Integration of Lean Principles with Fuzzy FMEA in a Small Scale Casting Industry

S Deepan¹, S Santhosh Raj¹, T S Ponselvan¹, R Praveenkumar¹, J. Alex¹
¹Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamilnadu, India, 641407.

*Corresponding author: deepangamer@gmail.com

Abstract. Economic growth of any nation is depending on the Gross Domestic Product. To improve a country economy, the industries needs to produce gross domestic products at large rate for export. Every industry has value added and non-value added (waste) activities. Non – value added activities always pulls down the efficiency, effectiveness and profit of the industry which will lets to devastating future. In order to overcome the waste many works and research has to be carried out with the focus on lean implementation. Lean implementation should be carried out progressively to obtain fruitful result. This project has been carried out on a casting industry in which non value added activities such as unnecessary transportation, motion, and waiting and high space conception are identified using current state mapping and current state layout. It is highly complicated to implement all the lean tools in a manufacturing system. So to prioritize only few lean tools which are essential to eliminate those wastes and an integrated model (combine fuzzy and FMEA environment) was used. Fuzzy is to avoid ambiguity in observation and FMEA is to prioritize the cause. After eliminating the wastes, future state value stream mapping is drawn and its performance is compared with the existing layout.

Keywords: Lean Manufacturing, value added and non-value added activities, FMEA, Fuzzy, Current state map, Future state map.

1. Introduction
A researcher of International Motor Vehicle Program, John Krafcik kicks off the lean production. Lean production system was established by the Toyota Production System (TPS) in order to maximise efficiency and produce large quantities. [1]. Lean's primary goal in evolving industries is to reduce the amount of input or increase the amount of performance that can be achieved with readily available resources. Organisations are demanding to create quality goods with least inputs with reduced cost, in order to remain best in the competitive global market. This can be achievable by implementing lean principles in industries [2]. Tools and techniques developed and widely used in lean manufacturing can be linked directly to TPS. It is not uncommon to make use of techniques like Single Minute Exchange of Dies (SMED) and One Piece Flow, as well as other methods such as Kaizen, Value Stream Mapping (VSM), Kanban, and cellular manufacturing so on. In manufacturing industries, Material requirement planning (MRP) echoes a positive upshot (major impact) in using the lean tools [3], where discrete manufacturing system make use of the most of these tools with the impeccable results. [4]. Even in process industries, [5] investigated positive effect of performance improvement in pull production system. Lean tools have not only made impressive foot prints in manufacturing side but also in further sectors such as locomotive, microchip technology, end user products, building constructions, hospitals and education. Although lean techniques have many tools available, there are difficulties to overcome include a failure to standardize, a failure to benefit from forecasting, a failure to control the entire value chain, and a lack of foresight for the technology advancements [6]. Even though lean manufacturing tools/ techniques are ample, in order to implement it, proper adoption of
lean tools is indispensable. In this modern age, as lean manufacturing has turn out to be an integrated system, there is still a dearth in standard lean implementation practices [7]. Many researchers [8,9,10] has spoken about the existing industrial problems in recent times but still for effective implementation of LM, they need to introduce several appropriate practicing models for diverse products of industry [11]. Having this idea this study suggests a new and better integrated methodology for dealing with industrial issues.

2. Techniques and Tools

2.1. Value Stream Mapping (VSM)

Starting with the raw materials and working all the way to the customer, there are two types of VSMs: those that focus on value-added (VA) operations and those that focus on non-value-added (NVA) operations, as well as the statistics, facts, and information needed to manufacture a product through the primary flows [4]. The term "value added" refers to any activity that adds importance to the process flow of the product, whereas the operations of product or process that do not add significance, then it termed as "non-value added activities". They can be detected in processes, practises, policies, design, and operations when they are not readily apparent. Not only does VSM play an important role in identifying uselessness in processes, lost data or information, and other non-important activities, but it also directs us toward the development of a new programme [12]. The foundation of mapping is a continuous observation method. Mapping is built on a foundation of collecting data by keeping a close eye on the surroundings. To gather data for a mapping project, it is helpful to observe the production process on the shop floor while it is in progress [13]. VSM is divided into two sections: the current state map (CSM) and the future state map (FSM). An organization's current state map reveals the true condition of activity and the flow of supplies. With the better results of lean implementation in future state is visualised in Future state map [14].

Importance of VSM for lean implementation was signified by many researchers. VSM was successfully used by [15] in an auto parts manufacturing company as a primary diagnostic and planning tool, and advances have been made to most of the functionalities. There have been numerous other studies, such as [16] in the automotive industry, [17] in manufacturing companies,[18] in the textile industry,[19] in the auto component manufacturing industry, [20] in product development, [21] in the supply chain of the Indian Cottonseed oil industry, [22] in house construction that have used VSM and e-learning techniques. These concepts and research methods have influenced my decision to practice VSM to detect the wastes and gave prospects for lean implementation.

2.2 Fuzzy Logic

In order to remove the ambiguity and uncertainty associated with linguistic judgments, fuzzy logic is a concept that uses fuzzy numbers to do so [23]. Fuzzy logic can be used effectively in many industrial applications, but it is less commonly used in the specific use of fuzzy logic in the manufacturing sector [24], compared to automobile and aerospace industries which has some quite few applications [25]. However, the general application of fuzzy logic in manufacturing sectors for performance improvement processes has become widespread [26].

2.3 FMEA

Risk priority number (RPN) is used to describe enhancement priorities in the FMEA basic method. To arrive at the RPN, three indices are multiplied together and then

- A scale from 1 to 10 based on the severity of the failure modes' indicated potential or present effects.
- On a scale of 1 to 10, rate the likelihood that each of the possible failure scenarios will occur; and
- Between 10 and 1, the reliability of the detecting methods to avert failure modes. [27].
3. Methodology

The goal is to identify non-value-added activities and prioritise those using Fuzzy FMEA techniques. As depicted in Figure 1, a proposed step-by-step methodology for accomplishing the goal of this work is outlined. Material flow can be plotted by closely observing the activities taking place. The first step is to identify the waste process based on the current state of the plant layout and the value stream mapping.

![Figure 1. Methodology](image)

3.1 Existing Plant Layout

VSM and plant layout are the first steps in this model's development. Below figure shows the current Plant Layout of the industry. By using the AutoCAD 2018, the plant layout of the company is drawn and analysed.

![Figure 2. Existing Plant Layout](image)

By using the Microsoft Office Visio Professional 2007, the Current state Map is drawn. The overall lead time and overall cycle time can be determined by utilising the Current state Map.

Overall lead time: 2597 min.
Overall cycle time: 1691 min.
3.2 Identification of Waste
So by analysing the plant layout and CSM, the following wastes are identified by discussing with supervisor and Manager.
- Transportation
- Waiting
- Motion

Due to these wastes following issues were formed
- High Lead Time,
- Ineffective Space Utilization,
- Less use of worker

3.3 Integration of FMEA with Fuzzy

3.4 Fuzzy Risk Priority Numbers for FMEA
The risk factors O, S, and D have been widely observed to be difficult to accurately assess. They have thus been evaluated in a linguistic manner, which has taken a significant amount of time and effort. Tables (1-3) shows the linguistic variables and their fuzzy numbers used for evaluating the risk factors.

3.4.1 Fuzzy ratings for occurrence of a failure

| Linguistic Term       | Probability of occurrence | Linguistic Variables |
|-----------------------|----------------------------|----------------------|
| Very high             | Happening is almost inevitable | (9, 10)             |
| High                  | Repeated occurring         | (7, 8)               |
| Moderate              | Occasional happening       | (5, 6)               |
| Low                   | Quite few occurring        | (3, 4)               |
| Remote                | Improbable                 | (1, 2)               |

Table 1 shows the fuzzy linguistic term and linguistic variable for the occurrence of failure.

3.4.2 Fuzzy ratings for detection of a failure

| Linguistic Term       | Likelihood of Detection    | Linguistic Variables |
|-----------------------|----------------------------|----------------------|
| Very high             | Almost Certain             | (8,9)                |
| High                  | High Chance                | (6,7)                |
| Moderate              | Moderate Chance            | (3,4,5)              |
| Low                   | Very Remote Chance         | (1,2)                |
| None                  | No chance                  | (0,1)                |

Table 2 shows the fuzzy linguistic term and linguistic variable for the detection of failure.

3.4.3 Fuzzy ratings for failure severity

| Linguistic Term       | Severity of effect         | Linguistic Variables |
|-----------------------|----------------------------|----------------------|
| Very high             | Very High Bottleneck       | (8,9)                |
| High                  | Problem for Target         | (6,7)                |
| Moderate              | Incompatible with a        | (3,4,5)              |
change
Low System operable with performance loss (1,2)
None No Effect (0,1)
Table 3 shows the fuzzy linguistic term and linguistic variable for the severity of effect.

3.5 FMEA table for RPN calculation

3.5.1 FMEA table for Movement
Failure mode of movement has been identified and analysed in the Table 4.

| Lean system | Assumed condition | Probability of occurrence | Potential effect | Severity | Potential root cause | Detection | RPN | RPN ranking |
|-------------|-------------------|---------------------------|------------------|----------|----------------------|----------|-----|------------|
| Movement    | No Proper Arrangement Of Machine | 7 | High movement | 8 | No gangway | 9 | 504 | 4 |
|             | Movement between work | 8 | High movement | 7 | Initial wrong plan | 7 | 392 | 6 |

From the table 4 RPN values of the movement has been calculated through the occurrence, detection and severity of the failure and RPN ranking has been made. The main reason for the failures in movement parameters were the machine arrangements are not properly done which lets to the high movement of work between the operations. The core root cause for the problem is the wrong ignorant plan while initializing the layout of the industry.

3.6 Corrective Actions
From the tables (4) through the RPN values RPN ranking has been made and the solution has been provided below.

| Problems                          | Solutions                                      |
|-----------------------------------|-----------------------------------------------|
| No Capable & Trained personnel    | Training and Responsibility                   |
| Ineffective job & Workplace       | Safety issue-5S                                |
| No Multifunctional Worker         | Cross Functional training                      |
| Poor Leader Ship                  | Leader Ship training and Motivation            |
| Poor Forecasting                  | Exports                                        |
| No Proper records                 | E-Business suits                               |
| Underutilization of worker        | Key Performance Indicator (KPI)                |
| High Movement                     | Layout Modification                             |
| High Molten wastages              | Installment of low capacity furnace            |
| Improper scheduling               | Time study                                     |
3.7 Modified Plant Layout

Future state maps are created by analysing the new layout which is shown in the figure 3. Tools such as 5S is implemented in pattern shop, knock out and in letter punch. FIFO concept is applied in Pouring and Hand grinding area.

By using the FSM overall lead time and overall cycle time is examined.
Overall lead time: 2317 min
Overall cycle time:1467 min

3.8 Before Scenario VS After Scenario

| Table 6. Time Comparisons |
|---------------------------|
| Overall cycle time (min)  | Overall lead time |
| Current State Map         | 1691              | 2597              |
| Future State Map          | 1467              | 2317              |
| Time Saved                | 224               | 280               |

Table 6 shows the change in the overall cycle time and lead time after implementing the lean tools. And also 98.54 sq.m of space is saved, which can be used for other purposes, including unnecessary transportation of material for about 111.7m is avoided.

4. Results And Discussion

So after implementing lean principles and by modifying the plant layout it is clearly seen that nearly 280min of production time is reduced per unit, which means a worker’s half day working time is saved, which can utilized for other work in the plant. Also for every order 111.7 m transportation of material is avoided, which means waiting time and idle worker is almost reduced. Also due to proper arrangement and modified layout, 98.54 sq.m of space is saved, which can be used for installing required machines in the plant. These results may seem smaller, but in the annual turnover these changes will lead to the big profit. And also due to this profit, with in small period of time management can install a low capacity furnace which will reduce the wastage further. So with all these changes production cost is merely reduced and delivery of product to the customer is done in time.
Here in this work a medium level casting industry is identified and a complete method study and work measurement was carried out. Then with the use of many researchers idea from literature, many tools and techniques of lean manufacturing were identified, in which some of the most powerful tools like 5S, VSM, FIFO and KPI have shown a tremendous change in several industries.

After completely analysing the entire production and manufacturing process, a plan was developed to distribute solutions to the major non value added process. In this to get the linguistic measure of their relative weight and to judge the risk factors, integrated Fuzzy FMEA is used. At first failure modes have been prioritized in view of the relative importance of all the risk factors and then it is evaluated with the integrated Fuzzy FMEA. This proposed method provided a more linguistic, practical and precise result for this casting industry. With the help of the result and ideas, small necessary changes have been made in the plant layout which helped for the undisturbed material flow between various plant location, reduced movement in man and material, which lead to profitable cycle and lead time. That being said, the operative responsible by this task, now can focus on other value-added tasks, as well as not getting so tired of transporting large batches of WIP from station to station, reflecting in its personal productivity.

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