Design for X

- Design for X
- Failure Modes & Effects Analysis
- Injury, Hazards, Conditional Circumstances
- Legal Responsibilities
- Guidelines for Safe Products/systems
- Safety Hierarchy, Safe Design Principles
- Summary

Predicting Performance (and redesigning)

Why bother?

Want to assure that:

- product "performs as expected"
- "lasts a long"
- "easy to maintain"

AND THAT…

- no damage occurs to product
- no damage or harm to environment
- no harm or injury to operator or user

Are there other methods to ensure performance?

Design for X

Def- a term used to describe….
a variety of design methods…
that focus on…
specific product development concerns.

Specifically, in this chapter:
Failure (FMEA)
Safety
Tolerances and
Environment

Failure Modes and Effects Analysis (FMEA)

Method to systematically identify and correct potential product or process deficiencies before they occur.

to:

1. eliminate the causes of the potential failure modes and or
2. reduce a severity of the failure

(Multi-phase, i.e. used in any design phase)

What can go wrong with hydraulic log splitter?

Hydraulic hose, on a home-use log splitter, begins to leak.

The leak reduces the pressure to the piston/ram resulting in poor splitting.

The leak drips oil on ground, creating a mess, costly too!

Upon examination, a weak spot is found on hose due to poor manufacturing!

A defect in design or manufacturing might cause the part (product or process) to fail to perform.

Fundamental concepts of FMEA

Failure mode: the "way" a part fails to perform

e.g. failure mode: hose leaks

Effect: *adverse consequence* of failure mode

e.g. hose leak results in oil spills, refill costs

Effects can be *severe* or hardly noticeable.

Cause: *why* it fails (or may fail)

e.g. poor hose manufacturing, under-designed

Causes *occur* with some likelihood or probability

Dectectability: the ability to discover the *cause* before the part is shipped from the factory.

e.g. conduct a pressure test to detect leaks?

Measuring the Risk of a Failure Mode

Determine a rating for each mode of failure ….
using a "risk priority number" (RPN)

RPN = Severity rating x Occurrence rating x Detection rating
= (S)(O)(D)

e.g. RPN_a = (1)(1)(1) = 1 = very good
RPN_b = (10)(10)(10) = 1000 = very bad

RPN will range from 1 to 10000

How do we determine the RPN?

Step 1: determine the failure modes

Engineering design specifications
Function decomposition diagrams
functions ---- matter, energy, signal
HoQ
free body diagrams
force flow diagrams
process flow diagrams
configuration sketches / drawings

Step 2: determine potential effects of each failure mode

Step 3: determine a severity (S) rating for each effect from the Severity rating table.

Severity (S) Rating	Type of effects	Description
10	***Catastrophic***	Causes injury to people, property and or the environment
9	Extremely Harmful	Causes damage to product, property or environment
8	Very Harmful	Causes damage to product
7	***Harmful***	Major degradation of function
6	Moderate	Causes partial malfunction of product
5	Significant	Performance loss causes customer complaints
4	***Annoying***	Loss of function is annoying, cannot be overcome
3	Minor	Some loss of performance, but can be overcome
2	Insignificant	Very little function degradation
1	***None***	No noticeable effects in function or harm to others

Step 4: determine an occurrence (O) rating for each cause from the Occurrence rating table.

Occurence (O) Rating	Likelihood	Description	
10	***Expected***	>30 %	> One per *day*
9	Very likely	30 % (3 per 10)	
8	Probable	5 % (5 per 100)	One per week
7	***Occasional***	1 % (1 per 100)	One per *month*
6	More plausible	0.3 % (3 per 1,000)	One per three months
5	Plausible		
4	***Remote***	0.006 % (6 per 10^5)	One per *year*
3	Unlikely	0.00006 % (6 per 10^7)	One per three years
2	Very unlikely		
1	***Improbable***	< 2 per 10^9 events	> *five years* per failure

Step 5: determine a detection (D) rating for each <u>cause</u> from the Detection rating table

Detection (D) Rating	Detectability	Description
10	***Impossible***	Impossible to detect, or no inspection
9	Very rare	
8	Rare	
7	***Possible***	Some chance of detecting, or 50% inspection
6	Quite possible	
5	Somewhat likely	
4	***Likely***	Quite likely to detect, or 75% inspection
3	Quite likely	
2	Almost certain	
1	***Certain***	Will be detected, or 100% inspection

FMEA Steps Continued

Step 6: calculate the risk priority number for each effect

Step 7: prioritize or rank the failure modes for action

Step 8: take action to eliminate the failure mode or reduce its severity

Step 9: recalculate the risk priority number as failure modes are reduced or eliminated

RPN Calculation Summary Table

	Severity (S)		Occurrence (O)		Detection (D)			
Failure mode	Effects	S Rating	Causes	O Rating	controls tests	D Rating	RPN	Recommended Action

Design for Safety..What is a safe product or system?

- No injury to user, (products liability)
- No injury to consumer /society
- No injury to production worker (e.g. OSHA)
- No damage to personal property
- No damage to real property (environment)

Hazards

hazard – a source of danger which has the potential to injure people or damage property or the environment

Hazards include (Lindbeck, 1995):

1. Entrapment – pinch, crush
2. Contact – heat, sharp edges, electric
3. Impact – hammer, robot arm
4. Ejection – grinder sparks, saw dust
5. Entanglement – hair, clothing
6. Noise & Vibration – hearing loss, HAVS

Safety Hierarchy Method (Pahl & Beitz)

1. ***Eliminate the hazard*** pro-active approach, "design-out" the hazard (eliminate any moving parts, hot or sharp surfaces)
2. ***Protect against the hazard*** passive approach, (machine guards, seat belts)
3. ***Warn against the hazard*** - weak remedy, (warning labels, alarms)
4. ***Provide training*** Provide and require operating training.
5. ***Provide personal protection*** – least effective, (safety glasses, gloves, shoes)

Safe Design Principles

Safe-Life

entire predicted useful life without malfunction.

designers to identify *all* operating conditions, misuses and abuses

design appropriate maintenance and repair schedules.

Fail-Safe

upon failure of a component, product/system shuts down safely,

critical functions are sometimes still performed..

(e.g. boiler feed-water valve failing in the open position)

Redundant design

additional product components or systems are designed

to take over the principle function of the failed component or system.

(e.g. multi-engine airplanes, emergency brakes)

Design for Safety Summary

- Design for Safety: Prevent injury or damage
- Hazards exist, and depend on conditions
- We have Legal Responsibilities
- Guidelines for Safe Products/systems
- Safety Hierarchy – maximize our efforts
- Safe Design Principles

> Safety is no accident
>
> anonymous

Design for the Environment

(maintaining & improving the environment)

Use design methods that aim to:

- *Reduce use of materials ("Reduce" or "Renew")*
- *Increase recyclability*
- *Improve remanufacture*
- *Increase energy efficiency*
- *Improve the workplace environment*

Design for Minimal use of Materials

Upon receipt of the raw materials, were any damaged in transit, or spoiled due to aging?

During the fabrication of parts, how much waste material was manufactured as scrap? Was the scrap recyclable?

During assembly, were any parts damaged, or thrown away because they were not within specifications?

Was product packaged carefully to protect it during shipping?

What are some of the ripple effects (by minimizing material usage)?

Design for Recylability

- i.e. returning materials back into the product stream. (Non-recyclable materials sent to waste disposal sites, should be designed to reduce volume or toxicity)
- Some recyclable materials
  - Polymers, such as polyethylenes, and polystyrenes and
  - Metals such as steel, copper, silver, and brass are very recyclable
  - Cermaics such as glass (bottles)
- <u>Design for Disassembly</u> considers aspects such as the appropriate use of fasteners to facilitate disassembly, as well as decreasing separation labor time

Design for Remanufacture

Not all components in a product simultaneously fail.

- Some replacement parts include simple, low cost parts such as:
  - Fan belts
  - Automotive wheel bearings
  - Tires
- More expensive subassemblies also:
  - Laser printer - toner cartridge
  - Inkjet – cartridge
  - Engine block
  - Water pumps
- Design for Remanufacture considers disassembly, inspecting, cleaning and replacement of worn or broken parts.

Design for Energy Efficiency

- Products should be designed to be manufactured and used with less energy.
- Less electrical/energy use during manufacture
  - means less fossil fuel consumed,
  - less air pollution, and
  - possibly less global warming.
- Similarly, energy efficiency during usage reduces air, noise and thermal pollution.

Summary

- FMEA eliminates or reduces the occurrence of failures and/or mitigate the severity of the effects of failures.
- Hazards that can injure people or damage property exist in the manufacture, use, and retirement of products.
- Engineers have legal and ethical responsibilities regarding the safety, health, and welfare of employees, customers, and general public.
- Design-for-safety practices include the safety hierarchy, safe-life design, fail-safe design and redundant design.
- Tolerance design ensures part interchangeability.
- Design for the environment methods consider minimal use of materials, recyclability, remanufacture, energy efficiency, and workplace conditions.