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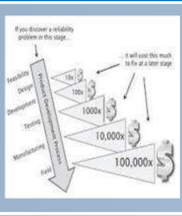


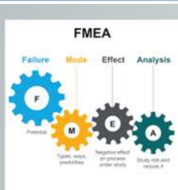


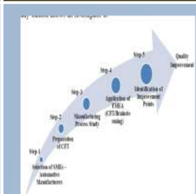


# Failure Mode and Effects Analysis (FMEA) Specialist Certification

## What is Failure Mode and Effects Analysis (FMEA) Specialist Certification?

**Failure mode and effects analysis** (**FMEA**; often written with "failure modes" in plural) is the process of reviewing as many components, assemblies, and subsystems as possible to identify potential failure modes in a system and their causes and effects. For each component, the failure modes and their resulting effects on the rest of the system are recorded in a specific FMEA worksheet. There are numerous variations of such worksheets. An FMEA can be a qualitative analysis, but may be put on a quantitative basis when mathematical failure rate models are combined with a statistical failure mode ratio database. It was one of the first highly structured, systematic techniques for failure analysis. It was developed by reliability engineers in the late 1950s to study problems that might arise from malfunctions of military systems. An FMEA is often the first step of a system reliability study.

A few different types of FMEA analyses exist, such as:

- Functional
- Design
- Process

Sometimes FMEA is extended to FMECA (failure mode, effects, and criticality analysis) to indicate that criticality analysis is performed too.

FMEA is an inductive reasoning (forward logic) single point of failure analysis and is a core task in reliability engineering, safety engineering and quality engineering.

A successful FMEA activity helps identify potential failure modes based on experience with similar products and processes—or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle. *Effects analysis* refers to studying the consequences of those failures on different system levels.

Functional analyses are needed as an input to determine correct failure modes, at all system levels, both for functional FMEA or piece-part (hardware) FMEA. An FMEA is used to structure mitigation for risk reduction based on either failure (mode) effect severity reduction or based on lowering the probability of failure or both. The FMEA is in principle a full inductive (forward logic) analysis, however the failure probability can only be estimated or reduced by understanding the *failure mechanism*. Hence, FMEA may include information on causes of failure (deductive analysis) to reduce the possibility of occurrence by eliminating identified *(root) causes*.

# Introduction

The FME(C)A is a design tool used to systematically analyze postulated component failures and identify the resultant effects on system operations. The analysis is sometimes characterized as consisting of two sub-analyses, the first being the failure modes and effects analysis (FMEA), and the second, the criticality analysis (CA). Successful development of an FMEA requires that the analyst include all significant failure modes for each contributing element or part in the system. FMEAs can be performed at the system, subsystem, assembly, subassembly or part level.
The FMECA should be a living document during development of a hardware design. It should be scheduled and completed concurrently with the design. If completed in a timely manner, the FMECA can help guide design decisions. The usefulness of the FMECA as a design tool and in the decision-making process is dependent on the effectiveness and timeliness with which design problems are identified. Timeliness is probably the most important consideration. In the extreme case, the FMECA would be of little value to the design decision process if the analysis is performed after the hardware is built. While the FMECA identifies all part failure modes, its primary benefit is the early identification of all critical and catastrophic subsystem or system failure modes so they can be eliminated or minimized through design modification at the earliest point in the development effort; therefore, the FMECA should be performed at the system level as soon as preliminary design information is available and extended to the lower levels as the detail design progresses.

Remark: For more complete scenario modelling another type of reliability analysis may be considered, for example fault tree analysis (FTA); a *deductive* (backward logic) failure analysis that may handle multiple failures within the item and/or external to the item including maintenance and logistics. It starts at higher functional / system level. An FTA may use the basic failure mode FMEA records or an effect summary as one of its inputs (the basic events). Interface hazard analysis, human error analysis and others may be added for completion in scenario modelling.

## Functional failure mode and effects analysis

The analysis should always be started by listing the functions that the design needs to fulfill. Functions are the starting point of a well done FMEA, and using functions as baseline provides the best yield of an FMEA. After all, a design is only one possible solution to perform functions that need to be fulfilled. This way an FMEA can be done on concept designs as well as detail designs, on hardware as well as software, and no matter how complex the design.

When performing an FMECA, interfacing hardware (or software) is first considered to be operating within specification. After that it can be extended by consequently using one of the 5 possible failure modes of one function of the interfacing hardware as a cause of failure for the design element under review. This gives the opportunity to make the design robust for function failure elsewhere in the system.

In addition, each part failure postulated is considered to be the only failure in the system (i.e., it is a single failure analysis). In addition to the FMEAs done on systems to evaluate the impact lower level failures have on system operation, several other FMEAs are done. Special attention is paid to interfaces between systems and in fact at all functional interfaces. The purpose of these FMEAs is to assure that irreversible physical and/or functional damage is not propagated across the interface as a result of failures in one of the interfacing units. These analyses are done to the piece part level for the circuits that directly interface with the other units. The FMEA can be accomplished without a CA, but a CA requires that the FMEA has previously identified system level critical failures. When both steps are done, the total process is called an FMECA.

## Ground rules

The ground rules of each FMEA include a set of project selected procedures; the assumptions on which the analysis is based; the hardware that has been included and excluded from the analysis and the rationale for the exclusions. The ground rules also describe the indenture level of the analysis (i.e. the level in the hierarchy of the part to the sub-system, sub-system to the system, etc.), the basic hardware status, and the criteria for system and mission success. Every effort should be made to define all ground rules before the FMEA begins; however, the ground rules may be expanded and clarified as the analysis proceeds. A typical set of ground rules (assumptions) follows:

1. Only one failure mode exists at a time.
2. All inputs (including software commands) to the item being analyzed are present and at nominal values.
3. All consumables are present in sufficient quantities.
4. Nominal power is available

## Benefits

Major benefits derived from a properly implemented FMECA effort are as follows:

1. It provides a documented method for selecting a design with a high probability of successful operation and safety.
2. A documented uniform method of assessing potential failure mechanisms, failure modes and their impact on system operation, resulting in a list of failure modes ranked according to the seriousness of their system impact and likelihood of occurrence.
3. Early identification of single failure points (SFPS) and system interface problems, which may be critical to mission success and/or safety. They also provide a method of verifying that switching between redundant elements is not jeopardized by postulated single failures.
4. An effective method for evaluating the effect of proposed changes to the design and/or operational procedures on mission success and safety.
5. A basis for in-flight troubleshooting procedures and for locating performance monitoring and fault-detection devices.
6. Criteria for early planning of tests.

From the above list, early identifications of SFPS, input to the troubleshooting procedure and locating of performance monitoring / fault detection devices are probably the most important benefits of the FMECA. In addition, the FMECA procedures are straightforward and allow orderly evaluation of the design.

# History

Procedures for conducting FMECA were described in US Armed Forces Military Procedures document MIL-P-1629 (1949); revised in 1980 as MIL-STD-1629A. By the early 1960s, contractors for the U.S. National Aeronautics and Space Administration (NASA) were using variations of FMECA or FMEA under a variety of names. NASA programs using FMEA variants included Apollo, Viking, Voyager, Magellan, Galileo, and Skylab. The civil aviation industry was an early adopter of FMEA, with the Society for Automotive Engineers (SAE, an organization covering aviation and other transportation beyond just automotive, despite its name) publishing ARP926 in

1967. After two revisions, Aerospace Recommended Practice ARP926 has been replaced by ARP4761, which is now broadly used in civil aviation.

During the 1970s, use of FMEA and related techniques spread to other industries. In 1971 NASA prepared a report for the U.S. Geological Survey recommending the use of FMEA in assessment of offshore petroleum exploration. A 1973 U.S. Environmental Protection Agency report described the application of FMEA to wastewater treatment plants. FMEA as application for HACCP on the Apollo Space Program moved into the food industry in general.

The automotive industry began to use FMEA by the mid-1970s. The Ford Motor Company introduced FMEA to the automotive industry for safety and regulatory consideration after the Pinto affair. Ford applied the same approach to processes (PFMEA) to consider potential process induced failures prior to launching production. In 1993 the Automotive Industry Action Group (AIAG) first published an FMEA standard for the automotive industry. It is now in its fourth edition. The SAE first published related standard J1739 in 1994. This standard is also now in its fourth edition. In 2019 both method descriptions were replaced by the new AIAG / VDA FMEA handbook. It is a harmonization of the former FMEA standards of AIAG, VDA, SAE and other method descriptions.

Although initially developed by the military, FMEA methodology is now extensively used in a variety of industries including semiconductor processing, food service, plastics, software, and healthcare. 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. The standard failure modes and effects analysis (FMEA) and failure modes, effects and criticality analysis (FMECA) procedures identify the product failure mechanisms, but may not model them without specialized software. This limits their applicability to provide a meaningful input to critical procedures such as virtual qualification, root cause analysis, accelerated test programs, and to remaining life assessment. To overcome the shortcomings of FMEA and FMECA a failure modes, mechanisms and effect analysis (FMMEA) has often been used.

## Basic terms

The following covers some basic FMEA terminology.

**Action priority (AP)**

The AP replaces the former risk matrix and RPN in the AIAG / VDA FMEA handbook 2019. It makes a statement about the need for additional improvement measures.

**Failure**

The loss of a function under stated conditions.

**Failure mode**

The specific manner or way by which a failure occurs in terms of failure of the part, component, function, equipment, subsystem, or system under investigation. Depending on the type of FMEA performed, failure mode may be described at various levels of detail. A piece part FMEA will focus on detailed part or component failure modes (such as fully fractured axle or deformed axle, or electrical contact stuck open, stuck short, or intermittent). A functional FMEA will focus on functional failure modes. These may be general (such as no function, over function, under function, intermittent function, or unintended function) or more detailed and specific to the equipment being analyzed. A PFMEA will focus on process failure modes (such as inserting the wrong drill bit).

**Failure cause and/or mechanism**

Defects in requirements, design, process, quality control, handling or part application, which are the underlying cause or sequence of causes that initiate a process (mechanism) that leads to a failure mode over a certain time. A failure mode may have more causes. *For* *example; "fatigue or corrosion of a structural beam" or "fretting corrosion in an electrical contact" is a failure mechanism and in itself (likely) not a failure mode. The related failure mode (end state) is a "full fracture of structural beam" or "an open electrical contact". The initial cause might have been "Improper application of corrosion protection layer (paint)" and /or "(abnormal) vibration input from another (possibly failed) system".*

**Failure effect**

Immediate consequences of a failure on operation, or more generally on the needs for the customer / user that should be fulfilled by the function but now is not, or not fully, fulfilled.

**Indenture levels (bill of material or functional breakdown)**

An identifier for system level and thereby item complexity. Complexity increases as levels are closer to one.

**Local effect**

The failure effect as it applies to the item under analysis.

**Next higher-level effect**

The failure effect as it applies at the next higher indenture level.

**End effect**

The failure effect at the highest indenture level or total system.

**Detection**

The means of detection of the failure mode by maintainer, operator or built in detection system, including estimated dormancy period (if applicable).

**Probability**

The likelihood of the failure occurring.

**Risk priority number (RPN)**

Severity (of the event) × probability (of the event occurring) × detection (probability that the event would not be detected before the user was aware of it).

**Severity**

The consequences of a failure mode. Severity considers the worst potential consequence of a failure, determined by the degree of injury, property damage, system damage and/or time lost to repair the failure.