ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 8, February 2013

A Review: Implementation of Failure Mode and Effect Analysis

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Abstract- A failure modes and effects analysis (FMEA) is a procedure in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures. A successful FMEA activity helps a team to identify potential failure modes based on past experience with similar products or processes, enabling the team to design those failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs.

I. INTRODUCTION

A failure modes and effects analysis (FMEA) is a methodology in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures. A successful FMEA activity helps a team to identify potential failure modes, based on past experience with similar products or processes. Failure modes are any errors or defects in a process, design, or item, especially those that affect the customer, and can be potential or actual. Effects analysis refers to studying the consequences of those failures. An example of this is the Apollo Space program. It was also used as application for Hazard Analysis Critical Control Point (HACCP) for the Apollo Space Program, and later the food industry in general. The primary push came during the 1960s, while developing the means to put a man on the moon and return him safely to earth. In the late 1970s the Ford Motor Company introduced FMEA to the automotive industry for safety and regulatory consideration after the Pinto affair. They applied the same approach to processes (PFMEA) to consider potential process induced failures prior to launching production. It is integrated into the Automotive Industry Action Group's (AIAG), Advanced Product Quality Planning (APQP) process to provide risk mitigation in both product and process development phases. Each potential cause must be considered for its effect on the product or process and based on the risk, actions are determined and risks revisited after actions are complete. Toyota has taken this one step further with its Design Review Based on Failure Mode (DRBFM) approach. The method is now supported by the American Society for Quality which provides detailed guides on applying the method. FMEA can provide an analytical approach, when dealing with potential failure modes and their associated causes. When considering possible failures in a design – like safety, cost, performance, quality and reliability – an engineer can get a lot of information about how to alter the development/manufacturing process in order to avoid these failures. The process for conducting an FMEA developed in three main phases, in which appropriate actions need to be defined. But, before starting with an FMEA, it is important to complete some pre-work to confirm that robustness and past history are included in the analysis.

A. What is an FMEA?

"A systematic process for identifying potential design and process failures before they occur, with the intent to eliminate them or minimize the risk associated with them" FMEA procedures are based on standards in the reliability engineering industry, both military and commercial.[4]

B. Types of FMEA

There are several types of FMEA˝s; some are used much more often than others. The types of FMEA˝s are shown in Figure [2].

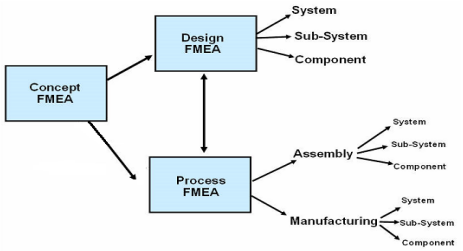


Fig 1. Types of FMEA

Basically two types of FMEA˝s are used in manufacturing industries: (i) The Design FMEA and (ii) The Process FMEA. The Design FMEA is used to analyze products before they are released to production and it focuses on potential failure modes of products, caused by design deficiencies. Design FMEA˝s are normally done at three levels – system, sub-system, and component levels. [2] The Process FMEA is normally used to analyze manufacturing and assembly processes at the system, sub-system or component levels. This type of FMEA focuses on potential failure modes of the process that are caused by manufacturing or assembly process deficiencies. A robustness analysis can be obtained from interface matrices, boundary diagrams and parameter diagrams. A lot of failures are due to noise factors and shared interfaces with other parts and/or systems, because engineers tend to focus on what they control directly. To start, it is necessary to describe the system and its function. A good understanding of FMEA simplifies further analysis. This way an engineer can see which uses of the system are desirable and which are not. It is important to consider both intentional and unintentional uses. Unintentional uses are a form of hostile environment. It is useful to create a coding system to identify the different system elements. Before starting the actual FMEA, a worksheet needs to be created, which contains the

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 8, February 2013

important information about the system, such as the revision date or the names of the components. On this worksheet all the items or functions of the subject should be listed in a logical manner. [2].

C. Objectives of FMEA

- To identify potential design and process failures before they occur and to minimize the risk of failure by either proposing design changes or, if these cannot be formulated, proposing operational procedures. Essentially the FMEA is to.[4]
- Identify the equipment or subsystem, mode of operation and the equipment.[4]
- Identify potential failure modes and their causes.[4]
- Evaluate the effects on the system of each failure mode.[4]
- Identify measures for eliminating or reducing the risks associated with each failure mode.[4]
- Identify trials and testing necessary to prove the conclusions. [4]
- Provide information to the operators and maintainers so that they understand the capabilities and limitations of the system to achieve best performance.[4]

D. How is the FMEA Process Progressed?

- Selecting the team
  - Nominating the required specialists
- Defining the standard
- Defining the reporting procedures
  - e.g. FMEA Team → Client Focal Point → Designers →Client Focal Point → FMEA Team.
- Defining the boundaries of the system to be analysed
  - The benefit of block diagrams. These break the DP system down from a high system level to lower system levels to give a graphic representation of how each system level interacts with another.
- Organising system design information
  - Drawing log
  - Question and Answer ("Q&A") Punchlists
  - Worksheets
- FMEA Report Forms
- Traceability of information
- Evaluating the effects on the system of each failure mode
- Identifying failure detection methods/corrective actions
- Formulating practical FMEA tests, dockside
- Conclusions
- FMEA report structure

E. FMEA Procedure

Following steps are used to implement the FMEA:

1. Severity (S)

Determine all failure modes, based on the functional requirements and their effects. Examples of failure modes are: electrical short-circuiting, corrosion or deformation. A failure mode in one component can lead to a failure mode in another component; therefore each failure mode should be listed in technical terms and for function. Thereafter the ultimate effect of each failure mode needs to be considered. A failure effect is defined as the result of a failure mode on the function of the system as perceived by the user. In this way it is convenient to write these effects down in terms of what the user might see or experience. Examples of failure effects are: degraded performance, noise or even injury to a user. Each effect is given a *severity number (S)* from 1 (no danger) to 10 (critical). These numbers help an engineer to prioritize the failure modes and their effects. If the severity of an effect has a number 9 or 10, actions are considered to change the design by eliminating the failure mode, if possible, or protecting the user from the effect. A severity rating of 9 or 10 is generally reserved for those effects which would cause injury to a user or otherwise result in litigation.

2. Occurrence (O)

In this step it is necessary to look at the cause of a failure mode and the number of times it occurs [5]. This can be done by looking at similar products or processes and the failure modes that have been documented for them in the past [5]. A failure cause is looked upon as a design weakness. All the potential causes for a failure mode should be identified and documented. Again this should be in technical terms.[5]

3. Detection (D)

When appropriate actions are determined, it is necessary to test their efficiency. In addition, design verification is needed. The proper inspection methods need to be chosen. First, an engineer should look at the current controls of the system, that prevent failure modes from occurring or which detect the failure before it reaches the customer. Thereafter one should identify testing, analysis, monitoring and other techniques that can be or have been used on similar systems to detect failures. From these controls an engineer can learn how likely it is for a failure to be identified or detected. Each combination from the previous two steps receives a *detection number (D)*. This ranks the ability of planned tests and inspections to remove defects or detect failure modes in time. The assigned detection number measures the risk that the failure will *escape detection*. A high detection number indicates that the chances are high that the failure will escape detection, or in other words, that the chances of detection are low.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 8, February 2013

After these three basic steps, risk priority number (RPN) is calculated

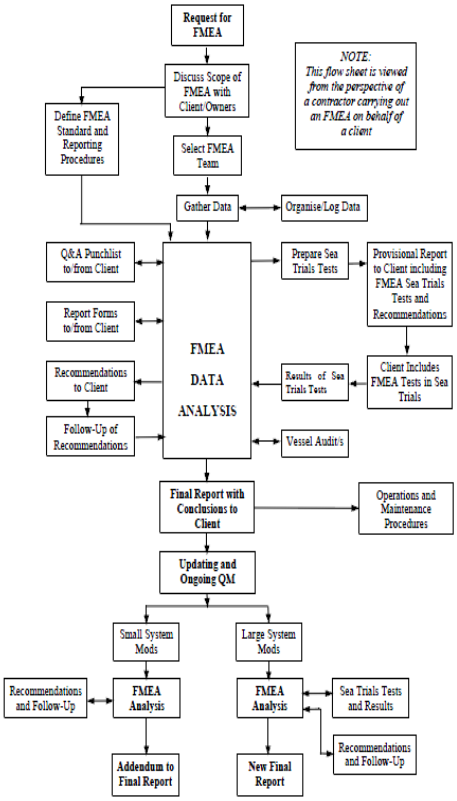
4. Risk priority number (RPN)

Risk priority number (RPN) does not play an important part in the choice of an action against failure modes. They are more threshold values in the evaluation of these actions. After ranking the severity, occurrence and detectability, the RPN can be easily calculated by multiplying these three numbers:

$$RPN = S \times O \times D$$

This has to be done for the entire process and/or design. Once this is done it is easy to determine the areas of greatest concern. The failure modes that have the highest RPN should be given the highest priority for corrective action. This means it is not always the failure modes with the highest severity numbers that should be treated first. There could be less severe failures, but which occur more often and are less detectable. After these values are allocated, recommended actions with targets, responsibility and dates of implementation are noted. These actions can include specific inspection, testing or quality procedures, redesign (such as selection of new components), adding more redundancy and limiting environmental stresses or operating range. Once the actions have been implemented in the design/process, the new RPN should be checked to confirm the improvements. These tests are often put in graphs, for easy visualization. Whenever a design or a process changes, an FMEA should be updated. The applications of FMEA techniques broadly categorized in the following sub-sections in the Literature Review section, as discussed below:

FMEA Process Flow sheet



FMEA Form

Failure Modes Effects Analysis

Process or Product Name:
Process Owner:
Prepared by:
FMEA Date (Orig):
Page ... of ...
Rev.

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **Often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		what are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.				
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II. LITERATURE REVIEW

A. FMEA Designs

- Various researchers have used FMEA in the analysis of products prior to production i.e. in the initial design stage of the product. This research work in this area is discussed as follows:

➢ Janakiram and Keats (1995) found that the FMEA was well-known useful tool in the design process but it is virtually ignored in most process quality improvement paradigms. Sheng and Shin (1996) discussed the implementation of FMEA for both product design and process control. They implemented the FMEA in two ways to ensure that the reliability requirements can be met for the production of an airbag inflator. They performed Design FMEA to generate a process control plan, visual aids, and a process verification list. They also integrated Design FMEA and Process FMEA through reliability prediction and supplier PPM reports. The supplier PPM reports contained the information that can be employed to update the probabilities used in design FMEA.

➢ Pantazopoulos and Tsinopoulos (2005) found that FMEA is one potential tool with extended use in reliability engineering for the electrical and electronic components production field as well as in complicated assemblies (aerospace and automotive industries). The main purpose for study was to reveal system weaknesses and thereby minimize the risk of failure occurrence. They used FMEA technique in the design stage of a system or product (DFMEA) as well as in the manufacturing process (PFMEA). They applied this technique in a critical process in the metal forming industry. Cassanelli et al. (2006) applied ordinary FMEA during the design phase of an electric motor control system for Heating/Ventilation/Air Conditioning (HVAC) vehicle. The analysis of the field data from the second year forced to review FMEA. They planned the corrective actions on the basis of the sole failure mode, as usual in FMEA, and experienced that taken actions are inadequate [5] .

➢ Segismundo and Miguel (2008) proposed a systematization of technical risk management through the use of FMEA to optimize the decision making process in new product development (NPD). They adopted methodological approach to a case study at an automaker in Brazil for two important NPD programs. Their results show a reduction in the number of project and test planning looping as well as a reduced number of prototypes needed to approve product components.

➢ Implementation of FMEA and related techniques are discussed in the initial design stage of the product in this section. Various Failure identification procedures, such as FMEA, failure modes, effects and criticality analysis (FMECA), fault tree analysis (FTA)) and design of experiments etc. have been used for both quality control and for the detection of potential failure modes during the design stage or post-product launch. Although all of these methods have their own advantages, they did not provide the designer with an indication of the predominant failures that should receive considerable attention while the product is being designed.

B. Manufacturing Sectors

➢ Hoseynabadi et al. (2010) used the Failure Modes and Effects Analysis (FMEA) method to study the reliability of a wind turbine (WT) system, using a proprietary software reliability analysis tool. They compared the quantitative results of an FMEA and reliability field data from real wind turbine systems and their assemblies. Their results may be useful for future wind turbine design[s] [7].

III. CONCLUSION

Quality and reliability of products and manufacturing processes are critical to the performance of the final products. They are also important indices for meeting customer satisfaction. In order to fulfill customer's requirements for quality and reliability, some actions for assuring the quality and reliability of products or processes should be taken by all the persons involved. One of the most powerful methods available for measuring the reliability of products or process is FMEA. Probably the greatest criticism of the FMEA has been its limited use in improving designs. Customers are placing increased demands on companies for high quality and reliable products. FMEA provides an easy tool to determine which risk has the greatest concern and therefore an action is needed to prevent a problem before it arises. The development of these specifications will ensure the product will meet the defined requirements. Before starting the actual FMEA, a worksheet needs to be created, which contains the important information about the system, such as the revision date or the names of the components. On this worksheet all the items or functions of the subject should be listed in a logical manner. The initial output of an FMEA is the prioritization of failure modes based on their risk priority numbers and this alone does not eliminate the failure mode. Additional action that might be outside the FMEA is needed. This paper will definitely enhance the knowledge of researchers who really want to carry their research in this area.

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ISSN: 2277-3754
ISO 9001:2008 Certified
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