DESIGN PRACTICUM
IC 201P

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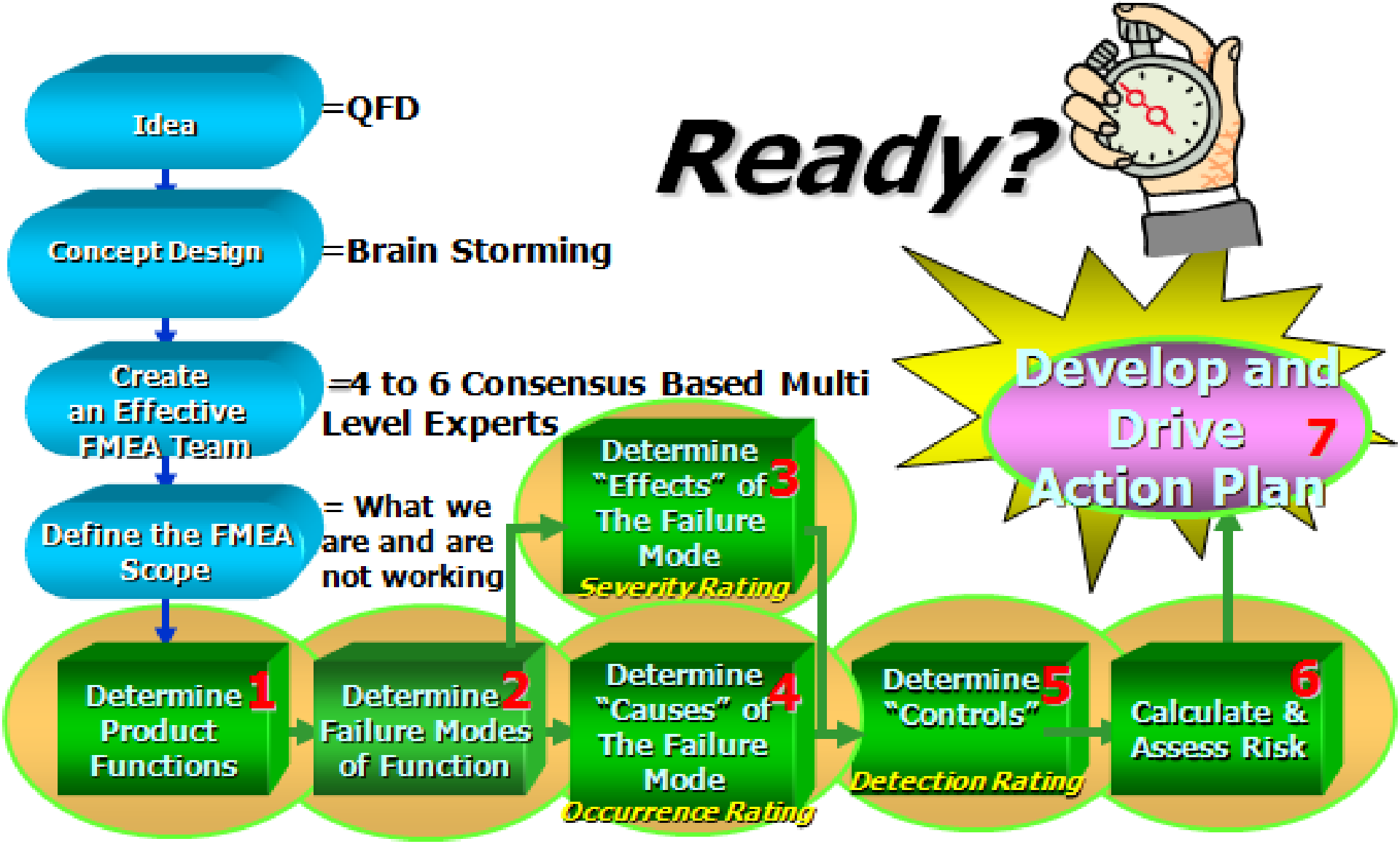
FMEA
(Failure Mode and Effect Analysis)

FMEA


Idea
=QFD
Concept Design
=Brain Storming
Create an Effective FMEA Team
=4 to 6 Consensus Based Multi Level Experts
Define the FMEA Scope
= What we are and are not working
Ready?
Develop and Drive Action Plan 7
Determine 1 Product Functions
Determine 2 Failure Modes of Function
Determine "Effects" of 3 The Failure Mode
Severity Rating
Determine "Causes" of 4 The Failure Mode
Occurrence Rating
Determine 5 "Controls"
Detection Rating
6 Calculate & Assess Risk

Introduction

What is FMEA?

- Failure Mode and Effect Analysis (FMEA) is a systematic method of identifying and preventing product and process problems before they occur.

- It is a powerful method for designing products with high reliability and safety

Introduction (contd...)

- Since prevention is always better than cure, a particular industry can use the FMEA to evaluate risk areas and take action to prevent future problems

- Ideally, FMEA's are conducted in the product design or process development stages, although conducting an FMEA on existing products or processes may also yield benefits

Introduction (contd...)

FMEA History

- It is developed by the aerospace industry to identify and mitigate structural weaknesses in mid1950s. Since then, the tool has come to be widely used in a majority of industries to identify and manage risks in product and process design.

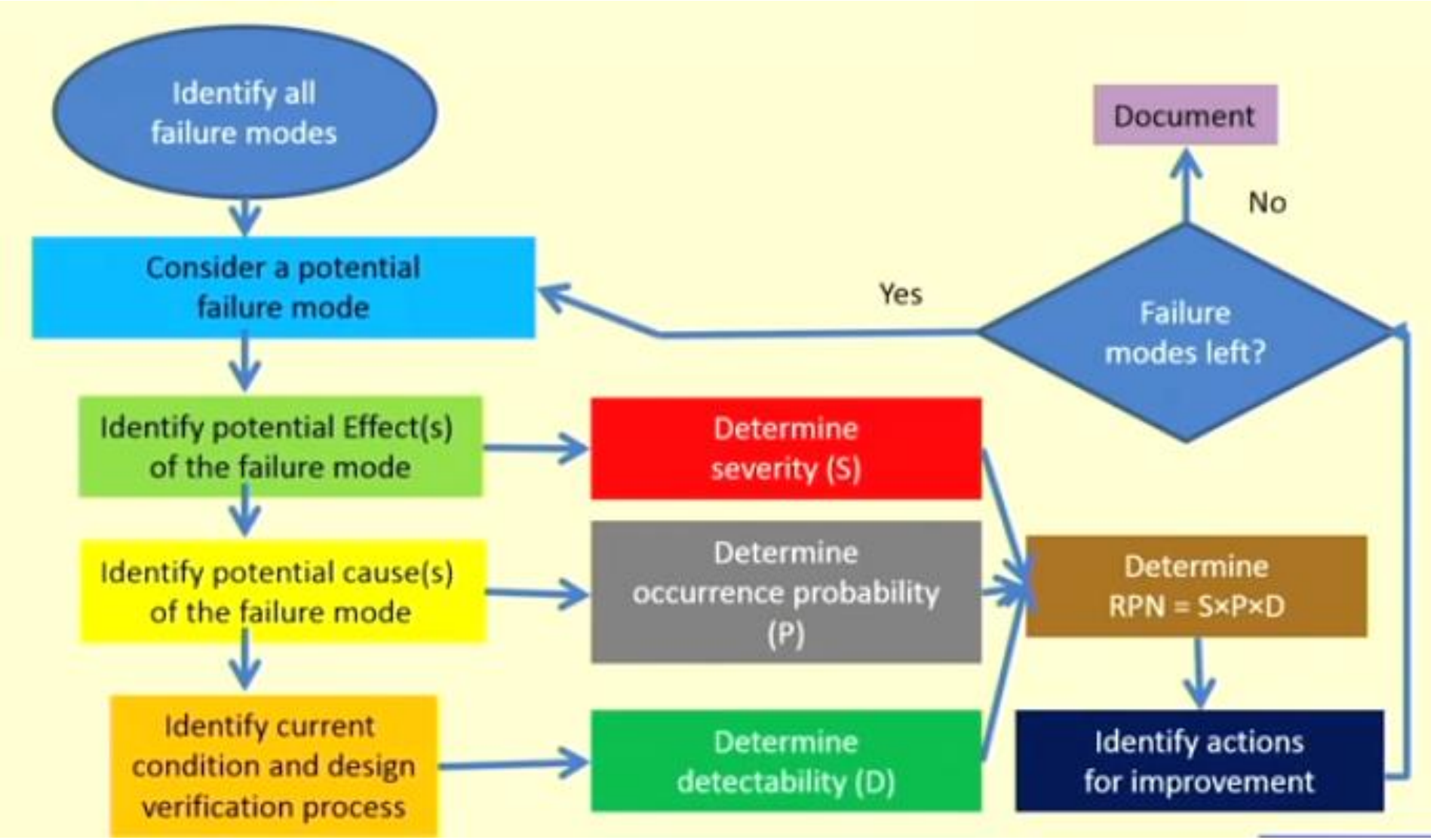
LOGIC OF FMEA

♦ The FMEA process is a way to identify the failures, effects, and risks within a process or product, and then, eliminate or reduce them

♦ Each failure mode has a potential effect, and some effects are more likely to occur than others

♦ In addition, each potential effect has a relative risk associated with it

Procedure of FMEA



10 STEPS FOR AN FMEA

1. Review the product/process to know function
2. Brainstorm potential failure modes
3. List potential effects of each failure mode
4. Assign a severity rating for each effect
5. Assign an occurrence rating for each FM
6. Assign detection rating for each FM and/or effects
7. Calculate the risk priority #(RPN) for each effect
8. Prioritize the FMs for action
9. Take action to eliminate or reduce the high-risk FMs
10. Calculate the Resulting RPN as the FMs are reduced or eliminated

Failure Modes (What could go wrong?)

A failure mode describes how (not why) a component or process may fail to satisfy its functions. When the functions have been clearly defined, describing possible failure modes becomes relatively simple, for example:-

Function/Requirement /Expectation	***Potential failure mode***
Radiator contains water at 5 bar, 120 degrees C	Radiator does not contain water, when hot (water leaks from top tank)
Motor rotates	Motor does not rotate
A.C cools the room	A.C partially cools the room

Failure Modes

Switch Failure Modes	Motor Failure Modes	Human Failure Modes
• Open • Partially open • Close • Partially closed	• Fails to start • Fails off while running • Starts prematurely • Operates too long • Operates at degraded torque/rotational speed	• Fails to perform task • Perform tasks in the wrong sequence • Performs an additional task • Performs the wrong task

Effects of Failure Modes

What would be the consequences of each failure mode?

- A description of the consequence of a component failure.
- A typical failure mode may have several *"effects"* depending on which user/customer you consider

Effects of Failure Modes

Examples

- *Injury to the user*
- *Inoperability of the product/process*
- *Improper appearance of the product/process*
- *Degraded performance*
- *Noise*
- Human death

Severity Rating/Rank

It is Seriousness of the Effect. Severity is the numerical rating of the impact on customers.

✓When multiple effects exist for a given failure mode, enter the worst case severity on the worksheet to calculate risk.

Effect	Rank	Criteria
None	1	No effect
Very Slight	2	Negligible effect on Performance. Some users may notice.
Slight	3	Slight effect on performance. Non vital faults will be noticed by many users.
Minor	4	Minor effect on performance. User is slightly dissatisfied.
Moderate	5	Reduced performance with gradual performance degradation. User dissatisfied.
Severe	6	Degraded performance, but safe and usable. User dissatisfied.
High Severity	7	Very poor performance. Very dissatisfied user.
Very High Severity	8	Inoperable but safe.
Extreme Severity	9	Probable failure with hazardous effects. Compliance with regulation is unlikely.
Maximum Severity	10	Unpredictable failure with hazardous effects almost certain. Non-compliant with regulations.

Effects of Failure Modes

System	Component	Failure Mode	Failure Effect
Electrical	Battery	Discharged	Not turn engine —not start
Electrical	Battery connector	Corroded	Not turn engine —not start
Fuel	Fuel tank	Empty	No fuel to engine —not start
Fuel	Fuel pump	Mechanical failure	No fuel to engine —not start
Etc.			

Causes of Failure Mode

Why would the failure happen?

- The 'causes of failure' describe the specific errors and omissions in the design or production process that could generate or allow the failure mode being considered. If all the causes of failure can be identified and eliminated, then the failure mode will also be eliminated

- Although every failure mode will have at least one possible 'cause of failure', many will have several 'potential causes' that must be recognized and controlled if failure is to be avoided.

✓ You must look at the causes not the symptoms of the failure. Most failure Modes have more than one *Cause.*

Causes of Failure Mode

Examples

- *INADEQUATE LUBRICATION*
- *CONTAMINATION*
- *ERRONEOUS ALGORITHMS*
- *IMPROPER ALIGNMENT*
- *EXCESSIVE LOADING*
- *EXCESSIVE VOLTAGE*
- *IMPROPER INSTRUCTIONs*

Occurrence Rating/Rank

It is numerical rating of probability or frequency of the failure occurring (based on experience) for a given cause over the intended "life of the component".

Occurrence	Rank	Criteria
Extremely Unlikely	1	Less than 0.01 per thousand
Remote Likelihood	2	≈0.1 per thousand rate of occurrence
Very Low Likelihood	3	≈0.5 per thousand rate of occurrence
Low Likelihood	4	≈1 per thousand rate of occurrence
Moderately Low Likelihood	5	≈2 per thousand rate of occurrence
Medium Likelihood	6	≈5 per thousand rate of occurrence
Moderately High Likelihood	7	≈10 per thousand rate of occurrence
Very High Severity	8	≈20 per thousand rate of occurrence
Extreme Severity	9	≈50 per thousand rate of occurrence
Maximum Severity	10	≈100 per thousand rate of occurrence

Failure Mode *"Controls"*

They are mechanisms, methods, tests, procedures, or controls that we have in place to *PREVENT* the Cause of the Failure Mode or *DETECT* the Failure Mode

✓Design Controls prevent or detect the Failure Mode prior to engineering release

Detection Rating/Rank

It is a numerical rating of the probability of the failure being detected by controls before the impact of the effect is realized

✓Assuming that the cause of the failure did occur, assess the capabilities of the controls to find the design flaw.

Detection	Rank	Criteria
Extremely Likely	1	Can be corrected prior to prototype/ Controls will almost certainly detect
Very High Likelihood	2	Can be corrected prior to design release/Very High probability of detection
High Likelihood	3	Likely to be corrected/High probability of detection
Moderately High Likelihood	4	Design controls are moderately effective
Medium Likelihood	5	Design controls have an even chance of working
Moderately Low Likelihood	6	Design controls may miss the problem
Low Likelihood	7	Design controls are likely to miss the problem
Very Low Likelihood	8	Design controls have a poor chance of detection
Very Low Likelihood	9	Unproven, unreliable design/poor chance for detection
Extremely Unlikely	10	No design technique available/Controls will not detect

FMEA Terminology(contd…)

Risk Priority Number (RPN): It is the product of Severity, Occurrence, & Detection.

RPN= S x O x D

- The failure modes with the highest RPNs should be attended first, although special attention should be given when the severity rating is high regardless of the RPN. General guideline is : If RPN > 100 then recommended action
- Once corrective action has been taken, a new RPN is determined by re-evaluating the severity, occurrence, and detection ratings

✓Based on the FMEA analysis, strategies to reduce risk are focused on:

- Reducing the *Severity Rating.*
- Reducing the *Occurrence Rating.*
- Reducing the *detection Rating.*

FMEA Sheet

Product:

Process/ Component/ Function	Potential failure mode(s)	Potential effect(s) of failure	SEV	Potential Cause(s)/ Mechanisms of Failure	PROB	Current design controls	DET	**RPN**	*Recommended Action*

Function

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- **Functions should be written in verb-noun context if practical.**
- **An associated measurable metric is desirable.**

As an example:

The problem is to design an automotive HVAC system which must *defog windows* and *heat or cool cabin* to 70 degrees in all operating conditions (-40 degrees to 100 degrees) within 3 to 5 minutes.

Functions

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- Therefore in this example, the functions are…
  - Defog windows
  - Heat cabin
  - Cool cabin

Failure Modes

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- **Identify Failure Modes. A failure mode is defined as the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent.**
  - **How can the part/system fail to meet specifications?**
  - **What would a customer consider objectionable?**

- **There are 5 classes of failure modes:**
  - **complete failure,**
  - **partial failure,**
  - **intermittent failure,**
  - **over-function, and**
  - **unintended function**

Failure Modes, examples

- **Examples:**
  - **Complete failure**
    - **HVAC system does not heat vehicle or defog windows**
  - **Partial failure**
    - **HVAC system takes more than 5 minutes to heat vehicle**
  - **Intermittent failure**
    - **HVAC system does heat cabin to 70 degrees in below zero temperatures**
  - **Over-function**
    - **HVAC system cools cabin to 50 degrees**
  - **Unintended functions**
    - **HVAC system activates rear window defogger**

Effect(s) of Failure

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- **Effects should be listed as customer would describe them (consider…)**
  - **Reduced performance**
  - **Customer dissatisfaction**
  - **Potential risk of injury**
  - **Product liability**
- **Effects should include (as appropriate) safety / regulatory body, end user, internal customers (manufacturing, assembly, service)**
- **For example:**
  - **Cannot see out of front window**
  - **Air conditioner makes cabin too cold**
  - **Does not get warm enough**
  - **Takes too long to heat up**

Severity

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

Determine the *severity* of the failure effects (as a rating value)

Severity values may be available from governing bodies. In this example AIAG and SAE.

If severity is based upon internally defined criteria or is based upon standard with specification modifications, rating tables should be included with the analysis.

Examples:

- **Cannot see out of front window: severity 9**
- **Air conditioner makes cab too cold: severity 5**
- **Does not get warm enough: severity 5**
- **Takes too long to heat up: severity 4**

Example of a Severity Table

Rating	Severity Description
1	The effect is not noticed by customer
2	Very slight effect noticed by customer, does not annoy or inconvenience customer
3	Slight effect that causes customer annoyance, but they do not seek service
4	Slight effect, customer may return product for service
5	Moderate effect, customer requires immediate service
6	Significant effect, causes customer dissatisfaction; may violate regulation or design code
7	Major effect, system may not be operable; elicits customer complaint; may cause injury
8	Extreme effect, system is inoperable and a safety problem. May cause severe injury.
9	Critical effect, complete system shutdown; safety risk
10	Hazardous; failure occurs without warning; life threatening

Cause(s) of Failure

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- Causes must be identified for a failure mode
- Brainstorm causes (man, machine, material, method, environment…)
- Causes should be limited to design issues (what you can control)
- There is usually more than one cause of failure for each failure mode

For our example:

  - Poor vent location
  - Routing of vent hoses (too close to heat source)
  - Inadequate coolant capacity for application

Occurrence (or Probability)

Item / Function	Potential Failure Mode	Potential Failure Effects	S E V	Potential Causes Mechanism(s) of Failure	O C C	Current Controls	D E T	R P N	Recommended Actions	Target Complete Date	Actions Taken	S E V	O C C	D E T	R P N

- **Occurrence ratings for design FMEA are based upon the likelihood that a cause may occur, based upon past failures, and/or performance of similar systems in similar applications**
- **Occurrence rating values may be standardized (AIAG, SAE in this example)**
- **If occurrence values are based upon internally defined criteria, a rating table should be included in FMEA (with explanation for use)**
- **Occurrence values of 1 should have objective data to provide justification for inclusion (since failure level so low…)**

Examples

- **Poor vent location: occurrence 3**
- **Routing of vent hoses (too close to heat source): occurrence 6**
- **Inadequate coolant capacity for application : occurrence 2**

Sample of an Occurrence Table

Rating	Approx. Probability of Failure	Description of Occurrence
1	$\leq 1 \times 10^{-5}$	Extremely remote
2	1×10^{-5}	Remote, very unlikely
3	1×10^{-5}	Very slight chance of occurrence
4	4×10^{-4}	Slight chance of occurrence
5	2×10^{-3}	Occasional occurrence
6	1×10^{-2}	Moderate occurrence
7	4×10^{-2}	Frequent occurrence
8	0.20	High occurrence
9	0.33	Very high occurrence
10	≥ 0.50	Extremely high occurrence

Current Design Controls

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- **Identify the existing controls that identify and reduce failures**

- **Controls may be *Preventive (designed in)* or *Detective (found by functional testing, etc.)***
  - Preventive controls are those that help reduce the likelihood that a failure mode or cause will occur (affect occurrence value)
  - Detective controls are those that find problems that have been designed into the product (assigned detection value)
  - If detective and preventive controls are not listed in separate columns, they must include an indication of the type of control

Current Design Controls

- **Examples:**

  Engineering specifications provide preventive control (P)

  Historical data provide preventive control (P)

  Functional testing provides detective control (D)

Detection

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- Detection values should correspond any existing standards (AIAG, SAE)
- If detection values are based upon internally defined criteria, a rating table should be included in FMEA (with explanation for use)
- Detection is the value assigned to each of the detective controls.
- Detection values of 1 mean the potential for failure is eliminated due to design solutions.

Examples:

Engineering specifications:	no detection value
Historical data:	no detection value
Functional testing:	detection 3
General vehicle durability:	detection 5

RPN (Risk Priority Number)

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- **Risk Priority Number is the product of the severity, occurrence and detection ratings. (RPN = S*O*D)**
  Note: Lowest detection rating is used to determine RPN

- **RPN threshold should not be used as the primary trigger for definition of recommended actions**

From previous examples:

Cannot see out of front window	**(S = 9)**
Incorrect vent location	**(O = 2)**
Detection by functional testing	**(D = 3)**

RPN = 54

Recommended Actions

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- **The RPN is used to identify items which require attention and assign a priority to them.**
- **All critical or significant failures should have recommended actions associated with them.**
- **Recommended actions should be focused on design, and directed toward mitigating the cause of failure, or eliminating the failure mode.**

Recommended Actions

Item / Function	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes Mechanism(s) of Failure	OCC	Current Controls	DET	RPN	Recommended Actions	Target Complete Date	Actions Taken	SEV	OCC	DET	RPN

- Recommended Actions (examples)
  - Try to eliminate the failure mode (some failures are more preventable than others)
  - Minimize the severity of the failure
  - Reduce the occurrence of the failure mode
  - Improve the detection

FMEA Sheet : Example

Product: Computer Station

Component	Mode of Failure	Cause of Failure	Effect of Failure	Frequency of Occurrence (1-10)	Degree of Severity (1-10)	Chance of Detection (1-10)	Risk Priority (1-1000)	Design Action
Hardware Installation	Hardware not installed on time	Shipping delay from manufacturer	Customer loses time/$	2	6	8	96	Agent reviews timeline with supplier
		Inaccurate estimate of time required	Customer loses time/$	3	4	1	12	
		Unavailable/ overscheduled installers	Customer loses time/$	6	4	3	72	
		Missing components	Customer loses time/$	5	7	5	175	Installers verify components needed for job
	Hardware not installed properly	Inexperienced installers	Hardware must be reinstalled	1	8	10	80	
		Customer requirements not clear	Hardware must be reinstalled	7	8	7	392	Installer meets/ calls customer to verify design

Product DC motor

No.	Part Name Part No.	Function	Failure Mode	Mechanism(s) & Causes(s) of Failure	Effect(s) Of Failure	Current Control	P.R.A.				Recommended Corrective Action(s)
							P	S	D	R	
1	Position Controller	Receive a demand position	Loose cable connection	Wear and tear	Motor fails to move		2	4	1	8	Replace faulty wire.
			Incorrect demand signal	Operator error	Position controller breakdown in a long-run		4	4	3	48	Q.C checked. Intensive training for operators.
2	Drive	Receive speed demand	Incorrect speed demand being received	Fault in position controller's output	Extensive damage to the machine		2	4	4	32	Indicator and Audile warning
		Measures actual speed	Incorrect speed reading	Wear and tear	Extensive damage		4	4	5	80	Voltmeter Improve check procedures
3	Motor	Provides voltage signal	Signal loss	Faulty leads	Unstable control loop Endanger operators Serious damage		3	5	4	60	Durability test on leads

Home Assignment#6

carryout FMEA analysis and suggestive corrective actions to improve the reliability and safety of your product