# Failure Modes and Effects Analysis (FMEA)

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# Failure Mode and Effects Analysis (FMEA)

- An analysis technique used to identify potential design or process problems
- Method examines causal relationship and effects of lower level failures on devices or systems.
- Identifies where actions or compensating provisions are needed to
  - reduce the likelihood of the problem occurring, and
  - mitigate the risk, if problem does occur.

# Failure Mode and Effects Analysis (FMEA)

- Application in Industry
  - FMEA Project teams made up of experts from engineering, manufacturing, etc assigned to review the concept, design, process or system
  - The FMEA team determines the effect of each failure and identifies single failure points that are critical.
  - Team may also rank each failure according to failure effect probability and criticality, to assign importance.

# Varieties of FMEAs.

- ***Conceptual*** **FMEAs**
- ***Functional*** **FMEAs**
- ***Design*** **FMEAs**
- ***Process*** **FMEAs**

(e.g. *Manufacturing* process)

– Some Alternative FMEA Approaches:
  - **Review just hardware**
  - **Review hardware and function.**

# <u>Design</u> failure modes effects analysis (DFMEA)

DFMEA procedure probably the most common FMEA encountered by MEs/METs

- Identifies potential design failures <u>before</u> they occur.
- Investigates the potential effects of the failures, and their cause.
- Anticipates <u>when</u> failures might occur, how often.
- Estimates <u>severity</u> of effect

# Manufacturing Process FMEA (Process FMEA, or PFMEA)

- Recognize and evaluate the potential failure of a <u>process</u> and its effect
- Identify actions which could eliminate or reduce the occurrence of failure, or improve likelihood of detection
- Documents the process
- Track changes to the processes that have been incorporated to avoid potential or anticipated failures

# Contrast FMEA with Forensics

- Forensics – Determine what happened.
  - Equipment Failures, Car Crashes, Injuries, etc
  - Lots of Engineering, Consulting activity in field

- FMEA – Anticipate what MIGHT occur
  - Identify possible issues
  - Prioritize actions, take steps for improvement
  - Document process

# Why is FMEA / FMECA Important?

- FMEA provides a basis for identifying root failure causes and developing effective corrective actions
- The FMEA identifies reliability/safety of critical components
- An FMEA facilitates investigation of design alternatives at all design or implementation stages
- Provides a foundation for other maintainability, safety, testability, and logistics analyses
- A <u>Pro-active</u> engineering quality method

# An FMEA also …

- Helps to **identify** and **counter** weak points in a design or system
- Works in the early conception phase of all kinds of ***products*** (hardware, software) and ***processes***
- Is a commonly recognized, structured approach = **easy to use** even for a non-specialist
- Widely used in **engineering**, **industrial, medical, business** areas.
- Provides DOCUMENTATION of quality improvement actions!

# FMEA / FMECA Background and History

- An offshoot of 1949 Military Procedure MIL-P-1629, entitled “Procedures for Performing a Failure Mode, Effects and Criticality Analysis”
  - Used as a reliability evaluation technique to determine the effect of system and equipment failures.
  - Failures were classified according to their impact on mission success and personnel/equipment safety.
- Formally developed and applied by NASA in the 1960’s to improve and verify reliability of space program hardware.
- The procedures called out in **MIL-STD-1629A** are the most widely accepted methods throughout the military and commercial industry.
- Similar **SAE J1739** is a prevalent FMEA standard in the automotive industry.
- Aerospace industry sometimes utilizes Society of Automotive Engineers Aerospace Recommended Practice **ARP5590** .

# Mil-Std-1629A - Related FMEA Definitions

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

**Criticality:** a measure of the frequency of occurrence of an effect. May be based on qualitative judgement or may be based on failure rate data

**Detection Method:** The method by which a failure can be discovered by the system operator under normal system operation or by a maintenance crew carrying out a specific diagnostic action.

**End Effect:** The consequence a failure mode has upon the operation, function or status at the highest indenture level.

**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. **(Past)**

**Failure Effect:** The consequence of a failure mode has upon the operation, function or status of a system or equipment. **(Future)**

# FMEA Definitions (cont.)

**Failure Mode:** The way in which a failure is observed, describes the way the failure occurs, and its impact on equipment operation.

**Indenture Levels**: The levels which identify or describe the relative complexity of an assembly or function.

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

**Mission Phase Operational Mode:** The statement of the mission phase and mode of operation of the system or equipment in which the failure occurs.

**Next Higher Level Effect:** The consequence a failure mode has on the operation, functions, or status of the items in the next higher indenture level above the specific item begin analyzed.

**Severity:** Considers the worst possible consequence of a failure classified by the degree of injury, property damage, system damage and mission loss that could occur (ref: **Mil-Std-1629A FMECA severities**).

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

# A Bottom-to-top FMEA approach…

- What are the effects of box failures on the **system**?

  – What are the effects of board failures on the box?

- What are the effects of part failures on the board?

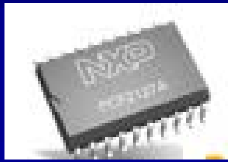
What if a part suffers Basic functional failure?

# A Top-to-Bottom approach …

•What system-level failures could occur, and what would cause them? How to mitigate effects?

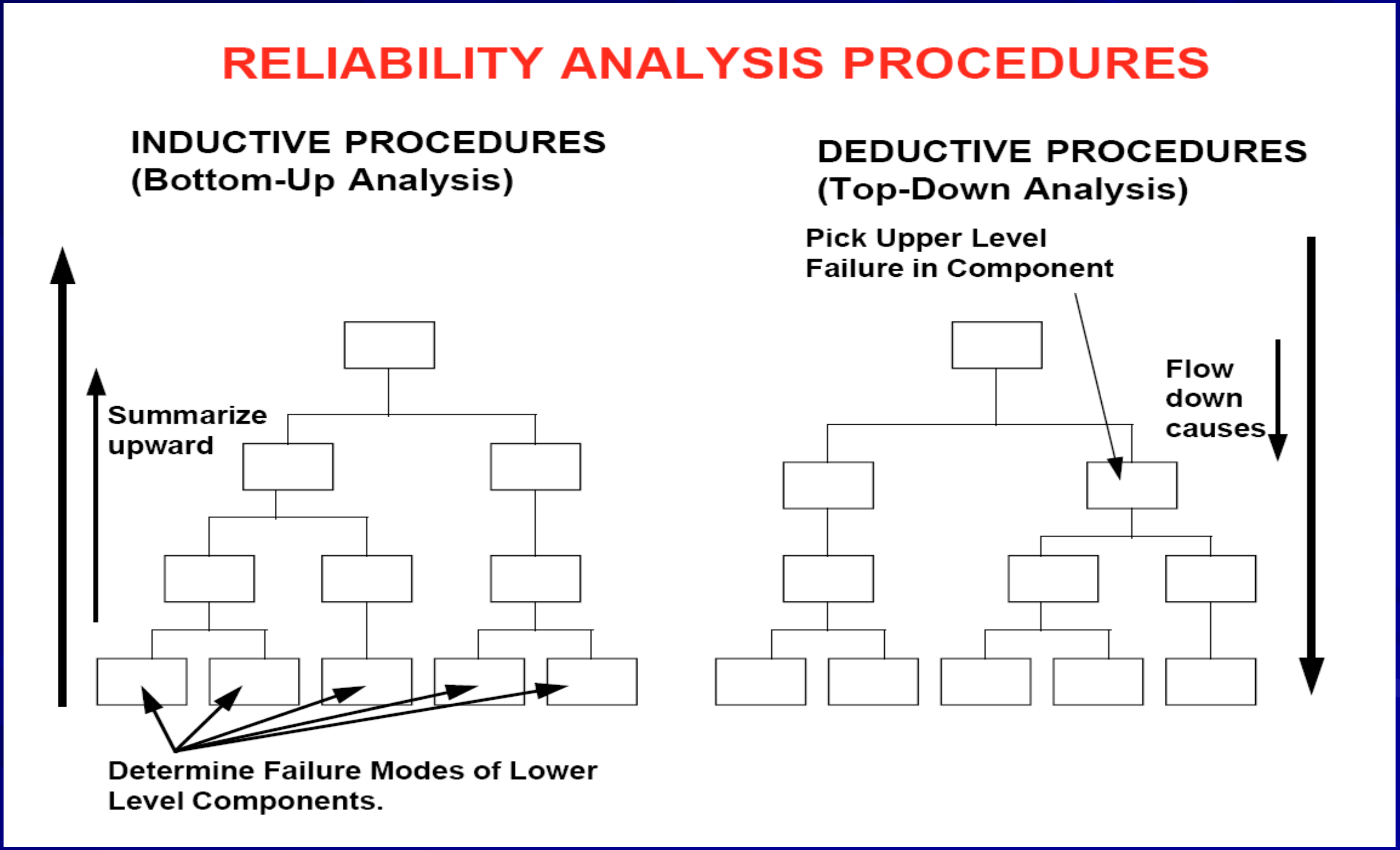
•If assembly-level failures could cause the system problem, what would cause the assembly failure? How to mitigate effects?

•If board-level could cause sub-assembly problems, what could cause the board failure? How to mitigate effects?

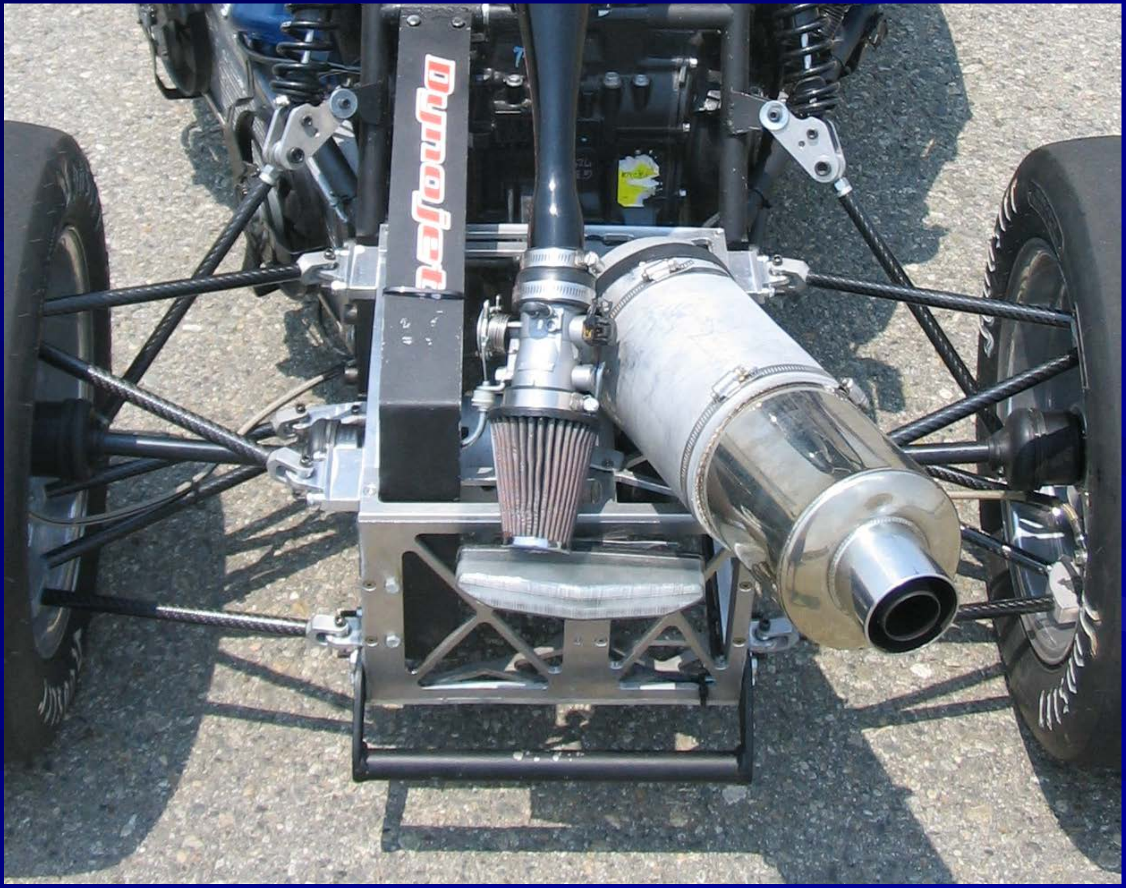


•If component-level failures could cause the board-level problem, what in-turn would cause that failure? How to mitigate effects?

# Block Diagrams of two approaches: Bottom-Up vs Top-Down



# Failure case study:
# 2008 Formula SAE Car

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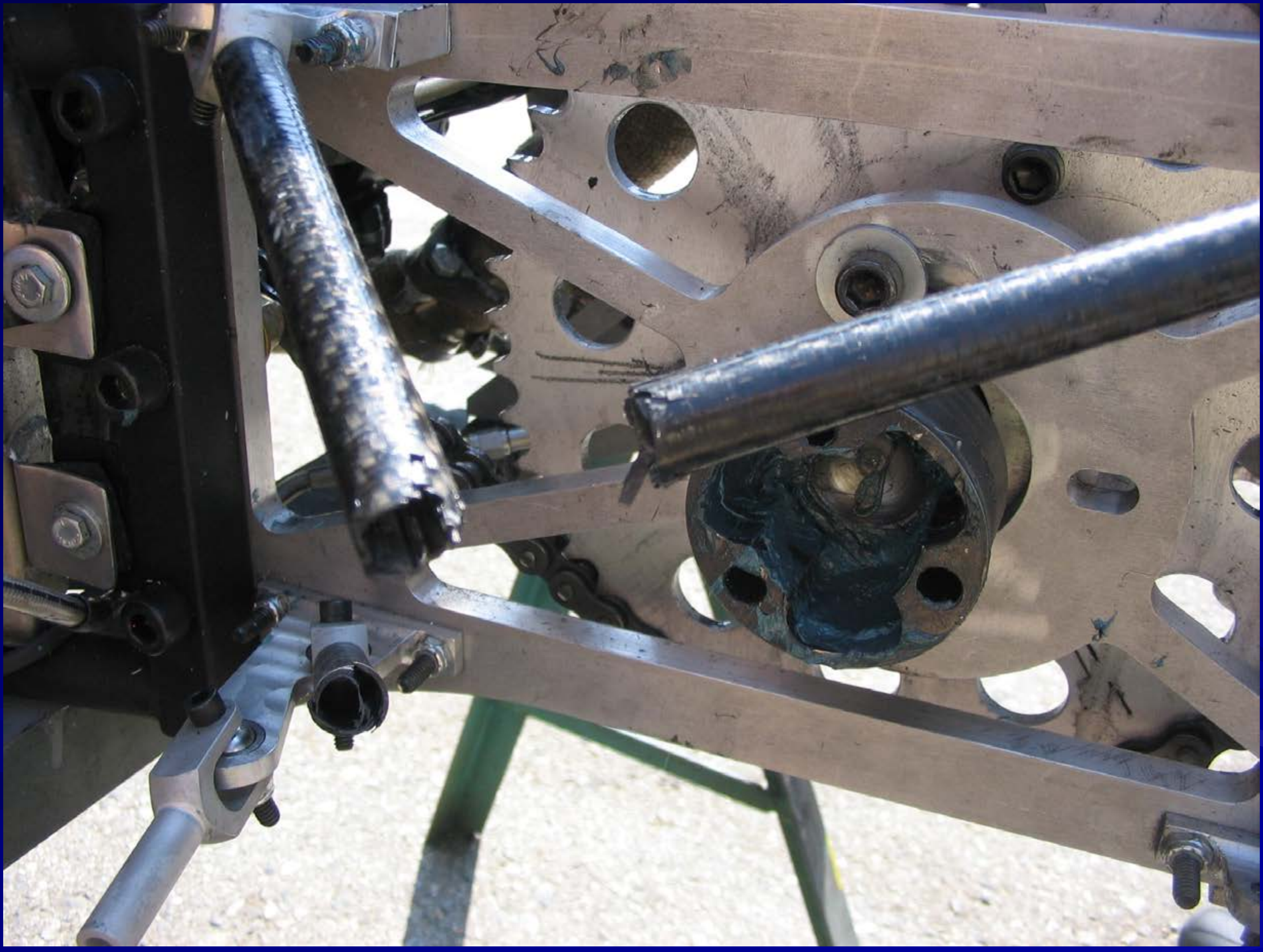
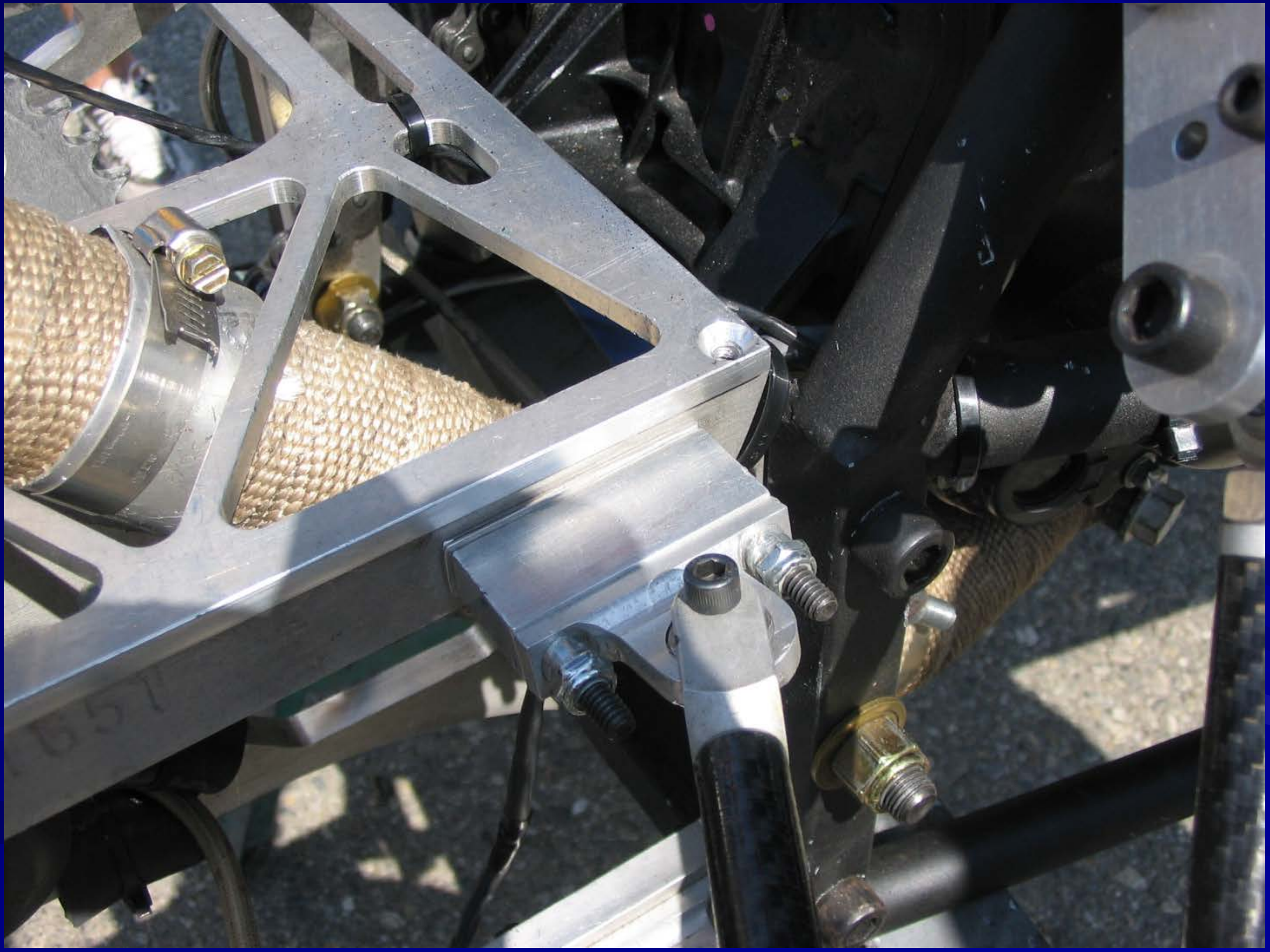
SAE
Kawasaki



# Secondary Effects of Failure

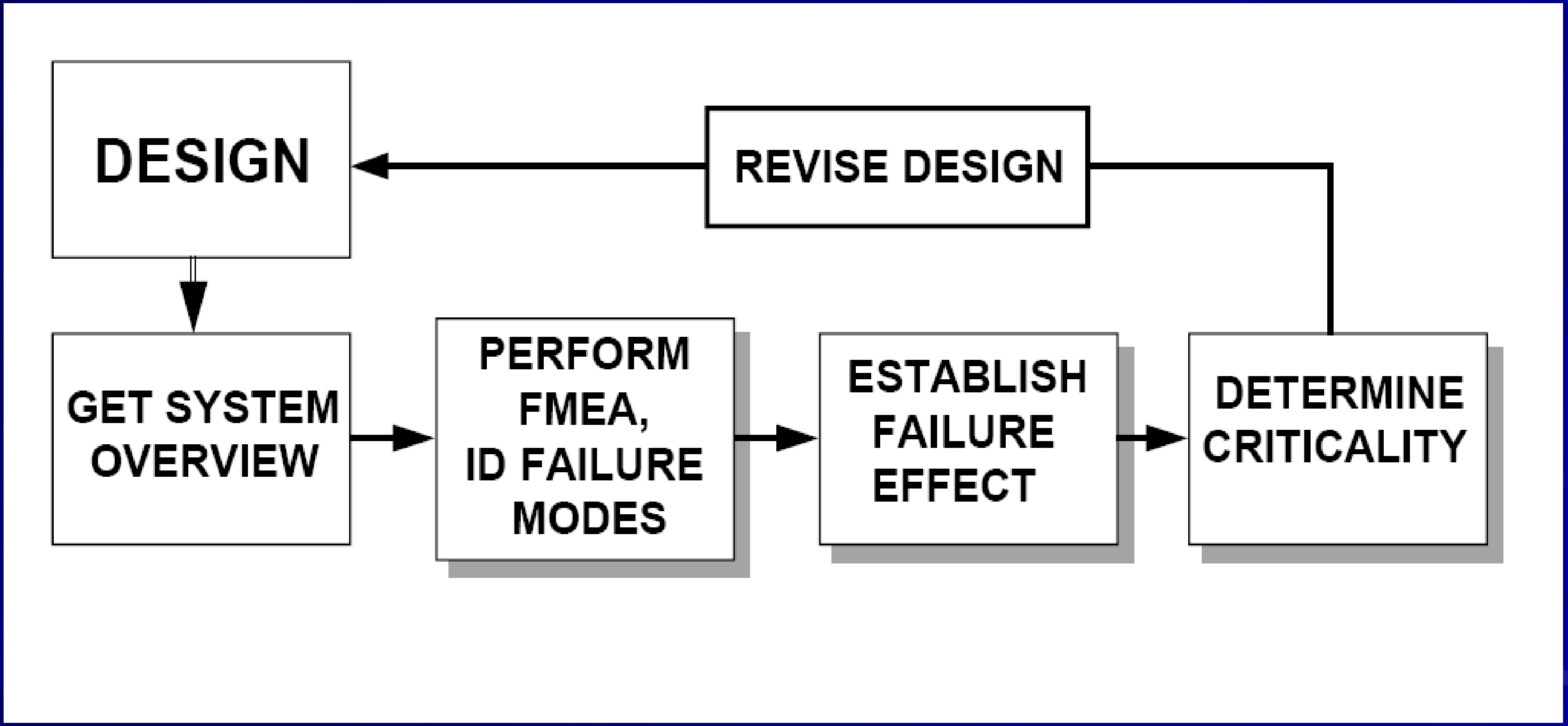


# Contributing Cause: NO significant testing prior to event

- Photo: 2:30 AM on morning of race, California Hotel Parking Lot, Car still under construction


26
Kawasaki

# Implementation into Design Process Methodology



# 1) Define the system

- List each subassembly and component number along with basic functions
- Basic functions should match design intent
- May list environmental and operational parameters (temperature, vibration, pressure, duty cycle, limits of operation) to clarify design intent

# 2) Identify and list the potential failures

- Try to understand the <u>physics</u> of potential problems
- Use Free-body Diagrams, Storyboards, Process-flow diagrams, etc.
- Do some research. Compare with existing or similar products. Build scale models.
- Brainstorm with knowledgeable experts.
- Discuss with individuals *outside* that expertise area
- Analyze via computer or otherwise.
  (Notice FEA is <u>not</u> the only method!)

# 3) List possible causes or mechanisms of a possible failure

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**_Some Example Failures_**

| | | |
|---|---|---|
| *Acoustic noise* | *Fracture* | *Seizure* |
| *Binding* | *Intermittent Operation* | *Staining* |
| *Buckling* | *Leaks* | *Stall* |
| *Burning* | *Material Yield* | *Stripping* |
| *Corrosion* | *Misalignment* | *Surge* |
| *Cracking* | *Open Circuit* | *Thermal Expansion* |
| *Creep* | *Oxidation* | *Unstable Unbalanced* |
| *Deflection/Deformation* | *Radiation Damage* | *UV Deterioration* |
| *Delamination* | *Resonance* | *Vibrations* |
| *Electrical short* | *Ringing* | *Wear* |
| *Erosion* | *Sagging* | *Wobble* |
| *Fatigue* | *Scoring* | |

# 4) List the potential effects of the failure

- Noise
- Odor
- Fire
- Erratic performance
- Inoperative
- Excessive vibration
- Fit problems
- Durability issues
- Shortened lifetime
- Other Quality or functional problems…

# 5) Rate the likelihood of occurrence (O)

- Occurrence is a numerical, subjective estimate of the LIKELIHOOD that the cause, if it occurs, will produce the failure mode and its particular effect.

# Occurrence (O)

| Probability of Failure | Possible Failure Rates | Ranking |
|---|---|---|
| Very High: Failure is almost inevitable | >= 1 in 2 | 10 |
| | 1 in 3 | 9 |
| High: Repeated failures | 1 in 8 | 8 |
| | 1 in 20 | 7 |
| Moderate: Occasional failures | 1 in 80 | 6 |
| | 1 in 400 | 5 |
| | 1 in 2,000 | 4 |
| Low: Relatively few failures | 1 in 15,000 | 3 |
| | 1 in 150,000 | 2 |
| Remote: Failure is unlikely | <= 1 in 1,500,000 | 1 |

# 6) Estimate potential severity (S)

- Severity is a numerical, subjective estimate of severity of the failure

- Can also be construed as how severe the customer or end user will perceive the failure effect

(Note that these are not always the same!)

# Severity (S)

| Effect | Criteria: Severity of the Effect | Ranking |
|---|---|---|
| Hazardous - without warning | Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning. | 10 |
| Hazardous - with warning | Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning. | 9 |
| Very High | Vehicle / item inoperable, with loss of primary function. | 8 |
| High | Vehicle / item operable, but at reduced level of performance. Customer dissatisfied. | 7 |
| Moderate | Vehicle / item operable, but Comfort/Convenience item(s) inoperable. Customer experiences discomfort. | 6 |
| Low | Vehicle / item operable, but Comfort/Convenience item(s) operable at reduced level of performance. Customer experiences some dissatisfaction. | 5 |
| Very Low | Fit & Finish/Squeak & Rattle item does not conform. Defect noticed by most customers. | 4 |
| Minor | Fit & Finish/Squeak & Rattle item does not conform. Defect noticed by average customer. | 3 |
| Very Minor | Fit & Finish/Squeak & Rattle item does not conform. Defect noticed by discriminating customer. | 2 |
| None | No Effect. | 1 |

# 7) Assess detection (D)

- Detection is a numerical, subjective estimate of the effectiveness of the controls used to prevent or detect the cause or failure mode
- Detection should occur before the failure affects the finished product (before product reaches the customer.)
- For this parameter, the assumption is that the cause has occurred.

# Detection (D)

| Detection | Criteria: Likelihood of Detection by Design Control | Ranking |
|---|---|---|
| Absolute Uncertainty | Design Control will not and/or can not detect a potential cause/mechanism and subsequent failure mode; or there is no Design Control. | 10 |
| Very Remote | Very remote chance the Design Control will detect a potential cause/mechanism and subsequent failure mode. | 9 |
| Remote | Remote chance the Design Control will detect a potential cause/mechanism and subsequent failure mode. | 8 |
| Very Low | Very low chance the Design Control will detect a potential cause/mechanism and subsequent failure mode. | 7 |
| Low | Low chance the Design Control will detect a potential cause/mechanism and subsequent failure mode | 6 |
| Moderate | Moderate chance the Design Control will detect a potential cause/mechanism and subsequent failure mode. | 5 |
| Moderately High | Moderately high chance the Design Control will detect a potential cause/mechanism and subsequent failure mode. | 4 |
| High | High chance the Design Control will detect a potential cause/mechanism and subsequent failure mode | 3 |
| Very High | Very high chance the Design Control will detect a potential cause/mechanism and subsequent failure mode. | 2 |
| Almost Certain | Design Control will almost certainly detect a potential cause/mechanism and subsequent failure mode. | 1 |

# 8) Calculate the Risk Priority Number (RPN)

**RPN = (S) * (O) * (D)**

**where**

Severity = (S),

Occurrence  = (O),

and Detection = (D).

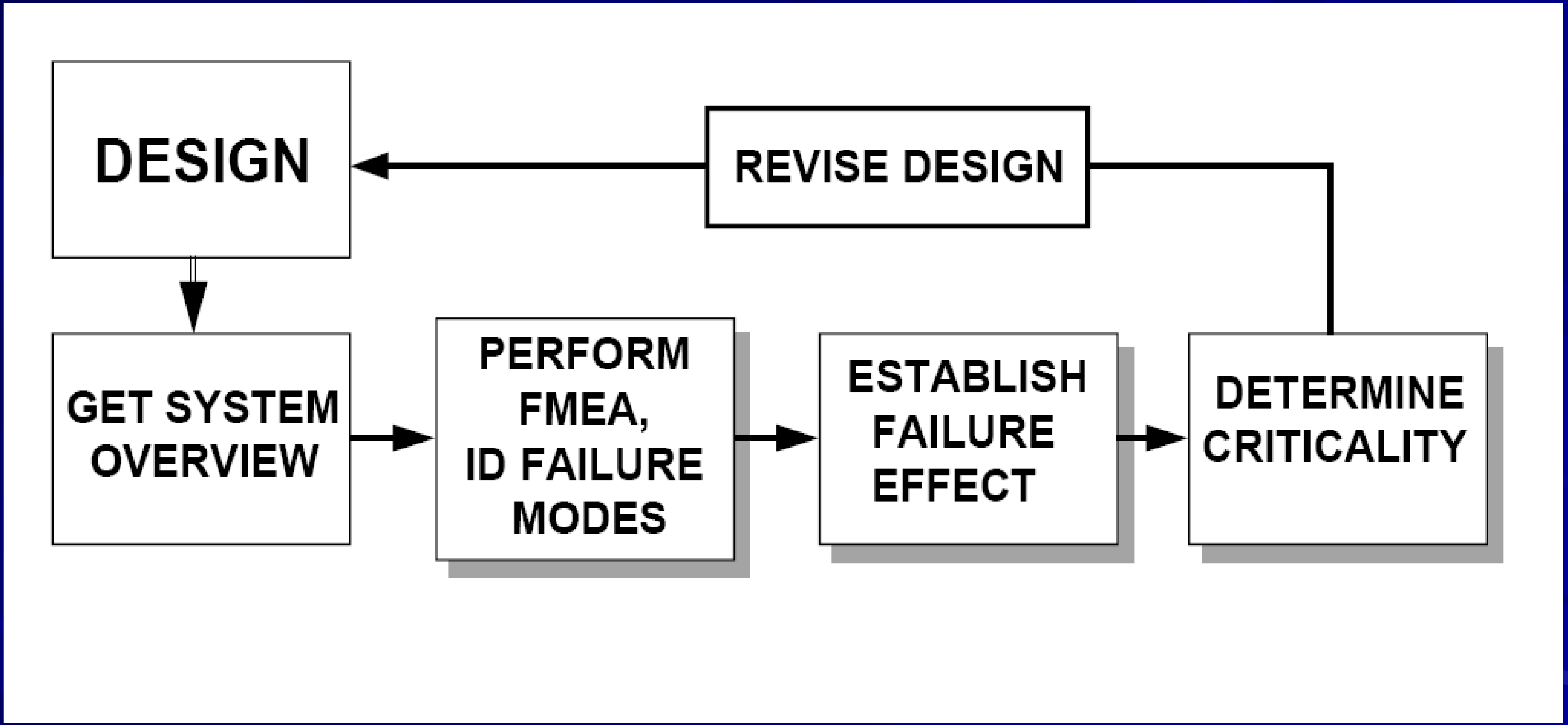
# Risk Priority Number **(RPN)**

- Provides a qualitative numerical estimate of design risk.
- Nonlinear in risk, numbers are relative for a given evaluation process and evaluation team.
- Review carefully to  determine critical items in your system
- Be careful If comparing work of different teams, different products

# 9) Feed results back into design process

- Corrective actions should be developed on a priority basis based on RPN ranking
- Responsibility for development assigned to key individuals
- Scheduling of corrective action items key to product development and improvement

# Implementation into Design Process Methodology



# 10) Implement corrective action or Redesign.

- Repeat RPN analysis to determine effectiveness of the actions

# FMEA Template for Design and Development

| Product Name: ________<br>___ System<br>___ Subsystem Name: ____<br>___ Component | Devel. Team: ____________<br>____________ | Page No. ____ of ____<br>FMEA Number ______<br>Date: ______ |
|---|---|---|

| Part # & Functions | Potential Failure Mode | Potential Effect(s) of Failure | Severity (S) | Potential Causes/ Mechanism(s) of Failure | Occurrence (O) | Current Design Controls/ Tests | Detection (D) | Recommended Actions | RPN |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**TABLE 12.4. PARTIAL FMEA EXAMPLE OF AN AUTOMOBILE FRONT DOOR (AFTER FMEA 1995)**

Product Name: 200X/Lion 4dr/Wagon
____ System
_X_ Subsystem Name: Body Closure
____ Component

Devel. Team: __________

Page No. _1_ of _N_
FMEA Number _1234_
Date: _0X-03-02_

| Part # & Functions | Potential Failure Mode | Potential Effect(s) of Failure | SEVER (S) | Potential Cause(s)/ Mechanism(s) of Failure | OCCUR (O) | Current Design Controls/Tests | DETECT (D) | Recommended Actions | RPN |
|---|---|---|---|---|---|---|---|---|---|
| Front Door LH, H8HX-0000-A<br>Ingress to and egress from vehicle<br>Protect occupant from weather, noise, and side impact<br>Support door hardware including mirror, hinges, etc.<br>Provide proper surface for appearance items (display surface)<br>Adhere paint and soft trim | Corroded interior lower door panels | Deteriorated life of door leading to: Unsatisfactory appearance due to rust through paint over time and impaired function of interior door hardware | 7 | Upper edge of wax for inner door panel is too low | 6 | Vehicle general durability test vah. T-118, T-109, T-301 | 7 | Add laboratory accelerated corrosion testing | 294 |
| | | | | Insufficient wax thickness specified | 4 | Vehicle general durability testing as above | 7 | Add laboratory accelerated corrosion testing; Conduct design of experiments of wax thickness | 196 |
| | | | | Inappropriate wax formulation specified | 2 | Physical and Chem Lab test—Report No. 1265 | 2 | None | 28 |
| | | | | Entrapped air prevents wax from entering corner/edge access | 5 | Design aid investigation with nonfunctioning spray head | 8 | Add team evaluation using production spray equipment and specified wax | 280 |
| | | | | . . . | . . . | . . . | . . . | . . . | . . . |
| | | | | Insufficient room between panels for spray head access | 4 | Drawing evaluation of spray head access | 4 | Add team evaluation using design aid buck and spray head | 112 |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

# Failure Mode Effects and *Criticality* Analysis (FMECA)

- Another similar technique, extension of FMEA
- The **FMECA** is the result of two steps:
  - Failure Mode and Effect Analysis (FMEA)
  - Criticality Analysis (CA) to evaluate the frequency of occurrence of the problems identified.

# FMECA

## CRITICALITY ANALYSIS

- Assign critically categories based on redundancy, results of failure, safety etc.
- Develop criteria for what failure modes are to be included in a critical items list (CIL).
- Develop screens to evaluate redundancy.
- Analyze each critical item for ways to remove it, or develop “retention rational” to support the premise that the risk can be retained.
- Cross check critical items with hazard reports.

# CRITICALITY CATEGORIES (TYP.)

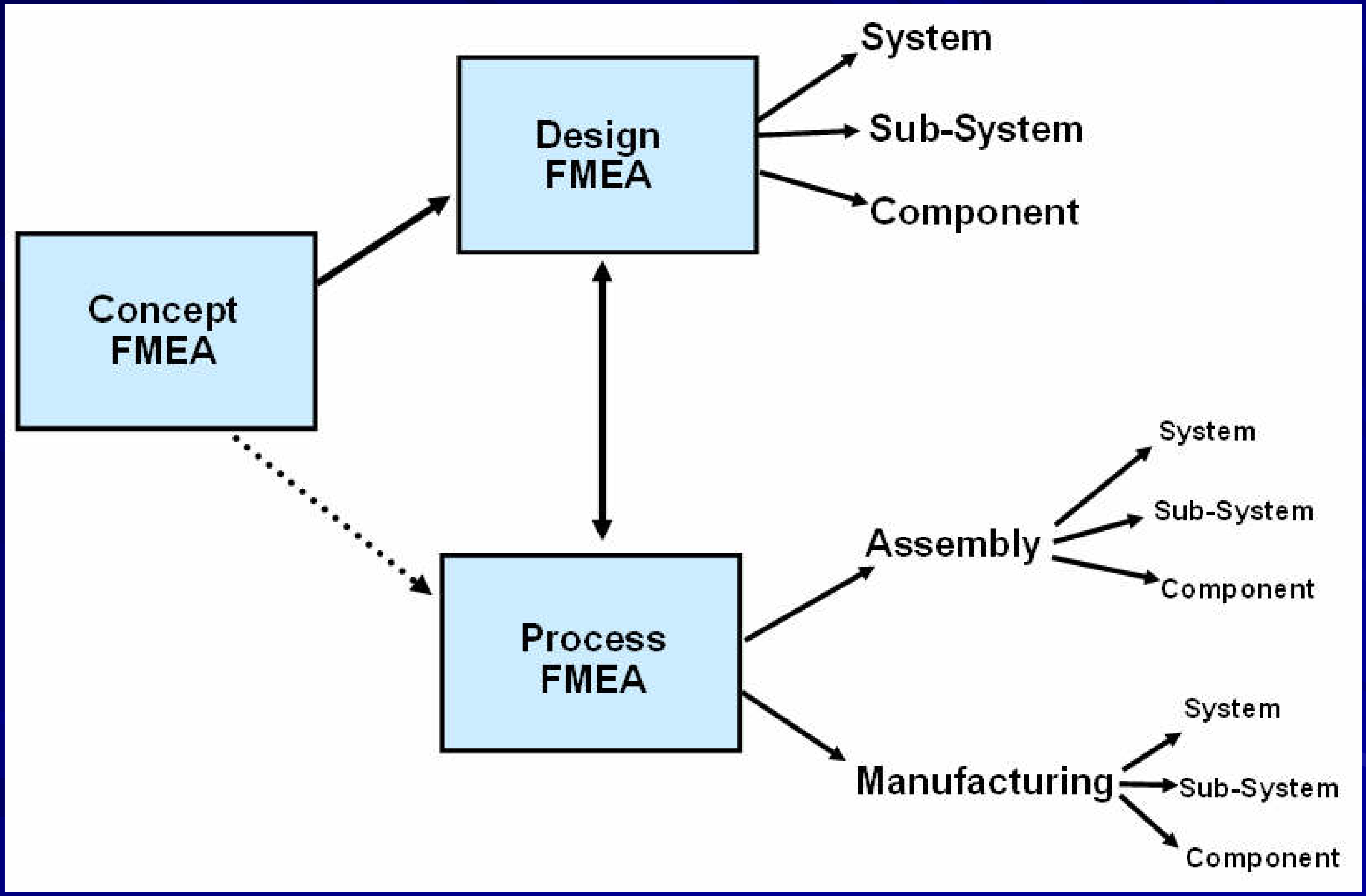
- **1** Single failure point that could result in loss of vehicle or personnel.
- **1R** Redundant items, where if all failed, the result is loss of vehicle or personnel.
- **1S** A single failure point of a system component designed to provide safety or protection capability against a potential hazardous condition or a single point failure in a safety monitoring system (e.g. fire suppression system).
- **1SR** Redundant components, where if all failed, the result is the same as 1S above.
- **1P** A single failure point which is protected by a safety device, the functioning of which prevents a hazardous condition from occurring.
- **2** Single point failure that could result in loss of critical mission support capability.
- **3** All other.

# Analyze Critical Items

- Redesign item, add redundant unit, etc.
- Prepare retention rationale for item.
  - What current design features minimize the probability of occurrence.
  - What tests can detect failure modes during acceptance tests, cert. tests, prelaunch and/or on-orbit checkout.
  - What inspections can be performed to prevent the failure mode from being mfg, into hardware.
  - What failure history justifies the CIL retention.
  - How does operational use of the unit mitigate the hardwares failure effect.
  - How does maintainability prevent the failure mode.

# CONCEPT FMEA (CFMEA)

- The Concept FMEA is used to analyze concepts in the early stages before hardware is defined (most often at system and subsystem)
- It focuses on potential failure modes associated with the proposed functions of a concept proposal
- This type of FMEA includes the interaction of multiple systems and interaction between the elements of a system at the concept stages.



Concept
FMEA
Design
FMEA
System
Sub-System
Component
Process
FMEA
Assembly
System
Sub-System
Component
Manufacturing
System
Sub-System
Component

# references


- http://www.fmeainfocentre.com/examples/36VbatFMEA.pdf
- http://www.fmeainfocentre.com/examples/FMEAworksheet.pdf
- http://www.fmeainfocentre.com/examples/xfmea_dfmea.pdf
- "Product Design", Kevin Otto and Kristin Wood, Prentice Hall, 2001

# FMEA ASSIGNMENT

- Review your Group's Conceptual Design
- EACH GROUP MEMBER is to Identify a unique, major critical subsystem function or component: (Each group member should do a different function or component.)
- Individually perform an FMEA on the identified component, and Document The Process Used: (You may use the form from this presentation, or generate your own similar form.)
- Meet as a group, and RANK the importance of all the items addressed in the individual FMEAs.
- For the function or component that you identify as the most critical, create an ACTION PLAN on how minimize the risk.
- Submit your individual FMEA's plus the GROUP ACTION PLAN via D2L drop-box by due date.