FMEA - FMECA

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1. Introduction

During the last decades customers changed their buying behavior. After World War II the customer demand was very high and unsatisfied. Suppliers were producing only necessary goods and in restricted quantities. During the time transaction between customer and suppliers took place. The transaction from the typical sellers market too the buyers market was the result.

Globalization and World Wide Web are keywords for the society nowadays. Due to the fact that time and distance are becoming relative, customers are placing increased demands on high quality and reliable products. Therefore manufacturers invest a lot of time and money to increase quality. But 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.

Therefore engineers introduced *Failure Modes and Effects Analysis* (FMEA). FMEA is a methodology for analyzing potential reliability problems early in the development cycle where 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. A crucial step is anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible. [1]

The early and consistent use of FMEA in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEA does also capture historical information for use in future product improvement.

[1] Crow, Kenneth (2002) Failure Modes and Effects Analysis (FMEA):Online: URL: http://www.npd-solutions.com/fmea.html; [28.04.2005]

2. Definitions

To gain a better comprehension we should define some terms in the following pages. Therefore we start with the definition of FMEA and FMECA.

2.1. What is FMEA - Failure Modes and Effects Analysis?

Let us take a look into the World Wide Web, there we can find several definitions of FMEA. The National Aeronautics and Space Administration (NASA)[2] define FMEA as *a forward logic (bottom-up), tabular technique that explores the ways or modes in which each system element can fail and assesses the consequences of each of these failures.* For them *FMEA is a useful tool for cost and benefit studies to implement effective risk mitigation and countermeasure.* It is also *a precursor to a fault tree analysis (FTA).*

For Wikipedia[3], the free online encyclopedia, *Failure Mode and Effect Analysis is a method that examines potential product or process failures, evaluates risk priorities, and helps determine remedial actions to avoid identified problems. It is an integral part of any ISO 9000 compliant quality system.*

Also the American Society for Quality[4] has his own approach to Failure Mode Effects Analysis. For them it is a *procedure in which each potential failure mode in every sub item of an item is analyzed to determine its effect on other sub items and on the required function of the item.*

All these definitions have some terms in common. There is always a system and an examination of potential failures. After that follows an assessment of the identified failures.

[2] NASA online: URL: http://pbma.hq.nasa.gov/mainframe_docs/Hardware_Design/4_3_4_5.htm ; [28.04.2005]

[3] Wikipedia (2005): FMEA: online: URL:http://en.wikipedia.org/wiki/FMEA ; [30.04.2005]

[4] American Society for Quality: FMEA: online: URL: http://www.asq.org/info/glossary/f.html; [28.04.2005]

2.2. What is FMECA - Failure Modes Effects and Criticality Analysis?

The next step in the FMEA evolution was FMECA. FMECA is an acronym for Failure Modes and Effects Criticality Analysis. The American Society for Quality[5] define it as a *procedure that is performed after a failure mode effects analysis to classify each potential failure effect according to its severity and probability of occurrence.*

2.3. Background Information

The FMEA process was originally developed by the US military in 1949 to classify failures "according to their impact on mission success and personnel/equipment safety". FMEA has since been used on the 1960s Apollo space missions. Also large Motor Companies like Ford used FMEA in the 1980s. The aim was to reduce risks after one model of car, the Pinto, suffered a fault in several vehicles causing the fuel tank to rupture and it to subsequently burst into flames after crashes.[6]

FMECA has been developed by NASA, and several useful databases of failure rates and failure modes have been compiled by the Reliability Analysis Center (RAC), a U.S. Department of Defense Information Analysis Center. One important Report is the Failure Mode, Effects, and Criticality Analysis (FMECA) Report Number F30602-91-C-0002 from the RAC.[7]

Various industries have their own Failure Mode and Effects Analysis standards. Aerospace and defense companies generally use either the MIL-STD-1629A FMECA standard (failure mode effect and criticality analysis) or the SAE ARP5580 FMEA standard. Automotive suppliers use SAE J1739 FMEA's, or they may use the Automotive Industry Action Group (AIAG FMEA), Daimler Chrysler,

[5] American Society for Quality: FMECA online: URL: http://www.asq.org/info/glossary/f.html; [28.04.2005]

[6] Wikipedia (2005): FMEA: online: URL:http://en.wikipedia.org/wiki/FMEA ; [30.04.2005]

[7] Predictive Maintenance Corporation (2004) FMECA Introduction: online: URL: http://www.pmaint.com/EFMECA.html ; [10.05.2005]

Ford, or GM FMEA methodologies. Other industries generally adopt one of these FMEA standards or others such as IEC 60812 or BS 5760, sometimes customizing them to meet their own requirements.[8]

3. Theoretical Approach

After the theoretical definitions about FMEA and FMECA in the chapter before, we have to distinguish between different types of FMEA's and the usage of FMEA. But the main part of the following chapter discussed the FMEA process.

But first let as take a look on one further standard. The IEEE Standard 352-1975 is the *IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems*. There they define the purposes of an FMEA as being to assist in selecting design alternatives with high reliability and high safety potential during early design phase and ensure that all conceivable failure modes and their effects on operational success of the system have been considered. The next step should be to list potential failures and identify the magnitude of their effects. Then to develop early criteria's for test planning and the design of the test and check-out systems. The FMEA can then provide a basis for quantitative reliability and availability analyses and also provide historical documentation for future reference to aid in analysis of field failures and consideration of design changes. It can also provide input data for trade off studies and provide basis for establishing corrective action priorities. FMEA assist in the objective evaluation of design requirements related to redundancy, failure detection systems, fail-safe characteristics and automatic and manual override.[9]

3.1. Types of FMEA's

There are several types of FMEA's. Some o them are used much more often than others. FMEA's should always be done whenever failures would mean potential

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[8] Relex Software (2005) FMEA/FMECA: online URL:
http://www.relexsoftware.com/products/fmeafmeca.asp ; [10.05.2005]

[9] Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems ; IEEE Std 352-1975;

harm or injury to the user of the end item being designed. The different types of FEA can be seen in table 3-1.

FMEA – types	usage
System	focuses on global system functions
Design or Construction	focuses on components and subsystems
Process	focuses on manufacturing and assembly processes
Service	focuses on service functions
Software	focuses on software functions

table 3-1: FMEA types

3.2. FMEA Timing

What is the right timing for FMEA? Failure Modes and Effects Analysis is a living document. Throughout the product development cycle change and updates are made to the product and process. As a matter of fact these changes can and often do introduce new failure modes. And so it is therefore important to review and update the FMEA in special cases like when a new product or process is being initiated (at the beginning of the cycle) or changes are made to the operating conditions the product or process is expected to function in. Next possible reason for changing the FMEA is when a change is made to either the product or process design. The product and process are inter-related that means when the product design is changed the process is impacted and vice versa. Two further reasons are new regulations are instituted and last but not least customer feedback indicates problems in the product or process. [10]

It is also possible to perform an FMEA with limited design information. But in this case the basic questions should be answered by the FMEA. These questions are:

- How can each part conceivably fail?
- What mechanisms might produce these modes of failure?
- What could the effects be if these failures did occur?
- Is the failure in the safe or unsafe direction?

[10] Crow, Kenneth (2002) Failure Modes and Effects Analysis (FMEA):Online: URL: http://www.npd-solutions.com/fmea.html; [18.05.2005]

- How is the failure detected?
- What inherent provisions are provided in the design to compensate for the failure?

3.3. FMEA usage

When do we use FMEA? In the past, engineers have done a good job of evaluating the functions and the form of products and processes in the design phase. But the designing in reliability and quality was a huge problem. 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 an article from the Mechanical Engineering:

> *"A large safety factor does not necessarily translate into a reliable product. Instead, it often leads to an over designed product with reliability problems."*[11]

With FMEA the engineer get a tool with can assist in providing reliable, safe, and customer pleasing products and processes. FMEA helps the engineer to identify potential product or process failures.

FMEA can be used to develop product or process requirements that minimize the likelihood of those failures. FMEA is also the basis for:

- 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.

[11] Failure Analysis Beats Murphy's Law; Mechanical Engineering , September 1993

FMEA ensures that any failures that could occur will not injure or seriously impact the customer of the product or process. [12]

3.4. FMEA Procedure

figure 3-1: FMEA Process[13]

There are several different approaches to do a Failure Modes and Effects Analysis. One possible way is described in the following chapter. This way is a combination of two different internet sources. One is from Kenneth Crow[14] and the

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[12] Crow, Kenneth (2002) Failure Modes and Effects Analysis (FMEA):Online: URL: http://www.npd-solutions.com/fmea.html; [18.05.2005]

[13] CAQ AG (2004) Failure Modes and Effects Analysis online: URL: http://www.caq.de/english/default.asp [16.05.2005]

[14] Crow, Kenneth (2002) Failure Modes and Effects Analysis (FMEA):Online: URL: http://www.npd-solutions.com/fmea.html; [18.05.2005]

other from Nomogen[15]. In figure 3-1 we can see an overview about the FMEA procedure.

It starts with the *FMEA Planning and Team Creation* down to *FMEA – Development* and then to the *Evaluation* of the results.

3.4.1. Preparation

Before undertaking an FMEA it is essential to undertake certain preparatory steps. The scope will depend on the complexity of the system being studied. First we have to define the system and its mission which should be analyzed. After that a description of the operation of the system has to be performed. And in the next steps the failure categories and the environmental conditions should be identified and described.

3.4.2. Describing the product or process

We start with *describing the product or process* and its function. An overall understanding of the product or process is very important. This understanding simplifies the process of analysis by helping the engineer identify those product/process uses that fall within the intended function and which ones fall outside. It is important to consider both intentional and unintentional uses since product failure often ends in litigation, which can be costly and time consuming.

3.4.3. Creating a Block Diagram

In the next step we are *creating 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.

[15] Nomogen (2005): Failure Mode and Effect Analysis - Methodology: online: URL: http://www.nomogen.co.uk/QualityPublications/fmea.htm; [15.05.2005]

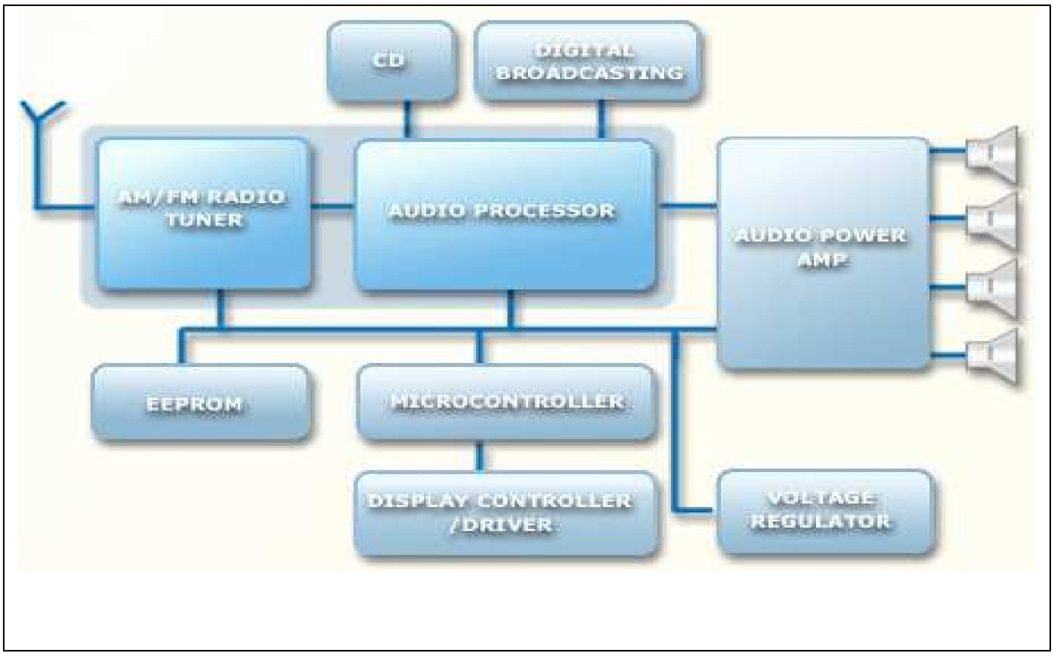

figure 3-2: Example for a Block-Diagram (Car radio)

3.4.4. Header of the FMEA Form worksheet

As we can see in the example worksheet in figure 3-3 the missing headings should be completed as needed. Some proper headings are Product/System, Subsystem, Component, Design Lead, Prepared By, Revision (letter or number), Revision Date and FMEA-Date.

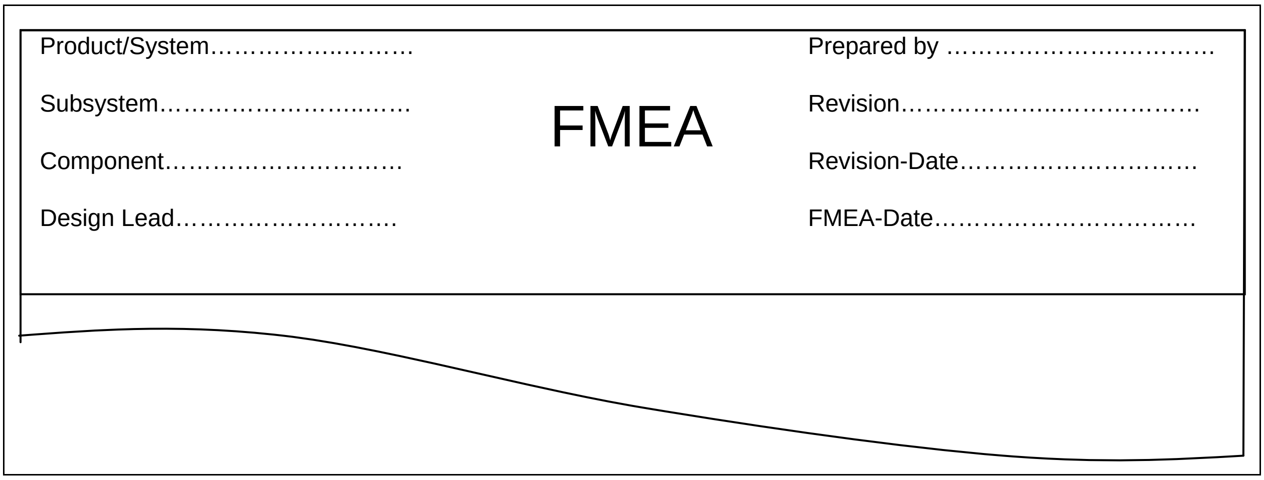

figure 3-3: Example on an FMEA worksheet header

In the next step use a table like table 3-2: Example FMEA for ball-point pen to begin listing parts and functions. If items are components, list them in a logical manner under their subsystem/assembly based on the block diagram.

After that we have to identify Failure Modes. A failure mode is defined as the manner in which a component, subsystem, system, process, etc. could potentially fail. 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.

At this point the failure mode should be identified whether or not the 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.

Describe the effects of those failure modes. For each failure mode identified the engineer should determine what the ultimate effect will be. A failure effect is defined as the result of a failure mode on the function of the product/process as perceived by the customer. They should be described in terms of what the customer might see or experience should the identified failure mode occur. The customer is to see as internal as well as external one. Some examples of failure effects are e.g. injury to the user, inoperability of the product or process, degraded performance, noise, etc.

Part	Function	Potential Failure Mode	Potential effects of failure	SEVERITY	Potential causes of failure	OCCURRENE	How will the potential failure be detected?	DETECTION	RPN	Actions
Outer tube	Provides grip for writer	Hole gets blocked	Vacuum on ink supply stops flow	7	Debris ingress into hole	3	Check clearance of hole	5	105	Make hole larger
Ink	Provide writing medium	Incorrect viscosity	High flow	4	Too much solvent	2	QC on ink supply	4	32	Introduce more rigid QC
Ink	Provide writing medium	Incorrect viscosity	Low flow	4	Too little solvent	2	QC on ink supply	3	24	No action required

table 3-2: Example FMEA for ball-point pen[16]

3.4.5. Severity

Severity is an assessment of the seriousness of the effect and refers directly to the potential failure mode being studied. The Customer in process FMEA is both the internal and where appropriate, external Customer. The severity ranking is also an estimate of how difficult it will be for the subsequent operations to be carried out to its specification in Performance, Cost, and Time. The Ranking and suggested criteria are listed in table 3-3.

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 the analyst determine whether a failure would be a minor nuisance or a catastrophic occurrence to the customer. This enables the engineer to prioritize the failures and address the real big issues first.

Effect	**Criteria**	**Severity of Effect**	**Rank**
None		No Effect	1
Very Minor	Minor disruption to production line	A portion of the product may have to be reworked. Defect not noticed by average customers; cosmetic defects.	2
Minor	Minor disruption to production line.	A portion of the product may have to be reworked. Defect noticed by average customers; cosmetic defects.	3
Very Low	Minor disruption to production line.	The product may have to be sorted and reworked. Defect noticed by average customers; cosmetic defects.	4
Low	Some disruption to product line.	100% of product may have to be reworked. Customer has some dissatisfaction. Item is fit for purpose but may have reduced levels of performance.	5
Moderate	Some disruption to product line.	A portion of the product may have to be scrapped. Customer has some dissatisfaction. Item is fit for purpose but may have reduced levels of performance.	6
High	Some disruption to product line.	Product may have to be sorted and a portion scrapped. Customer dissatisfied. Item is useable but at reduced levels of performance.	7
Very High	Major disruption to production line.	100% of product may have to be scrapped. Loss of primary function. Item unusable. Customer very dissatisfied.	8
Hazard with warning	May endanger machine or operator.	Failure occurs with warning. The failure mode affects safe operation and involves noncompliance with regulations	9

Hazard without warning	May endanger machine or operator	Failure occurs without warning. The failure mode affects safe operation and involves noncompliance with regulations	10

table 3-3: Severity Ranking and suggested criteria[17]

3.4.6. Causes of failure mode

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, too much solvent, improper alignment, excessive voltage etc.

3.4.7. Occurrence

The *Occurrence* is the assessment of the probability that the specific cause of the Failure mode will occur. A numerical weight should be assigned to each cause that indicates how likely that cause is (probability of the cause occurring).

For that failure history is helpful in increasing the truth of the probability. Therefore historical data stored in databases can be used and questions like the following are very helpful to solve this problem.

- What statistical data is available from previous or similar process designs?
- Is the process a repeat of a previous design, or have there been some changes?
- Is the process design completely new?
- Has the environment in which the process is to operate changeable?
- Have mathematical or engineering studies been used to predict failure?

A common industry standard scale uses 1 to represent unlikely and 10 to indicate inevitable. The Ranking and suggested criteria are can seen in table 3-4: Occurrence ranking and suggested criteria.

Notional probability of failure	Evaluated Failure Rates	Cpk	Rank
Remote: Failure is unlikely. No Failures ever associated with almost identical processes	1 in 1,500,000	>1.67	1
Very Low: Only Isolated Failures associated with almost identical processes	1 in 150,000	1.50	2
Low: Isolated Failures associated with similar processes	1 in 15,000	1.33	3
Moderate: Generally associated with processes similar to previous processes Failures, but not in 'major' proportions	1 in 2,000	1.17	4
	1 in 400	1.00	5
	1 in 80	0.83	6
High: Generally associated with processes similar to previous processes that have often failed	1 in 20	0.67	7
	1 in 8	0.51	8
Very High: Failure is almost inevitable	1 in 3	0.33	9
	1 in 2	<0.33	10

table 3-4: Occurrence ranking and suggested criteria[18]

3.4.8. Detection

Here we have to distinguish between two types of detection. On one hand we have to identify Current Controls (design or process).

Current Controls (design or process) are the mechanisms that prevent the cause of the failure mode from occurring or which detect the failure before it reaches the Customer. The engineer should now 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. After a new product or process has been in use previously undetected or unidentified failure modes may appear. The FMEA should then be updated and plans made to address those failures to eliminate them from the product/process.

The other thing is to asses the probability that the proposed process controls will detect a potential cause of failure or a process weakness. Assume the failure has occurred and then assess the ability of the Controls to prevent shipment of the part with that defect. Low Occurrence does not mean Low Detection - the Control should detect the Low Occurrence. Statistical sampling is an acceptable Control. Improving Product and/or Process design is the best strategy for reducing the Detection ranking - Improving means of Detection still requires improved designs with its subsequent improvement of the basic design. Higher rankings should question the method of the Control.

The ranking and suggested criteria are shown in table 3-5: Detection ranking and suggested criteria.

Detection	**The likelihood the Controls will detect a Defect**	**Rank**
Almost Certain	Current controls are almost certain to detect the Failure Mode. Reliable detection controls are known with similar processes.	1
Very High	Very High likelihood the current controls will detect the Failure Mode.	2
High	High likelihood that the current controls will detect the Failure Mode.	3
Moderately High	Moderately high likelihood that the current controls will detect the Failure Mode.	4
Moderate	Moderate likelihood that the current controls will detect the Failure Mode.	5
Low	Low likelihood that the current controls will detect the Failure Mode	6
Very Low	Very Low likelihood that the current controls will detect the Failure Mode	7
Remote	Remote likelihood that the current controls will detect the Failure Mode	8
Very Remote	Very Remote likelihood that the current controls will detect the Failure Mode	9
Almost Impossible	No known controls available to detect the Failure Mode.	10

table 3-5: Detection ranking and suggested criteria[19]

3.4.9. Risk Priority Numbers (RPN)

The *Risk Priority Number* is a mathematical product of the numerical Severity, Probability, and Detection ratings:

RPN = (Severity) x (Probability) x (Detection)

The RPN is used to prioritize items than require additional quality planning or action.

3.4.10. Actions

Determine *Recommended Action(s)* to address potential failures that have a high RPN. These actions could include specific inspection, testing or quality procedures; selection of different components or materials; de-rating; limiting environmental stresses or operating range; redesign of the item to avoid the failure mode; monitoring mechanisms; performing preventative maintenance; and inclusion of back-up systems or redundancy.

After that we have to assign *Responsibility* and a *Target Completion Date* for these actions. This makes responsibility clear-cut and facilitates tracking.

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

4. Case Study with axiomatic approach

The following case study is based on a paper from 4 Italian authors[20]. The aim of the authors was to show the reliability improvement of a car sliding door using FMEA with a special axiomatic approach. In this chapter this special FMEA approach will be introduced and shown on a real case of FIAT Auto.

The *Axiomatic Design (AD)* provides a general theoretical framework that helps designers to understand design problems. The approach is based on the AD as framework methodology that optimizes the functional analysis which is at the beginning of Failure Mode and Effect Analysis. As one of the most commonly used reliability techniques for system risk assessment, FMEA is for the proper identification of failures.

The way how companies execute this technique is very important. This case study shows the *Fiat Auto FMEA-process*. It is based on the drawing up of two technical reports. First is the *Correlation Matrix (CM)* and second is the *Risk Matrix (RM).*

The *Correlation Matrix* is document in which we can find all the leaves functions, all the components and the intensity of their correlations. And the *Risk Matrix* which is some kind of FMEA form.

It is self-evidence how the AD can help the designer to draw and to optimize the CM. It leads the designer in this operation, providing rules to make the decomposition. By using Mapping and Zigzagging, the design can be summarized in two structures which are hierarchically arranged in levels of increasing detail and correlated by the Design Matrices (DM).

4.1. FMEA AND AD

The FMEA allows us to develop a qualitative and quantitative analysis of the reliability. In connection with a great simplicity of this method, a careful evaluation of the system decomposition is needed by identifying a list of the functions of the sub-systems.

The *modus operandi* is the following. First we start with an application of AD to the System or to the Component which is studied. The second step is the compilation of the Correlation Matrix and than the evaluation of the results obtained through the comparison with the standard of the enterprise. After that we have to identify the critical elements. This is the basis for the execution of the FMEA on these elements. And last but not least follows the storage of the results and an eventual updating of the enterprise standard.

All these operations are studied in detail in the following steps (see figure 4-1). The first step is a physical and functional decomposition and a drawing up for the correlation matrix. And the second step is the identification of the succession of elements on the basis of their criticality and then their correction.

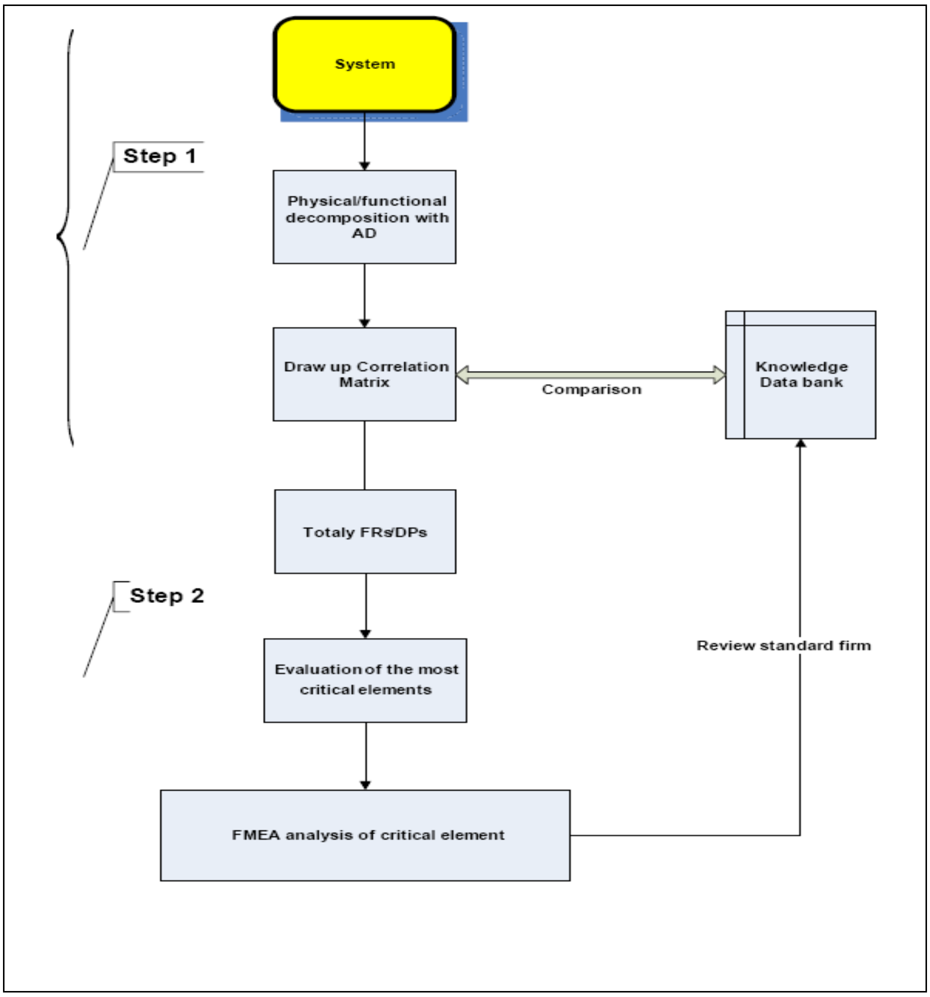

figure 4-1: Scheme of the approach

4.2. Step one

A correct and complete individualization of the functions and the parts forming the object of the study is essential for the next FMEA.

Choosing the most important functional requirement, this step starts with the design parameter selection. The functional requirement of the next level can be determined only when the design parameter is properly selected. Zigzagging among function requirements and design parameters is also necessary because two sets of each level are not only connected but also dependent on each other.

With axiomatic approach, the ideas in the initial stages of design can be materialized in a scientific way. Firstly because the functional requirement has to be defined and secondarily for the selection of design parameters that satisfy the functional requirement.

The Process Mapping between the Functional Domain and the Physical Domain can be expressed mathematically in terms of the characteristic vectors that define design goals and design solution using the Design Matrix.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ \vdots \\ FR_n \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ \vdots \\ DP_m \end{Bmatrix}$$

figure 4-2: matrix of the Functional Requirements

In order to quantify the intensity of the links is necessary to know the relationship between Functional Requirements (FRs) and Design Parameters (DPs):

$$A_{ij} = \frac{\partial FR_i}{\partial DP_j}$$

figure 4-3: Relationship between FR and DP

In general it is difficult to calculate this relation, so that it could be better to fix three numbers corresponding to three different kinds of links. The result we can find in table 4-1.

link	Description
1 weak link	the function is lightly degraded failing contribution of the component
3 middle link:	the function is only reduced failing contribution of the component
9 strong link:	the function is completely annulled failing contribution of the component

table 4-1: linkage of the Relationship FR and DP

The result of AD application is a tree structure which gives an accurate picture of the physical and functional decomposition, showing the links between FR's and DP's. We can see the outcome in figure 4-4.

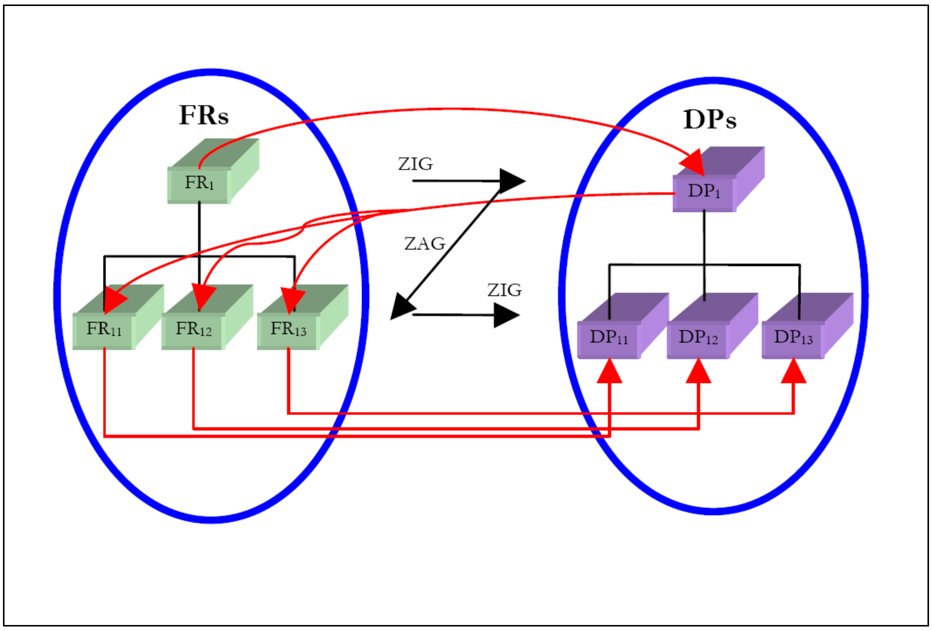

figure 4-4: FR's and DP's process mapping

4.3. Step two

In this step are reducing the numbers of functions or elements which we should analyze. The authors has been defined an evaluation method of the most critical elements. In particular an index has been calculated by considering both functional and reliability aspects.

This index is called by authors *Reliability-Functionality* (RF) and is expressed as you can see in figure 4-5.

$$RF = \frac{RPNe}{RPN_{Critical}} \cdot \prod_{l} \left\{ 1 + \frac{\left[\left(\sum_{j} A_{ij} \right) - a \right]}{N_{Tot}} \right\}_{l} == \frac{ISPR}{IPR_{Critico}} \cdot K$$

figure 4-5: Reliability-Functionality

In this equation the terms are defined as followed in table 4-2: definition of terms for the RF formula.

term	definition
l	Decomposition level of the system
A_{ij}	element of the Correlation Matrix at the considered level
N_{Tot}	Total number of functions defined at the decomposition level considered
RPNe	Risk Priority Number estimated
$RPN_{Critical}$	Risk Priority Number Critical (threshold value fixed by company)
a	Maximum value A_{ij} referring to the line considered

table 4-2: definition of terms for the RF formula

If we have a system which is characterized by decomposition into two levels - sub-system and component – we get a formula which we find in figure 4-6.

It is necessary to calculate this index to fill the FMEA document shown in figure 4-7. As we can observe there are some common fields in the FMEA sheet. These fields are *Potential failure mode, Potential effect(s) of failure, Potential causes of failure* and *Severity*. The *Occurrence (O*)* and the *Detection (D*)* are only estimated.

$$RF = \frac{RPNe}{RPN_{Critical}} \cdot \left\{ 1 + \frac{\left[\left(\sum_j A_{ij} \right) - a \right]}{N_{Tot}} \right\}_{sub-system} \cdot \left\{ 1 + \frac{\left[\left(\sum_j A_{ij} \right) - a \right]}{N_{Tot}} \right\}_{componenet}$$

figure 4-6: Reliability-Functionality for a two level system

So it is essential not to make confusion between the esteemed Risk Priority Number (RPNe) and the true RPN. This index allows giving importance as much highest RPN as those who’s malfunctioning influences a high number of Functional Requirements (FR’s).

FRs	DPs	Potential failure mode	Potential effect(s) of failure	Potential causes of failure	G	O*	D*	RPNe

figure 4-7: Document necessary to calculate RPNe

4.4. Real case – sliding door FIAT

The above defined and discussed axiomatic approach has been validated optimizing the functional analysis of the sliding door used by Fiat Auto (figure 4-8). In this case study the AD process is shown.

figure 4-8: Sliding door

From the analysis of some internal data bank of Fiat Auto the authors observed that the sliding door has a higher number of failures than a "classic" door hinged at a side and rolling around a fixed axis. The reasons are due to the major complexity of the opening and lock system.

At present time the two steps introduced before can be applied. The results of the decomposition we can see in figure 4-9 and figure 4-10. This has been realized through the identification of the functions tree and elements tree.

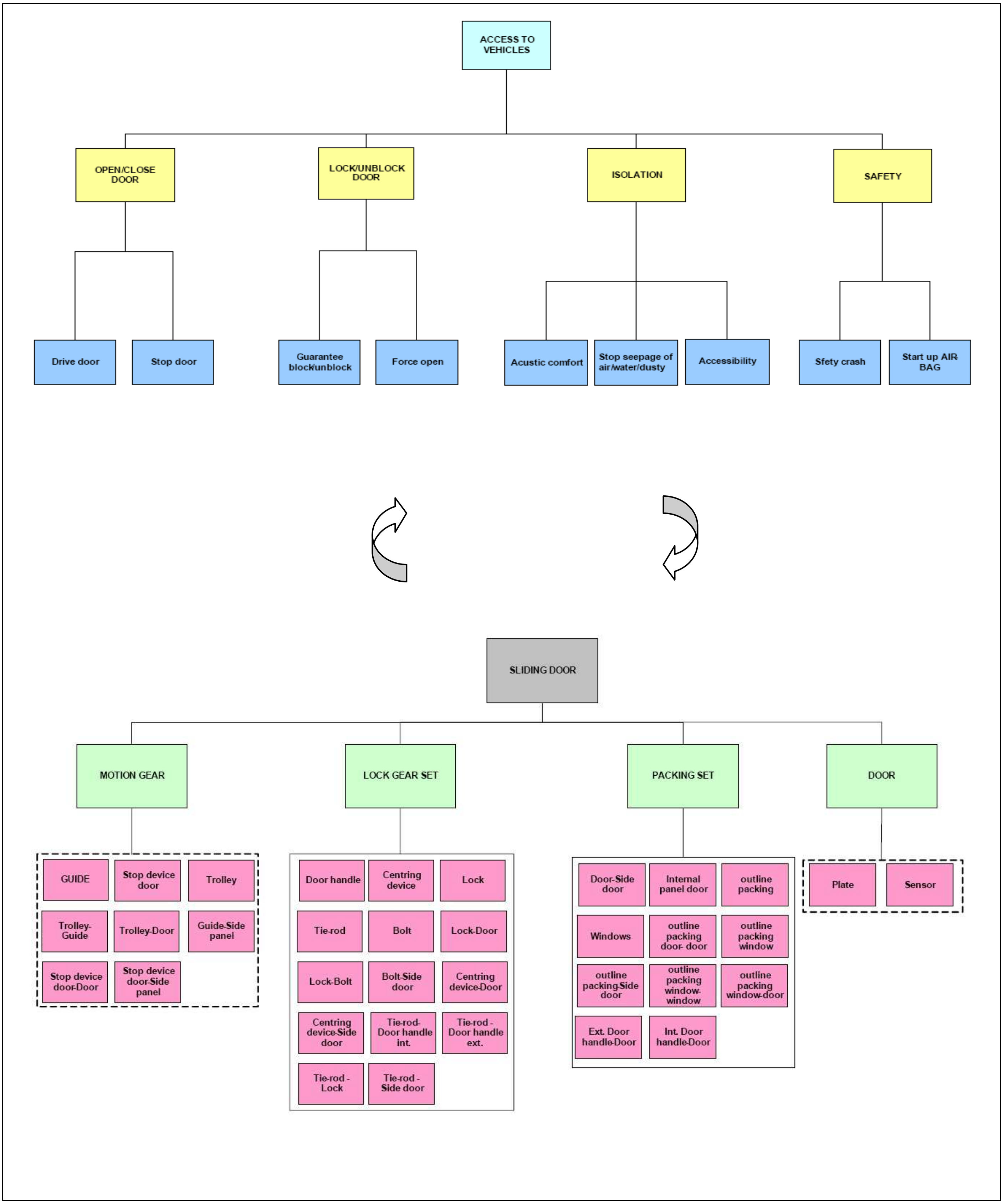

figure 4-9: Functional and physical tree of the sliding door

		FR1: Open/Close door		FR2: Block/Unblock door		FR3: Isolation			FR4: Safety	
		Drive door	Stop door	Guarantee block/unblock	Force open	Acustic comfort	Stop seepage of air/water/dusty	Accessibility	Sfety crash	Start up Air-Bag
DP1: Motion gear	Guide	9								
	Stop device door		9							
	Trolley-Guide	9				3				
	Trolley	9				3				
	Trolley-Door	3				3				
	Guide-Side panel					3				
	Stop device door-Door		9							
	Stop device door-Side panel		9							
DP2: Lock gear set	Door handle			9	9	3				
	Centring device		1	9						
	Lock			9	9	3				
	Tie-rod			9	1					
	Bolt		3	9						
	Lock-Door		3	9	3					
	Lock-Bolt		3	3		3				
	Bolt-Side door		3							
	Centring device-Door		1	3		3				
	Centring device-Side door		1	3		3				
	Tie-rod- Door handle int.			3		3				
	Tie-rod - Door handle ext.			3		3				
	Tie-rod - Lock			3		3				
	Tie-rod - Side door					3				
DP3: Paking set	Door-Side door	3				9			3	
	Internal panel door					9				
	outline packing						9			
	Windows							9		
	outline packing door- door						9			
	outline packing window						9			
	outline packing-Side door						9			
	outline packing window-window						9	1		
	outline packing window-door						9			
	Ext. Door handle-Door					3	9			
	Int. Door handle-Door					9				
DP4: Door	Plate					3			9	
	Sensor									9

figure 4-10: Correlation Matrix of the sliding door

In the first level the function and the element have been obtained. Respectively the Functional Requirements (FR's) is the *access to vehicles* and the Design Parameters (DP's) is the *sliding door.* Through the *Zigzagging* we get down into the second level. There the functional requirements can defined as shown in table 4-3. For satisfying the functional requirements the second level design parameters have been defined (table 4-4).

name	FR's
FR1	Open/close door
FR2	Block/unblock the door
FR3	Isolation
FR4	Safety

table 4-3: second level FR's

name	DP's
DP1	Motion gear
DP2	Lock gear set
DP3	Packing set
DP4	Door

table 4-4: second level DP's

Consequently the *Correlation Matrix* is to be filled and the more critical elements need to be defined. In accordance with Fiat Auto, it has been paid attention to the functions D*rive door* and *Guarantee hooking.* The elements involved in these function leaves are *Guide, Trolley, Lock, Handle* etc.

On the basis of the index RF, calculated with (figure 4-5), it is possible to obtain the sequence for the actions taken (table 4-5) and e.g. the components with RF ≥ 1 must be analyzed with a further FMEA.

DP's	Potential causes of failure	RF
Door Handle	High force of inertia	2.50
Trolley	Deterioration of roller	2.38
Trolley	Deformation of trolley	2.38
Lock	Oxidation of the leverage	2.08
Door Handle	Ice on the leverage	1.66
Lock	Ice on the leverage	1.66
Bolt	Dimension error	1.52
Bolt	Corrosion	1.52
Bolt	Deterioration of form	1.52

Centering Device	Release door clamp	1.38
Tie-Rod	Errors of the size	1.27
Tie-Rod	Corrosion	1.27
Tie-Rod	Deformation of form	1.27
Trolley-Guide	Error of section size	1.20
Door-Side Door	Interference between door and side door	1.18
Door Handle	Breaking elastic element	1.12
Door Handle	Oxidation of the metal objects	1.12
Guide	Oxidation of the way	1.08
Lock Surface	oxidation	1.07
Trolley-Guide	Interference between door and side door	1.01
Lock-Bolt	Release door clamp	0.96
Door Handle	Inadequate elastic force recovery	0.83
Lock	Climbing of the leverage	0.83
Tie-Rod	Surface oxidation	0.64
Lock	Surface oxidation	0.64
Door-Side Door	Interference between door and side door	0.59
Centering Device	Error of balancing	0.55
Tie-Rod	Climbing of the tie-rod	0.53
Trolley-Door	Interference between door and side door	0.50
Tie-Rod	Surface oxidation	0.38

table 4-5: List of less reliable components

5. Conclusion

FMEA is designed to assist the engineer improve the quality and reliability of design. And when the FMEA is used properly it provides several benefits. One of the most important benefits is the improvement of the product or process reliability and quality. This generates customer satisfaction. And customer satisfaction is necessary for long run benefits of the enterprise.

FMEA is also a tool for early identification and elimination of potential product or process failure modes. During the FMEA process, product or process deficiencies are prioritized and it documents risk and actions taken to reduce risk. Failure Modes and Effects Analysis also capture engineering and organization knowledge. But it also stores knowledge for further innovations. Therefore we need a good database system and knowledge sharing tools.

Now we should talk about costs. FMEA or FMECA minimizes late changes and associated cost. Here we should talk about the mentioned AD methodology. This procedure is very useful for complex systems, as well as those with a very high number of FR's and DP's. In particular, the use of *Zigzagging* allows to improve the physical-functional decomposition and establish an order of priority for intervening on system components (before to execute the FMEA completely). All this brings to the *reduction of time and cost* needed without affecting the effectiveness of the reliability analysis.

FMEA emphasizes on problem prevention and not on problem solving. As a matter of fact it provides focus for improved testing and development.

And last but not least it can be also seen as a Human Resources Management tool for teamwork, because Failure Modes and Effects Analysis is a catalyst for teamwork and idea exchange between functions and roles.

The author would close this paper with a phrase for thinking about the future.

Future happens, nothing is sure enough. The only sure thing is the change.

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Appendix

Definition of FMECA terms

(Source: Predictive Maintenance Corporation (2004) Definition of FMECA Terms: online: URL: http://www.pmaint.com/EFMECADefine.html [10.05.2005])

Part:
A part is any **component or assembly of components** in a system. Every part must have a parent. It can also have siblings and children.

System:
A system is the **top level** "part". It's children and grandchildren constitute all the parts of the system.

Indenture Level:
When the parts of a system are listed systematically one below the other and indented once relative to their respective parents, the **number of indents** of a part is called its indenture level.

System
Part 1
Part 1.1
Part 1.2
and so on. So, for example, Part 1 2 is said to be at the second indenture level.

Failure Mode:
This is the way a **failure of a part is observed.** For example a plain bearing or bushing is a part which can have several failure modes: Excessive Wear, Loose, Cracked. The bushing may be part of a blower assembly which can have the following failure modes: Bearing Failure, Sensor Failure, Blade Erosion, Out of Balance, Short Circuit, Switch Failure. It is important to make the distinction that a failure mode is an **"observed" or "external" effect** so as not to confuse failure mode with failure cause defined below. Each part type has a set of associated failure modes which can be derived from a variety sources. One of the most complete sources is the **Failure Mode/Mechanism Distributions 1997**, compiled by the **Reliability Analysis Center,** and is available to you conveniently from within the **FMECA** database.

Failure Effect:
The consequence a failure mode has upon the operation, function, or status of a part or the system.

Local Effect:
The consequence a failure mode has on the operation, function, or status of the **part being analyzed.**

Next Higher Level Effect:
The consequence a failure mode has on the operation, function, or status of the **parent part.** It automatically becomes a failure mode of the parent (next higher indenture level) part.

In the example of a blain bearing or bushing given above, the failure effect of each of the failure modes of the bushing on the parent part is one of the failure modes of the blower assembly. **FMECA** will automatically assign next higher level effects as failure modes at the next higher level.

End Effect:
The consequence a failure mode has on the operation, function, or status of the **system.**

Failure Cause:
The physical or chemical processes, design defects, quality defects, part misapplication or other processes which are the **basic reason** for failure or which can initiate the physical process by which deterioration proceeds to failure.

Detection Method:
The method by which a failure mode **can be discovered** by the system operator under normal system operation or by a maintenance crew carrying out a specific diagnostic action. Oil analysis, vibration analysis, infrared analysis, and other condition monitoring techniques are possible detection methods. FMECA determines optimum condition monitoring techniques based on criticality analysis.

Mission Phase Operational Mode:
The mission phase or mode of operation of the system **in which the failure occurs**. For example a jet engine during takeoff, or a bottling line at full capacity would be operational modes.

Compensating Provision:
Actions available or that can be taken to **negate or reduce** the effect of a failure mode on a system.

Corrective Action:
A **documented** design, process, or procedure change used to eliminate the failure cause.

Criticality:
A relative measure of the consequences of a failure mode combined with the frequency of its occurrence.

Severity:
A measurement which considers the **worst possible consequence** of a failure. It is classified by the degree of injury, property damage, system damage, and mission (production) loss that could occur. A severity classification is assigned to each identified failure mode of each part in accordance with the following catagories:

> I - Catastrophic:
> A failure which may cause **death or total system loss**.
>
> II - Critical:
> A failure which may cause **severe** injury, **major** property damage, major system damage, or major loss of production.
>
> III - Marginal:
> A failure which may cause **minor** injury, minor property damage, minor system damage, or delay or minor loss of production.
>
> IV - Minor:
> A failure **not serious enough** to cause injury, property damage, or system damage, but which will result in unscheduled maintenance or repair.

Single Point Failure:
The failure of a part which can result in the **failure of the system** and is not compensated for by redundancy or alternative operational procedure.

Fault Isolation:
The process of determining the location of a fault to the **indenture level** necessary to effect repair.

Criticality Analysis (CA):
A procedure by which each potential failure mode is ranked according to the **combined influence of severity and probability of occurence.**

Alpha:
Failure Mode Ratio, Modal Probability. Represents the probability that a part will fail in an identified mode. If all of the potential failure modes for a part are considered, the sum of their alphas will equal 1.

How do I determine Alpha?

Determining Alpha is a **two part** process for each part being analyzed. First the **failure modes** are determined and secondly the **failure probabilities** are assigned. The source mentioned above, Failure Mode/Mechanism Distributions 1997, is one of the most comprehensive sources of part level failure distribution information available. It covers a wide variety of component types. The database was compiled by the Reliability Analysis Center from appoximately 50 sources of failure mode information including failure analysis reports, reliability modeling studies, RAC data summarization activity and published distributions from private research organizations. The Alpha data is provided by the FMD97 database integrated into PMC's **FMECA** web interface

Beta:
Failure Effect Probability.
Represents the conditional probability that the failure effect will result in the identified criticality classification, given that the failure mode occurs.

How do I determine Beta?

The Beta values come from the **engineering judgement** of the analysts who are performing the **FMECA**. Determining Beta is a process which utilizes the engineer's judgement of the percentage of time that the identified failure mode will cause the indicated failure effect. The **FMECA** analyst assigns a relative probability to each possible effect of a failure mode. For example:

FAILURE MODE	FAILURE EFFECT	BETA
Brakes Lock	1. Train skids on tracks and comes to a full stop 2. Train derails	0.9 0.1

The values of beta shown in the table represent the most probable system level effect under normal operating conditions which is that the train would suddenly come to a screeching halt. However, there is a chance that the train could skip the tracks depending on when and where this failure occurred.

Lamda:
Failure Probability, Failure Rate:
The overall probability of failure of a part. Failure rate data has been compiled by the **Reliability Analysis Center in a database called NPRD91 and MIL-HDBK-217E**. Failure rate data on parts comprising the system under consideration can also be obtained from the equipment manufacturer. When this value is not available the **FMECA** provides, in this case, is a relative ranking of failure modes. The **FMECA** is then said to be qualitative.

Modal Failure Rate:
The probability that the device or part will fail in the indicated mode. Therefore the modal failure rate is calculatd by multiplying the modal probability, alpha for that failure mode by the failure rate for the part.