# Failure Mode and Effect Analysis

## Lecture 4-1

### Examples

### Interpretation

### Criticality Analysis

Note: several of the concepts in this section are presented in *FMEA*, by Paul Palady, PT Publications, 1995

## Example - Cleaning Process

### FMEA

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Effect</th>
<th>Priority</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate cleanliness specs for new designed parts</td>
<td>8</td>
<td>A</td>
<td>Develop cleanliness specifications and review current processes</td>
</tr>
<tr>
<td>Incomplete cleaning cycle</td>
<td>5</td>
<td>B</td>
<td>Install timer to prevent operators from altering cleaning cycle</td>
</tr>
<tr>
<td>Contaminated cleaning solution due to failure to complete PM as scheduled</td>
<td>2</td>
<td>C</td>
<td>Add extra filters to system</td>
</tr>
<tr>
<td>Incorrect racks used due to availability</td>
<td>5</td>
<td>A</td>
<td>Add rack type to process instructions, evaluate availability</td>
</tr>
<tr>
<td>Operator not trained due to job rotation</td>
<td>2</td>
<td>D</td>
<td>Add lack type of process instructions, evaluate availability</td>
</tr>
</tbody>
</table>

### Detection

### Occurrence

### Severity

$RPN = D \times O \times S$
### Example - Accounting Process

**FMEA**

**PROCESS FMEA**

<table>
<thead>
<tr>
<th>Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effect of Failure</th>
<th>Occurrence</th>
<th>Severity</th>
<th>Detection</th>
<th>RPN</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voucher not issued by deadline</td>
<td>Transaction not closed in database</td>
<td>Weekly batch discrepancy report</td>
<td>1</td>
<td>2</td>
<td>C</td>
<td>6</td>
<td>160</td>
</tr>
<tr>
<td>Short circuit due to insufficient space allotment between conductors</td>
<td>Computer simulation</td>
<td>A</td>
<td>1</td>
<td>16</td>
<td>A</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

### Example - Design Rules

**FMEA**

**PROCESS FMEA**

<table>
<thead>
<tr>
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<th>Detection</th>
<th>RPN</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog signal used to process a sensor signal</td>
<td>Output stuck - high or low</td>
<td>Instrumentation shows zero reading</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Short circuit due to insufficient space placement between conductors</td>
<td>Computer simulation</td>
<td>A</td>
<td>1</td>
<td>16</td>
<td>A</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

**SUMMARY:**
### Example - Reducing Occurrence

**FMEA**

<table>
<thead>
<tr>
<th>PROCESS DESCRIPTI ON</th>
<th>FAILURE MODE</th>
<th>EFFECTS OF FAILURE</th>
<th>OCCURRENCE</th>
<th>DETECTION</th>
<th>SEVERITY</th>
<th>RPN</th>
<th>CURRENT COUNTERMEASURES</th>
<th>POTENTIAL COUNTERMEASURES</th>
<th>CORRECTIVE ACTION</th>
<th>S</th>
<th>O</th>
<th>D</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposit a uniform, particulate-free oxide at desire thickness</td>
<td>Flaking of the quartzware</td>
<td>Reduced reliability</td>
<td>7</td>
<td>Inspect oxide after deposition</td>
<td>4</td>
<td>160</td>
<td>B</td>
<td>Increase frequency of quartz cleaning, implement an automated visual inspection system</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>44</td>
<td></td>
</tr>
</tbody>
</table>

### Example - New Equipment or Process

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<table>
<thead>
<tr>
<th>PROCESS DESCRIPTI ON</th>
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<th>POTENTIAL COUNTERMEASURES</th>
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<th>O</th>
<th>D</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connect device to circuit</td>
<td>Open circuit</td>
<td>Non-functional circuit</td>
<td>9</td>
<td>Lifted wire at the device due to non-optimized wirebond process</td>
<td>6</td>
<td>211</td>
<td>A</td>
<td>Document process window, process spec to ensure that the process meets visual and performance standards</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Conduct process optimization at wirebond</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ordering on the device due to non-optimized wirebond process</td>
<td>Conduct process optimization at wirebond</td>
<td>4</td>
<td>104</td>
<td>B</td>
<td>Same</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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### Example - New Equipment or Process

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<th>D</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connect device to circuit</td>
<td>Open circuit</td>
<td>Non-functional circuit</td>
<td>3</td>
<td>Conduct process optimization at wirebond</td>
<td>5</td>
<td>103</td>
<td>B</td>
<td>Same</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

| | | | | Conduct process optimization at wirebond | | | | | | | | | | |
**Example - Weakness of Manual Inspection**

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>FUNCTION</th>
<th>FAILURE MODE</th>
<th>EFFECTS OF FAILURE</th>
<th>DETECTION OCCURRENCE</th>
<th>POTENTIAL SEVERITY</th>
<th>POTENTIAL FREQUENCY</th>
<th>CURRENT DETECTION</th>
<th>POTENTIAL OCCURRENCE</th>
<th>corrective ACTION</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pack and ship right product to the right customer</td>
<td>Mixed product</td>
<td>Fails to meet customer requirements and expectations</td>
<td>E</td>
<td>3</td>
<td>102</td>
<td>B</td>
<td>Install barcode system for product identification</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Interpreting the FMEA**
2 Methods

• RPN method (“traditional” approach)
• Area Chart

Consider the following:

<table>
<thead>
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<th>Detection</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>5</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>8</td>
<td>2</td>
<td>64</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>2</td>
<td>1</td>
<td>18</td>
</tr>
</tbody>
</table>

If you had the resources to only fix two of these potential failure modes, which ones would you choose?

RPN Limitations

• The RPN method has some limitations,
• It is very Reactive because equal weight is given to detection

Before the organization allocates resources to improve detection, all opportunities for reducing the occurrence and minimizing the effects of the failure modes should be considered.
Strategy for Addressing Failure Modes

Traditional
1. Reduce the severity
2. Reduce the occurrence
3. Improve the detection

A better approach:
1. Eliminate the occurrence
2. Reduce the severity
3. Reduce the occurrence
4. Improve the detection
5. Provide a means of detection for the customer during use
FMEA

RPN Cut Off

Another traditional approach is to not review RPN’s below a certain number (i.e. on a 10-point scale, worst case RPN = 1000, therefore no RPN’s below 20 will be considered)

Disadvantages to this approach:
- It is still possible to have very severe failure modes
- Some quick gains may be lost where the benefits exceed the costs
- Different teams (and facilitators) tend to score differently – lower of higher numbers

FMEA

Strategy for Addressing Failure Modes

• Control Upstream
  – Robust design
  – Concurrent Engineering
  – Voice of the Customer, Quality Function Deployment

Excluding the customers’ input from the FMEA is likely to result in both an incomplete list of the effects and low estimates of the severity numbers

Palady
More on Scoring

2 approaches
Rate the occurrence and detection of:
1. the failure mode
2. each individual cause contributing to the failure mode
Both are acceptable – both give the same result
The team (or organization) must decide which approach to take

1. Rating the O and D of the Failure Mode

Sequence:
1. Rate the failure mode
2. Measure the contribution of the causes
3. Quantify the improvement of the causes
4. Correlate the improvement in the causes to the failure mode (root cause analysis)
5. Assign the new rating to the failure mode
2. Rating the O and D of the Each Cause

Sequence
1. Correlate the causes to the failure mode
2. Rate the causes
3. Quantify the improvement in the causes
4. Correlate this improvement to the failure mode

Criticality Analysis (“Area” Chart)
Comparing The Methods

FMEA

RPN Method

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<td>B</td>
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<td>8</td>
<td>2</td>
<td>64</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>2</td>
<td>1</td>
<td>18</td>
</tr>
</tbody>
</table>

Criticality Method

Score the FMEA

FMEA WORKSHEET
PRODUCT: ____________________________
TYPE: DESIGN   PROCESS   OTHER

FUNCTION POTENTIAL EFFECTS OF POTENTIAL FAILURE MODE

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>POTENTIAL FAILURE MODE</th>
<th>EFFECTS OF FAILURE</th>
<th>POTENTIAL CAUSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>b</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>c</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>d</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
Leverage Causes

- A common problem shared by all organizations is the allocation of a fixed amount of resources to an unlimited number of opportunities.

<table>
<thead>
<tr>
<th>Causes</th>
<th>1a</th>
<th>1b</th>
<th>2b</th>
<th>2c</th>
<th>3a</th>
<th>3b</th>
<th>4b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cause B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cause C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Failure Mode / Effect

Criticality Analysis
Criticality Analysis

• Before resources in the form of time and money are spent to improve detection, all opportunities for reducing occurrence and minimizing the effects of failure modes should be explored.

• Criticality Analysis (MIL STD 1629A) - the degree of concern appropriate to any failure situation is related to
  – probability of occurrence
  – seriousness of its effects

Criticality Analysis shows . . .

• Items which require more intensive study to
  – eliminate a specific hazard
  – increase chance of fail-safe outcome
  – reduce risk of resultant damage

• Items needing special attention
  – handling
  – manufacturing
  – suppliers
  – storage
Criticality Analysis shows . . . .

- Special requirements in purchasing or design specifications
- Acceptance standards for incoming materials, supplier tests and controls

Criticality Levels

MIL STD 1629A 1980 defines 4 levels:

1. Degradation of system performance, negligible damage to system or environment, no damage to life or limb
2. Degrades system performance without appreciable damage to system, life of limb
3. Potential loss of primary system function resulting in significant system failure, negligible hazard to life and limb
4. Potential loss of primary system function resulting in significant system failure, significant hazard to life and limb
Establishing Criticality Criteria

- Number of levels is arbitrary
- Based on combination of criteria considering:
  - Personal harm (injuries, death)
  - Loss of system function
  - Environmental impact and material damage
- If terms such as catastrophic, critical, major, minor are used, they should be defined for individual cases.

NASA - Critical Items List (CIL)

- FMEA/CIL on single point failures and redundant failure elements that could cause loss of life/vehicle/mission
- Retention Rationale - justification for retaining a critical item in a spacecraft
- CIL defines the specific inspections, tests and process controls to minimize chance of failure
NASA - Lessons Learned

- Correlate every CIL characteristic to a specific engineering document
- Ensure that inspections required by the CIL are not ambiguous, redundant, and can be carried out
- Ensure that the organizations conducting the CIL audits define the audits to the “shop floor level.”

Control Plan
Tennessee Eastman Experience

Tennessee Eastman Corporation established a control plan methodology using SPC on critical process parameters that contributed to their winning the *Malcolm Baldrige National Quality Award*. Winners are required to share their quality systems knowledge with others.

*Eastman’s experience in using SPC for controlling process variables led to identification of three basic types of control actions which may be applied.*

Which of the control types on the next slide do you use, if any at all?
Control Action Types

**Compensate**
This type of control involves making a process adjustment to bring the variable back into control without identifying or correcting the factor which caused the situation.

**Correct**
In this type of control action, the cause of variation is identified and corrected temporarily. The problem may appear later.

**Prevent**
In this type of action, the cause of the variation is identified and permanently corrected. The cause will not happen again or at least will not occur with the same frequency.

- Typically, unsuccessful control programs utilize only *compensating actions*. Tennessee Eastman focused their control plan implementation on *preventive action*.

- Examples include
  - Root cause analysis
  - Operator training
  - Preventive maintenance
  - Controller tuning
  - Replacing defective equipment
How to take Preventive Action

When an undocumented out-of-control condition occurs, a cross-functional team consisting mainly of plant operators, process engineers, and production supervisors identifies the variable to be controlled and follows these steps:

1. Prepare or update a process flow diagram of the system.
2. A cause / effect (fishbone) diagram is prepared illustrating possible causes of variation in the process. Four basic areas to center on are: manpower, materials, methods, and machinery.
3. The team selects the most likely causes from the list.
4. Starting with the most likely causes, root causes of the variation are identified. Ask “WHY” five times!

Root Cause Analysis

IF

THEN

DEEP FIX
Taking Preventative Action Con’d

5. Prepare a Reaction Plan for each out-of-control condition and list likely causes. The team develops and documents “Action” to be taken if the cause is present. Causes are placed in the order that they should be checked, the most likely or easiest to check first. The team determines compensating actions to take should no cause be identified.

6. The Reaction Plan is reviewed by the team and the technical department for modifications. The team determines how the plan will be documented and how to train the work force.

7. Corrective action (permanent ones!) assignments are made and followed up to prevent recurrence!

8. Define a plan to collect data on how often the reaction plan is used and how well it works. Review results quarterly.
Tech Tips

• A control plan is a logical, systematic approach for documenting the results of the FMEA in an actionable format.

• A key advantage of the reaction plan form is its use as a troubleshooting guide for operators. A systematic guide of what to look for during upset conditions is valuable on its own.

Control Plan Check List

- Process maps detail manufacturing steps, material flow and important variables.
- Key product variables identified with importance to customer, desired target value and spec range defined.
- Long and short term capability trend charts track variation reduction progress.
- Key and critical input variables identified with targets, statistically determined control limits & control strategies defined.
- Reaction plan in place for out-of-spec material.
- Measurement systems are capable with calibration requirements specified.
- Sampling, inspection and testing plans include how often, where and to who results reported.
- Operating procedures identify actions, responsibilities, maintenance schedules and product segregation requirements.
- Training materials describe all aspects of process operation and responsibilities.
- ISO documentation standards met, if required.
- Process improvement efforts fully documented and available for reference.
- Control plan is reviewed and updated quarterly and resides in the operating area.