Failure Modes & Effects Analysis

The Failure Modes and Effects Analysis (FMEA), also known as Failure Modes, Effects, and Criticality Analysis (FMECA), is a systematic method by which potential failures of a product or process design are identified, analysed and documented. Once identified, the effects of these failures on performance and safety are recognised, and appropriate actions are taken to eliminate or minimise the effects of these failures. An FMEA is a crucial reliability tool that helps avoid costs incurred from product failure and liability.

Project activities in which the FMEA is useful:

- ☛ Throughout the entire design process but is especially important during the concept development phase to minimise cost of design changes
- ☛ Testing
- ☛ Each design revision or update

Other tools that are useful in conjunction with the FMEA:

- ☛ Brainstorming
- ☛ Fault Tree Analysis (FTA)
- ☛ Risk Management

Introduction

The FMEA process is an on-going, bottom-up approach typically utilised in three areas of product realization and use, namely design, manufacturing and service. A design FMEA examines potential product failures and the effects of these failures to the end user, while a manufacturing or process FMEA examines the variables that can affect the quality of a process. The aim of a service FMEA is to prevent the misuse or misrepresentation of the tools and materials used in servicing a product.

There is not a single, correct method for conducting an FMEA, however the automotive industry and the U.S. Department of Defense (Mil-Std-1629A) have standardised procedures/processes within their respective realms. Companies who have adopted the FMEA process will typically adapt and apply the process to meet their specific needs. Typically, the main elements of the FMEA are:

- The ***failure mode*** that describes the way in which a design fails to perform as intended or according to specification;
- The ***effect*** or the impact on the customer resulting from the failure mode; and
- the ***cause***(s) or means by which an element of the design resulted in a failure mode.

It is important to note that the relationship between and within failure modes, effects and causes can be complex. For example, a single cause may have multiple effects or a combination of causes could result in a single effect. To add further complexity, causes can result from other causes, and effects can propagate other effects.

Who Should Complete the FMEA

As with most aspects of design, the best approach to completing an FMEA is with cross-functional input. The participants should be drawn from all branches of the organisation including purchasing, marketing, human factors, safety, reliability, manufacturing and any other appropriate disciplines. To complete the FMEA most efficiently, the designer should conduct the FMEA concurrently with the design process then meet with the cross-functional group to discuss and obtain consensus on the failure modes identified and the ratings assigned.

Relationship between Reliability and Safety

Designers often focus on the safety element of a product, erroneously assuming that this directly translates into a reliable product. If a high safety factor is used in product design, the result may be an overdesigned, unreliable product that may not necessarily be able to function as intended. Consider the aerospace industry that requires safe and reliable products that, by the nature of their function, cannot be overdesigned.

Application of the Design FMEA

As mentioned previously, there is not one single FMEA method. The following ten steps provide a basic approach that can be followed in order to conduct a basic FMEA. An example of a table lamp is used to help illustrate the process. Attachment A provides a sample format for completing an FMEA.

Step 1: Identify components and associated functions

The first step of an FMEA is to identify all of the components to be evaluated. This may include all of the parts that constitute the product or, if the focus is only part of a product, the parts that make up the applicable sub-assemblies. The function(s) of each part within in the product are briefly described.

Example:

Part Description	***Part Function***
Light bulb	*Provides $x \pm y$ lux of illumination*
Plug	*2 wire electrical plug*
Cord	*Conducts power from outlet to lamp*

Step 2: Identify failure modes

The potential failure mode(s) for each part are identified. Failure modes can include but are not limited to:

- complete failures
- partial failures
- incorrect operation
- failure to cease functioning at allotted time
- intermittent failures
- failures over time
- premature operation
- failure to function at allotted time

It is important to consider that a part may have more than one mode of failure.

Example:

Part Description	***Failure Mode***
Cord	*Short circuit*
	Open curcuit
	Insulation failure

Step 3: Identify effects of the failure modes

For each failure mode identified, the consequences or effects on product, property and people are listed. These effects are best described as seen though the eyes of the customer.

Example:

Failure Mode	***Failure Effects***
Short	*No light/ Electrical fire/ Blown fuse*
Insulation fail	*Shock/injury hazard*

Step 4: Determine severity of the failure mode

The severity or criticality rating indicates how significant of an impact the effect is on the customer. Severity can range from insignificant to risk of fatality. Depending on the FMEA method employed, severity is usually given either a numeric rating or a coded rating. The advantage of a numeric rating is the ability to be able to calculate the Risk Priority Number (RPN) (see Step 9). Severity ratings can be customised as long as they are well defined, documented and applied consistently. Attachment B provides examples of severity ratings.

Example:

Failure Effects	***Severity***
No light	*8-Very high*
Shock/injury hazard	*10-Hazardous-no warning*

Step 5: Identify cause(s) of the failure mode

For each mode of failure, causes are identified. These causes can be design deficiencies that result in performance failures, or induce manufacturing errors.
Example:

Failure Mode	***Cause***
Insulation failure	*Cord pinched*

Step 6: Determine probability of occurrence

This step involves determining or estimating the probability that a given cause or failure mode will occur. The probability of occurrence can be determined from field data or history of previous products. If this information is not available, a subjective rating is made based on the experience and knowledge of the cross-functional experts.

Two of the methods used for rating the probability of occurrence are a numeric ranking and a relative probability of failure. Attachment C provides an example of a numeric ranking. As with a numeric severity rating, a numeric probability of occurrence rating can be used in calculating the RPN. If a relative scale is used, each failure mode is judged against the other failure modes. High, moderate, low and unlikely are ratings that can be used. As with severity ratings, probability of occurrence ratings can be customised if they are well defined, documented and used consistently.

Example:

Cause	***Prob. Of Occurrence***
Cord pinched	*2-Low (few failures)*

Step 7: Identify controls

Identify the controls that are currently in place that either prevent or detect the cause of the failure mode. Preventative controls either eliminate the cause or reduce the rate of occurrence. Controls that detect the cause allow for corrective action while controls that detect failure allow for interception of the product before it reaches subsequent operations or the customer.

Example:

Cause	**_Current controls_**
Cord pinched	*Review CSA standards*
	Warranty data from preceding products

Step 8: Determine effectiveness of current controls

The control effectiveness rating estimates how well the cause or failure mode can be prevented or detected. If more than one control is used for a given cause or failure mode, an effectiveness rating is given to the group of controls. Control effectiveness ratings can be customised provided the guidelines as previously outlined for severity and occurrence are followed. Attachment D provides example ratings.

Example:

Current controls	**_Control effectiveness_**
Review CSA standards	*5-Moderate*
Warranty data from preceding products	

Step 9: Calculate Risk Priority Number (RPN)

The RPN is an optional step that can be used to help prioritise failure modes for action. It is calculated for each failure mode by multiplying the numerical ratings of the severity, probability of occurrence and the probability of detection (effectiveness of detection controls) (RPN=S x O x D). In general, the failure modes that have the greatest RPN receive priority for corrective action. The RPN should not firmly dictate priority as some failure modes may warrant immediate action although their RPN may not rank among the highest.

Step 10: Determine actions to reduce risk of failure mode

Taking action to reduce risk of failure is the most crucial aspect of an FMEA. The FMEA should be reviewed to determine where corrective action should be taken, as well as what action should be taken and when. Some failure modes will be identified for immediate action while others will be scheduled with targeted completion dates. Conversely, some failure modes may not receive any attention or be scheduled to be reassessed at a later date.

Actions to resolve failures may take the form of design improvements, changes in component selection, the inclusion of redundancy in the design, or incorporation design for safety aspects. Regardless of the recommended action, all should be documented, assigned and followed to completion.

References

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Attachment A

FMEA Form

Failure Modes & Effect Analysis

Product: ______________________________ Completed by: ______________________________

Date Completed: ________________________ Revision No.: ______________________________

Item/Part No.	Part Description	Part Function	Failure Mode	Failure Effects	Severity	Causes	Prob. of Occurrence	Current Controls	Control Effectiveness	RPN	Recommended Actions
Step 1			Step 2	Step 3	S4	Step 5	S6	Step 7	S8	S9	Step 10

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Attachment B

Severity Ratings

Example 1

Critical	Safety hazard. Causes or can cause injury or death.
Major	Requires immediate attention. System is non-operational.
Minor	Requires attention in the near future or as soon as possible. System performance is degraded but operation can continue.
Insignificant	No immediate effect on system performance.

Example 2

1	None	Effect will be undetected by customer or regarded as insignificant.
2	Very minor	A few customers may notice effect and may be annoyed.
3	Minor	Average customer will notice effect.
4	Very low	Effect recognised by most customers.
5	Low	Product is operable, however performance of comfort or convenience items is reduced.
6	Moderate	Products operable, however comfort or convenience items are inoperable.
7	High	Product is operable at reduced level of performance. High degree of customer dissatisfaction.
8	Very high	Loss of primary function renders product inoperable. Intolerable effects apparent to customer. May violate non-safety related governmental regulations. Repairs lengthy and costly.
9	Hazardous – with warning	Unsafe operation with warning before failure or non-conformance with government regulations. Risk of injury or fatality.
10	Hazardous – without warning	Unsafe operation without warning before failure or non-conformance with government regulations. Risk of injury or fatality.

Attachment C

Probability of Occurrence Ratings[1]

1	Unlikely	≤ 1 in 1.5 million (≤ .0001%)
2	Low (few failures)	1 in 150, 000 (≤ .001%)
3		1 in 15, 000 (≤ .01%)
4	Moderate (occasional failures)	1 in 2,000 (0.05%)
5		1 in 400 (0.25%)
6		1 in 80 (1.25%)
7	High (repeated failure)	1 in 20 (5%)
8		1 in 8 (12.5%)
9	Very high (relatively consistent failure)	1 in 3 (33%)
10		≥1 in 2 (50%)

Note: if a failure rate falls between two values, use the lower rate of occurrence. For example, if failure is 1 in 5, use a rating of 8.

[1] Values from www.fmeca.com/ffmethod/tables/dfmeal.htm (January 2000)

Attachment D

Control Effectiveness Ratings

1	Excellent; control mechanisms are foolproof.
2	Very high; some question about effectiveness of control.
3	High; unlikely cause or failure will go undetected.
4	Moderately high
5	Moderate; control effective under certain conditions.
6	Low
7	Very low
8	Poor; control is insufficient and causes or failures extremely unlikely to be prevented or detected.
9	Very poor
10	Ineffective; causes or failures almost certainly not prevented or detected.