# Safety-Reliability-Risk Assessment: Failure Modes and Effects Analysis (FMEA)

An Online Continuing Education Course for Engineers

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# Safety-Reliability-Risk Assessment: Failure Modes and Effects Analysis (FMEA)

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## 1. INTRODUCTION

Failure modes and effects analysis (FMEA) identifies potential component failures, and assesses their effects on the system. If the criticality of the effects is also considered in the analysis, the analysis is referred to as the failure modes, effects and criticality analysis (FMECA).

During a failure modes and effects analysis, the following questions are answered for each and every component of the system.

1. How can the component fail? (There could be more than one mode of failure)
2. What are the consequences (effects) of the failure?
3. How critical are the consequences?
4. How is failure detected?
5. What are the safeguards against the failure?

(Some failure modes and effects analyses consider only the first two questions, while others consider one or more of the other questions also. What questions are considered depends on the scope and purpose of the analysis.) In answering these questions, all significant failure modes of the different components are identified, their detection and safeguards are documented, and their effects on the system are determined.

Failure modes and effects analysis is used to:

1. Ensure that all conceivable failure modes and their effects are understood.
2. Assist in the identification of design weaknesses.
3. Provide a basis for selecting design alternatives during early stages of design.
4. Provide a basis for recommending design improvements.
5. Provide a basis for corrective action priorities.
6. Provide a basis for recommending test programs.

7. Assist in trouble shooting existing systems with operating problems.

A well-organized failure modes and effects analysis can benefit the design team in a number of ways. It screens the whole system from a failure point of view, thus catching any weak spots in design. Communication about the effects of potential failures is established between the various component design teams and system design teams.

Preliminary hazard analysis is not a pre-requisite for a failure modes and effects analysis. Failure modes and effects analysis may be conducted at the conceptual design stages, preliminary design stages or at later stages of detailed design. In fact, one may conduct progressively more detailed failure modes and effects analyses at different stages of the design process. An initial failure modes and effects analysis may be conducted at the conceptual design stage and the findings are used in improving the conceptual design. Then one or more additional failure modes and effects analyses may be conducted during the preliminary and/or detailed design stages to further improve the design.

Some reliability analysis projects may end at the completion of the failure modes and effects analysis. Other projects may proceed to conduct more rigorous analyses such as the fault tree analysis; it depends on the purpose and scope of the project.

Failure modes and effects analysis may also be used for identifying failure causes in existing systems with operating problems. If a failure modes and effects analysis had been conducted during the design of the system, information from that analysis may be used as the basis for troubleshooting. If necessary, FMEA sheets from the old analysis may be updated using any newly available information.

## 2. ANALYSIS PROCEDURE

Failure modes and effects analysis consists of four steps.

1. Establishment of the scope of the analysis
2. Data collection
3. Preparation of components list
4. Preparation of the failure modes and effects sheets (FMEA sheets)

Each of these steps is described below.

### 2.1. Establishment of the Scope

Scope of the failure modes and effects analysis should clearly identify the following.

1. System boundaries: System boundaries should be specified so that no component is left out of consideration.

2. Extent of the analysis: FMEA sheets may include the following information about each potential component failure.

. Underlying causes of the failure

. Possible effects of the failure

. Failure detection

. Safeguards

. Frequency of the failure

. Criticality of the effects of the failure

All failure modes and effects analyses include information about the first two items listed above. Information about the other items may or may not be included, depending on the scope of the analysis. What information is to be included in the FMEA sheets should be specified in the scope of the FMEA.

The extent of a failure modes and effects analysis may depend on when it is performed. If two failure modes and effects analyses are performed for the same system, one at the conceptual design stage and another at the detailed design stage, the extent of the later analysis may be broader than the former. The extent of a failure modes and effects analysis should be decided on a case-by-case basis depending on the purpose of the analysis.

2.2. Data Collection

The team performing the analysis should have access to all pertinent documents relating to system configurations, designs, specifications and operating procedures. All these documents may not be available at the time of a failure modes and effects analysis. Whatever is available shall be used.

If possible, the analysis team should also interview (in person or by telephone) design personnel, operations, testing and maintenance personnel, component vendors and outside experts to gather as much information as possible and necessary. Sometimes questionnaires may be sent to these personnel in lieu of interviews.

2.3. Preparation of Components List

A list of all components in the system is prepared before examining potential failure modes of each of those components. Functions, operating conditions (temperature, loads, pressure, etc.) and

environmental conditions of each component may be included in the components list. Such a list would be useful during FMEA sheets preparation.

2.4. Preparation of FMEA Sheets

Findings of the failure modes and effects analysis are recorded in a tabular format in FMEA sheets. A sample FMEA sheet is shown in Table 1. There are ten items to be entered. Some of the items may be omitted or left blank depending on the scope of the analysis and information available at the time FMEA sheets are prepared. (NOTE: We have listed each item in a row. Some analysts prefer to list them column-wise. Either practice is acceptable.)

1. Component: The unique identifying name or code of the component is entered here. It is not sufficient to enter "valve"; it is prudent to enter the identifier name or code; for example, Valve-1 or Valve-B2K. This name should correspond to the names used in system drawings, design drawings or other pertinent documents. If it is a part of a component, it may be listed as, for example, "Impeller blades of Pump-17J".

2. Function: A brief statement of the intended function of the component in different modes of operation is entered here. Some failure modes and effects analyses (FMEAs) omit this item.

3. Failure modes: Possible ways in which the component can fail to function as intended are listed here. Failures due to degradation with age (corrosion, fatigue, etc.) should be considered. Possible failure modes in all operating modes of interest (automatic, manual, test, bypass, etc.) should be considered. Operation or shutdown of the system under all possible environmental conditions (earthquake, tornado, flood, etc.) should be considered, as applicable; failure to shutdown, when necessary, could cause property damage and personnel injury. Premature operation (for example, a valve which is expected to close at a certain time closes prematurely), failure to operate at the prescribed time (the valve fails to close when required) and failure during operation should be included. Excessive deformations of components (for example, excessive deflection of a spring), structural failures (for example, collapse of a pipe), etc. should also be included here.

4. Causes of failure: All possible causes of the failure are noted here.

5. Effects of failure: All possible effects of the failure are listed here.

6. Failure detection: How the failure will first become apparent to operating personnel is noted here. Failures may be initially detected because of an alarm, noise, meter reading, cessation of function, etc. Some failures may be detected only during maintenance or testing. This item is omitted in some FMEAs.

7. Safety features: Provisions built into the system that would reduce failure probability or mitigate the effects of the failure are listed here. This item is omitted in some FMEAs.

8. Failure frequency: If the failure probability (failure frequency) is known, it may be noted here.

In some FMEAs, instead of noting a numerical estimate of the failure probability, a frequency classification is noted. A sample frequency classification is given below:

I: Extremely remote; failure probability is less than $10^{-6}$ per hour

II: Remote; failure probability is between $10^{-5}$ and $10^{-6}$ per hour

III: Possible; failure probability is between $10^{-4}$ and $10^{-5}$ per hour

IV: Probable; failure probability is greater than $10^{-4}$ per hour

One may establish other frequency classifications but whatever system is used, it should be used consistently throughout the FMEA.

This item is omitted in some FMEAs. This is ...ient information is not available to esti... FMEA.

9. Criticality of e... ...ality. A sample ranking system is describe...

I: Insignificant; ...bility and availability

II: Minor; not a s... ...bility

III: Major; not a sa... ...lability

IV: Critical; potent...

One may establish oth... ...d, it should be used consistently throu... ...ent.

This item is omitted in s...

10. Remarks: Any comm... ...ant to the failure modes and effects are entered here. Recommendations for system changes may also be made here.



We have presented above a commonly used FMEA format. Other formats include SAE J1739 (by Society of Automotive Engineers International), AIAG FMEA-3 (by Automotive Industry Action Group) and MIL-STD-1629A (by U.S. Department of Defense). Some companies have developed their own formats to suit their specific products and systems. Whatever format is used they contain essentially the same information. FMEA sheets may be prepared on printed or typed forms or prepared using spreadsheets. FMEA software is also available for use in large or inter-related projects.

This course discusses only qualitative FMEA. If a quantitative FMEA is desired either the Risk Priority Number (RPN) method or criticality analysis method may be used. These topics are beyond