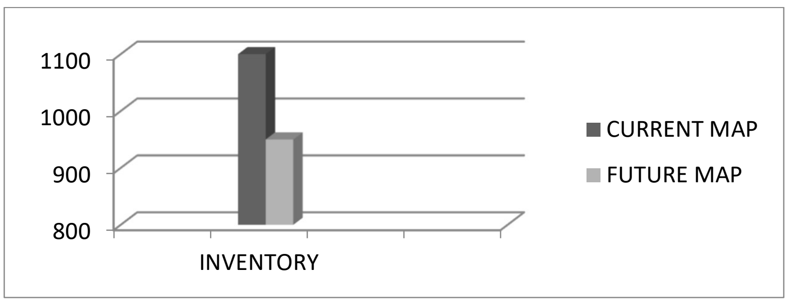


Figure 5.5: Inventory reduction chart Cell I & II

5.1.7 Results from case study I

After implementation the proposals, to quantify the benefits, the following measures were determined. In order to quantify the improvements from the perspective of leanness, the values of the parameters before and after implementation of VSM are presented as follows: Non value added time has been reduced from 19 days to 8 days. Total cycle time has been reduced from 10 days to 6 days. Total man power has been reduced from 15 to 07 Work in process inventory between work stations has been reduced from 1100 units to 950 units. The above result shows that, there is a significant improvement in leanness after implementing FSM.

5.1.8 Improvements

After analyzing the CSM, few proposals are identified and FSM has been proposed. Using Fuzzy QFD, proposals have been identified as 5 S, QCO, AM, VW and WC has been implemented in FSM . To achieve quick change over, automatic loading system has been introduced; CMM has been used to speed up inspection rate. Two work cell has been formed by combining machining and welding is one cell and combining the inspection and assembly in the other work station . By following the autonomous maintenance policy, the non value added has been reduced. After implementing the proposals, quantify the benefits, the following measures were determined. The practical feasibility of the proposed approach was validated with industry decision makers who expressed their opinion that this method enables scientific prioritizations of the improvement proposals. During early stages of implementing lean manufacturing, all improvement proposals cannot be concurrently implemented which consumes significant amount of resources and cost, Also, adequate training needs to be provided for work force on various tools of lean manufacturing.

5.1.9 Leanness Performance Measures;

In order to quantify the improvements from the perspective of leanness, the value of the parameters before and after implementation of VSM are presented as follows ;

- Non value added time has been reduced from 19 days to 8 days
- Total cycle time has been reduced from 10 days to 6 days
- Total man power has been reduced from 15 to 07
- Work in process inventory between work stations has been reduced from 1100 units to

950 units.

- On time delivery got increased from 75% to 85% .
- Product defect rate has been reduced from 10% to 3%. .
- Up time has been increased realistically by 2% .

The above result shows that , there is a significant improvement in leanness after implementing FSM.

5.2 Discussion and Results of Case Study II

In the chapter 4 ranking of different quality indicators were obtained, which showed the direction in which changes in the existing system should be made. For this purpose, each main station in the system was deeply analyzed and corrections were made, as per the ranking of different indicators. In this series, first of all, flow process chart for preparation operations was created, as shown in figure 5.6.

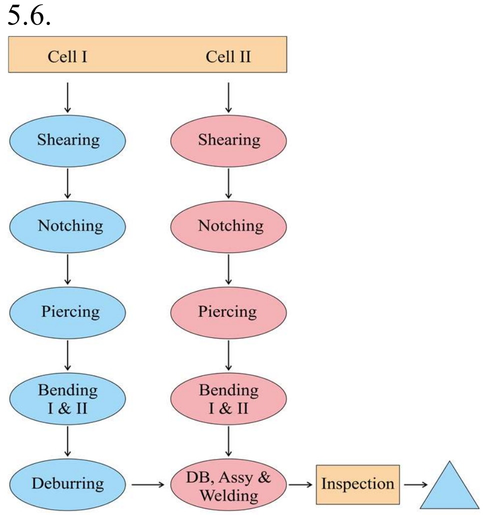


Figure 5.6: FSM Flow chart

The results of the case study are discussed as follows. The identified of waste in case study and their corresponding improvement proposals for industry are as follows:

- 5S should be necessary to improvement in the industry for work place cleanliness.
- Many times inspection in process of the component removed to eliminate for unnecessary activity.
- Reduced the defects of the component with help of implementing Poka Yoke in industry.
- Reduction of the change over time in process with the help of the process capability.
- Reduction of the inventory with the help of Kanban and pull system adaption in industry at shop floor.
- Reduction in transportation of the unnecessary movement.

The prioritized lean tools in our case study include the following; -

- Quick Change Over
- Kanban
- 5 S
- AM
- Work Cell
- Kaizen

The improvement techniques are being subjected to implementation in the case of organization. In order to minimize the raw materials and work in process, kanban is used.

At the shop floor redesigned the plan for the work force for the goal of achieving one-piece flow, in the future-state map should include the tools and techniques that will improve flow. Some improvements are necessary for achieving targets are identified.

- Work cell QCO at work station 1 and 2
- 5 S and Work cell at work station 3 and 4
- QCO at work station 5
- Kanban ,AM and kaizen at work all stations

5.2.1 Focus on levelling the production

Levelling the production is evenly distributing the work required to fulfil the customer demand over a shift or a day. If the levelling production is not carried out, some work stations will fall behind in production, causing idle time at downstream, while at other times they may be waiting for work.

5.2.2 Kanban

It has been decided that the value stream requires a production kanban which indicates operators in process in cell how many units must be produced to fill up against those pulled from finished goods super market.

5.2.3 Improvement in measures of Lean performance:

The improvements in the industry at various production steps of the various performance measures as a result of this case study have been given below**:**

- Reduced the total cycle time of the cell I from 1350sec to 970sec and of the cell II from 1145sec to 780sec as shown in figure 5.7.
- Reduced the total change over time of the cell I from 2100sec to 1400sec and of the cell II from 2000sec to 1250 sec as shown in figure 5.8.
- .Reduction of the lead time of the cell I &II from 18 days to 10 days as shown in figure 5.9.
- Reduction in man power in work cell at cell I& II from 18 to 11 as shown in fig. 5.10.
- Reduction of work- in- progress inventory from 5200 units to 2800 units , refer fig. 5.11.

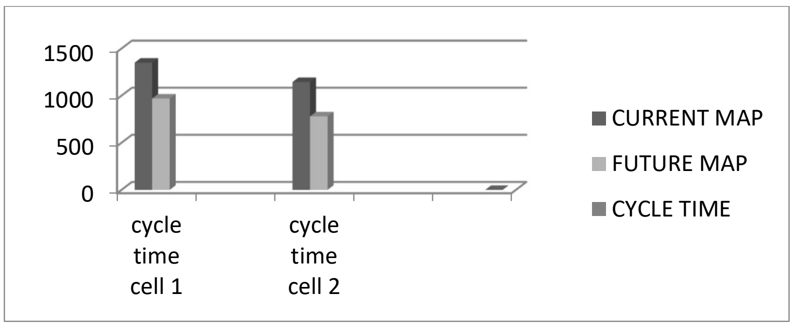


Figure 5.7: Cycle time reduction chart of the cell I 1350s to 970s and the cell II 1145s to780s

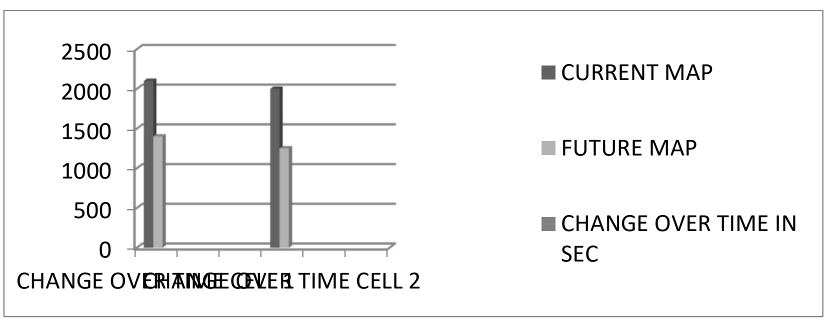


Figure 5.8: Change over time Reduction chart of the cell I 2100s to 1400s and the cell II 2000s to 1250s

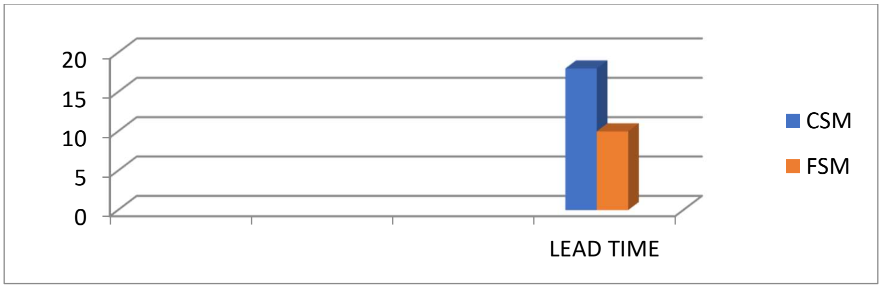


Figure 5.9: Lead time Reduction Chart of the cell I &II

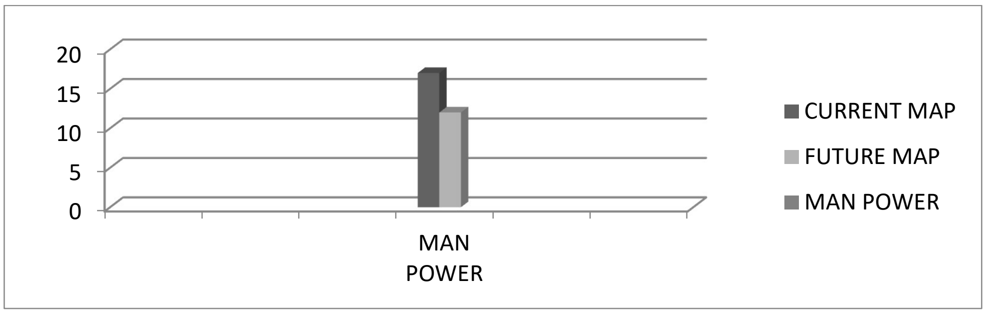


Figure 5.10: Reduction in man power in work cell at cell I & II

Figure 5.11: Reduction inventory in work cell at cell I & II

6. Conclusion, limitations & Future Scope of the Research

Present section tells about the conclusion, limitations and future scope of the research work, the details of which are presented in upcoming sub-sections.

6.1 Conclusion

Present research work focuses on the performance enhancement of a manufacturing firm with the help of value stream mapping and quality function deployment. In the research work, the manufacturing firm is targeted and its performance enhancement is accomplished using different tools, namely, 5S, logistic system improvement, Kaizen and Kanban. For this purpose, first of all existing parameters were investigated with the help of value stream map, followed by the creation of house of quality. In next step, based on the results obtained from house of quality, modifications were made in the firm with the help of modified value stream map. The results show the considerable increment in production efficiency. Following points represent the conclusion of present research work:

- Implementation of performance enhancement tools considerably enhance the performance of a firm;
- 5S implementation is the most important parameter for a firm; and
- Lead time plays very important role in increasing the performance of the firm.

6.2 Limitations of the Research Work

Following points represent the limitations of the research work:

- The research work is limited to a particular type of industry;
- The research work is limited to a particular set of fuzzy numbers;
- The research work is limited to a particular set of performance enhancement parameters.
- An extensive research considering a broader set of industries can be initiated.
- A broad research involving broader sets of fuzzy numbers may be expected.
- An extensive research involving a broader set of performance enhancement parameters can be initiated.

6.3 Future Scope of the Research

Following points represent the future scope of the research work:

- Based on the literature review, it has been found that there has been no concrete research reported on the integration of QFD with VSM frame work for enabling leanness.
- Based on literature review, application of fuzzy QFD for identifying the improvement proposals in VSM framework towards enabling leanness from the scope of this research study.
- Based on the literature review it has been found that lean manufacturing principles Provide scope for ensuring sustainable benefits.
- Though researchers have contributed certain theoretical concepts behind this extension , concrete studies to illustrate the scope of lean principles for ensuring sustainable performance is not justified . This aspect forms the scope of this study.

References and Web Resources

- Abu-Assab, S. Quality Function Deployment in New Product Development. In *Integration of Preference Analysis Methods into Quality Function Deployment*, 2012.
- Almomani, Mohamed Ali, Abdelhakim Abdelhadi, Ahmad Mumani, Amer Momani, and Mohammed Aladeemy. "A proposed integrated model of lean assessment and analytical hierarchy process for a dynamic road map of lean implementation." *The International Journal of Advanced Manufacturing Technology* 72, no. 1 (2014), pp. 161-172.

- Ashrafuzzaman, Md, Abdullah Al-Maruf, I. M. Mahbubul, ABM Abdul Malek, and A. M. M. Mukaddes. "Quality function deployment approach to measure supply chain performance: a case study on garments accessories industries." *International Journal of Industrial and Systems Engineering* 22, no. 1 (2016), pp. 96-120.
- Bowles, J.B. and Pelaez, C.E. (1995), "Application of fuzzy logic to reliability engineering", Proceedings of the IEEE, Vol. 83 No. 3, pp. 435
- Chen, S.J., Hwang, C.L. and Hwang, F.P. (1992), Fuzzy Multiple Attribute Decision Making: (Methods and Applications). Lecture Notes in Economics and Mathematical Systems, Springer
- Chowdhury, Md, Maruf Hossan, Nusrat Jusy Umme, and Md Nuruzzaman. "Strategies for mitigating supply-side barriers in the apparel supply chain: A study on the apparel industry of Bangladesh." *Global Journal of Flexible Systems Management* 19, no. 1 (2018), pp. 41-52.
- Chowdury, M. H., M. Dewan, Md Moazzem Hossain, and M. Quaddus. "An AHP-QFD integrated approach for mitigating the barriers of corporate sustainability." (2012).
- de Mattos Nascimento, Daniel Luiz, Osvaldo Luiz Gonçalves Quelhas, José Moyano-Fuentes, Guilherme Luz Tortorella, and Juan Manuel Maqueira. "Circular value stream mapping 4.0: Proposed general model and application to a digital 3D printing recycling factory." *Sustainable Production and Consumption* 34 (2022), pp. 600-612.
- de Oliveira, Leonardo Medeiros Vaz, Hugo Ferreira dos Santos, Mariana Rodrigues de Almeida, and Jose Alfredo Ferreira Costa. "Quality Function Deployment and Analytic Hierarchy Process: A literature review of their joint application." *Concurrent Engineering* 28, no. 3 (2020), pp. 239-251.
- Fernandes da Silva, Ana Lucia, Jandecy Cabral Leite, Manoel Henrique Reis Nascimento, and David Barbosa de Alencar. "Fuzzy Model for Lean Manufacturing Level Assessment in a Small Metallurgical Industry." *Exacta* 20, no. 1 (2021).
- Gonzalez, M., Quesada, G. and T. Bahill. Improving product design using quality function deployment: The school furniture case in developing countries. Quality Engineering *Journal* Vol.16, No.1 pp.47-58, 2010.
- Hamja, Abu, Malek Maalouf, and Peter Hasle. "The effect of lean on occupational health and safety and productivity in the garment industry–a literature review." *Production & Manufacturing Research* 7, no. 1 (2019), pp. 316-334.
- Hatsey, Niguss Haregot, and Kassu Jilcha Sileyew. "Quality function deployment knowledge transfer to Ethiopian industries and how it can be implemented." *Branna Journal of Engineering and Technology* 1, no. 1 (2019), pp. 1-19.
- Huang, Yu-Che, and Chia-Cheng Hsu. "Network virtual reality clothing silhouette design influencing factors." In *2019 IEEE 4th International Conference on Signal and Image Processing (ICSIP)*, pp. 707-711. IEEE, 2019.
- Kapuria, Taposh Kumar, and C. L. Karmaker. "Customer Driven Quality Improvement of Jute Yarn Using AHP Based QFD: A Case Study." *International Journal for Quality Research* 12, no. 1 (2018).

- Kapuria, Taposh Kumar, and Mustafizur Rahman. "Quality improvement of T-shirt using fuzzy QFD: a case study." *International Journal of Management Concepts and Philosophy* 11, no. 4 (2018), pp. 393-414.
- Klimecka-Tatar, Dorota. "Value stream mapping as lean production tool to improve the production process organization–case study in packaging manufacturing." *Production Engineering Archives* 17, no. 17 (2017), pp. 40-44.
- Klir, G.J. and Yuan, B. (1995), Fuzzy Sets and Fuzzy Logic, Prentice Hall, Upper Saddle River, NJ, pp. 487
- Kumar, B. Senthil, and V. R. Sampath. "Garment manufacturing through lean initiative-an empirical study on WIP fluctuation in T-shirt production unit." *International Journal of Lean Thinking* 3, no. 2 (2012) , pp. 102-116.
- Liao, Wei-Nien, Tseng-Chung Tang, and Li-Chiu Chi. "A Study of Applying Quality Function Deployment & Service Quality Model to Service Quality of Credit Department of Farmers' Association–a Case Study in Taiwan." *International Research Journal of Applied Finance* 8, no. 2 (2017), pp. 47-69.
- Lin, C.T., Chiu, H. and Tseng, Y.H. (2006), “Agility evaluation using fuzzy logic”, International Journal of Production Economics, Vol. 101 No. 2, pp. 353
- Liou, T.S. and Wang, M.J.J. (1992), “Ranking fuzzy numbers with integral value”, Fuzzy sets and systems, Vol. 50 No. 3, pp. 247
- Liu, Chaochao, and Yang Zhang. "Advances and hotspots analysis of value stream mapping using bibliometrics." *International Journal of Lean Six Sigma* ahead-of-print (2022).
- Mayatra, Mehul, N. D. Chauhan, Parthiv Trivedi, and M. N. Qureshi. "Implementation of value stream mapping Methodology in Bearing Industry." *International Journal of advance Research, Ideas and Innovations in Technology, 2 (3)* (2016).
- Murali, C. Shyam, and A. Prabukarthi. "Productivity improvement in furniture industry using lean tools and process simulation." *International Journal of Productivity and Quality Management* 30, no. 2 (2020), pp. 214-233.
- Nash, M., and S. Poling. "Value Stream Mapping: The Complete Guide to Production and Transactional Mapping." (2008).
- Oleghe, Omogbai, and Konstantinos Salonitis. "Variation modeling of lean manufacturing performance using fuzzy logic based quantitative lean index." *Procedia Cirp* 41 (2016), pp. 608-613.
- Paryani, Kioumars, Ali Masoudi, and Elizabeth A. Cudney. "QFD application in the hospitality industry: A hotel case study." *Quality Management Journal* 17, no. 1, 2010.
- Qin, Yanfang, and Hongrui Liu. "Application of Value Stream Mapping in E-Commerce: A Case Study on an Amazon Retailer." *Sustainability* 14, no. 2 (2022), pp. 713.
- Rother, Mike, and John Shook. "Value Stream Mapping." *Lean Enterprise Institute, Cambridge* (1999).

- Shyamal, A.K. and Pal, M. (2007), “Triangular fuzzy matrices”, Iranian Journal of Fuzzy Systems, Vol. 4 No. 1, pp. 75
- Song, Chao, Jian-Qiang Wang, and Jun-Bo Li. "New framework for quality function deployment using linguistic Z-numbers." *Mathematics* 8, no. 2 (2020), pp. 224.
- Talapatra, Subrata, and Jannatul Shefa. "Application of Value Stream Mapping to Improve Financial Performance of a Production Floor: a Case Study." In *Proceedings of the International Conference on Industrial Engineering and Operations Management Bangkok, Thailand, March*, pp. 5-7. 2019.
- Yildiz, Esra Zeynep, and MÜCELLA GÜNER. "Applying value stream mapping technique in apparel industry." *Tekstilve Konfeksiyon* 23, no. 4 (2013) , pp. 393-400.
- Zadeh, L.A. (1965), “Fuzzy sets”, Information and Control, Vol. 8 No. 3, pp. 338
- Zadeh, L.A. (1973), “Outline of a new approach to the analysis of complex systems and decision processes”, Systems, Man and Cybernetics, IEEE Transactions On, Vol. 3 No. 1, pp. 28-44.
- www.sixsigmadsi.com.com