Maintenance Management Concepts and Practices

Failure Modes Effects and Criticality Analysis

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Lecture Objectives

- **To understand the basic theory and practices of FMECA**

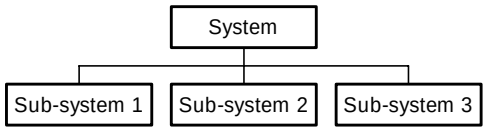
Agenda

- **MIL-STD-1629-A FMEA Generalised FMEA (45%)**
- **Risk Priority Number FMEA (45%)**
- **Matrix FMEA (4%)**
- **SODA FMEA (4%)**
- **Conclusions (2%)**

Generalised Failure Mode and Effect Analysis

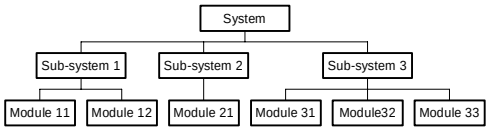
FMEA: The concept (1)

System under consideration



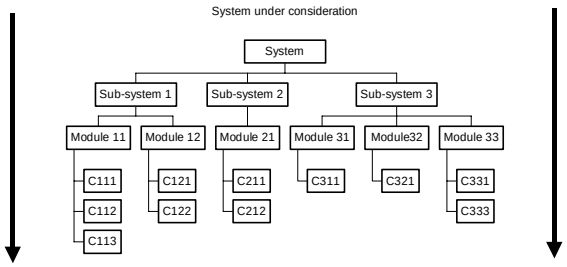
FMEA: The concept (2)

System under consideration



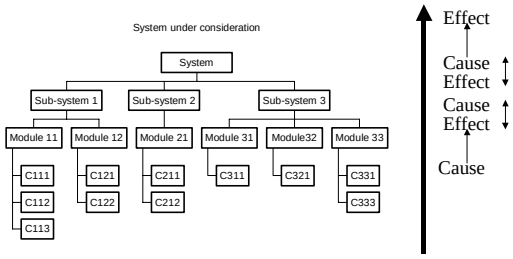
FMEA: The concept (3)

System under consideration



FMEA: The concept (4)

System under consideration



FMEA: The concept (5)

A bottom up approach detailing the causes of failure of components and associated effects, through all indenture levels (sub-systems, modules, etc..), to the system level.

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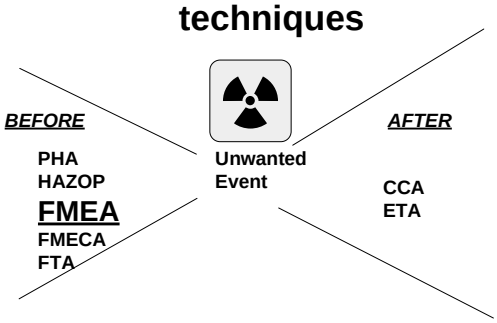
FMEA and other related techniques



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FMEA Defined

FMEA represents a powerful, documented method for analysts to present in a structured and formalised manner their subjective thinking and experience in terms of

- **What might go wrong**
- **What might cause it to go wrong**
- **What effects would it have.**

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Need for FMEA

- **Implementing "DIRTFTETON"**
- **Dealing with rapidly changing expectations**
- **Complying with increased regulation**
- **Minimising liability claims**
- **Ensuring efficient use of resources.**

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Approaches to FMEA

- **Mil-Std-1629 : US**
- **RPN Methodology : UK.**

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Mil-STD-1629 Criticality Analysis

Two attributes:

1. The Severity of the effect occurring

2. The Likelihood of each event in terms of a probabilistic value or class.

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Severity categories

Category	Description	Characteristics
1	Negligible	No injury or morbidity No damage to system
2	Marginal	Minor injury or morbidity Minor damage to system
3	Critical	Severe injury or morbidity Severe damage to system
4	Catastrophic	Death Loss of system

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Likelihood categories

Category	Description	Characteristics
1	**Impossible**	Physically impossible to occur.
2	**Extremely improbable**	Probability of occurrence can't be distinguished from zero.
3	**Remote**	So unlikely, it can be assumed that it will not be experienced.
4	**Occasional**	Likely to occur during the life of the item.
5	**Reasonably probable**	Will occur seceral times during the life of the item.
6	**Frequent**	Likely to occur frequently.

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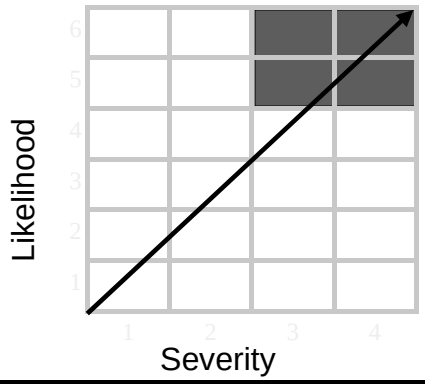
Criticality Matrix



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Criticality Matrix

Severity

Likelihood	Low	High
Low	Low - Low Low	Low - High Moderate
High	High - Low Moderate	High - High High

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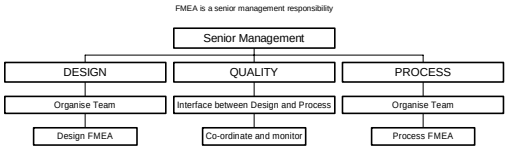
FMEA Management



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Analysis resolution

●The depth of the analysis and the level at which it should be started depend on the information and expertise available.

●This could depend on the state or progress of the design, the complexity of the system, and the type of system.

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FMEA Planning

- **Worksheet formats**
- **Ground rules**
- **Analysis assumptions**
- **Identification of lowest indenture level**
- **Coding**
- **System description**
- **Failure definitions**

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Failure Mode and Cause

- **A failure mode is the manner in which an item can fail (e.g.. broken).**
- **A failure cause is the cause for a given failure mode (because of corrosion).**

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Failure Effects

● Are the consequences of each failure mode on item operation, function or status.

● Can be described in terms of what the users experience or what would be drawn to their attention.

● Could apply to a number of failure modes and indenture levels.

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Severity of effects

●Can only be assessed in terms of potential consequences of the failure on the people who use or manufacture the system.

● Should indicate the worst case scenario and remain the same regardless of associated causes of failure.

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Occurrence and Detection

The occurrence rating represents an estimate based on available knowledge of the probability of the failure cause occurring.

The detection rating is defined as a factor that reflects how difficult it is to detect a failure mode before the item leaves the factory.

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Mil-Std-1629 A FMEA

MILITARY STANDARD

PROCEDURES FOR PERFORMING A FAILURE MODE, EFFECT AND CRITICALITY ANALYSIS

Mil-Std-1629 A FMEA Contents

1. **Scope**
2. **Referenced documents**
3. **Definitions**
4. **General requirements**
5. **Detail requirements**

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Mil-Std-1629 A: Table headings

- **Identification**
- **Function**
- **Failure Mode**
- **Failure Cause**
- **Failure Mode frequency**
- **Detection**
- **Corrective measure**
- **Severity**

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Criticality Analysis

- **Second stage of FMEA.**
- **The new information required is the likelihood of each event in terms of a probabilistic value or class.**
- **The combinations of Severity likelihood classes represent the so called "Criticality Matrix".**

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FMEA advantages

- **Simple technique.**
- **It can identify system failure modes which were not obvious before the analysis.**
- **Results can be presented in an easy to understand format.**
- **It considers all possible component and system failure modes individually.**
- **It can be reversed and used as a diagnostic tool for repair processes.**

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FMEA disadvantages

- **Cannot model redundant or standby equipment adequately.**
- **Cannot easily represent the effects of multiple failures on the system.**
- **Can get very complicated and complex.**

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Criticality Analysis (CA)

- **Can be used to determine priorities for corrective action and to establish a clear demarcation between acceptable and unacceptable risk.**

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CA: Advantages (1)

- Identifies which items should be given more attention to eliminate the hazard (Fail-safe design, redundancy, damage containment)
- Identifies which items require tighter quality control during manufacturing stages.

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CA: Advantages (2)

- Facilitates the identification of special requirements to be included in specifications for suppliers concerning design, performance, reliability, safety and quality assurance.
- Facilitates the establishment of special procedures, safeguards, protective equipment, monitoring devices and warning devices.

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The successful application of FMEA depends on

- The level of expertise of the people carrying out the analysis.
- The data available.
- The commitment of Management to implement the recommendations.

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FMEA should be a live document

- Specification changes
- Sales feedback
- Design changes
- Process changes
- Quality Control modifications
- Industrial engineering changes.
- New or revised Standards.

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RA: Examples of Models

- Mil-Std-1629-A
- BS 5760
- Mil-Std-882
- Def-Std. 00-56.
- NER

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Mil-Std-882

Frequency		Hazard Category			
Qualitative	Quantitative	Catastrophic	Critical	Marginal	Negligible
Frequent	$> 10^{-1}$				
Probable	10^{-1} to 10^{-2}				
Occasional	10^{-2} to 10^{-3}				
Remote	10^{-3} to 10^{-6}				
Improbable	$>10^{-6}$				

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Mil-Std-882: Categories

Frequency		Hazard Category			
Qualitative	Quantitative	Catastrophic	Critical	Marginal	Negligible
Frequent	$> 10^{-1}$	1	3	7	13
Probable	10^{-1} to 10^{-2}	2	5	9	16
Occasional	10^{-2} to 10^{-3}	4	6	11	18
Remote	10^{-3} to 10^{-6}	8	10	14	19
Improbable	$>10^{-6}$	12	15	17	20

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Def-Stan-00-56

Frequency		Hazard Category			
Qualitative	Quantitative	Catastrophic	Critical	Marginal	Negligible
Frequent	$> 10^{-2}$				
Probable	10^{-2} to 10^{-4}				
Occasional	10^{-4} to 10^{-6}				
Remote	10^{-6} to 10^{-8}				
Improbable	10^{-8} to 10^{-10}				
Incredible	10^{-10} to 10^{-12}				

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Def-Stan-00-56: Categories

Frequency		Hazard Category			
Qualitative	Quantitative	Catastrophic	Critical	Marginal	Negligible
Frequent	$> 10^{-2}$	A	A	A	B
Probable	10^{-2} to 10^{-4}	A	A	B	C
Occasional	10^{-4} to 10^{-6}	A	B	C	C
Remote	10^{-6} to 10^{-8}	B	C	C	D
Improbable	10^{-8} to 10^{-10}	C	C	D	D
Incredible	10^{-10} to 10^{-12}	C	D	D	D

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The RPN methodology

- **Severity rating (S)**
  1 2 3 4 5 6 7 8 9 10
- **Occurrence rating (O)**
  1 2 3 4 5 6 7 8 9 10
- **Detection rating (D)**
  1 2 3 4 5 6 7 8 9 10

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SMMT guidelines on Severity

Rating	*Severity Description*
1	Will have **no effect**.
2 or 3	Would cause slight annoyance but would only have a **minor effect**.
4 or 5	**Moderate** severity causing problems on subsequent operations.
6 or 7	**High severity** causing a hign degree of customer annoyance.
8 or 9	A **very high severity** failure which could affect safety in the long term.
10	A **most severe** failure which could result in a sudden safety - related failure.

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SMMT guidelines on Occurrence

Rating	*Likelihood of occurrence*
1	It is **unlikely** that this failure will occur.
2, 3 or 4	There is a **low probability** that this failure will occur.
5 or 6	Some failures are **likely** but in major proportions.
7, 8 or 9	There is **high probability** that this failure will occur.
10	This failure is **certain** to occur in high proportions.

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SMMT guidelines on Detection

Rating	Likelihood of detection
1	A **remote** probability of the failure reaching the customer.
2, 3 or 4	A **low** probability that this failure will reach the customer.
5, 6 or 7	There is a **moderate** probability of this failure reaching the customer.
8 or 9	There is a **high** probability of this failure reaching the customer.
10	It is **certain** that this failure will reach the customer.

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EITB guidelines on Severity

Rating	*Severity Description*
1	**Minor**: Would have no noticeable effect on the vehicle or system performance.
2 or 3	**Low**: Would cause slight customer annoyance but no noticeable deterioration of subsystem or vehicle.
4, 5 or 6	**Moderate**: Would cause some customer dissatisfaction or noticeable deterioration in subsystem or vehicle.
7 or 8	**High**: Would engender a high degree of customer dissatisfaction but does not affect vehicle safety.
9	**Very high**: Would affect safety.
10	**Catastrophic**: May cause damage to property, serious injury or death.

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EITB guidelines on Occurrence

Rating	*Likelihood of occurrence*
1	**Remote**: Would be unreasonable to expect the failure to occur.
2 or 3	**Low**: Generally associated with designs similar to previous ones with a relatively low number of failres.
4, 5 or 6	**Moderate**: Generally associated with designs similar to previous ones without thrown up occasional failures, but not in major proportions.
7 or 8	**High**: Generally associated with designs similar to previous ones which have traditionally caused problems.
9 or 10	**Very high**: Near certainty that major failures will occur.

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EITB guidelines on Detection

Rating	*Likelihood of detection*
1	**Remote**: Would be unreasonable to expect such a defect to undetected during inspection, test or assembly.
2 or 3	A **low probability** that the defect will reach the customer.
4, 5 or 6	There is a **moderate probability** that the defect will reach the customer.
7 or 8	There is a **high probability** that the defect will reach the customer.
9 or 10	There is a **very high probability** that the defect will reach the customer.

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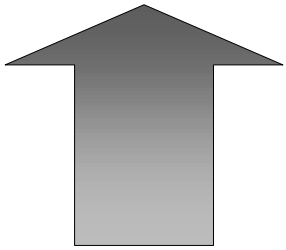
The Risk Priority Number

RPN = S x O x D

Minimum = 1
Maximum = 1000.



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The RPN methodology in practice

General rules

AND / OR

Special rules.

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RPN: General rules: Examples

- **The range of RPN values is divided into classes:**
  - From 1 to 180 : No action necessary
  - From 181 to 342 : Corrective action is advisable
  - From 343 to 1000 : Immediate corrective action
- **The classification varies from one organisation to another.**

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RPN: Special rules Examples

- **Any <u>one high</u> rating : Immediate corrective action**
- **Any <u>two medium</u> ratings : Immediate corrective action.**

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NER Factors (Number Estimating the Risk)

Four factors including:

1. **The <u>possibility of exposure</u> to the risk (0: Impossible to 15: Certain)**
2. **The <u>frequency of exposure</u> to the risk (0.1: Rare to 5: Continuous)**
3. **The <u>number of people at risk</u> (1: one or two people to 12: Fifty or more people)**
4. **The <u>maximum loss</u> (0.1: slight injury to 15: Death).**

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NER Categories

0 to 1 : <u>Acceptable</u> risk
1 to 5 : <u>Very Low risk</u> (action in 1 year)
5 to 10 : <u>Low risk</u> (action in 3 months)
10 to 50 : <u>Significant</u> risk (action in 1 month)
50 to 100 : <u>High</u> risk (Action in 1 week)
100 to 500 : <u>Very High</u> risk (action in 1 day)
500 to 1000 : <u>Extremely High</u> risk (Immediate action)
Over 1000 : <u>Unacceptable</u> risk (Emergency).

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The Risk Priority Number methodology

The RPN methodology

Risk Priority Number

Design FMEA | Process FMEA

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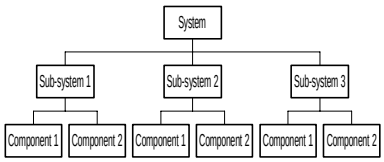
RPN FMEA: Step 1

Definition of system including functional and performance requirements.



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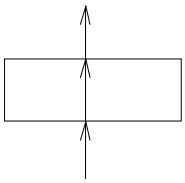
RPN FMEA: Step 2 (a)

Identification of potential failure modes and associated causes and effects



Failure Effect

Failure Mode

Failure Cause

Basic Triplet Model

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RPN methodology

- **FC--> FM --> FE ------> RPN1**
- **FC--> FM --> FE ------> RPN2**
- **FC--> FM --> FE ------> RPN3**
- **----------**
- **RPS = (RPN1 + RPN2 + RPN3)**
- **Compare RPSs and RPNs**

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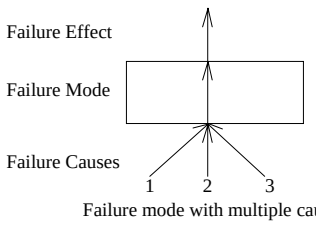
RPN FMEA Issues: Step 2 (b)

Bracket (for gearbox support)



Gear box falls on engine

Broken

1. Material too thin
2. Wrong material

Failure mode with multiple causes

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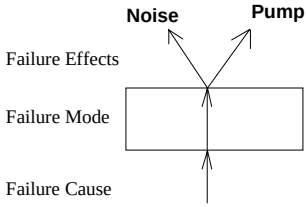
RPN FMEA Issues: Step 2 (c)

Bracket (for pump box support)



Corrosion

Wrong paint

Failure mode with multiple causes

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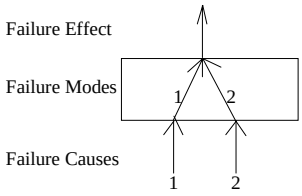
RPN FMEA Issues: Step 2 (d)

Level warning indicator



No warning

1. Failure to detect change in fluid level.
2. Failure to make contact.

1.Improper or no movement of float

2. No electrical continuity

Different failure modes and causes with the same effect. (SMMT)

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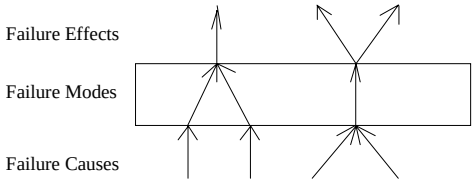
RPN FMEA Issues: Step 2 (e)

Generalised model



Different failure modes and causes with the same effect.

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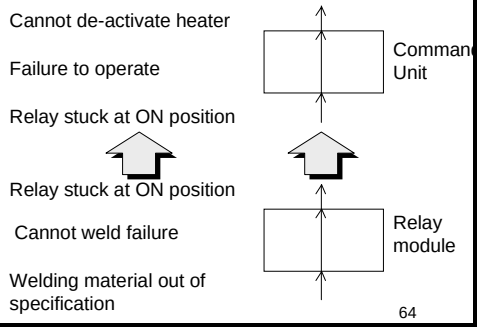
RPN FMEA Issues: Step 2 (f)

Effect at a lower level becomes a cause at the next hierarchical level (SMMT)



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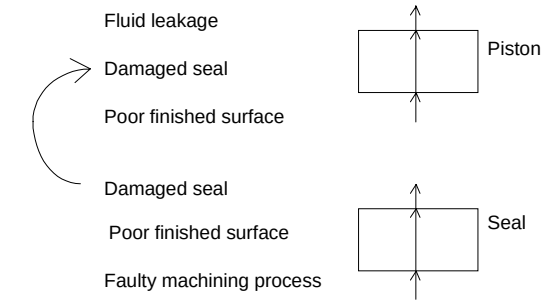
RPN FMEA Issues: Step 2 (g)

Effect at a lower level becomes a failure mode at the next hierarchical level (SMMT)



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Design FMEA

Design FMEA (1)

Item
B100

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Design FMEA (2)

Item	Issue No.
B100	Issue R

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Design FMEA (3)

Item	Issue No.	Description
B100	Issue R	Bracket

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Design FMEA (4)

Item	Issue No.	Description	Function
B100	Issue R	Bracket	Support Engine

70

Design FMEA (5)

Item	Issue No.	Description	Function	Failure Mode
B100	Issue R	Bracket	Support Engine	Curling of vertical walls

71

Design FMEA (6)

Failure Mode	Failure Effect	Failure Cause	Current Control	Current Occurrence
Curling of vertical walls	Engine drop	Incorrectly specified material thickness	Stress tested to 100	3

72

Design FMEA (7)

Failure Effect	Failure Cause	Current Control	Current Occurrence	Current Severity
Engine drop	Incorrectly specified material thickness	Stress tested to 100	3	8

73

Design FMEA (8)

Failure Cause	Current Control	Current Occurrence	Current Severity	Current Detection
Incorrectly specified material thickness	Stress tested to 100	3	8	3

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Design FMEA (9)

Current Control	Occurrence	Severity	Detection	Risk Priority Number
Stress tested to 100	3	8	3	3x8x3 = 72

75

Design FMEA (10)

Current Occurrence	Current Severity	Current Detection	Risk Priority Number	Corrective Action
3	8	3	3x8x3 = 72	Stress test to 150 and report.

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Design FMEA (11)

Current Severity	Current Detection	Risk Priority Number	Corrective Action	Action By
8	3	3x8x3 = 72	Stress test to 150 and report.	Test Department

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Design FMEA (12)

Current Detection	Risk Priority Number	Corrective Action	Action carried out by	Action to be completed by
3	3x8x3 = 72	Stress test to 150 and report.	Test Department	25/01/96

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Design FMEA (13)

Risk Priority Number	Corrective Action	Action carried out by	Action to be completed by	Action taken
3x8x3 = 72	Stress test to 150 and report.	Test Department	25/01/96	Stress Test to 150 completed. Satisfactory

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Design FMEA (14)

Corrective Action	Action carried out by	Action to be completed by	Action taken	Revised Occurrence
Stress test to 150 and report.	Test Department	25/01/96	Stress Test to 150 completed. Satisfactory	2

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Design FMEA (15)

Action carried out by	Action to be completed by	Action taken	Revised Occurrence	Revised Severity
Test Department	25/01/96	Stress Test to 150 completed. Satisfactory	2	8

81

Design FMEA (16)

Action to be completed by	Action taken	Revised Occurrence	Revised Severity	Revised Detection
25/01/96	Stress Test to 150 completed. Satisfactory	2	8	2

82

Design FMEA (17)

Action taken	Revised Occurrence	Revised Severity	Revised Detection	Revised Risk Priority Number
Stress Test to 150 completed. Satisfactory	2	8	2	2x8x2 = 32

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Process FMEA

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Process FMEA (1)

Item
B100

85

Process FMEA (2)

Item	Issue No.
B100	Issue R

86

Process FMEA (3)

Item	Issue No.	Description
B100	Issue R	Bracket

87

Process FMEA (4)

Item	Issue No.	Description	Process
B100	Issue R	Bracket	Drill two holes

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Process FMEA (5)

Item	Issue No.	Description	Process	Failure Mode
B100	Issue R	Bracket	Drill two holes	Holes out of position

89

Process FMEA (6)

Failure Mode	Failure Effect	Failure Cause	Current Control	Current Occurrence
Holes out of position.	Difficult assembly of engine mounting.	Incorrect location in drill fixture.	Inspection by Vernier on frequency basis.	5

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Process FMEA (7)

Failure Effect	Failure Cause	Current Control	Current Occurrence	Current Severity
Difficult assembly of engine mounting.	Incorrect location in drill fixture.	Inspection by Vernier on frequency basis.	5	7

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Process FMEA (8)

Failure Cause	Current Control	Current Occurrence	Current Severity	Current Detection
Incorrect location in drill fixture	Inspection by Vernier on frequency basis	5	7	6

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Process FMEA (9)

Current Control	Occurrence	Severity	Detection	Risk Priority Number
Inspection by Vernier on frequency basis	5	7	6	5x7x6 = 210

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Process FMEA (10)

Current Occurrence	Current Severity	Current Detection	Risk Priority Number	Corrective Action
5	7	6	5x7x6 = 210	Positive location using special gauge.

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Process FMEA (11)

Current Severity	Current Detection	Risk Priority Number	Corrective Action	Action By
7	6	5x7x6 = 210	Positive location using special gauge	Production Department

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Process FMEA (12)

Current Detection	Risk Priority Number	Corrective Action	Action carried out by	Action to be completed by
6	5x7x6 = 210	Positive location using special gauge.	Production Department	25/01/96

96

Process FMEA (13)

Risk Priority Number	Corrective Action	Action carried out by	Action to be completed by	Action taken
5x7x6 = 210	Positive location using special gauge.	Production Department	25/01/96	Special gauge used for positive location.

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Process FMEA (14)

Corrective Action	Action carried out by	Action to be completed by	Action taken	Revised Occurrence
Positive location using special gauge.	Production Department	25/01/96	Special gauge used for positive location.	2

98

Process FMEA (15)

Action carried out by	Action to be completed by	Action taken	Revised Occurrence	Revised Severity
Production Department	25/01/96	Special gauge used for positive location	2	7

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Process FMEA (16)

Action to be completed by	Action taken	Revised Occurrence	Revised Severity	Revised Detection
25/01/96	Special gauge used for positive location	2	7	2

100

Process FMEA (17)

Action taken	Revised Occurrence	Revised Severity	Revised Detection	Revised Risk Priority Number
Special gauge used for positive location	2	7	2	2x7x2 = 28

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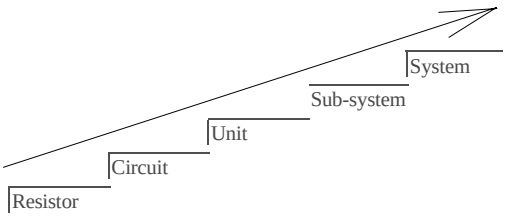
Matrix FMEA

The NASA approach

Hierarchical structure Electrical Example



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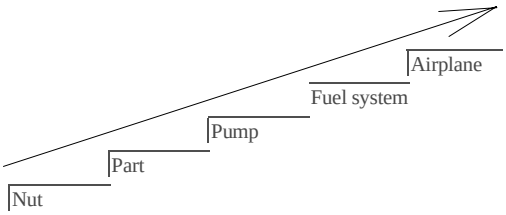
Hierarchical structure Mechanical Example



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Failure Modes Symbols

	Open mode
	Short mode
	Open / short mode
	Lower level effect mode

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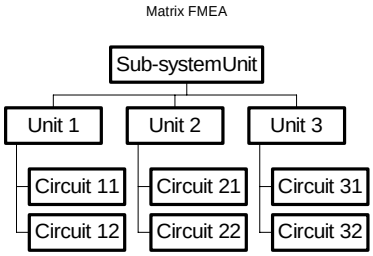
Hierarchical structure



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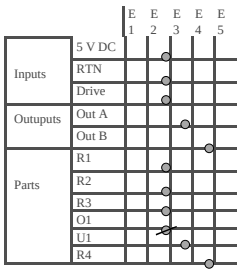
Matrix FMEA



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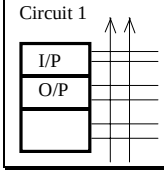
Indenture Levels (1)



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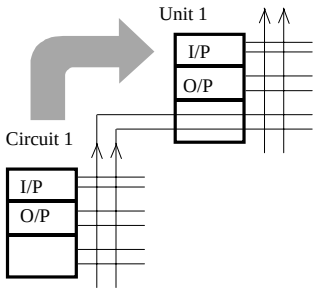
Indenture Levels (2)



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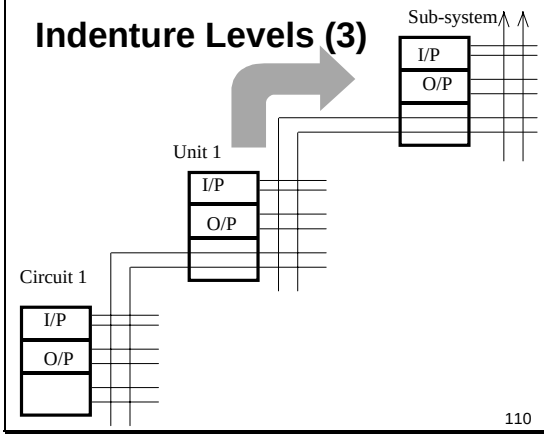
Indenture Levels (3)



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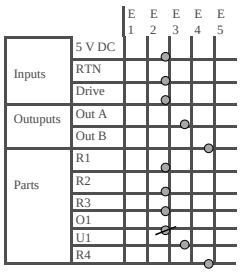
Matrix FMEA



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Matrix FMEA: Main advantage

Matrix FMEA can be used as a diagnostic tool

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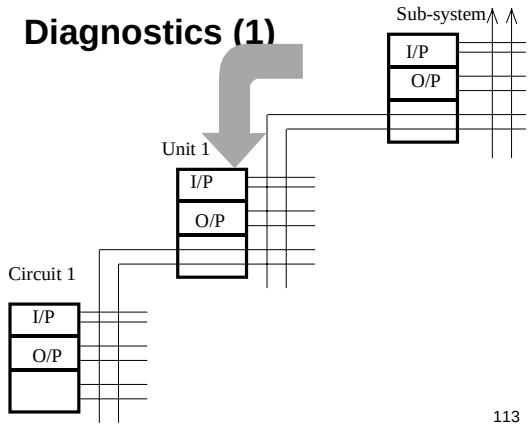
Diagnostics (1)



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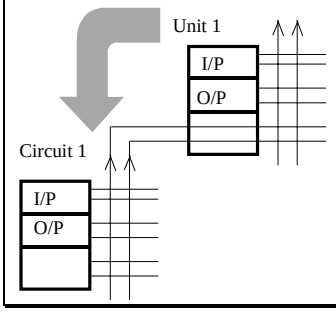
Diagnostics (2)



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Matrix FMEA advantages

- **FMEA results at each indenture level constitutes a discrete module of data which can be used in other FMEAs.**
- **Matrix FMEA results provide a traceable and graphical system.**
- **The methodology can be reversed and used for diagnostics.**
- **Matrix FMEA can also be used for contingency planning, fault isolation and safety and quality analyses.**

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FMEA: Survey results (1)

- **The majority of suppliers are using FMEA only because it is a contractual requirement placed on them by the customer.**
- **FMEA is perceived as difficult, laborious and boring.**
- **There is a need for improved computerised aids to reduce the effort in preparing and analysing FMEAs.**

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FMEA: Survey results (2)

- **There is insufficient time to carry out the analysis properly.**
- **A large number of practitioners have a poor understanding of the importance of FMEA.**
- **Practitioners are inadequately or poorly trained.**
- **There is a lack of senior management commitment to FMEA.**

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Summary

- **Team work and careful planning**
- **Parts count**
- **Criticality matrix**
- **Matrix FMEA**
- **SOD-A**

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