Advanced Failure Mode Effects Analysis

Improve Quality and Efficiency

Kathleen Stillings – CPM, CQE, CQA, MBB
Today’s Goals

- Understand what an advanced failure modes and effects analysis is. [3]
- Understand behavior modeling
- Apply the three phases of AFMEA: Identify, Analyze, and Act using behavior modeling to link behaviors and components. [3]
Refresher – FMEA – What is it?

- Used to assure that potential product failure modes and their associated causes have been considered and addressed in the design or manufacturing process.

It’s about taking steps to counteract or least minimize risks.

The process typically begins with identifying “failure modes”, the ways in which a product, service, or process could fail. A project team examines every element, starting the the inputs and working through the output delivered to the customer. We continually ask “what could go wrong” at each step.

Here are a few simple examples of failure modes related to the process of providing hot coffee at a truck stop:

One of the inputs to that process is a "clean coffee pot." What could go wrong? Perhaps the water in the dishwasher is not hot enough, so the coffee pot is not really clean.

The first step in the process is to fill the brewing machine with water. What could go wrong? Perhaps the water is not the right temperature or the staff puts in too much or too little.

An output from the process is a hot cup of coffee delivered to the customer. What could go wrong? The coffee could get too cool before it is delivered.

Of course, all failures are not the same. Being served a cup of coffee that is just hot water is much worse than being served a cup that is just a bit too cool. A key element of FMEA is analyzing three characteristics of failures:

- How severe they are
- How often they occur
- How likely it is that they will be noticed when they occur

Typically, the project team scores each failure mode on a scale of 1 to 10 or 1 to 5 in each of these three areas, then calculates a Risk Priority Number (RPN):

\[ RPN = (\text{severity}) \times (\text{frequency of occurrence}) \times (\text{likelihood of detection}) \]
What does the FMEA do for us?

- Reduces the likelihood of Customer complaints
- Reduces maintenance and warranty costs
- Reduces the possibility of safety failures
- Reduces the possibility of extended life or reliability failures
- Reduces the likelihood of product liability claims

Provides the tool to help the team (whether management, operators, or customers) focus on improvement efforts that pertain the failures that will have the biggest impact on customers. The highest scoring failure modes are those that happen frequently. They are bad when they do happen and unlikely to be detected. These are the nonconformances that get through the customers.

Three important items to address while working through CAPA: How did this happen?, How did it get out to the Customer?, What systemic failure allowed for the nonconformance in the first place? The FMEA will provide for a mechanism to address each of these questions.

Keep in mind to properly maintain the FMEA: update after product changes, update after process changes, review and update if needed after nonconformances are reported by customers.
Phases of the FMEA

- Identify – what is the input for the FMEA? Functions or items identified as part of the process being analyzed. Determine what can go wrong – list causes and effects
- Analyze – how likely is the failure to occur and what is the impact of the failure
- Act – what actions will be implemented to reduce the severity or eliminate the cause

Identify is the longest most arduous phase of the FMEA process.
One FMEA Challenge

- The standard FMEA approach is likely to miss some failure modes because it may not account for issues related to an item’s interface with the rest of a system. [3]

Ensure your FMEA does not drive ineffective actions.
What is an advanced FMEA based on behavioral modeling?

- Provides the structure for Engineers to identify failure modes and understand their relationship between sub-systems, controls, and the overall system performance.
- Failure modes identification as they are associated with their interactions.

There are many different approaches to “tackle” the FMEA monster: e.g.; tie into a correlation matrix, use process flow maps and value stream maps, splitting the FMEA assessment into cause and effect phases, etc…

The proposed method builds on preliminary work by Eubanks (1996) and Eubanks et al. (1997) which used behavior-based AFMEA on an automatic ice maker design.[3]

Empirical data shows that at least 50% of field problems occur at interfaces or integration with the system. Behavioral modeling FMEA approach is one method to help close the gap between processes and how they interface with the system.

Keep in mind the FMEA is somewhat subjective – this method also helps eliminate some subjectivity.
What is behavioral modeling?

- Behavioral modeling emphasizes the behavior of objects of the system including their interactions, events, and flow.
- Guided by the approach of function/state relationships.
- Qualitatively simulates normal operation and analyzes the effects of failures in terms of the resulting system state. [1]

A model is an abstracted picture of a concept. A model may represent a system, an object, or a problem constructed for the purpose of analysis. [7]
Advantages of Behavior Modeling
FMEA

- Behaviors rely on more than the process type structure
- Behaviors can reflect the customer’s requirements
- Provides a systematic structure for generating failure modes

(Kmenta, 1999)

Research has shown that nearly 80% of the costs and problems are created in product development and that cost and quality are essentially designed into products at the conceptual stage. Currently failure identification procedures (such as FMEA, FMECA and FTA) and design of experiments are being used for quality control and for the detection of potential failure modes during the detail design stage or post product launch. Though all of these methods have their own advantages, they do not give information as to what are the predominant failures that a designer should focus on while designing a product.
Behavior Modeling

- Define the relationships between:
  - Functions: the overall purpose of the process in verb + noun format
  - States: “what is required” and “what is expected”
  - Elements: physical entities that enable functions to achieve “what it expected”

States: pre-conditions (what is required) and post-conditions (what is expected)
Flowchart for Advanced FMEA

(Kmenta, 1999)
Application – What to consider
Define the boundary / system

- Clearly state the scope of the analysis
- E.g.; in a manufacturing process, the system scope might be a plant, manufacturing line, or manufacturing cell

Example – filling the ice bucket and the equipment associated with this proc
Bring your process flow diagram

1. Ice Bucket is Empty
   - Sense no ice in the bucket
2. Release water valve
3. Verify tray is empty
4. Fill tray with water
5. Freeze ice
6. Sense temperature
7. Rotate ice tray
8. Deposit ice in bucket
A **Functional Flow Block Diagram** (FFBD) is a multi-tier, time-sequenced, step-by-step flow diagram of a system’s functional flow.

This version presented is a very rudimentary version of the FFBD. More details will follow in future presentations.
Define the Process Functions

- Verb + noun
- What functions in your process convert an input into an output?
List the desired inputs and outputs

- Can be represented by 3 main categories: Energy, Information, and Material
- Will be listed as
  - \(<\text{variable}>\langle\text{attribute}\rangle\langle\text{value}\rangle\) [3]
- E.g.;
  - \(<\text{variable}>\langle\text{attribute}\rangle\langle\text{value}\rangle\n
Ice Bucket, Cube Level, Not Full

Examples:
- Energy: power, force, friction
- Information: data, bar codes, paperwork
- Material: fluid flow, components [3]
Behavior Mapping

What is required

$S_1$
INITIAL STATE

no ice cubes in bucket

Functions

BEHAVIOR

deposit ice cubes in bucket

What is expected

$S_2$
FINAL STATE

ice cubes in bucket

Elements

$<$OBJECT$>$ $<$ATTRIBUTE$>$ $<$VALUE$>$
ICE BUCKET, CUBE LEVEL, NOT FULL
SWITCH, POSITION, CLOSED
COIL, STATUS, ENERGIZED
CABLE, POSITION, 1 V SEC

Behaviors can be described:
Verbally – cause water flow to increase
Quantitatively – flow rate increases to .03 m$^3$/sec
Mathematically – $V = \dot{\theta}$
Decompose the process

Ice Cubes Empty or Fill ice Cubes

Water Source
  Supply Water
  Freeze water

Firezer
  Freeze water

Deposit ice Cubes in bucket
  Verify cube needed
  Harvest Cubes
  Verify bucket full

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An alternate decomposition method which can be used to assign dependencies. A mapping between the functions and the structure forms a link between the descriptions of the device in operation and the physical entities implementing those actions [3].

Activity: Create a function-state map for hair dryer (see attachment 1 for results)

The two things needed as assemblies to make ice are Ice maker (as shown here) and the freezer (not shown)
Exercise: create the behavior model for deposit ice cubes in bucket – see attachment 2
Identify the Elements

- Elements are the physical entities and agents responsible for performing functions and achieving post-conditions [3]

<table>
<thead>
<tr>
<th>ID</th>
<th>Behavior or Function</th>
<th>Type</th>
<th>Variable</th>
<th>Attribute</th>
<th>Value</th>
<th>Variable</th>
<th>Attribute</th>
<th>Value</th>
<th>Pre Conditions</th>
<th>Post Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>Create Cubes</td>
<td>desired</td>
<td>ice cubes present</td>
<td>no</td>
<td>mold</td>
<td>ice cubes present</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.1</td>
<td>fill mold with water</td>
<td>desired</td>
<td>water level</td>
<td>none</td>
<td>mold</td>
<td>water level</td>
<td>full</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.2</td>
<td>freeze water</td>
<td>desired</td>
<td>ice cubes present</td>
<td>no</td>
<td>mold</td>
<td>ice cubes present</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.2.1</td>
<td>freeze water</td>
<td>desired</td>
<td>water</td>
<td>liquid</td>
<td>water</td>
<td>state</td>
<td>solid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.2.2</td>
<td>freeze water</td>
<td>desired</td>
<td>freezer</td>
<td>temperature</td>
<td>&lt;32°F</td>
<td>&lt;32°F</td>
<td>Ice Cubes Present</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.2.3</td>
<td>Nominal Geometry</td>
<td>desired</td>
<td>mold</td>
<td></td>
<td></td>
<td>mold</td>
<td>ice shape</td>
<td>correct</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Identify Failure Modes

- Failure is defined as a manner in which a system failed

- Typical failure modes:
  1. premature operation,
  2. failure to operate at the prescribed time,
  3. failure to cease operation at the prescribed time,
  4. failure during operation, and
  5. degraded or excessive operational capability.
Failure Modes ID Process – Step 1

- Deposit cubes in bucket
- Create Cubes
- Fill with Water
- Freeze Water
- Nominal Geometry
- Mold
- Water Delivery System
- Freezer
- Mold
Failure Modes ID Process – Step 2

Main Function
Not (Deposit cubes in bucket)

End Effect

Major sub-function
Not (Create Cubes)

Local effect

Sub-function
Not (Fill with Water)

Not (Freeze Water)

Failure mode
Not (Nominal Geometry)

Mapped elements
Hole in Mold
Water turned off
Freezer not powered – circuit breaker blown
Freezer thermostat broke
Water level low in mold – due to inadequate pressure

Potential cause

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Plug the data into your FMEA template

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Pre Condition</th>
<th>Post Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>deposit ice cubes in bucket</td>
<td>ice cubes</td>
<td>water</td>
</tr>
</tbody>
</table>

**Handout sample Behavioral - FMEA Matrix**
Comparison – FMEA vs. AFMEA

Users of AFMEA claim it captures a richer set of potential failure modes than traditional FMEA. Many failure modes can be captured which do not necessarily relate to components, but to interaction with system components.

<table>
<thead>
<tr>
<th>FAILURE MODE</th>
<th>FMEA</th>
<th>AFMEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>thermostat failure</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>water switch failure</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>feeler arm damaged</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>power cord disconnected</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>high/low water pressure</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>bucket misplacement</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>refrigerator misalignment</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Iced gears</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>high freezer temperature</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

An alternate decomposition method which can be used to assign dependencies.
A mapping between the functions and the structure forms a link between the descriptions of the device in operation and the physical entities implementing those actions [3].
Activity: Create a function-state map for hair dryer (see attachment 1 for results)
The two things needed as assemblies to make ice are Ice maker (as shown here) and the freezer (not shown)
Coming Up

FMEA Continued…
How to measure your FMEA effectiveness

Possible Future Presentation:
Functional Flow Diagramming
References

Attachment 1

(Kmenta, 1999)
Attachment 2

**Behavior Model**

FMEA

<table>
<thead>
<tr>
<th>Index</th>
<th>Behavior Type</th>
<th>Behavior</th>
<th>Pre-Condition Spec</th>
<th>Post-Condition Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drained Color in Bucket</td>
<td>Drained</td>
<td>Ice Bucket</td>
<td>Color Level</td>
</tr>
<tr>
<td>1.1</td>
<td>Verify Color Need</td>
<td>Drained</td>
<td>Color Level</td>
<td>Ice Maker</td>
</tr>
<tr>
<td>1.2</td>
<td>Create Cube</td>
<td>Drained</td>
<td>Mold</td>
<td>Ice Color Present</td>
</tr>
</tbody>
</table>

**Decomposition of Behavior “Create Cubes”**

<table>
<thead>
<tr>
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<th>Behavior Type</th>
<th>Behavior</th>
<th>Pre-Condition Spec</th>
<th>Post-Condition Spec</th>
</tr>
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<tbody>
<tr>
<td>1.2.1</td>
<td>Fill Mold with Water</td>
<td>Drained</td>
<td>Mold</td>
<td>Ice Color Present</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Freeze Water</td>
<td>Drained</td>
<td>Ice Color Present</td>
<td>Yes</td>
</tr>
</tbody>
</table>

(“Failure Mode and Effect”, 2004)