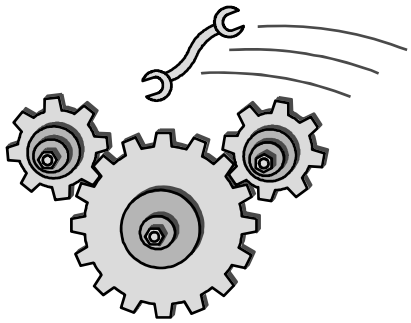
Chapter 8.4
Failure Mode and Effects Analysis (FMEA)



Everything that can fail, shall fail!

Failure Mode and Effects Analysis Definition

A bottoms-up, iterative approach for analyzing a design of a product or process in order to determine

- what could wrong
- how badly it might go wrong
- and what needs to be done to prevent it

Alternate Definition

Failure Mode and Effects Analysis (FMEA for short) is a systematic way to identify and evaluate the potential failures of a product or process. It provides a formal process for eliminating or mitigating the risks of a failure. It is an on-going process that documents and tracking problems and changes through the product development phase.

Yet Another Definition

A formal, structured process which is applied in developing something new to assure that as many potential problems as are reasonably possible to predict have been considered, analyzed, and their causes remedied before the item under development reaches the hands of the end user.

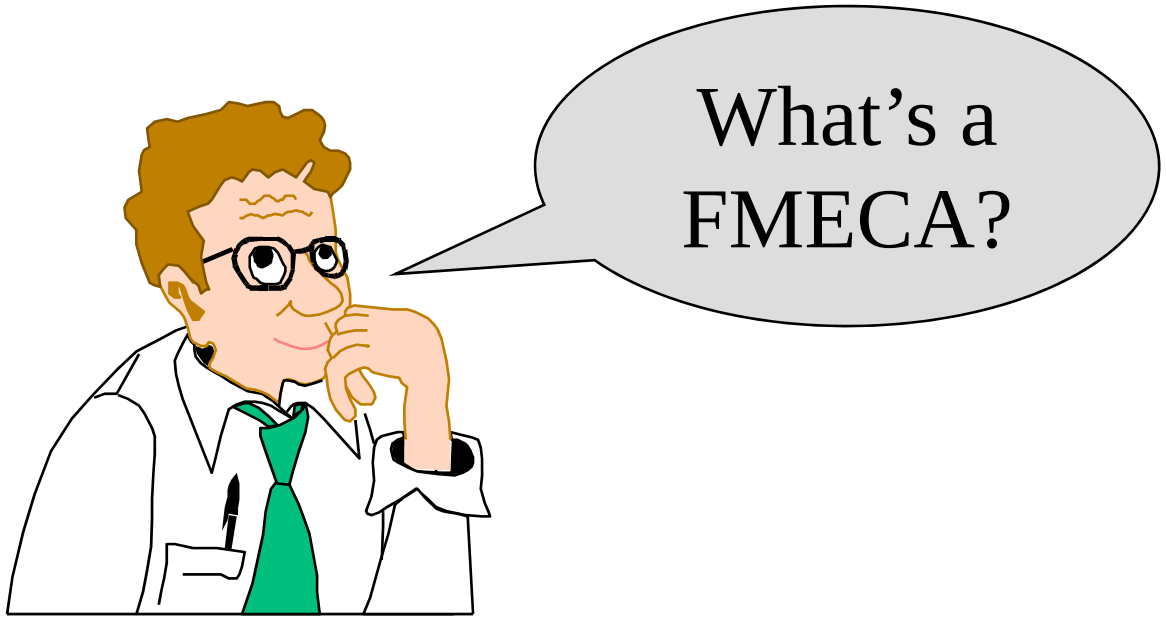
Applicable to

- product development
- idea development
- organization development
- process development
- software development

Objective

...to identify early in the product or process design all manner of failures so they can be eliminated or their impact reduced through redesign at the earliest possible time.

Failure Mode, Effects, and Criticality Analysis (FMECA)



FMEA and FMECA promotes...

- An objective and detailed evaluation of a product or process leading to
- a critical analysis of failure modes and processes
- with a corresponding assignment of responsibility

Benefits

- Improved product or process functionality
- Verify design integrity
- Provide rationale for change
- Reduced warranty and replacement costs
- Reduction in day-to-day manufacturing problems and costs
- Improved safety of products and processes

Background

- 1949 - US military
  - Military Procedure MIL-P-1629 (procedures for performing a FMEA
  - used as reliability evaluation technique
- 1960's - Used in the by the aerospace industry and NASA during the Apollo program
- 1988 – ISO 9000 business management standards
  - required organizations to develop quality systems
  - QS 9000 developed by Chrysler, Ford and GM
  - compliant automotive suppliers shall utilize FMEA
- 1993 – Automotive Industry Action Group (AIAG) and American Society for Quality Control (ASQC)
  - Society of Automotive Engineers (SAE) procedure SAE J-1739
  - Provides general guidelines for performing a FMEA

Basic Concept

- begin at the lowest level of the system
- identify potential failure modes
- assess their effect and causes
- prioritize based upon effect
- through redesign
  - eliminate the failure
  - or mitigate its effect

Basic Concept - Example

- component – computer monitor
- part – capacitor
- identify two failure modes
  - fail “open”
    - effect are wavy lines appearing on monitor
  - fail “short”
    - effect is the monitor going blank
- prioritize – short more critical than open
- determine cause of failure mode
  - underrated capacitor
- investigate ways of eliminating failure
  - resize capacitor

More Basic Concepts

- Team effort
  - 5 to 7 members
  - team lead engineer
  - representation from design, assembly, manufacturing, materials, quality, and suppliers
- Usually done near the end of the product or process design phase
- Analysis should continue throughout the product development cycle
- Should be a living document that is updated as design changes and new information becomes available

Product versus Process

- Product or Design FMEA.
  - What could go wrong with a product while in service as a result of a weakness in design.
  - Product design deficiencies
- Process FMEA.
  - What could go wrong with a product during manufacture or while in service as a result of non-compliance to specification or design.
  - Manufacturing or assembly deficiencies
  - Focus on process failures and how they cause bad quality products to be produced

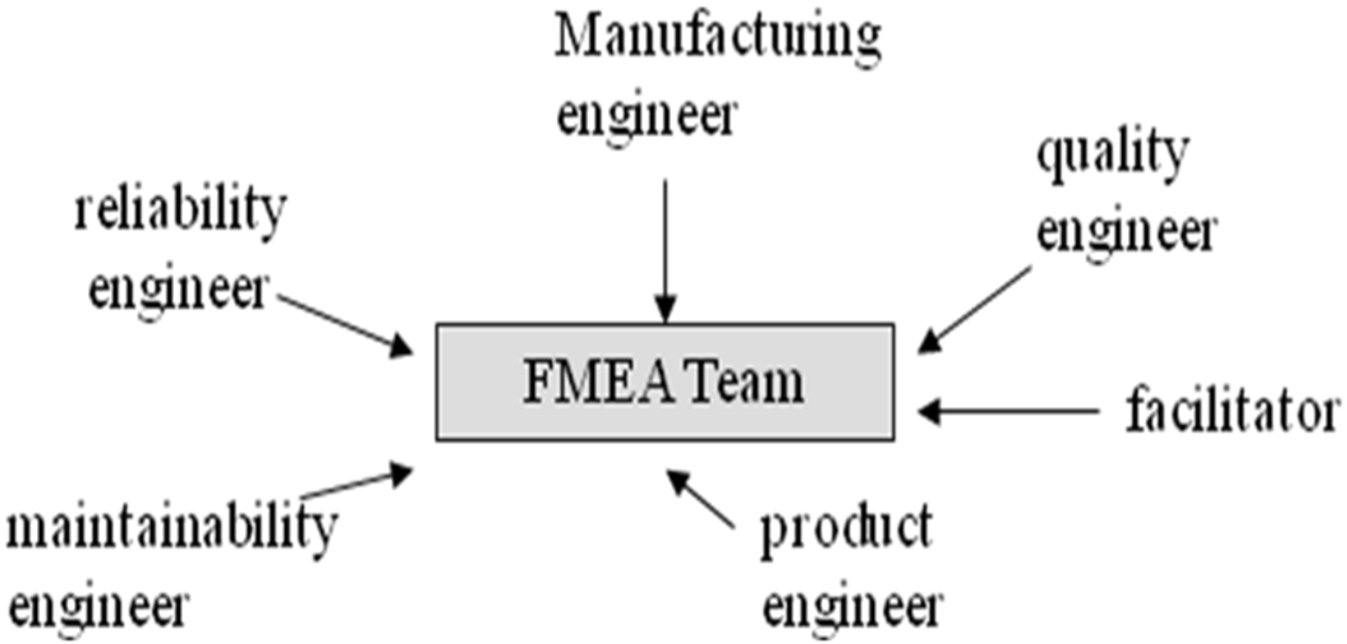
Product (Design) FMEA

- Assumes manufacturing and assembly will produce to design specifications.
- Does not need to include failure modes resulting from manufacturing and assembly.
- Does not rely on process controls to overcome design weaknesses.
- Does consider technical and physical limitations of the manufacturing and assembly process.

Process FMEA

- Assumes the product meets the intent of the design.
- Does not need to include failure modes originating from the design.
  - assumes a design FMEA covers these failures
- Usually originates from a flow chart of the process

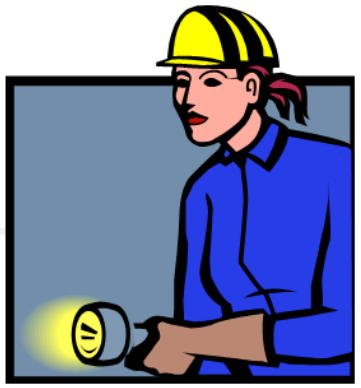
The FMEA Team



Affected Functional Areas

- design
- materials
- manufacturing
- assembly
- packaging
- shipping
- service
- recycling
- quality
- reliability
- vendors
- customers.
  - downstream engineering functions
  - downstream manufacturing functions
  - end users
  - service functions,
  - recycling or reuse functions

Methodology

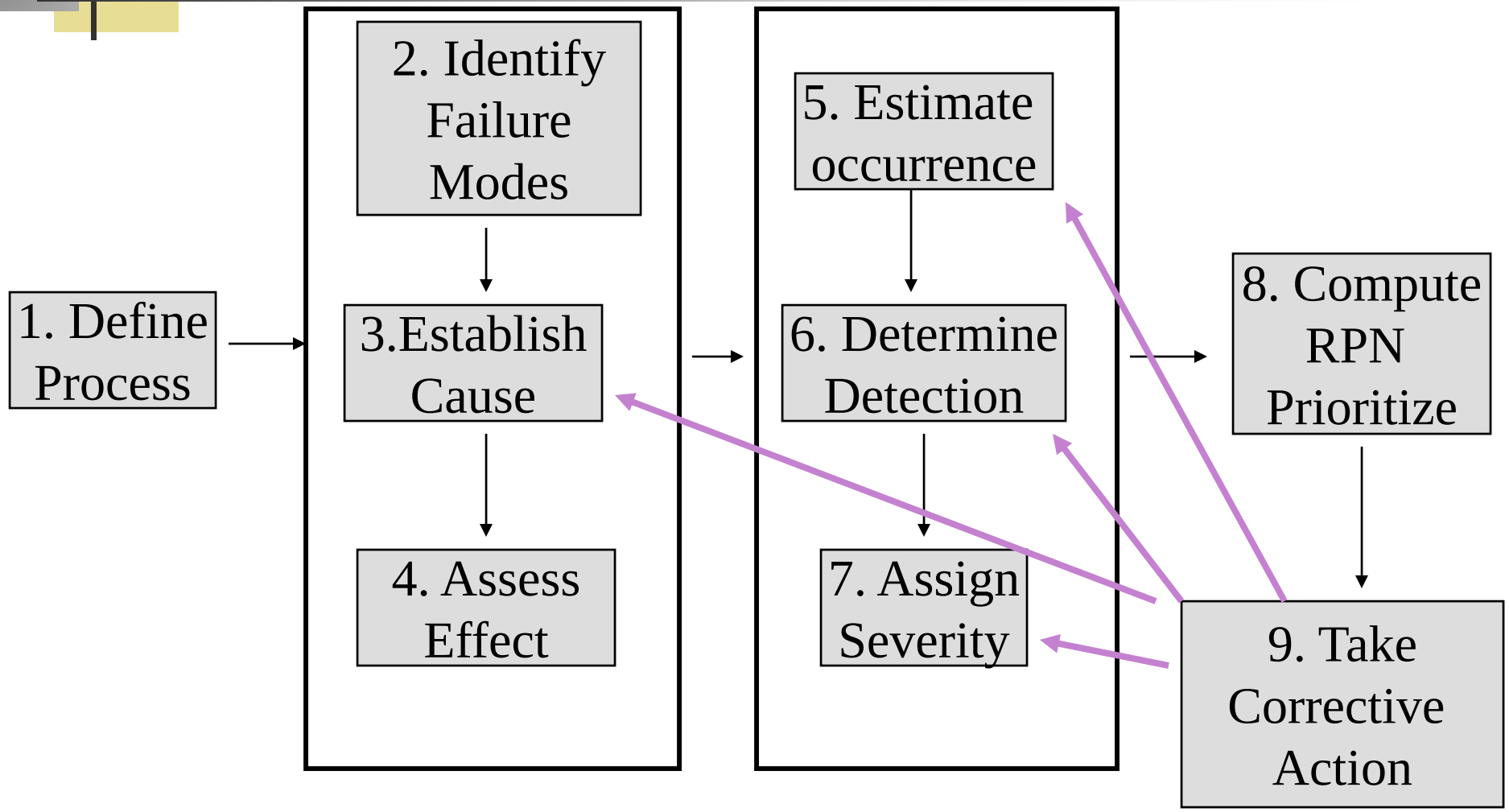


A worker looking
for the 9 easy steps
to complete a FMECA

1. System or Process Definition
2. Determination of Failure Modes
3. Determination of Cause
4. Assessment of Effect
5. Estimation of Probability of Occurrence (O)
6. Estimation of Detecting a Defect (D)
7. Classification of Severity (S)
8. Computation of Criticality (Risk Priority Number)

   RPN = (S) x (O) x (D)
9. Determination of Corrective Action

FMEA Flow Diagram



FMEA Worksheet

Component or Process	Failure Mode	Failure Cause	Failure Effect	Correction
CRT Picture tube	Bad pixels	excessive heat	picture degraded	larger fan
CRT Picture tube	Bad pixels	dropping or bumping	picture degraded	improve packaging
Cabling to unit	broken or frayed	fatigue, heat	will not conduct	higher grade wire
Cabling to unit	internal short	heat, brittle insulation	shock, damage to unit	higher grade wire

Step 1. Product / Process Definition

- Describe product and its design or the process and its operations
- Identify the purpose or function of each component or each operation
- Use functional diagrams, design drawings, flow charts and other graphical techniques
- Include each significant element that is likely to fail

Step 2. Determination of Failure Modes

- A failure mode is the manner in which a process could potentially fail to meet the process requirement or the design intent.
- It is a statement of non-performance or a non-conformance to a design specification.
- Questions to be answered include:
  - how can the process/part fail to meet specs
  - regardless of the specs, what would customer find objectionable?

Examples of Failure Modes

- ruptures
- fractures or cracks
- short or open circuits
- deformation
- contamination
- loss of power
- buckling

Step 3. Determination of Cause

- Identify how the failure could occur
- Find the root cause!
- State in terms of something that can be corrected
- Attempt to establish an exhaustive list
- Further analysis may be required to isolate cause (e.g. a design of experiments)

Potential Failure Mode Causes

Abnormal stress. usually external or environmental, could be an internal power surge

Mechanical stress. Continued vibration may loosen fittings, for example.

Contamination. Dirt can cause electrical failure.

Evaporation. Filaments age because of filament molecules evaporating.

Fatigue. Physical changes in material may result in fracture.

Friction. This is a common cause of failures in belts, gears, and machinery

Temperature cycling. Repeated expansion and contraction

Aging /wearout. not a prime cause, but prolonged exposure to other causes.

Substandard or defective parts. poor quality control during manufacture.

Poor workmanship. Lack of training or proper motivation, fatigue

Operator-or maintenance-induced error. human error.

Corrosion. This is chemical change that weakens material.

Analysis of Failure Mode Causes

Failure mode	Category	Cause	Failure mechanism	Possible corrective action
Capacitor short	Electrical	High voltage	Dielectric breakdown	Derating
Failure of metal contacts	Chemical	Humid and salty atmosphere	Corrosion	Use of a protective casing
Connector fractures	Mechanical	Excessive vibration	Fatigue	Redesign of mountings

Step 4. Assessment of Effect

- Assess the effect of the failure mode on the customer
- Customer may be next operation, subsequent operations, the end-user, or the seller
- Answer the question what might the customer observe or experience.

Failure Mechanisms, Modes, And Effects

Failure Mechanism	Failure Mode	Failure Effect
produces→	which causes →	
corrosion	failure in tank wall seam	tank rupture
manufacturing defect in casing	leaking battery	flashlight failure to light
prolonged excessive vibration and fatigue	break in a motor mount	loss of engine power and excessive noise
friction and excessive wear	drive belt break	shut down of production line
contamination (dust and dirt)	loss of contact	circuit board failure
evaporation	filament breaks	light bulb burns out
prolonged low temperatures	brittle seals	leakage in hydraulic system

Step 5. Estimation of Probability of Occurrence (O)

- Occurrence refers to how frequently the specific failure mode will be observed.
- Estimated on a scale from “1” to “10”
- Statistical analysis may be used if historical data is available
- Otherwise estimated subjectively

Step 6. Estimation of Detecting a Defect (D)

- The probability that the current process controls will detect the failure mode before the part or component leaves the process.
- Assume failure has occurred, and then assess the likelihood that the product will continue to its next stage.
- Rank on scale of “1” (almost certain to detect) to “10” (no way of detecting failure)

Step 7. Classification of Severity (S)

- An assessment of the seriousness of the **effect** of the failure mode on the customer
- Estimated on a scale of “1” to “10.”
- Assessed against
  - safety; i.e. injury or death
  - extent of damage
  - or amount of economic loss

Step 8. Computation of Criticality

- Risk Priority Number (RPN)
- Product of Severity (S), Probability of Occurrence (O), and Detecting a Defect (D)
- RPN = (S) x (O) x (D)
- Range is 1 to 1000 with the higher the number, the more critical the failure mode.
- Rank order RPN from highest to lowest

Probability of Failure

Probability of Failure Mode	Possible failure rates	Probability	Ranking
Very high: failure is almost inevitable	≥ 1 in 2	$.50 \le p \le 1.00$	10
Very high	≥ 1 in 3	$.33 \le p < .50$	9
High: repeated failures	≥ 1 in 8	$.125 \le p < .33$	8
High	≥1 in 20	$.05 \le p < .125$	7
Moderate: occasional failures	≥ 1 in 80	$.0125 \le p < .05$	6
Moderate	≥ 1 in 400	$.0025 \le p < .0125$	5
Moderate: infrequent failures	≥ 1 in 2000	$.0005 \le p < .0025$	4
Low: relatively few failures	≥ 1 in 15,000	$.0000667 \le p < .0005$	3
Low	≥ 1 in 150,000	$6.7 \times 10^{-6} \le p < 6.67 \times 10^{-5}$	2
Remote: failure is unlikely	≥ 1 in 1,500,000	$6.7 \times 10^{-7} \le p < 6.67 \times 10^{-6}$	1

Adopted from FMEA Manual (Chrysler, Ford, General Motors Supplier Quality Requirements Task Force)

Likelihood of Detection

Detection	Criteria	Ranking
Almost impossible	No known way to detect failure mode	10
Very remote	Very unlikely to detect failure mode	9
Remote	Unlikely to detect failure mode	8
Very Low	Very low chance to detect failure mode	7
Low	Low chance to detect failure mode	6
Moderate	Moderate chance to detect failure mode	5
Moderately High	Moderately high chance to detect failure mode	4
High	Likely to detect failure mode	3
Very high	Very likely to detect failure mode	2
Almost certain	Will almost certainly detect failure mode	1

Severity Rating

Severity	Criteria	Ranking
Hazardous-without warning	May endanger operator; noncompliance with regulations; affects the safe use of the product; failure will occur without warning.	10
Hazardous-with warning	May endanger operator; noncompliance with regulations; affects the safe use of the product; failure will occur with warning.	9
Very high	Process or product inoperable with loss of primary function; major disruption to the production line; product may have to be scrapped; customer very dissatisfied.	8
High	Process or product operable but at reduced level of performance; minor disruption to production line; the product may have to be sorted and a portion (less than 100%) scrapped; customer dissatisfied	7
Moderate	Process or product operable but comfort or convenience items inoperable; minor disruption to production line; a portion (less than 100%) of the product may have to be scrapped (no sorting); customer experience discomfort	6

Severity Rating

Severity	Criteria	Ranking
Low	Process or product operable but comfort or convenience at reduced level of performance; minor disruption to production line; a 100% of the product may have to be reworked; customer experiences some dissatisfaction	5
Very low	Minor disruption to production line; product may have to be sorted and a portion (less than 100%) reworked; cosmetic (fit and finish) defect (nonconformance) noticed by most customers	4
Minor	Minor disruption to production line; a portion of the product may have to be (less than 100%) reworked on-line but out-of-station; cosmetic (fit and finish) defect (nonconformance) noticed by average customer	3
Very minor	Minor disruption to production line; a portion of the product may have to be (less than 100%) reworked on-line but in-station; cosmetic (fit and finish) defect (nonconformance) noticed by discriminating customers	2
None	No effect	1

Step 9. Corrective Action

- Removing the cause of the failure,
- Decreasing the probability of occurrence, or
- Increase the likelihood of detection, or
- Reducing the severity of the failure.

FMECA worksheet

Company:	The ABC Company				**FMECA**			**Date:**	1/1/2009
Department:	Design Engineering								
Author:	Mr. Facilitator							**Product**	**XYZ**
1. Part Description / Function	**2. Failure Mode**	**5. Occurrenc**	**3. Cause**	**6. Detection**	**4. Effect**	**7. Severity**	**8. RPN**	**9. Action**	**OPR / Due Date**
Part 1	failure 1								
	failure 2								
Part 2	failure 1								
	failure 1								
	failure 2								

Related Concepts

- Quality Functional Deployment (QFD)
  - customer requirements
- Total Quality Management (TQM)
- Statistical Process Control (SPC)
  - detection
- Design of Experiments (DOE)
  - root causes
- Six Sigma
  - process improvement
- Fault Tree Analysis (FTA)
- On-going Reliability Testing (ORT)

Difficulties in Implementation

- Time and resource constraints
- Lack of understanding of the purpose of FMEA
- Lack of training
- Lack of management commitment

Dale and Shaw, 1990: "Failure Mode and Effects Analysis in the Motor Industry," *Quality and Reliability Engineering International*.

Conclusion & Questions