



1



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Practical workshop with tools to improve the reliability of your plant.

The Toolbox Session is a workshop where you will learn practical and useful knowledge that will serve you in your work at the plant. The speaker explains the objective of the tool to be learned and facilitates the learning process through examples and exercises.

Additionally, tools, templates, spreadsheets, and tips are provided so you can acquire the skills that will improve your performance on a day-to-day basis.



TOOLBOX



CONGRESO DE
MANTENIMIENTO
& CONFIABILIDAD
COLOMBIA

1^a
EDICIÓN



Reliability Centered Maintenance (RCM)

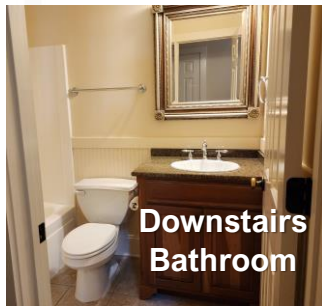
A Case Study for FMEA and Protective Systems

Nancy Regan

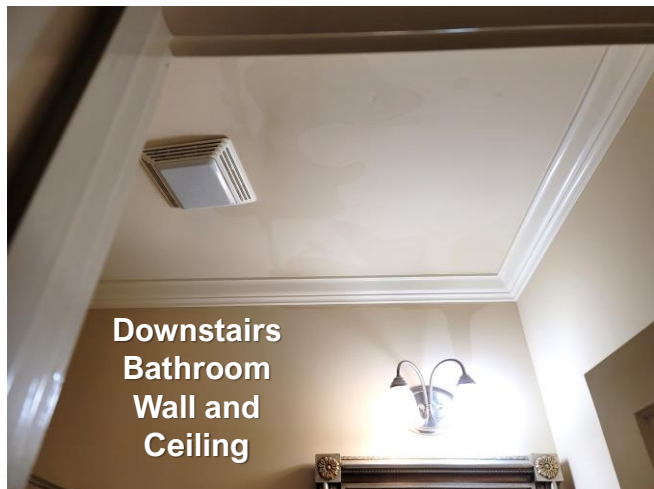
RCM Practitioner

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Case Study: Home HVAC System



Downstairs Bathroom



Downstairs Bathroom Wall and Ceiling

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Goals of Toolbox Session



Understand SAE-JA1011 Compliant RCM through a Real-World (personal!) Case Study

RCM Process

1. Functions
2. Functional Failures
3. Failure Modes
4. Failure Effects
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies

- ✓ Learn the basics and power of FMEA
- ✓ Identify Evident and Hidden Failure Modes
- ✓ Overview of the RCM Decision Diagram and how to use it
- ✗ **NOT** a comprehensive introduction to RCM. It is an overview of some key RCM concepts.
- ✓ You **WILL** leave understanding what "True" RCM is.

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Case Study: Home HVAC System

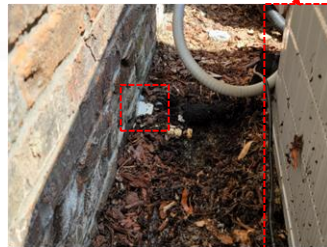


In Attic: Air Handler and Evaporator Coil

Condensate Overflow Switch

Downstairs Condenser Unit

Condensate Drain Pan



Multiple Failure



Leaked into Downstairs Bathroom

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Reliability Centered Maintenance (RCM) Overview

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Reliability Centered Maintenance

RCM is a zero-based process used to identify the Failure Management Strategies that are required to ensure an asset meets its mission requirements in its operational environment in the most safe and cost-effective manner.

RCM Process

1. Functions
2. Functional Failures
3. Failure Modes
4. Failure Effects
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7. Default Strategies

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Operating Context

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Operating Context Excerpt



- Home is in Madison, Alabama, USA.
- The mulch is replaced by a landscaper twice per year.
- In the summer, the average high is 90°F/32°C, so the air conditioner is required 24/7.
- During the summer months, the HVAC unit produces up to 2 gallons (7.5 liters) per hour of condensate.
- The *Condensate Drain Pan* can hold two quarts (1.9 liters) before reaching the *Condensate Overflow Switch*.
- There is no backup air conditioner.
- Scope of analysis is limited to the *Condensate Drain Line* and the *Condensate Overflow Switch* “system”

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Operating Context Excerpt, cont'd



Theory of Operation Excerpt

...Chilled Refrigerant is pumped through the evaporator coil (located in the attic). The blower circulates air over the evaporator coil and the air cools down. During this process, condensation forms on the outside of the coils and is drained outside through the *Condensate Drain Line*.

The attic unit is fitted with a *Condensate Drain Pan* to catch any condensate that accumulates in the event that the *Condensate Drain line* is clogged. The *Condensate Drain Pan* is fitted with a *Condensate Overflow Switch*.

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Operating Context Excerpt, cont'd



Theory of Operation Excerpt, continued

In the event that the *Condensate Drain Line* is clogged, the condensate accumulates in the *Condensate Drain Pan*. When the condensate reaches the *Condensate Overflow Switch*, the switch is energized, the thermostat is automatically shut off, and the HVAC unit is automatically shut down. This prevents additional condensate from being produced, preventing condensate from overflowing the *Condensate Drain Pan* and leaking onto the attic floor and then through the ceiling to the downstairs bathroom.

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Reliability Centered Maintenance

RCM is a zero-based process used to identify the Failure Management Strategies that are required to ensure an asset meets its mission requirements in its operational environment in the most safe and cost-effective manner.

“Reliability”

- RCM Process**
1. Functions
 2. Functional Failures
 3. Failure Modes
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 7. Default Strategies

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Evident and Hidden Functions

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Classifying Functions: Evident

Evident
Function



Failure of the Function becomes evident to the operating crew under normal conditions.

Your Car

- Starter motor
- Tires
- Battery

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Writing Evident Functions

To + **Verb** + **Object** + **Performance Standard(s)** + **Operating Context**

Oil Pressure Indicator

To indicate oil pressure

RCM Process

1. Functions
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3. Failure Modes
4. Failure Effects
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies

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Writing Evident Functions

To + **Verb** + **Object** + **Performance Standard(s)** + **Operating Context**

Oil Pressure Indicator

To indicate oil pressure

To visually indicate oil pressure to within +/- 5 psi

RCM Process

1. Functions
2. Functional Failures
3. Failure Modes
4. Failure Effects
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies

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Writing Evident Functions

Verb + **Object** + **Performance Standard(s)** + **Operating Context**

Condensate drain line

To drain condensate

RCM Process

1. Functions
2. Functional Failures
3. Failure Modes
4. Failure Effects
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies



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Writing Evident Functions



Condensate drain line

To drain condensate

To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required.

Evident Function

RCM Process

1. Functions
2. Functional Failures
3. Failure Modes
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7. Default Strategies

Classifying Functions: Hidden

Hidden Function

Hidden Functions are almost always Protective Devices

Failure of the Function is *not* evident to the operating crew under normal conditions.

Protective Devices and Hidden Failures

Protective Device:
 Device or System intended to protect
in the event that another failure occurs.



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Hidden Functions To be capable of [...] in the event that [...]



Home Smoke Detector
 To be capable of sounding an audible alarm *in the event* there is a fire in the room

→ **Protective Device**

Hidden Function

Failure of the Function is *not* evident to the operating crew under normal conditions.

No fire
(normal condition)

+

Smoke detector fails



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Hidden Functions



Home Smoke Detector
 To be capable of sounding an audible alarm *in the event* there is a fire in the room

→ Protective Device

There IS a fire in the room (failure condition)

+

Smoke detector fails

=

Multiple Failure

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Writing Hidden Functions



To be capable of [...] in the event that [...]

Condensate Overflow Switch “System”

- RCM Process
1. Functions
 2. Functional Failures
 3. Failure Modes
 4. Failure Effects
 5. Failure Consequences
 6. Proactive Maintenance and Intervals
 7. Default Strategies

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Writing Hidden Functions



To be capable of [...] in the event that [...]

Condensate Overflow Switch “System”

To be capable of shutting down the HVAC unit *in the event that* the condensate drain line clogs.

RCM Process

1. Functions
2. Functional Failures
3. Failure Modes
4. Failure Effects
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies

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Reliability Centered Maintenance

RCM is a zero-based process used to identify the Failure Management Strategies that are required to ensure an asset meets its mission requirements in its operational environment in the most safe and cost effective manner.

We manage assets at the Failure Mode level.

We proactively identify what could cause each Functional Failure, and then use the remaining four steps of the RCM process to figure out what (if anything at all) we should do to manage it.

RCM Process

1. Functions
2. Functional Failures
3. Failure Modes
4. Failure Effects
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies

What specifically *causes* failure



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Failure Modes

Destination:
Failure Management Strategies
Proactive Maintenance
and
Default Strategies

Failure Mode

A properly written Failure Mode puts you on the right road and sends you in the right direction.

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Potential Products of an RCM Analysis

RCM Can Yield

- Proactive Maintenance Plan
- New/Modifications to Operating Procedures
- Updates/Additions to Technical Publications
- New/Modifications to Training Programs
- Equipment Redesigns
- Supply Changes
- Failure Finding tasks
- Troubleshooting Procedures

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How to Compose Failure Modes

Noun + **Verb** + *(as necessary) Operating Context*

Intercooler tubes corrode

Brake pads wear

Compressor disc fatigues

Alternator belt deteriorates

Power turbine blade fatigues

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How to Compose Failure Modes

Noun + **Verb** + *(as necessary) Operating Context*

Intercooler tubes corrode **due to normal use**

Brake pads wear **due to normal use**

Compressor disc fatigues **due to normal use**

Alternator belt deteriorates **due to normal use**

Power turbine blade fatigues **due to normal use**

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How to Compose Failure Modes

Noun + **Verb** + *(as necessary) Operating Context*

Hydraulic line chafes **due to normal equipment vibration**

Hydraulic line chafes **due to improper routing**

Oil filter clogs **due to normal use**

Oil filter clogs **due to gearbox break-in**

Foreign object enters aircraft engine air inlet **during flight**

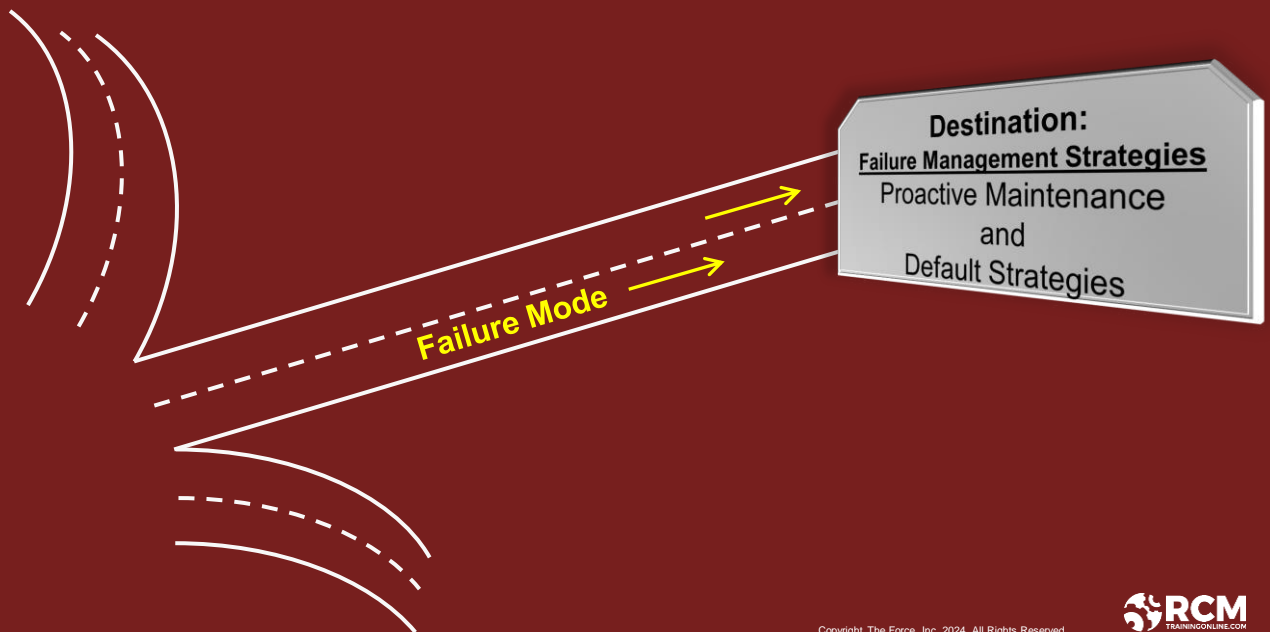
Foreign objects accumulate in aircraft engine inlet **while on the ground, with engine off**

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Why Including Operating Context in Failure Modes Matters



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Why Operating Context Matters in Failure Modes

Failure Modes with operating context in italics

Hydraulic line chafes *due to normal equipment vibration.*

Hydraulic line chafes *due to improper routing.*

Failure Management Strategies

Visually inspect hydraulic line every 25 hours of operation. Replace line, as required.

Augment training program to include proper routing of hydraulic lines.



Why Operating Context Matters in Failure Modes

Failure Modes with operating context in italics

Hydraulic line chafes *due to normal equipment vibration.*

Hydraulic line chafes *due to improper routing.*

Oil filter clogs *due to normal use*

Oil filter clogs *due to gearbox break-in*

Failure Management Strategies

Visually inspect hydraulic line every 25 hours of operation.

Augment training program to include proper routing of hydraulic lines.

Change the oil filter after every 500 hours of operation.

Change the oil filter after the first 50 hours of operation.



Why Operating Context Matters in Failure Modes

Failure Modes with operating context in italics

Failure Management Strategies

Hydraulic line chafes *due to normal equipment vibration.*

Visually inspect hydraulic line every 25 hours of operation.

Hydraulic line chafes *due to improper routing.*

Augment training program to include proper routing of hydraulic lines.

Oil filter clogs *due to normal use*

Change the oil filter after every 500 hours of operation.

Oil filter clogs *due to gearbox break-in*

Change the oil filter after the first 50 hours of operation.

Foreign object enters engine air inlet *during flight.*

Implement emergency procedure for an in-flight engine failure.

Foreign object accumulates in engine inlet *while aircraft is on the ground with the engine not running.*

Inspect the engine inlet for foreign objects prior to engine start.

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Why Operating Context Matters in Failure Modes

Failure Modes with operating context in italics

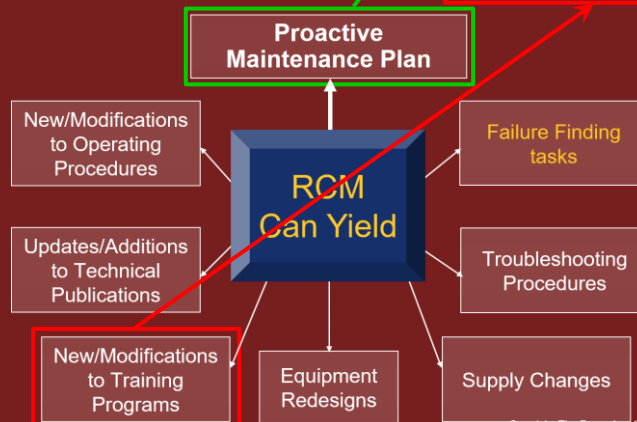
Failure Management Strategies

Hydraulic line chafes *due to normal equipment vibration.*

Visually inspect hydraulic line every 25 hours of operation. Replace line, as required.

Hydraulic line chafes *due to improper routing.*

Augment training program to include proper routing of hydraulic lines.




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	Function		Functional Failure	Failure Mode	Failure Effect
1	To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required. (Condensate drain line)	A	Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.		<p>Question to ask to identify Failure Modes:</p> <p><i>What specifically causes it to be unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required?</i></p>

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	Function		Functional Failure	Failure Mode	Failure Effect
1	To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required. (Condensate drain line)	A	Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.		<p>Question to ask to identify Failure Modes:</p> <p><i>What specifically causes it to be unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required?</i></p>
	<p>Operating Context!</p> 				

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	Function		Functional Failure	Failure Mode	Failure Effect
1	To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required. (Condensate drain line)	A	Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.	1 Drain line clogged due to normal use.	
				2 Drain line on the outside of the house is covered with mulch after landscaping.	
				3 Drain line on the outside of house is clogged with mulch and yard debris due to normal use.	

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Reliability Centered Maintenance

Failure Effect

A story of what would happen if nothing were done to predict, prevent, or manage its associated Failure Mode.

Important Points

- Document worst-case-scenario
- Write in enough detail to assess consequences

RCM Process

1. Functions
2. Functional Failures
3. Failure Modes
4. Failure Effects
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies

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Failure Effects Include:

- ▶ A description of the failure process from the occurrence of the Failure Mode to the Functional Failure
- ▶ Physical evidence that the failure has occurred
- ▶ How it adversely affects safety and/or the environment
- ▶ How it affects operational capability/mission
- ▶ Specific operating restrictions as a result of the failure
- ▶ Secondary damage
- ▶ What must be done and how long it takes to repair the failure

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	Function		Functional Failure		Failure Mode	Failure Effect
1	To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required. (Condensate drain line)	A	Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.	1	Drain line clogged due to normal use.	Over time, bacteria, dust, and gunk builds up inside the PVC pipe. Eventually, condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit is automatically shut down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the drain line is cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.
1		A		2		

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Failure Mode 1A1: Drain line clogged due to normal use.



Failure Effect: Over time, bacteria, dust, and gunk builds up inside the PVC pipe. Eventually, condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down.

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Failure Mode 1A1: Drain line clogged due to normal use.



Failure Effect: Over time, bacteria, dust, and gunk builds up inside the PVC pipe. Eventually, condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to the occupants. However, it makes for an uncomfortable weekend.

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Failure Mode 1A1: Drain line clogged due to normal use.



Failure Effect: Over time, bacteria, dust, and gunk builds up inside the PVC pipe. Eventually, condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to the occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the drain line is cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.

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Failure Mode 1A1: Drain line clogged due to normal use.

Failure Effect: Over time, bacteria, dust, and gunk builds up inside the PVC pipe. Eventually, condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to the occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the drain line is cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.

Failure Effects Include:

- ▶ A description of the failure process from the occurrence of the Failure Mode to the Functional Failure
- ▶ Physical evidence that the failure has occurred
- ▶ How it adversely affects safety and/or the environment
- ▶ How it affects operational capability/mission
- ▶ Specific operating restrictions as a result of the failure
- ▶ Secondary damage
- ▶ What must be done and how long it takes to repair the failure

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	Function		Functional Failure	Failure Mode	Failure Effect
1	To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required. (Condensate drain line)	A	Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.	3 Drain line on the outside of the house is covered with mulch after landscaping.	Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the mulch is cleared from the drain line and is also cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.

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Failure Mode 1A3: Drain line on the outside of the house is covered with mulch after landscaping.

Failure Effect: Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down.

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Failure Mode 1A3: Drain line on the outside of the house is covered with mulch after landscaping.

Failure Effect: Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend.

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Failure Mode 1A3: Drain line on the outside of the house is covered with mulch after landscaping.

Failure Effect: Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the mulch is cleared from the drain line and is also cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.

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Failure Mode 1A1: Drain line clogged due to normal use.

Failure Effect: Over time, bacteria, dust, and gunk builds up inside the PVC pipe. Eventually, condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the drain line is cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.

Failure Mode 1A3: Drain line on the outside of the house is covered and clogged with mulch after landscaping.

Failure Effect: Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the mulch is cleared from the drain line and is also cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.

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	Function		Functional Failure	Failure Mode	Failure Effect
2	To be capable of shutting down the HVAC unit in the event that the condensate drain line clogs.	A	Incapable of shutting down the HVAC unit in the event that the condensate drain line clogs.		

Question to ask to identify Failure Modes:

What specifically could cause it to be incapable of shutting down the HVAC unit in the event that the condensate drain line clogs?

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	Function		Functional Failure	Failure Mode	Failure Effect	
2	To be capable of shutting down the HVAC unit in the event that the condensate drain line clogs.	A	Incapable of shutting down the HVAC unit in the event that the condensate drain line clogs.	1 Drain pan is damaged during routine HVAC maintenance.		
				2 Drain pan cracked due to manufacturing defect.		
					3 Drain pan cracked during installation.	
					4 Drain pan corrodes due to normal use.	
					5 Condensate switch “system” fails open.	

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	Function		Functional Failure	Failure Mode	Failure Effect
2	To be capable of shutting down the HVAC unit in the event that the condensate drain line clogs.	A	Incapable of shutting down the HVAC unit in the event that the condensate drain line clogs.	3 Drain pan is cracked during installation.	This Failure Mode only matters in the event that the condensate drain line is clogged. Water backs up into the drain pan. Because it is cracked, the water leaks from the pan, on to the attic floor, and through the downstairs bathroom ceiling. Water also leaks through the bathroom exhaust fan and on to the floor. The leak is visually detectable on the bathroom ceiling, wall, and floor. It does not pose a slip risk. Since this bathroom is used daily, it is unlikely that significant water damage occurs because the homeowner recognizes it relatively quickly. The homeowner goes into the attic to see if the roof is leaking. When the roof is found dry, it is likely obvious to the homeowner that there is a leak with the HVAC unit. The homeowner shuts off the HVAC unit until the HVAC company can come to troubleshoot and repair. Worst case, this happens on a Friday night during the hottest months of the year (when this actually happened!) and the home is without air conditioning for the entire weekend. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the drain line is cleared using compressed nitrogen and the condensate drain pan is replaced at a total cost of \$680. This takes up to four hours, including troubleshooting time.

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Failure Mode 2A3: Drain pan is cracked during installation.

Failure Effect: This Failure Mode only matters in the event that the condensate drain line is clogged. Water backs up into the drain pan. Because it is cracked, the water leaks from the pan, on to the attic floor, and through the downstairs bathroom ceiling. Water also leaks through the bathroom exhaust fan and on to the floor. The leak is visually detectable on the bathroom ceiling, wall, and floor. It does not pose a slip risk.

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Failure Mode 2A3: Drain pan is cracked during installation.

Failure Effect: This Failure Mode only matters in the event that the condensate drain line is clogged. Water backs up into the drain pan. Because it is cracked, the water leaks from the pan, on to the attic floor, and through the downstairs bathroom ceiling. Water also leaks through the bathroom exhaust fan and on to the floor. The leak is visually detectable on the bathroom ceiling, wall, and floor. It does not pose a slip risk. Since this bathroom is used daily, it is unlikely that significant water damage occurs because the homeowner recognizes it relatively quickly. The homeowner goes into the attic to see if the roof is leaking. When the roof is found dry, it is likely obvious to the homeowner that there is a leak with the HVAC unit. The homeowner shuts off the HVAC unit until the HVAC company can come to troubleshoot and repair. Worst case, this happens on a Friday night during the hottest months of the year (when this actually happened!) and the home is without air conditioning for the entire weekend.

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Failure Mode 2A3: Drain pan is cracked during installation.

Failure Effect: This Failure Mode only matters in the event that the condensate drain line is clogged. Water backs up into the drain pan. Because it is cracked, the water leaks from the pan, on to the attic floor, and through the downstairs bathroom ceiling. Water also leaks through the bathroom exhaust fan and on to the floor. The leak is visually detectable on the bathroom ceiling, wall, and floor. It does not pose a slip risk. Since this bathroom is used daily, it is unlikely that significant water damage occurs because the homeowner recognizes it relatively quickly. The homeowner goes into the attic to see if the roof is leaking. When the roof is found dry, it is likely obvious to the homeowner that there is a leak with the HVAC unit. The homeowner shuts off the HVAC unit until the HVAC company can come to troubleshoot and repair. Worst case, this happens on a Friday night during the hottest months of the year (when this actually happened!) and the home is without air conditioning for the entire weekend. **The hotter temperature inside the home does not pose any health issues to occupants.** However, it makes for an uncomfortable weekend. Once the technician reaches the home, the drain line is cleared using compressed nitrogen and the condensate drain pan is replaced at a total cost of \$680. This takes up to four hours, including troubleshooting time.

57

Failure Mode 1A1: Drain line clogged due to normal use.

Failure Effect: This Failure Mode only matters in the event that the condensate drain line is clogged. Water backs up into the drain pan. Because it is cracked, the water leaks from the pan, on to the attic floor, and through the downstairs bathroom ceiling. Water also leaks through the bathroom exhaust fan and on to the floor. The leak is visually detectable on the bathroom ceiling, wall, and floor. **It does not pose a slip risk.** Since this bathroom is used daily, it is unlikely that significant water damage occurs because the homeowner recognizes it relatively quickly. The homeowner goes into the attic to see if the roof is leaking. When the roof is found dry, it is likely obvious to the homeowner that there is a leak with the HVAC unit. The homeowner shuts off the HVAC unit until the HVAC company can come to troubleshoot and repair. Worst case, this happens on a Friday night during the hottest months of the year (when this actually happened!) and the home is without air conditioning for the entire weekend. **The hotter temperature inside the home does not pose any health issues to occupants.** However, it makes for an uncomfortable weekend. Once the technician reaches the home, the drain line is cleared using compressed nitrogen and the condensate drain pan is replaced at a total cost of \$680. This takes up to four hours, including troubleshooting time.

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Failure Effects Include:

- ▶ A description of the failure process from the occurrence of the Failure Mode to the Functional Failure
- ▶ Physical evidence that the failure has occurred
- ▶ **How it adversely affects safety and/or the environment**
- ▶ **How it affects operational capability/mission**
- ▶ Specific operating restrictions as a result of the failure
- ▶ Secondary damage
- ▶ What must be done and how long it takes to repair the failure

FMEA

PROACTIVE!

Define Reliability

Identify what specifically causes Functional Failure.

Story of what would happen if we did nothing to manage the Failure Mode.

Function	Functional Failure	Failure Mode	Failure Effect
1	A	1	
1	A	2	
1	B	1	
2	A	1	
And so on...	A	1	

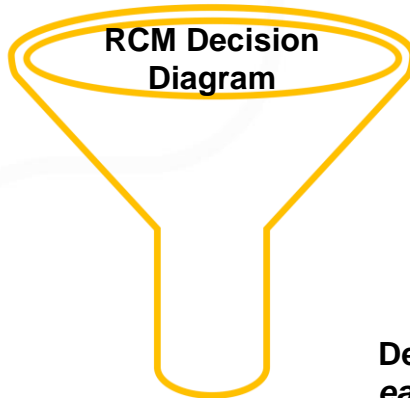
Written so Consequences can be assessed.

RCM Decision Diagram

FMEA

Function	Functional Failure	Failure Mode	Failure Effect
1 To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required. (Condensate drain line)	A Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.	1 Drain line clogged due to normal use.	
		2 Drain line on the outside of the house is covered and clogged with mulch after landscaping.	
		3 Drain line on the outside of house is clogged with mulch and yard debris due to normal use.	

Failure Modes



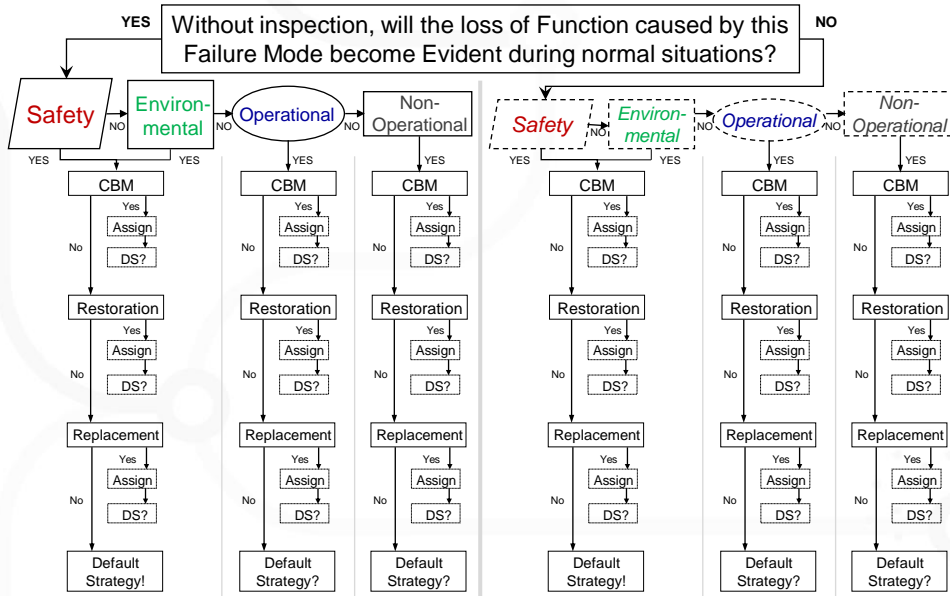
Decisions → How to manage each Failure Mode

- Proactive Maintenance
- Default Strategies

RCM Decision Diagram



EVIDENT SIDE

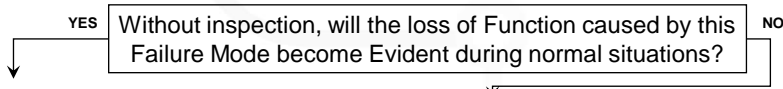


HIDDEN SIDE

RCM Decision Diagram



EVIDENT SIDE

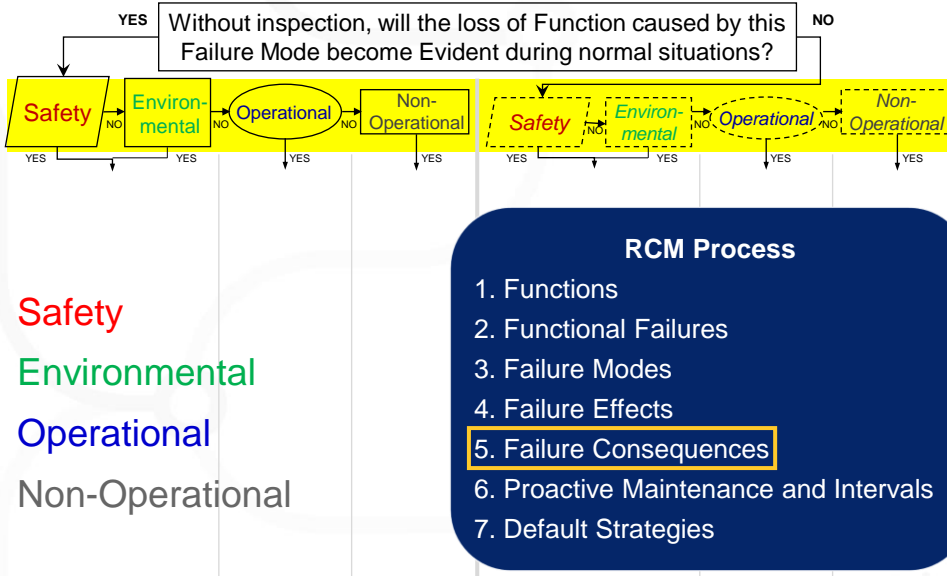


HIDDEN SIDE

RCM Decision Diagram

EVIDENT SIDE

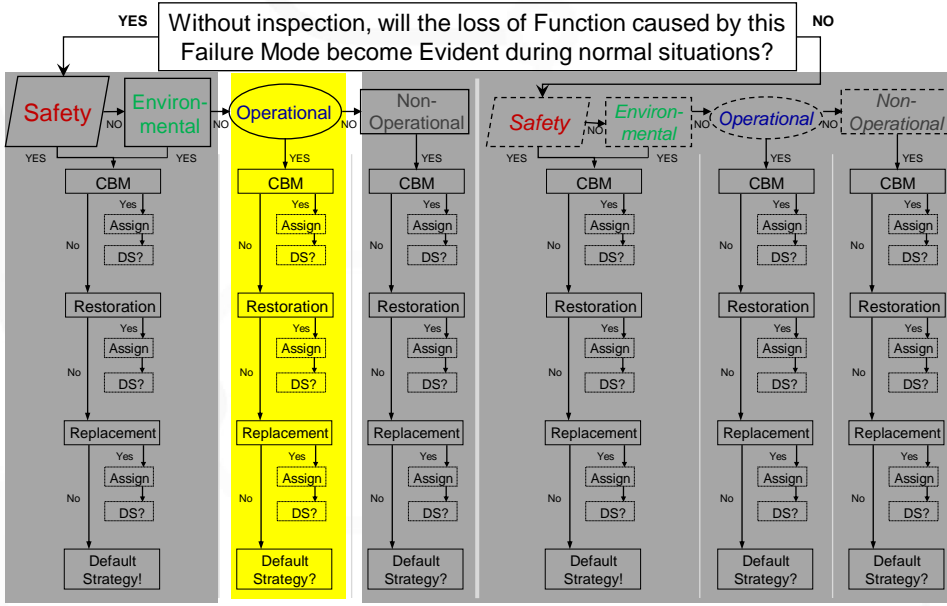
HIDDEN SIDE



RCM Decision Diagram

EVIDENT SIDE

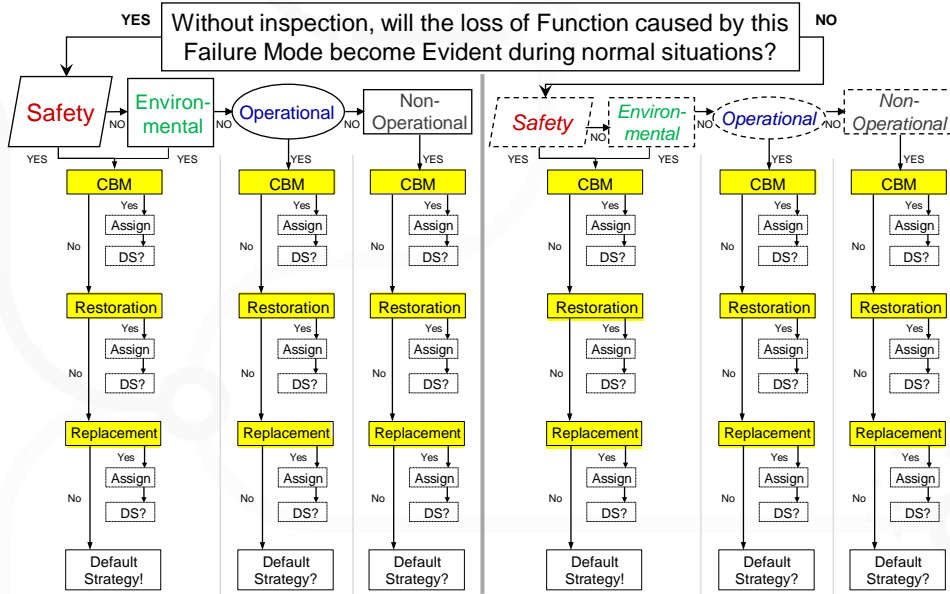
HIDDEN SIDE



RCM Decision Diagram



EVIDENT SIDE

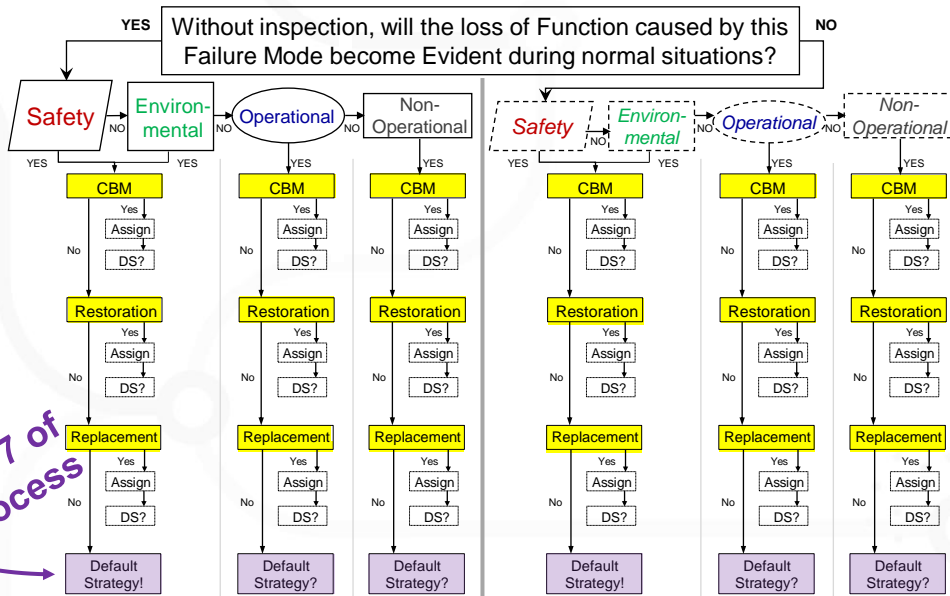


HIDDEN SIDE

RCM Decision Diagram



EVIDENT SIDE

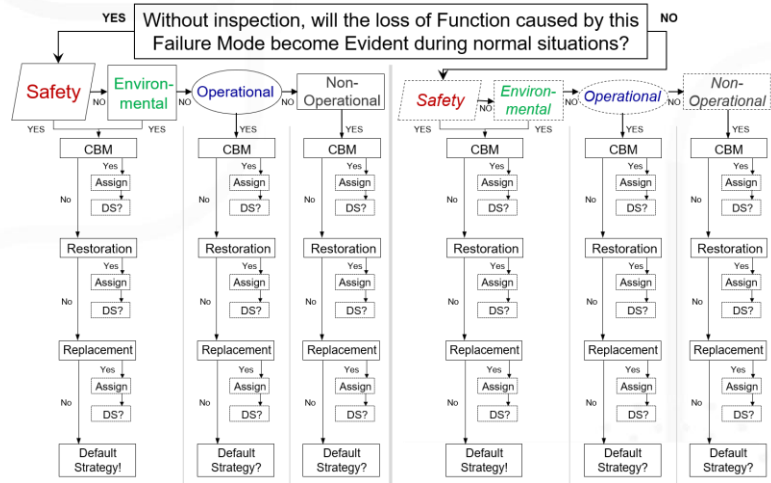


HIDDEN SIDE

Apply the RCM Decision Diagram



Let's apply the RCM Decision Diagram to two Failure Modes.



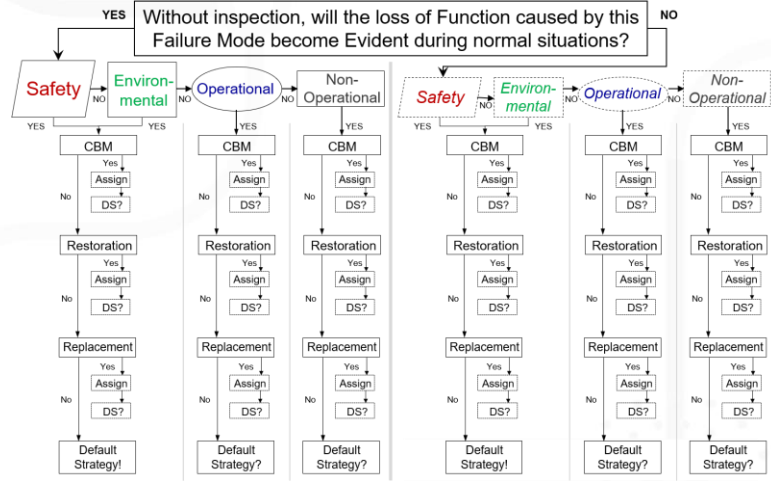
67

Apply the RCM Decision Diagram



Function	Functional Failure	Failure Mode	Failure Effect
1 To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required. (Condensate drain line)	A Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.	3 Drain line on the outside of the house is covered with mulch after landscaping.	Condensate leaks onto the finished floor in the room below. This can create a slip hazard or water damage. This can create a mold hazard. This can create a pest infestation. This can create a fire hazard. This can create a health hazard. This can create a property damage. This can create a liability. This can create a safety hazard. This can create a financial loss. This can create a reputational damage. This can create a legal liability. This can create a criminal liability. This can create a civil liability. This can create a criminal offense. This can create a civil offense. This can create a criminal record. This can create a civil record. This can create a criminal conviction. This can create a civil conviction. This can create a criminal sentence. This can create a civil sentence. This can create a criminal fine. This can create a civil fine. This can create a criminal imprisonment. This can create a civil imprisonment. This can create a criminal death sentence. This can create a civil death sentence. This can create a criminal life sentence. This can create a civil life sentence. This can create a criminal parole. This can create a civil parole. This can create a criminal probation. This can create a civil probation. This can create a criminal community service. This can create a civil community service. This can create a criminal restitution. This can create a civil restitution. This can create a criminal compensation. This can create a civil compensation. This can create a criminal reimbursement. This can create a civil reimbursement. This can create a criminal indemnification. This can create a civil indemnification. This can create a criminal settlement. This can create a civil settlement. This can create a criminal agreement. This can create a civil agreement. This can create a criminal contract. This can create a civil contract. This can create a criminal deed. This can create a civil deed. This can create a criminal will. This can create a civil will. This can create a criminal trust. This can create a civil trust. This can create a criminal estate plan. This can create a civil estate plan. This can create a criminal inheritance. This can create a civil inheritance. This can create a criminal probate. This can create a civil probate. This can create a criminal executor. This can create a civil executor. This can create a criminal trustee. This can create a civil trustee. This can create a criminal beneficiary. This can create a civil beneficiary. This can create a criminal heir. This can create a civil heir. This can create a criminal estate. This can create a civil estate. This can create a criminal inheritance tax. This can create a civil inheritance tax. This can create a criminal gift tax. This can create a civil gift tax. This can create a criminal estate tax. This can create a civil estate tax. This can create a criminal probate tax. This can create a civil probate tax. This can create a criminal inheritance tax. This can create a civil inheritance tax. This can create a criminal gift tax. This can create a civil gift tax. This can create a criminal estate tax. This can create a civil estate tax. This can create a criminal probate tax. This can create a civil probate tax.

Failure Mode 1A3: Drain line on outside of the house is covered with mulch after landscaping.



68

Failure Mode 1A3: Drain line on the outside of the house is covered with mulch after landscaping.

Failure Effect: Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down.

69

Failure Mode 1A3: Drain line on the outside of the house is covered with mulch after landscaping.

Failure Effect: Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend.

70

Failure Mode 1A3: Drain line on the outside of the house is covered with mulch after landscaping.

Failure Effect: Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the mulch is cleared from the drain line and is also cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.

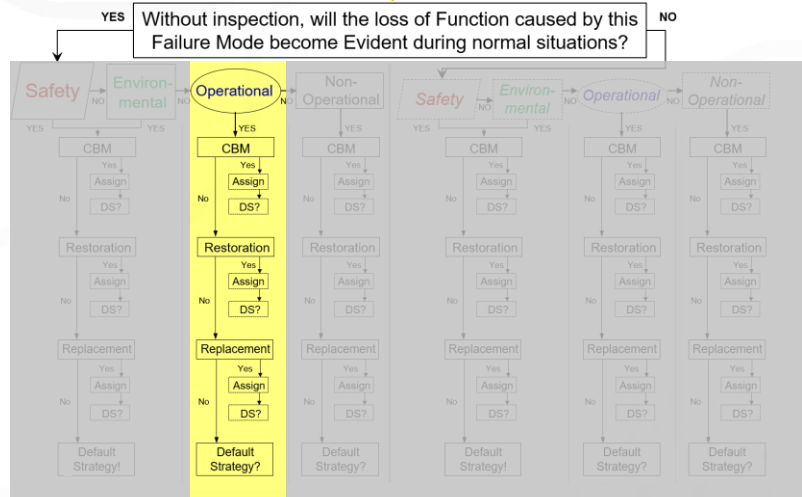
71

Apply the RCM Decision Diagram



Function	Functional Failure	Failure Mode	Failure Effect
1 To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the outside of the house, as required. (Condensate drain line)	A Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.	3 Drain line on the outside of the house is covered with mulch after landscaping.	Condensate backs up into the drain pan and is visually detectable. If this goes unnoticed, when the level of water in the pan reaches the condensate switch, the contacts are energized and power to the thermostat is cut off. The HVAC unit shuts down. The temperature in the house increases. The home occupant likely goes to the thermostat to turn down the air conditioning temperature setpoint but finds that the thermostat is off. The occupant calls the HVAC company. Worst case, the home is without air conditioning for up to 48 hours while the homeowner waits for the HVAC company to come and make the repair. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the mulch is cleared from the drain line and is also cleaned using compressed nitrogen at a cost of \$150. This takes up to one hour, including troubleshooting time.

Failure Mode 1A3:
Drain line on outside of the house is covered with mulch after landscaping.



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Apply the RCM Decision Diagram

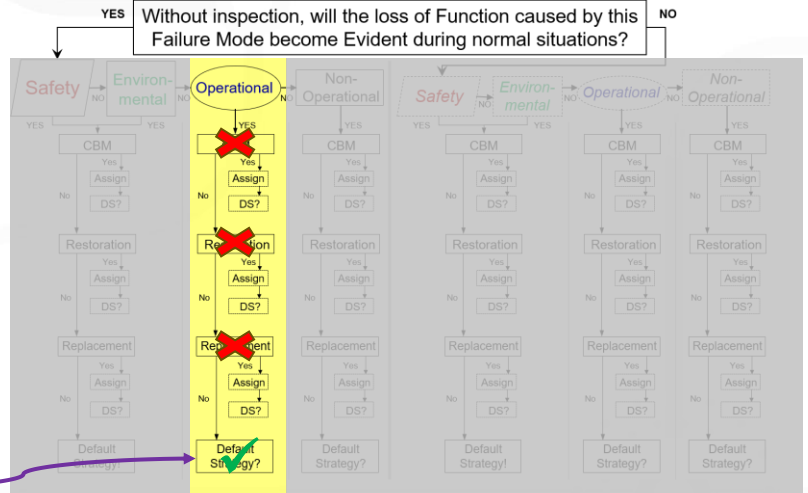
Function	Functional Failure	Failure Mode	Failure Effect
1 To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the attic to the outside of the house, as required. (Condensate drain line)	A Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.	3 Drain line on the outside of the house is covered with mulch after landscaping.	Condensate builds up and overflows, causing water damage to the house. This can also cause mold growth and other health issues. The homeowner may have to clean up the water damage and may have to replace the HVAC unit. The homeowner may also have to pay for the cost of the mulch that was used to cover the drain line.

Failure Mode 1A3:
Drain line on outside of the house is covered with mulch after landscaping.

Question 7 of RCM Process

Is a Default Strategy recommended to manage the Failure Mode?

73



Apply the RCM Decision Diagram



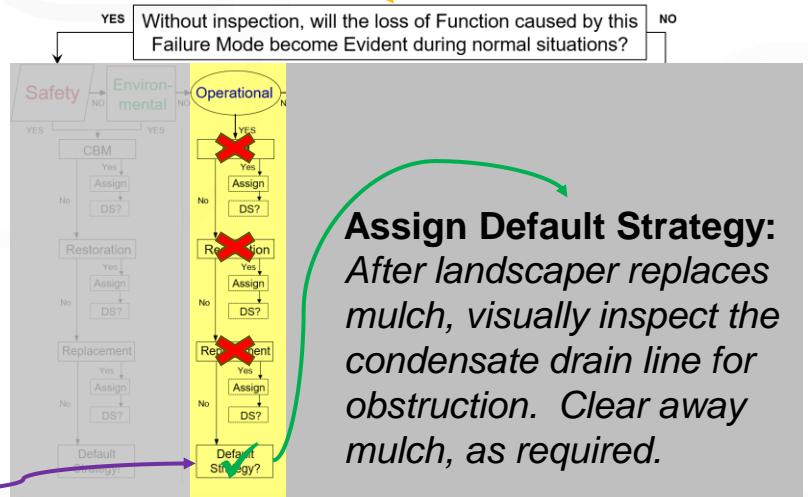
Function	Functional Failure	Failure Mode	Failure Effect
1 To drain up to two gallons per hour of condensate from the HVAC unit in the attic to the attic to the outside of the house, as required. (Condensate drain line)	A Unable to drain condensate from the HVAC unit in the attic to the outside of the house, as required.	3 Drain line on the outside of the house is covered with mulch after landscaping.	Condensate builds up and overflows, causing water damage to the house. This can also cause mold growth and other health issues. The homeowner may have to clean up the water damage and may have to replace the HVAC unit. The homeowner may also have to pay for the cost of the mulch that was used to cover the drain line.

Failure Mode 1A3:
Drain line on outside of the house is covered with mulch after landscaping.

Question 7 of RCM Process

Is a Default Strategy recommended to manage the Failure Mode?

74



Failure Mode 2A3: Drain pan is cracked during installation.

Failure Effect: This Failure Mode only matters in the event that the condensate drain line is clogged. Water backs up into the drain pan. Because it is cracked, the water leaks from the pan, on to the attic floor, and through the downstairs bathroom ceiling. Water also leaks through the bathroom exhaust fan and on to the floor. The leak is visually detectable on the bathroom ceiling, wall, and floor. It does not pose a slip risk. Since this bathroom is used daily, it is unlikely that significant water damage occurs because the homeowner recognizes it relatively quickly. The homeowner goes into the attic to see if the roof is leaking. When the roof is found dry, it is likely obvious to the homeowner that there is a leak with the HVAC unit. The homeowner shuts off the HVAC unit until the HVAC company can come to troubleshoot and repair. Worst case, this happens on a Friday night during the hottest months of the year (when this actually happened!) and the home is without air conditioning for the entire weekend.

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Failure Mode 2A3: Drain pan is cracked during installation.

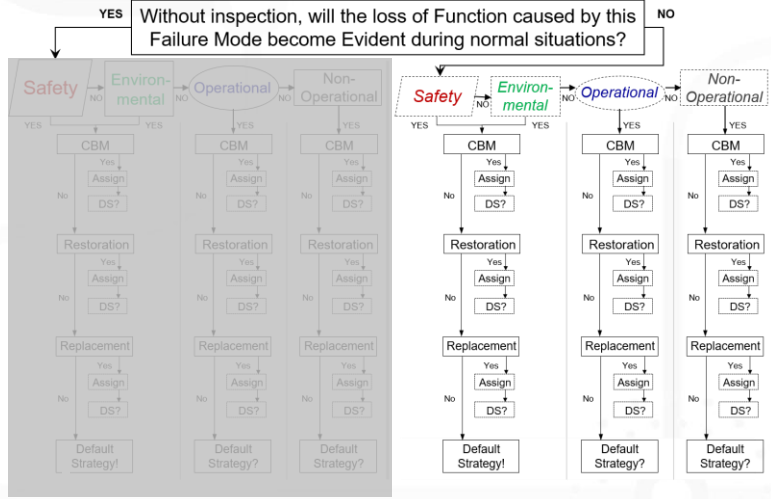
Failure Effect: This Failure Mode only matters in the event that the condensate drain line is clogged. Water backs up into the drain pan. Because it is cracked, the water leaks from the pan, on to the attic floor, and through the downstairs bathroom ceiling. Water also leaks through the bathroom exhaust fan and on to the floor. The leak is visually detectable on the bathroom ceiling, wall, and floor. It does not pose a slip risk. Since this bathroom is used daily, it is unlikely that significant water damage occurs because the homeowner recognizes it relatively quickly. The homeowner goes into the attic to see if the roof is leaking. When the roof is found dry, it is likely obvious to the homeowner that there is a leak with the HVAC unit. The homeowner shuts off the HVAC unit until the HVAC company can come to troubleshoot and repair. Worst case, this happens on a Friday night during the hottest months of the year (when this actually happened!) and the home is without air conditioning for the entire weekend. The hotter temperature inside the home does not pose any health issues to occupants. However, it makes for an uncomfortable weekend. Once the technician reaches the home, the drain line is cleared using compressed nitrogen and the condensate drain pan is replaced at a total cost of \$680. This takes up to four hours, including troubleshooting time.

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Apply the RCM Decision Diagram

Function	Functional Failure	Failure Mode	Failure Effect
2 To be capable of shutting down the HVAC unit in the event that the condensate drain line clogs.	A Inability of shutting down the HVAC unit in the event that the condensate drain line clogs.	3 Drain pan is cracked during installation.	The Failure Mode only occurs if the essential for the condensate drain line is clogged. If the drain pan is cracked, the condensate drain line will not be able to drain properly. This will cause the condensate to accumulate in the drain pan and eventually leak out through the ceiling of the room below. The leak is usually visible on the ceiling and may cause damage to the ceiling and the room below. The leak may also cause a fire hazard if the condensate comes into contact with electrical wiring. The homeowner may not be able to see the leak until it is too late. The homeowner may not be able to see the leak until it is too late. The homeowner may not be able to see the leak until it is too late. The homeowner may not be able to see the leak until it is too late.

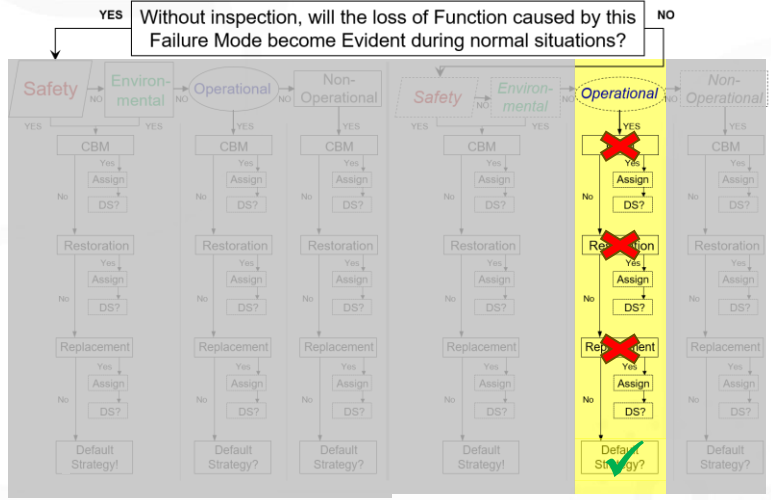
Failure Mode 2A3:
Drain pan is cracked during installation.



Apply the RCM Decision Diagram

Function	Functional Failure	Failure Mode	Failure Effect
2 To be capable of shutting down the HVAC unit in the event that the condensate drain line clogs.	A Inability of shutting down the HVAC unit in the event that the condensate drain line clogs.	3 Drain pan is cracked during installation.	The Failure Mode only occurs if the essential for the condensate drain line is clogged. If the drain pan is cracked, the condensate drain line will not be able to drain properly. This will cause the condensate to accumulate in the drain pan and eventually leak out through the ceiling of the room below. The leak is usually visible on the ceiling and may cause damage to the ceiling and the room below. The leak may also cause a fire hazard if the condensate comes into contact with electrical wiring. The homeowner may not be able to see the leak until it is too late. The homeowner may not be able to see the leak until it is too late. The homeowner may not be able to see the leak until it is too late. The homeowner may not be able to see the leak until it is too late.

Failure Mode 2A3:
Drain pan is cracked during installation.



Question 7 of RCM Process
Is a Default Strategy recommended to manage the Failure Mode?

Thank You!

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