Failure Modes, Effects, and Criticality Analysis (FMECA)

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1. General description

Failure Modes, Effects, and Criticality analysis (FMECA) is a tabulation of the system/plant equipment, their failure modes, each failure mode's effect on the system/plant, and a criticality ranking for each failure mode. The failure mode is a description of how equipment fails (open, closed, on, off, leaks, etc.). The effect of the failure mode is the system response or accident resulting from the equipment failure. FMECA identifies single failure modes that either directly result in or contribute significantly to an important accident. Human/operator errors are generally not examined in an FMECA; however, the effects of a mis-operation are usually described by an equipment failure mode. FMECA is not efficient for identifying combinations of equipment failures that lead to accidents.

Criticality rankings are generally expressed as probabilities but may also be indicated in other ways. In some instances, they are designated in categories from 1 to 10 (or from A to Z) to show the principal items that could generate problems. These categories are often not based on probabilities but reflect experience.

2. Uses

a. **Design:** FMECA can be used to identify additional protective features that can be readily incorporated into the design.
b. **Construction:** FMECA can be used to evaluate equipment changes resulting from field modifications.
c. **Operation:** FMECA can be used to evaluate an existing facility and identify existing single failures that represent potential accidents, as well as to supplement more detailed hazard assessment such as Hazop or Fault Tree analysis.

Results: Systematic reference listing of system/ plant equipment, failure modes, and their effects. Easily updated for design changes or system/plant modifications. Basically qualitative. Includes worst-case estimate of consequence resulting from single failures. Contains a relative ranking of the equipment failures based on estimates of failure probability and/or hazard severity.

3. Data requirements

a. System/plant equipment list
b. Knowledge of equipment function
c. Knowledge of system/plant function.

4. Guidelines for using procedure

The FMECA procedure contains five steps:

- Determine level of resolution
- Develop a consistent format
- Define the problem and boundary conditions
- Complete the FMECA table
- Report the results

Each of these is discussed below.

4.1 Determine level of resolution

The level of resolution determines the detail to be included in the FMECA Tables. If a plant-level hazard is being addressed, the FMECA should focus on the individual system or subsystems in the plant and on their failure modes and effects with respect to the plant-level hazard; for example, the FMECA might focus on the feed system, batch mixing system oxidizing system, product separation system, and the various super system that make up the plant. When a system-level hazard is being addressed, the FMECA should focus on individual equipment that makes up the system and on its failure modes and effects with respect to the system-level hazard, such as loss of temperature control in the oxidizing system, the FMECA might focus on the feed pump. Cooling water pump, Cooling water flow control valve, and temperature sensor and alarm that make up the oxidizing system. Of

course, effects identified at the system or equipment level may subsequently be related to potential plant hazards in the FMECA tables.

4.2 Develop a consistent format

A standard FMECA format promotes consistency in the information contained in the FMECA tables and assists in maintaining the level of resolution defined in Step 1. Figure 1 shows as example format for an FMECA table. Additional information, such as the failure mode probability, may be included in the tables to support the criticality ranking definition or other types of hazard assessment. For example, equipment failure probability may be entered in the table to provide as reference source for subsequent quantitative analyses.

4.3 Define the problem and boundary conditions

This step identifies the specific items to be included in the FMECA within the previously defined level of resolution. The problem and boundary condition definition specifically states what systems and equipment are to be included in the FMECA. Minimum requirements for the problem definition include:

- ✓ Identifying the plant and or systems that are the subject of the analysis.

- ✓ Establishing the physical system boundaries that encompass the equipment contained in the FMECA. This statement specifies the interfaces with other processes and utility/support systems and what portions of these interfaces are to be included in the FMECA. One way to indicate the physical system boundaries is to mark them on a system drawing that encompasses all equipment in the FMECA. These boundary conditions should also state the operating conditions at the interface that are assumed for the FMECA.

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PLANT: REFERNCE:----------
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Item	Identification	Description	Failure Modes	Effects	Criticality

Figure 1: Sample format for an FMECA Table

- ✓ Collecting up-to-date reference information that identifies the equipment and its functional relationship to the plan/system. This information is needed for all equipment included within the system boundary.

- ✓ Providing a consistent criticality ranking definition that addresses the potential effects of the equipment failures. Table 1 provides an example of a criticality ranking definition. The criticality ranking may be defined in terms of the probability of the probability of the failure, the severity of the resulting accident, or a combination of these factors. The problem definition may also include other facility-or process-specific assumptions that have a direct influence on the effects resulting from equipment failures.

Table 1: Example of criticality ranking definitions for FMECA

Effects	Criticality Ranking
None Minor process upset, small hazard to facilities and personnel, process shutdown not required	1 (best) 2
Major process upset, significant hazard to facilities and personnel, orderly process shutdown required.	3
Immediate hazard to facilities and personnel, emergency shutdown required	4 (worst)

4.4 Complete the FMECA Table

The FMECA table should be completed in a deliberate, systematic manner to reduce the possibility of omissions and to enhance the completeness of the FMECA. A table can be produced by beginning at a system boundary on a reference drawing and systematically evaluating the items in order as they appear in the process flow path. Each equipment item can then be checked off "red-lined" on the reference drawing when its failure modes have been evaluated completely. All entries for each item or system being addressed in the FMECA should be completed before proceeding to the next item. The following items should be standard entries in the FMECA table:

Equipment Identification: A unique equipment identifier that relates the equipment to a system drawing, process, on location. This identifier distinguishes between similar equipment (e.g., two motor-operated valves) that perform different functions within the same system. Equipment numbers or identifiers from system drawings, such as piping and instrumentation diagrams, are usually available and provide a reference to existing system information.

Equipment Description: The equipment, description should include the equipment type, operating configuration, and other service characteristics (such as high temperature, high pressure, or corrosive service) that may influence the failure modes and their effects: for example, "motor-operated valve, normally open, three-inch sulfuric acid line". These descriptions need not be unique for each item of equipment.

Failure Modes: The analyst should list all failure modes for each item consistent with the equipment description. Considering the equipment's normal operating condition, the analyst should consider all conceivable malfunctions that alter the equipment's normal operation. For example, the failure modes of a normally open valve may include:

- ✓ Fails open (or fails to close when required)
- ✓ Transfers to a closed position
- ✓ Leaks to external environment
- ✓ Valve body ruptures

Table 204 contains additional examples of equipment failure modes. The analyst should concentrate on identifying the various failure modes rather than the potential causes of the failure. Considering various causes will assist in identifying different failure modes. However, the analyst should limit the table entries to failure modes even though there may be several causes of the failure mode. The analyst should include all postulated failure modes so that their effects can be addressed.

Effects: For each identified failure mode, the analyst should describe both the immediate and expected effects of the failure on other equipment and the process or system. For example, the immediate effect of a pump a leak is a spill in the area of the pump. If the fluid is flammable, a fire could be expected (because the pump is a potential ignition source) that might involve additional nearby equipment.

Table 2: Example of Equipment Failure Modes for FMECA

Equipment description	Failure modes
Pump, normally operating	a. Fails on (fails to stop when reared) b. Transfers off c. Seal rupture / leak d. Pump casing rupture / leak
Heat exchanger, high pressure on tube side	a. leak/rupture, tube side to shell side b. Leak/rupture, shell side to external environment c. Tube side, plugged d. Shell side, plugged.

Criticality Ranking: The analyst should classify each failure mode and effect according to the criticality ranking definition developed in the problem definition. Each effect is examined in terms of its hazard and the potential result of that hazard and then compared to the ranking definition for classification.

4.5 Report the results

The result of the FMECA is a systematic and consistent tabulation of the effects of equipment failure within a process or system. The equipment identification in the FMECA provides a direct reference between the equipment and system piping and instrumentation drawings or process flow diagrams. The criticality raining provides relative measure of the equipment failure mode's contribution to the system hazards.

Equipment failures with an unacceptable criticality ranking should be re examined to verify the failure modes and their effects. These failures are the most likely candidates for protective measures, especially if the failure leads directly to a serious accident.

References

1. Guidelines for Hazard Evaluation Procedures, AIChE-CCPS (1985).

2. Hammer, W., Handbook of system and Product Safety, Prentice-Hall, Inc., 1972.

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