Advanced Failure Mode Effects Analysis

Improve Quality and Efficiency

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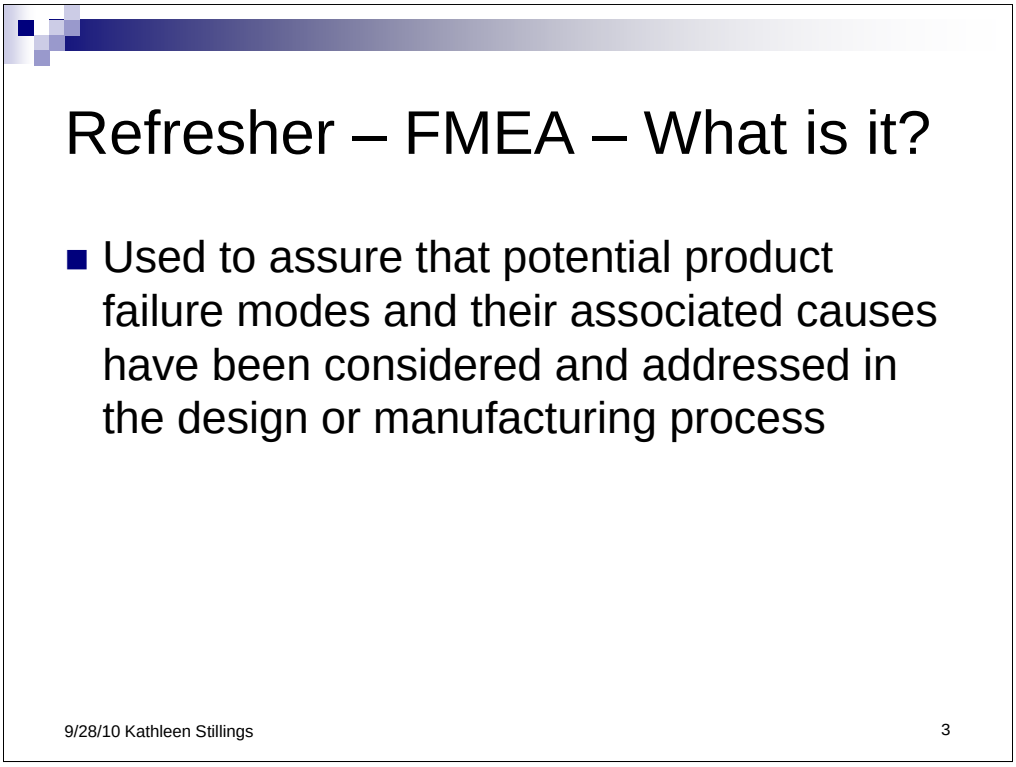
Today's Goals

- 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]



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 = (severity) x (frequency of occurrence) x (likelihood of detection)

What does the FMEA do for us?

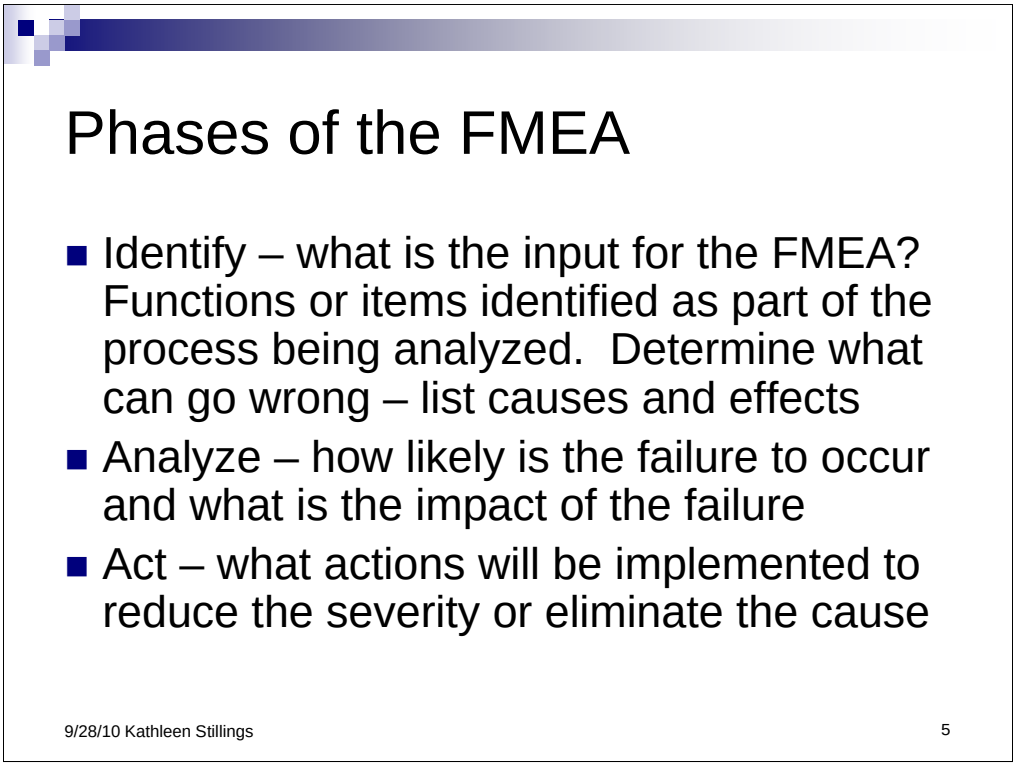
- Reduces the likelihood of Customer complaints
- Reduces maintenance and warranty costs
- Reduces the possibility of safety failures
- Reduces the possibility of extended life or reliability failures
- Reduces the likelihood of product liability claims

9/28/10 Kathleen Stillings 4

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 a 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.



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.

9/28/10 Kathleen Stillings 7

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]

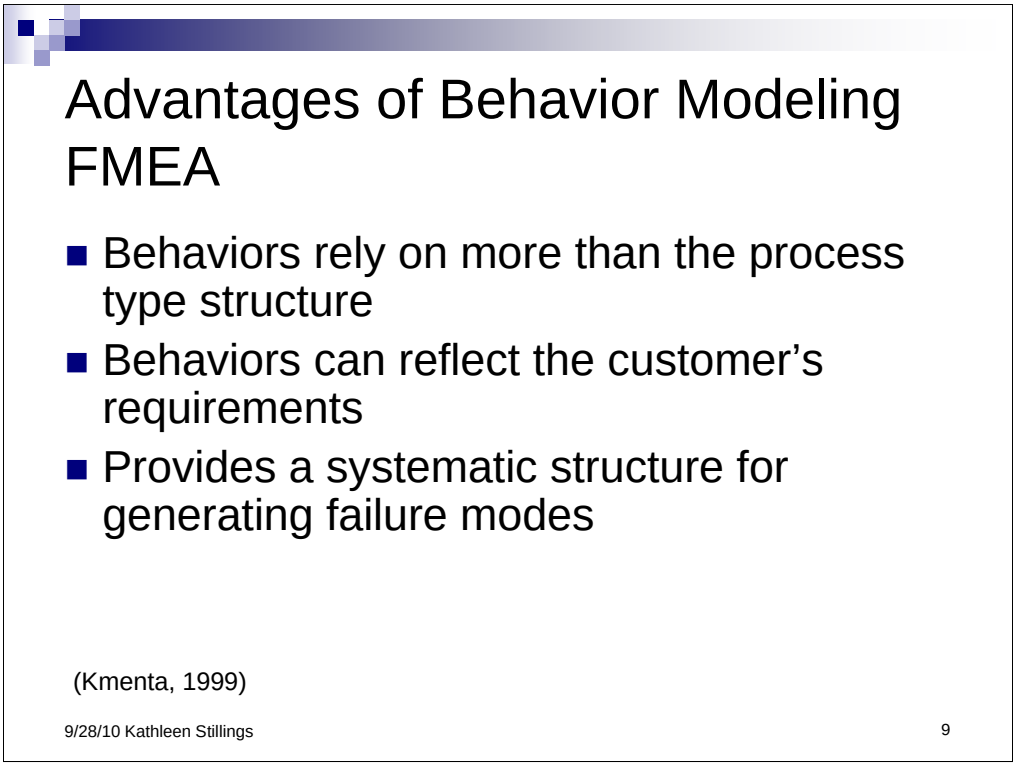
Empirical data shows that at least 50% of field problems occur at interfaces or integration with the system. Behavioral modeling FMEA approach is one method to help close the gap between processes and how they interface with the system.

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

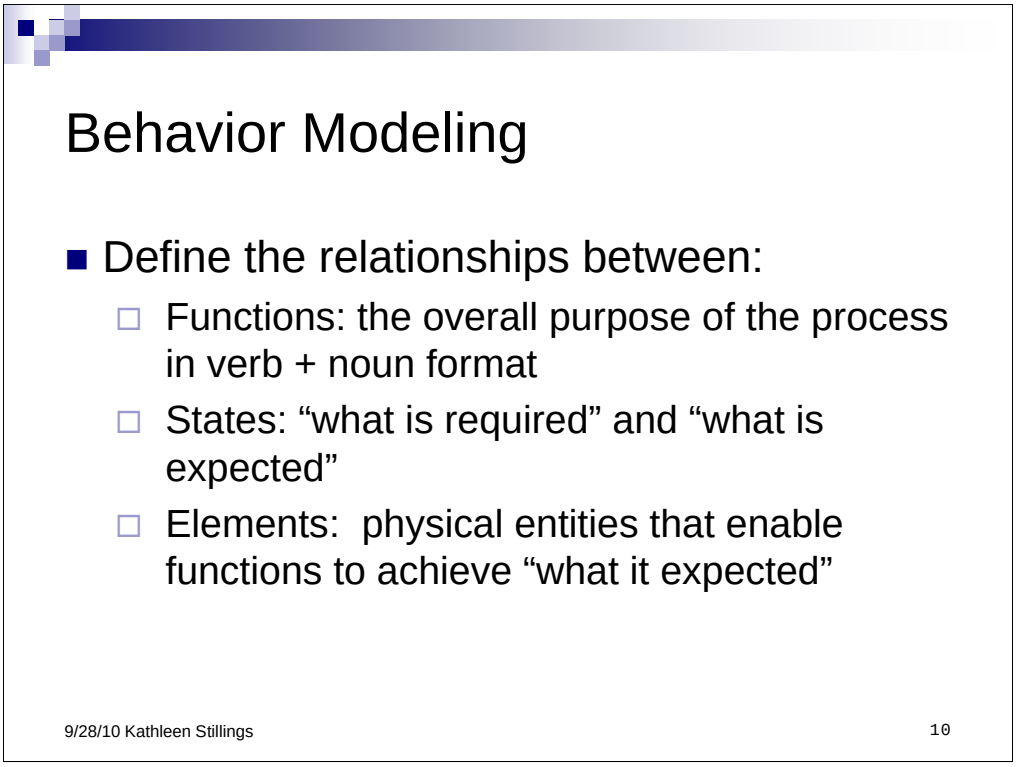
What is behavioral modeling?

- 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 prepresent a system, an object, of a problem constructed for the purpose of analysis. [7]

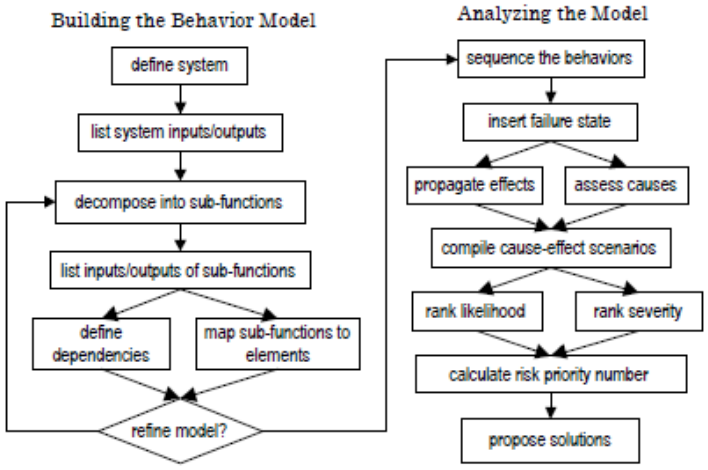


Research has shown that nearly 80% of the costs and problems are created in product development and that cost and quality are essentially designed into products at the conceptual stage. Currently failure identification procedures (such as FMEA, FMECA and FTA) and design of experiments are being used 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.



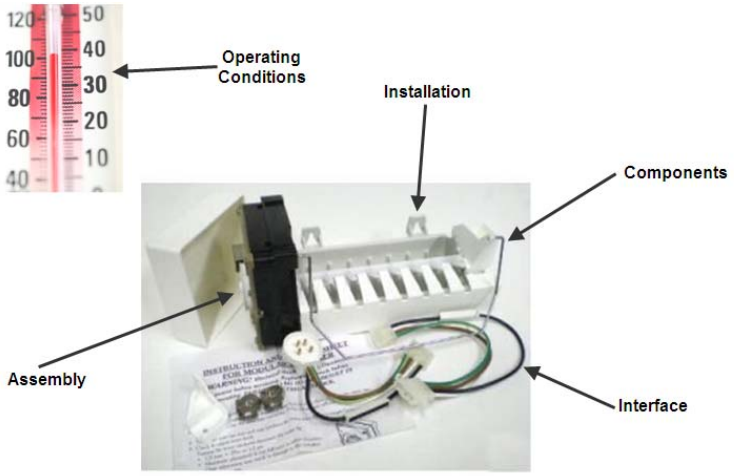
States: pre-conditions (what is required) and post-conditions (what is expected)

Flowchart for Advanced FMEA



(Kmenta, 1999)

Application – What to consider

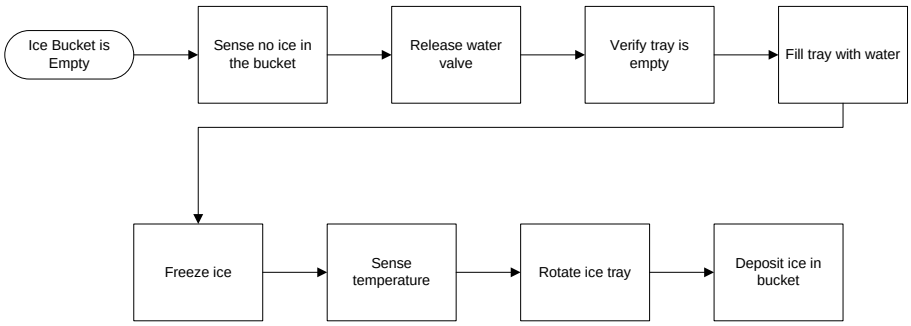


Define the boundary / system

- 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

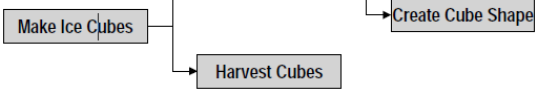
Bring your process flow diagram

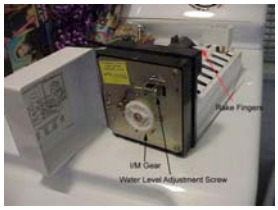


Functional Block Diagram

- Functional Block Diagram

Ice maker





Each behavior is mapped to a specific state transition

Behavior: deposit ice cubes in bucket

Initial State: no ice cubes in bucket

Desired Final State: ice cubes in bucket

("Failure Mode and Effect", 2004)

9/28/10 Kathleen Stillings 15

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 <variable><attribute><value> [3]
- E.g.;

<variable><attribute><value>

Ice Bucket, Cube Level, Not Full

9/28/10 Kathleen Stillings 17

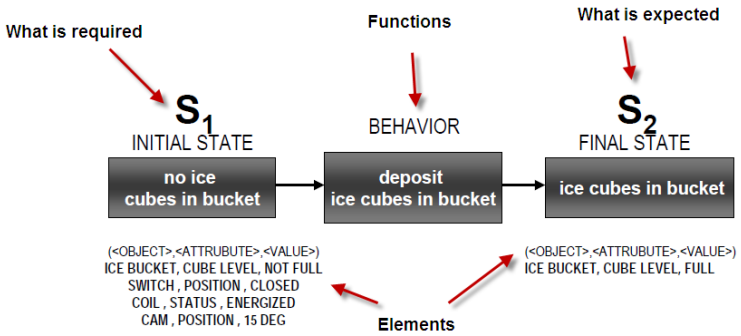
Examples:

Energy: power, force, friction

Information: data, bar codes, paperwork

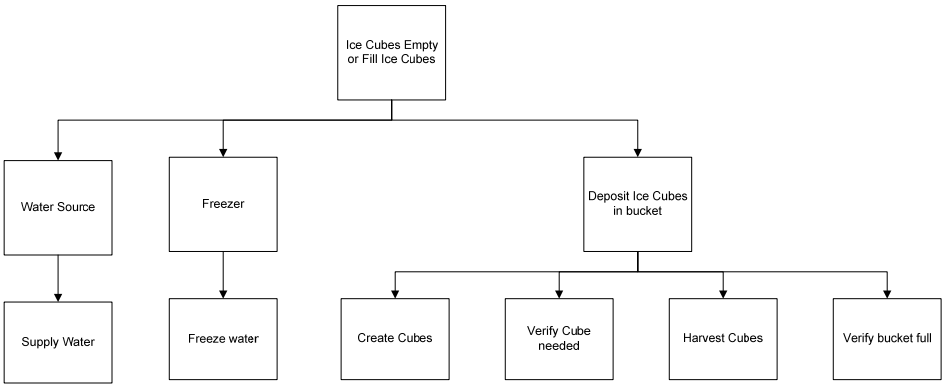
Material: fluid flow, components [3]

Behavior Mapping

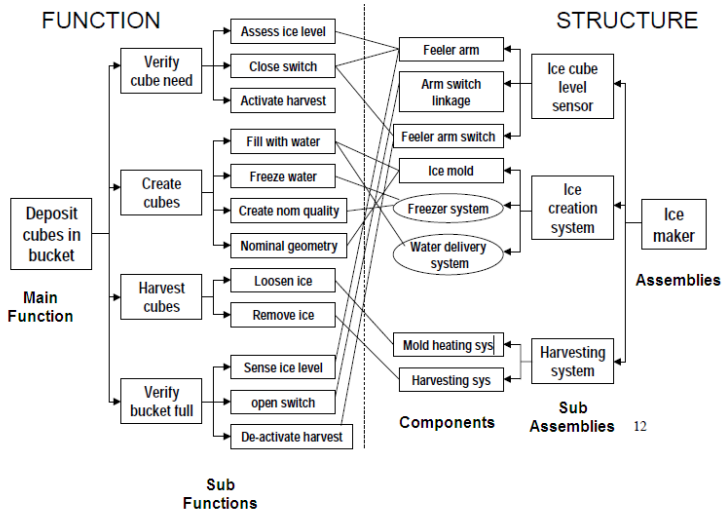


Behaviors can be described:
Verbally – *cause water flow to increase*
Quantitatively – *flow rate increases to .03 m^3/sec*
Mathematically – *V = ...*

Decompose the process



Function-Structure Mapping



("Failure Mode and Effect", 2004)

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)

Map the Behavior to the Structure

BEHAVIOR				PRE-CONDITION SPEC			POST-CONDITION SPEC		
index	behavior	type	mapped to	object	attribute	value	object	attribute	value
1	deposit cubes in bucket	desired	ice maker	ice bucket	cube level	not full	ice bucket	cube level	full
			freezer	freezer	temperature	>8 & <15 °F	freezer	temperature	>8 & <15 °F
			V/ater Source	Faucet	Supply V/ater	On	Faucet	Supply V/ater	Off
1.1	verify cube need	desired	cube level sensor	ice maker	harvesting status	inactive	ice maker	harvesting	active
				ice bucket	cube level	not full			
1.2	create cubes	desired	mold	mold	ice cubes present	no	mold	ice present	yes
1.3	harvest cubes	desired	mold	mold	ice cubes present	yes	mold	ice present	no
			ice bucket	ice bucket	cube level	not full	ice bucket	cube level	full
			ice maker	ice maker	harvesting status	active			

Decomposition of behavior "create cubes"

BEHAVIOR				PRE-CONDITION SPEC			POST-CONDITION SPEC		
index	behavior	type	mapped to	object	attribute	value	object	attribute	value
1.2	create cubes	desired	ice creation system	mold	ice cubes present	no	mold	ice cubes present	yes
1.2.1	fill mold with water	desired	water delivery	mold	water level	none	mold	water level	full

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]

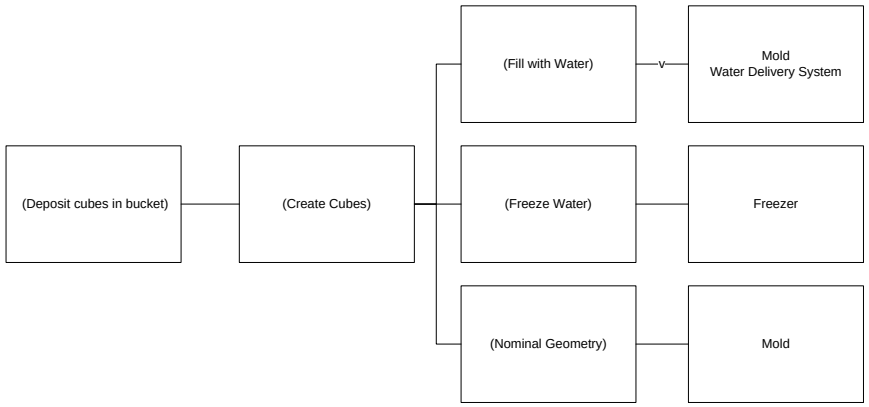
ID	Behavior or Function Key Process Step or Input	Type	Mapped To (Element)	Pre Conditions			Post Condition		
				Variable	Attribute	Value	Variable	Attribute	Value
1.2	Create Cubes	desired	ice creation system	mold	ice cubes present	no	mold	ice cubes present	yes
1.2.1	fill mold with water	desired	water delivery system	mold	water level	none	mold	water level	full
1.2.1.1		desired	mold	mold	ice cubes present	no			
1.2.2	freeze water	desired	freezer sysm	water	state	liquid	water	state	solid
1.2.2.1		desired	mold	freezer	temperature	<32°F	<32°F	Ice Cubes Present	Yes
1.2.2.2		desired		mold	water level	full			
1.2.2.3	Nominal Geometry	desired	mold				mold	ice shape	correct

Identify Failure Modes

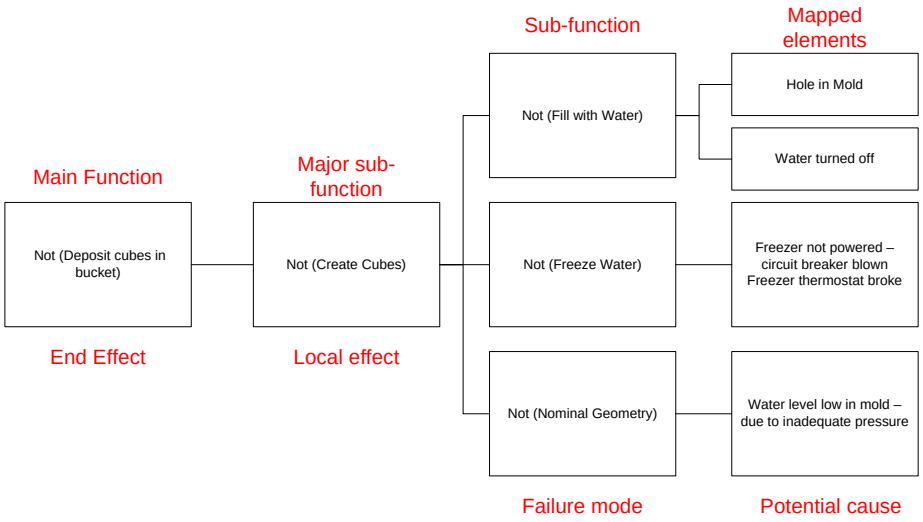
- Failure is defined as a manner in which a system failed

- 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



Failure Modes ID Process – Step 2



Plug the data into your FMEA template

Deposit Ice Cubes in Bucket - Behavorial Analysis

ID	Behavior or Function Key Process Step or Input	Type	Mapped To	Pre Conditions			Post Condition		
				Variable	Attribute	Value	Variable	Attribute	Value
			ice maker	ice bucket	cube level	not full	ice bucket	cube level	full
1	deposit ice cubes in bucket	desired	freezer	freezer	temperature	>8 & <15°F	freezer	temperature	>8 & <15°F
1.1	verify cube needed	desired							
1.2	Create Cubes	desired							
1.2.1	fill mold with water	desired							
1.2.1.1		desired							
1.2.2	freeze water	desired							
1.2.2.1		desired							
1.2.2.2		desired							
1.3	harvest cubes	desired							

Deposit Ice Cubes in Bucket - FMEA

Process Name: Prepared by: Rev:

Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Resp.	Actions Taken	SEV	OCC	DET	RPN

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.

FAILURE MODE	FMEA	AFMEA
thermostat failure	yes	yes
water switch failure	yes	yes
feeler arm damaged	yes	yes
power cord disconnected	yes	yes
high/low water pressure	no	yes
bucket misplacement	no	yes
refrigerator misalignment	no	yes
iced gears	no	yes
high freezer temperature	no	yes

("Failure Mode and Effect", 2004)

An alternate decomposition method which can be used to assign dependencies.

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Coming Up

FMEA Continued…

How to measure your FMEA effectiveness

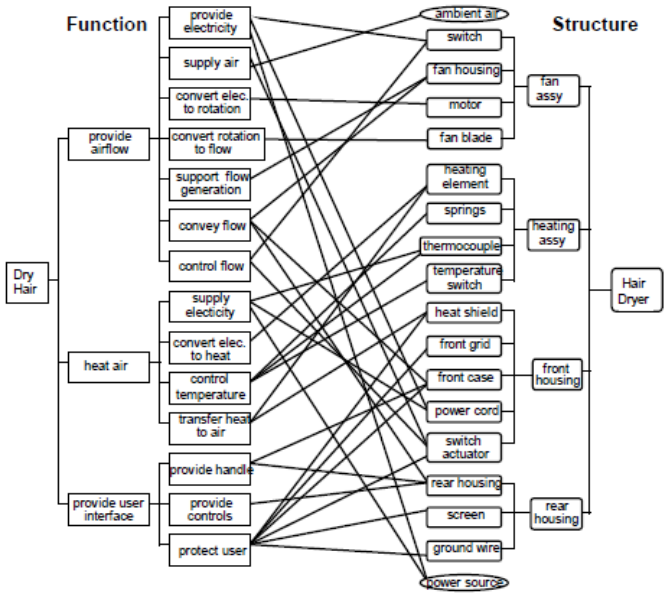
Possible Future Presentation:

Functional Flow Diagramming

References

1. "Failure Mode and Effect", 2004, *"Failure Mode and Effects Analaysis Lecture 5-1 Advanced FMEA",* Retrieved from http://www.okstate.edu/ceat/msetm/courses/etm5291/documents/FMEA_MSETM_5291_5a.pdf
2. S. Kmenta, K. Ishii, 1998, "ADVANCED FMEA USING META BEHAVIOR MODELING FOR CONCURRENT DESIGN OF PRODUCTS AND CONTROLS, " *Proceedings of DETC 1998 ASME Design Engineering Technical Conferences, Atlanta Ga.*
3. S. Kmenta, P Fitch, K. Ishii, 1999, "ADVANCED FAILURE MODES AND EFFECTS ANALYUSIS OF COMPLEX PROCESSES," *Proceedings of DETC 1999 ASME Design Engineering Technical Conferences, Las Vegas, Nevada*
4. Bowles, J. 1998, "The New SAE FMECA Standard," *Proceedings of the 1992 IEEE Annual Reliability and Maintainability Symposium*, pp. 48-53
5. Eubanks, C.F., S. Kmenta, and K. Ishii, 1996, "System Behavior Modeling as a Basis for Advanced Failure Modes and Effects Analysis," *Proceedings of the 1996 ASME Design Engineering Technical Conferences*, Irvine, CA.
6. Eubanks, C.F., S. Kmenta, and K. Ishii, 1997, "Advanced Failure Modes and Effects Analysis Using Behavior Modeling," *Proceedings of the 1997 ASME Design Engineering Technical Conferences*, Sacramento, CA.
7. PC Teoh, K Case, 2004, "Modelling and reasoning for failure modes and effects analysis generation," *Proc instn Mech. Engrs Vol. 218 Part B: J. Engineering Manufacture*

Attachment 1



(Kmenta, 1999)

Attachment 2

Behavior Model

FMEA

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			Water Source	Faucet	Supply Water	On	Faucet	Supply Water	Off
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				ice bucket	cube level	not full			
1.2	create cubes	desired	mold	mold	ice cubes present	no	mold	ice present	yes
1.3	harvest cubes	desired	mold	mold	ice cubes present	yes	mold	ice present	no
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			mold	mold	ice cubes present	no			
1.2.2	freeze water	desired	freezer system	water	state	liquid	water	state	solid
			mold	freezer	temperature	<32 °F	mold	ice cubes present	yes
				mold	water level	full			

("Failure Mode and Effect", 2004)