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
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.
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.
What’s a 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

Manufacturing engineer

reliability engineer

maintainability engineer

quality engineer

product engineer

facilitator
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

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)
   \[ RPN = (S) \times (O) \times (D) \]
9. Determination of Corrective Action

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

1. Define Process

2. Identify Failure Modes

3. Establish Cause

4. Assess Effect

5. Estimate occurrence

6. Determine Detection

7. Assign Severity

8. Compute RPN Prioritize

9. Take Corrective Action
<table>
<thead>
<tr>
<th>Component or Process</th>
<th>Failure Mode</th>
<th>Failure Cause</th>
<th>Failure Effect</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT Picture tube</td>
<td>Bad pixels</td>
<td>excessive heat</td>
<td>picture degraded</td>
<td>larger fan</td>
</tr>
<tr>
<td>CRT Picture tube</td>
<td>Bad pixels</td>
<td>dropping or bumping</td>
<td>picture degraded</td>
<td>improve packaging</td>
</tr>
<tr>
<td>Cabling to unit</td>
<td>broken or frayed</td>
<td>fatigue, heat</td>
<td>will not conduct</td>
<td>higher grade wire</td>
</tr>
<tr>
<td>Cabling to unit</td>
<td>internal short</td>
<td>heat, brittle insulation</td>
<td>shock, damage to unit</td>
<td>higher grade wire</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>Category</th>
<th>Cause</th>
<th>Failure mechanism</th>
<th>Possible corrective action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitor short</td>
<td>Electrical</td>
<td>High voltage</td>
<td>Dielectric breakdown</td>
<td>Derating</td>
</tr>
<tr>
<td>Failure of metal</td>
<td>Chemical</td>
<td>Humid and salty</td>
<td>Corrosion</td>
<td>Use of a protective casing</td>
</tr>
<tr>
<td>Connector fractures</td>
<td>Mechanical</td>
<td>Excessive vibration</td>
<td>Fatigue</td>
<td>Redesign of mountings</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Failure Mechanism</th>
<th>Failure Mode</th>
<th>Failure Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>corrosion</td>
<td>failure in tank wall seam</td>
<td>tank rupture</td>
</tr>
<tr>
<td>manufacturing defect in casing</td>
<td>leaking battery</td>
<td>flashlight failure to light</td>
</tr>
<tr>
<td>prolonged excessive friction and excessive wear</td>
<td>break in a motor mount</td>
<td>loss of engine power and excessive noise</td>
</tr>
<tr>
<td>contamination (dust and dirt)</td>
<td>drive belt break</td>
<td>shut down of production line</td>
</tr>
<tr>
<td>evaporation</td>
<td>loss of contact</td>
<td>circuit board failure</td>
</tr>
<tr>
<td>prolonged low temperatures</td>
<td>filament breaks</td>
<td>light bulb burns out</td>
</tr>
<tr>
<td></td>
<td>brittle seals</td>
<td>leakage in hydraulic system</td>
</tr>
</tbody>
</table>
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)
- \[ RPN = (S) \times (O) \times (D) \]
- 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

<table>
<thead>
<tr>
<th>Probability of Failure Mode</th>
<th>Possible failure rates</th>
<th>Probability</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high: failure is almost inevitable</td>
<td>≥ 1 in 2</td>
<td>.50 ≤ p ≤ 1.00</td>
<td>10</td>
</tr>
<tr>
<td>Very high</td>
<td>≥ 1 in 3</td>
<td>.33 ≤ p &lt; .50</td>
<td>9</td>
</tr>
<tr>
<td>High: repeated failures</td>
<td>≥ 1 in 8</td>
<td>.125 ≤ p &lt; .33</td>
<td>8</td>
</tr>
<tr>
<td>High</td>
<td>≥1 in 20</td>
<td>.05 ≤ p &lt; .125</td>
<td>7</td>
</tr>
<tr>
<td>Moderate: occasional failures</td>
<td>≥ 1 in 80</td>
<td>.0125 ≤ p &lt; .05</td>
<td>6</td>
</tr>
<tr>
<td>Moderate</td>
<td>≥ 1 in 400</td>
<td>.0025 ≤ p &lt; .0125</td>
<td>5</td>
</tr>
<tr>
<td>Moderate: infrequent failures</td>
<td>≥ 1 in 2000</td>
<td>.0005 ≤ p &lt; .0025</td>
<td>4</td>
</tr>
<tr>
<td>Low: relatively few failures</td>
<td>≥ 1 in 15,000</td>
<td>.0000667 ≤ p &lt; .0005</td>
<td>3</td>
</tr>
<tr>
<td>Low</td>
<td>≥ 1 in 150,000</td>
<td>6.7 x 10⁻⁶ ≤ p &lt; 6.67 x 10⁻⁵</td>
<td>2</td>
</tr>
<tr>
<td>Remote: failure is unlikely</td>
<td>≥ 1 in 1,500,000</td>
<td>6.7 x 10⁻⁷ ≤ p &lt; 6.67 x 10⁻⁶</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Detection</th>
<th>Criteria</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost impossible</td>
<td>No known way to detect failure mode</td>
<td>10</td>
</tr>
<tr>
<td>Very remote</td>
<td>Very unlikely to detect failure mode</td>
<td>9</td>
</tr>
<tr>
<td>Remote</td>
<td>Unlikely to detect failure mode</td>
<td>8</td>
</tr>
<tr>
<td>Very Low</td>
<td>Very low chance to detect failure mode</td>
<td>7</td>
</tr>
<tr>
<td>Low</td>
<td>Low chance to detect failure mode</td>
<td>6</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate chance to detect failure mode</td>
<td>5</td>
</tr>
<tr>
<td>Moderately High</td>
<td>Moderately high chance to detect failure mode</td>
<td>4</td>
</tr>
<tr>
<td>High</td>
<td>Likely to detect failure mode</td>
<td>3</td>
</tr>
<tr>
<td>Very high</td>
<td>Very likely to detect failure mode</td>
<td>2</td>
</tr>
<tr>
<td>Almost certain</td>
<td>Will almost certainly detect failure mode</td>
<td>1</td>
</tr>
</tbody>
</table>
## Severity Rating

<table>
<thead>
<tr>
<th>Severity</th>
<th>Criteria</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous-without warning</td>
<td>May endanger operator; noncompliance with regulations; affects the safe use of the product; failure will occur without warning.</td>
<td>10</td>
</tr>
<tr>
<td>Hazardous-with warning</td>
<td>May endanger operator; noncompliance with regulations; affects the safe use of the product; failure will occur with warning.</td>
<td>9</td>
</tr>
<tr>
<td>Very high</td>
<td>Process or product inoperable with loss of primary function; major disruption to the production line; product may have to be scrapped; customer very dissatisfied.</td>
<td>8</td>
</tr>
<tr>
<td>High</td>
<td>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</td>
<td>7</td>
</tr>
<tr>
<td>Moderate</td>
<td>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</td>
<td>6</td>
</tr>
</tbody>
</table>
## Severity Rating

<table>
<thead>
<tr>
<th>Severity</th>
<th>Criteria</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>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</td>
<td>5</td>
</tr>
<tr>
<td>Very low</td>
<td>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</td>
<td>4</td>
</tr>
<tr>
<td>Minor</td>
<td>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</td>
<td>3</td>
</tr>
<tr>
<td>Very minor</td>
<td>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</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>No effect</td>
<td>1</td>
</tr>
</tbody>
</table>
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.
## Company: The ABC Company

### Department: Design Engineering

### Author: Mr. Facilitator

### Product XYZ

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<tr>
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</thead>
<tbody>
<tr>
<td>Part 1</td>
<td>failure 1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>failure 2</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Part 2</td>
<td>failure 1</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>failure 1</td>
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<td>failure 2</td>
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</tbody>
</table>
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

Conclusion & Questions

What is a FMEA?