

Failure Modes and Effects Analysis

Introduction

Customers are placing increased demands on companies for high quality, reliable products. The increasing capabilities and functionality of many products are making it more difficult for manufacturers to maintain the quality and reliability. Traditionally, reliability has been achieved through extensive testing and use of techniques such as probabilistic reliability modeling. These are techniques done in the late stages of development. The challenge is to design in quality and reliability early in the development cycle.

Failure Modes and Effects Analysis (FMEA) is a methodology for analyzing potential reliability problems early in the development cycle. By performing this analysis earlier in the design process, it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures. FMEA can also capture historical design information for use in future product improvement. It can be used to perform the crucial step of anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the design team should formulate as extensive a list of potential failure modes as possible.

Types of FMEA's

There are several types of FMEAs; some used more often than others. FMEAs should always be done whenever failures would mean potential harm or injury to the user of the end item being designed. Among the types of FMEA are:

- System - focuses on global system functions
- Design - focuses on components and subsystems
- Process - focuses on manufacturing and assembly processes
- Service - focuses on service functions
- Software - focuses on software functions

FMEA Usage

Historically, engineers have done a good job of evaluating the functions and the form of products and processes in the design phase. They have not always done so well at designing in reliability and quality. Often the engineer uses safety factors as a way of making sure that the design will work and protected the user against product or process failure. As described in a recent article:

"A large safety factor does not necessarily translate into a reliable product. Instead, it often leads to an over designed product with reliability problems."

Failure Analysis Beats Murphey's Law *Mechanical Engineering*, September 1993

FMEA provides the engineer with a tool that can assist in providing reliable, safe, and customer pleasing products and processes. Since FMEA help the engineer identify potential product or process failures, they can use it to:

- Develop product or process requirements that minimize the likelihood of those failures.
- Evaluate the requirements obtained from the customer or other participants in the design process to ensure that those requirements do not introduce potential failures.
- Identify design characteristics that contribute to failures and design them out of the system or at least minimize the resulting effects.
- Develop methods and procedures to develop and test the product/process to ensure that the failures have been successfully eliminated.
- Track and manage potential risks in the design. Tracking the risks contributes to the development of corporate memory and the success of future products as well.
- Ensure that any failures that could occur will not injure or seriously impact the customer of the product/process.

Benefits of FMEA

FMEA is designed to assist the engineer improve the quality and reliability of design. Properly used the FMEA provides the engineer several benefits. Among others, these benefits include:

- Improve product/process reliability and quality
- Increase customer satisfaction
- Early identification and elimination of potential product/process failure modes
- Helps prioritize product/process deficiencies
- Capture engineering/organization knowledge
- Emphasizes problem prevention
- Documents risk and actions taken to reduce risk
- Provides focus for improved testing and development
- Minimizes late changes in the design and its associated costs
- Provides a catalyst for teamwork and idea exchange

FMEA within the Product Design Cycle

The FMEA is a living document. Throughout the product development cycle change and updates are made to the product and process. These changes can and often do introduce new failure modes. It is therefore important to review and/or update the FMEA when:

- A new product or process is being initiated (at the beginning of the cycle).
- Changes are made to the operating conditions the product or process is expected to function in.
- A change is made to either the product or process design.

- New regulations are instituted.
- Customer feedback indicates problems in the product or process.

FMEA Procedure

The process for conducting an FMEA is straightforward. The basic steps are outlined below.

1. Describe the product/process and its function. A clear understanding of the product or process under consideration is important. This understanding simplifies the process of analysis by helping the engineer identify those product/process uses that fall within the intended overall function and which do not. It is important to consider both intentional and unintentional uses since product failure can end in litigation, which may be costly and time consuming.
2. Create a [Block Diagram](#) of the product or process. This diagram shows major components or process steps as blocks connected together by lines that indicate how the components or steps are related. The diagram shows the logical relationships of components and establishes a structure around which the FMEA can be developed. The block diagram should always be included with the FMEA form. For help in generating a block diagram see the [attached document](#).
3. Complete the header on the FMEA Form worksheet: Product/System, Subsys./Assy., Component, Design Lead, Prepared By, Date, Revision (letter or number), and Revision Date. Modify these headings as needed.
4. Begin listing items or functions in the FMEA worksheet. If items are components, list them in a logical fashion within their subsystem/assembly as indicated on the block diagram.

Identify Failure Modes. A failure mode is defined as the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent. Examples of potential failure modes include:

- Corrosion
 - Hydrogen embrittlement
 - Electrical Short or Open
 - Fatigue
 - Deformation
 - Cracking
5. A failure mode in one component can serve as the cause of a failure mode in another component. Each failure should be listed in technical terms. Failure modes should be listed for functions of each component or process step. The failure mode should be identified whether or not failure is likely to occur. Looking at similar products or processes and the failures that have been documented for them is an excellent starting point.

6. Describe the effects of those failure modes. For each failure mode identify what the ultimate effect will be. A failure effect is defined as “the effect of a failure mode on the product/process function as perceived by the customer.” The effects should be described in terms of what the customer might see or experience should the identified failure occur. Examples of failure effects include:
 - Injury to the user
 - Inoperability of the product or process
 - Improper appearance of the product or process
 - Odors
 - Degraded performance
 - Noise
7. Establish a numerical ranking for the severity of the effect. A common industry standard scale uses 1 to represent no effect and 10 to indicate very severe with failure affecting system operation and safety without warning. The intent of the ranking is to help determine whether a failure would be a minor nuisance or a catastrophic occurrence to the customer. This enables the designer to prioritize the failures and address the real big issues first.
8. Identify the causes for each failure mode. A failure cause is defined as a design weakness that may result in a failure. The potential causes for each failure mode should be identified and documented. The causes should be listed in technical terms and not in terms of symptoms. Examples of potential causes include:
 - Improper torque applied
 - Improper operating conditions
 - Contamination
 - Erroneous algorithms
 - Improper alignment
 - Excessive loading
 - Excessive voltage
9. Enter the Probability factor. A numerical weight should be assigned to each cause that indicates how likely the cause is (i.e. the probability of the cause occurring). A common industry standard scale uses 1 to represent not likely and 10 to indicate inevitable.
10. Identify Current Controls (design or process). Current Controls are the mechanisms that either 1) prevent the cause of the failure mode from occurring or 2) detect the failure before it reaches the Customer. The engineer should identify testing, analysis, monitoring, and other techniques that can or have been used on the same or similar products/processes to detect failures. Each of these controls should be assessed to determine how well it is expected to identify or detect failure modes. Note that after a new product or process has been in use,

previously undetected or unidentified failure modes may appear. The FMEA can then be updated and plans made to address these new failure modes.

11. Determine the likelihood of Detection. Detection is an assessment of the likelihood that the Current Controls (see above) will detect the Cause of the Failure Mode or the Failure Mode itself, thus preventing it from reaching the Customer. Based on the Current Controls, consider the likelihood of Detection using [standard tables](#) for guidance.

12. Review Risk Priority Numbers (RPN). The Risk Priority Number is the mathematical product of the numerical Severity, Probability, and Detection ratings:

$$\text{RPN} = (\text{Severity}) \times (\text{Probability}) \times (\text{Detection})$$

The RPN is used to prioritize items that require additional quality planning or action. Items with a higher RPN are frequently addressed first. However, be aware that a high occurrence and low severity failure may be less critical than a failure with a lower occurrence value but a higher severity.

13. Determine Recommended Action(s) to address potential failures that have a high RPN. These actions could include:

- specific inspection techniques, testing or quality procedures;
- selection of different components or materials;
- limiting operating environmental stresses or operating range;
- redesign of the system to avoid the failure mode;
- inclusion of monitoring mechanisms;
- performing preventative maintenance;
- inclusion of back-up systems or redundancy.

14. Assign Responsibility and a Target Completion Date for these actions. This makes responsibility clear-cut and facilitates tracking.

15. Indicate Actions Taken. After these actions have been taken, re-assess the severity, probability and detection and review the revised RPN's. Are any further actions required?

16. Update the FMEA as the design or process changes, the assessment changes or new information becomes known.