



TOOLBOX
SESIÓN

Reliability Centered Maintenance (RCM)

A Case Study

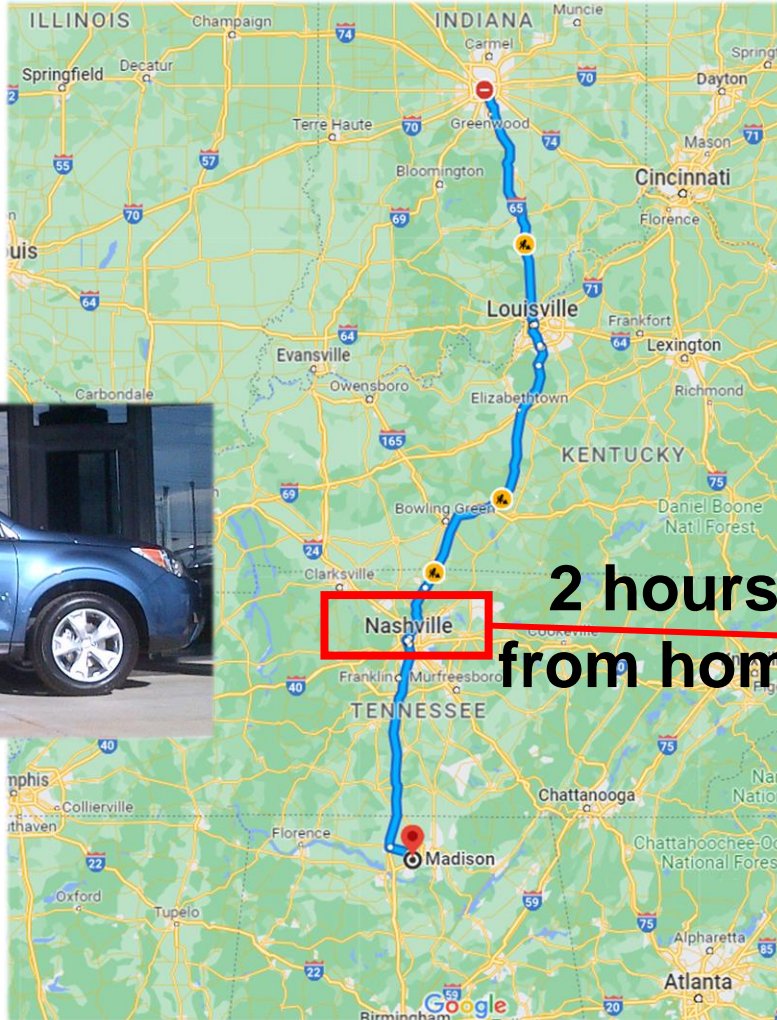


Nancy Regan

RCM Practitioner

Case Study

2014 Subaru Forester Low Engine Oil Light



Workshop Agenda



Goal: Understand SAE-JA1011 Compliant RCM

- Real-World (personal!) Case Study
 - FMEA
 - Assess Consequences
 - Use RCM Logic to establish a CBM task
- **NOT** a comprehensive introduction to RCM. It is an overview of some key RCM concepts.
- You **WILL** leave understanding what “True” RCM is.

RCM Process

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

Reliability Centered Maintenance (RCM) Overview

Operating Context Excerpt

- 2014 Subaru Forester – personal use vehicle. (I drive it almost exclusively.)
- Drive approximately 12,000 miles per year in the Southeastern United States (almost entirely in Alabama). Longest journey ~ 4 hours from home.
- I do have a “backup” car – 2004 Toyota Corolla.
- Scope of analysis is limited to Failure Modes that result in illumination of the Low Engine Oil Light and the “Low Engine Oil Light system” itself.
- 2.5-liter horizontally opposed four-cylinder (boxer) engine, 170 horsepower.
- Low Engine Oil Light illuminates in the event that the engine oil decreases to the lower limit (~1 quart low).

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
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies

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”

Include Primary & Secondary Functions

RCM Process

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

Primary Function: My 2014 Subaru Forester



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

To get from “~~Point A~~” to “Point B.”

RCM Process

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

Primary Function: My 2014 Subaru Forester



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

Verb	
Object	
Performance Standards	
Operating Context	

Primary Function: My 2014 Subaru Forester



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

Verb	Transport
Object	
Performance Standards	
Operating Context	

Primary Function: My 2014 Subaru Forester



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

Verb	Transport
Object	Up to 5 adult passengers and 3 medium-size suitcases
Performance Standards	
Operating Context	

Primary Function: My 2014 Subaru Forester



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

Verb	Transport
Object	Up to 5 adult passengers and 3 medium-size suitcases
Performance Standards	- Along paved roads and highways
Operating Context	

Primary Function: My 2014 Subaru Forester



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

Verb	Transport
Object	Up to 5 adult passengers and 3 medium-size suitcases
Performance Standards	<ul style="list-style-type: none">- Along paved roads and highways- Drive up to 360 miles without stopping
Operating Context	

Primary Function: My 2014 Subaru Forester



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

Verb	Transport
Object	Up to 5 adult passengers and 3 medium-size suitcases
Performance Standards	<ul style="list-style-type: none">- Along paved roads and highways- Drive up to 360 miles without stopping- In climates that range from 0° to 115° F (-17° to 46° C)
Operating Context	

Primary Function: My 2014 Subaru Forester



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

Verb	Transport
Object	Up to 5 adult passengers and 3 medium-size suitcases
Performance Standards	<ul style="list-style-type: none">- Along paved roads and highways- Drive up to 360 miles without stopping- In climates that range from 0° to 115° F (-17° to 46° C)- While protecting passengers from the elements
Operating Context	

Primary Function: My 2014 Subaru Forester



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

Verb	Transport
Object	Up to 5 adult passengers and 3 medium-size suitcases
Performance Standards	<ul style="list-style-type: none">- Along paved roads and highways- Drive up to 360 miles without stopping- In climates that range from 0° to 115° F (-17° to 46° C)- While protecting passengers from the elements
Operating Context	As required

To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE		FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.						

To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.

Failure Modes and Effects Analysis (FMEA)

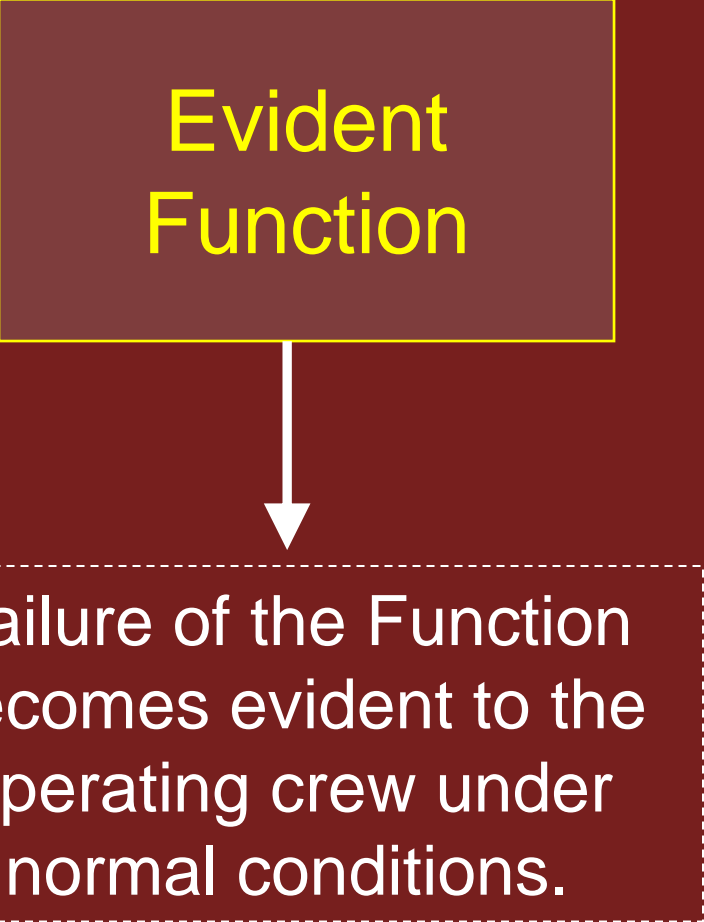
	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE	FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.					
2						
3						
4						
...	And so on					

Continue listing Secondary Functions.

Evident and Hidden Functions

Classifying Functions: Evident

Evident
Function



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

Primary Function: My 2014 Subaru Forester



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

Verb	Transport
Object	Up to 5 adult passengers and 3 medium-size suitcases
Performance Standards	<ul style="list-style-type: none"> - Along paved roads and highways - Go up to 360 miles without stopping - In climates that range from 0° to 115° F (-17° to 46° C) - While protecting passengers from the elements
Operating Context	As required

Evident Function

To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.

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.

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**

Hidden Function

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

No fire
(normal condition)

+

Smoke detector fails

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

Case Study

2014 Subaru Forester Low Engine Oil Light



What is the Function?

To be capable of visually alerting the driver *in the event that* the engine oil level decreases to the low level limit. (LOW OIL LEVEL Light)

Case Study

2014 Subaru Forester Low Engine Oil Light



What is the Multiple Failure?

1. Oil in the reservoir falls to the low level limit
2. Low Engine Oil Light “system” is failed.

	FUNCTION	FUNCTIONAL FAILURE			
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit (LOW OIL LEVEL Light)				

Is this

**Hidden
Function**

on?

To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower level limit. (LOW OIL LEVEL Light)

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.

Total Failure
Partial Failure

RCM Process

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

	FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.			

What is Total Failure?

To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.

Failure Modes and Effects Analysis (FMEA)

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE	FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.	A	Completely unable to transport.		Total Failure	

Completely unable to transport.

	FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit (LOW OIL LEVEL Light)			

What is Total Failure?

To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower level limit. (LOW OIL LEVEL Light)

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE		FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.				

Total Failure

Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.

To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower level limit. (LOW OIL LEVEL Light)

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.			
	<p>How else can it fail?</p>					
	<p>To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower level limit. (LOW OIL LEVEL Light)</p>					

Failure Modes and Effects Analysis (FMEA)

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.			
		B	Falsely illuminates the LOW OIL LEVEL Light.			

Falsely illuminates the
LOW OIL LEVEL Light.

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.

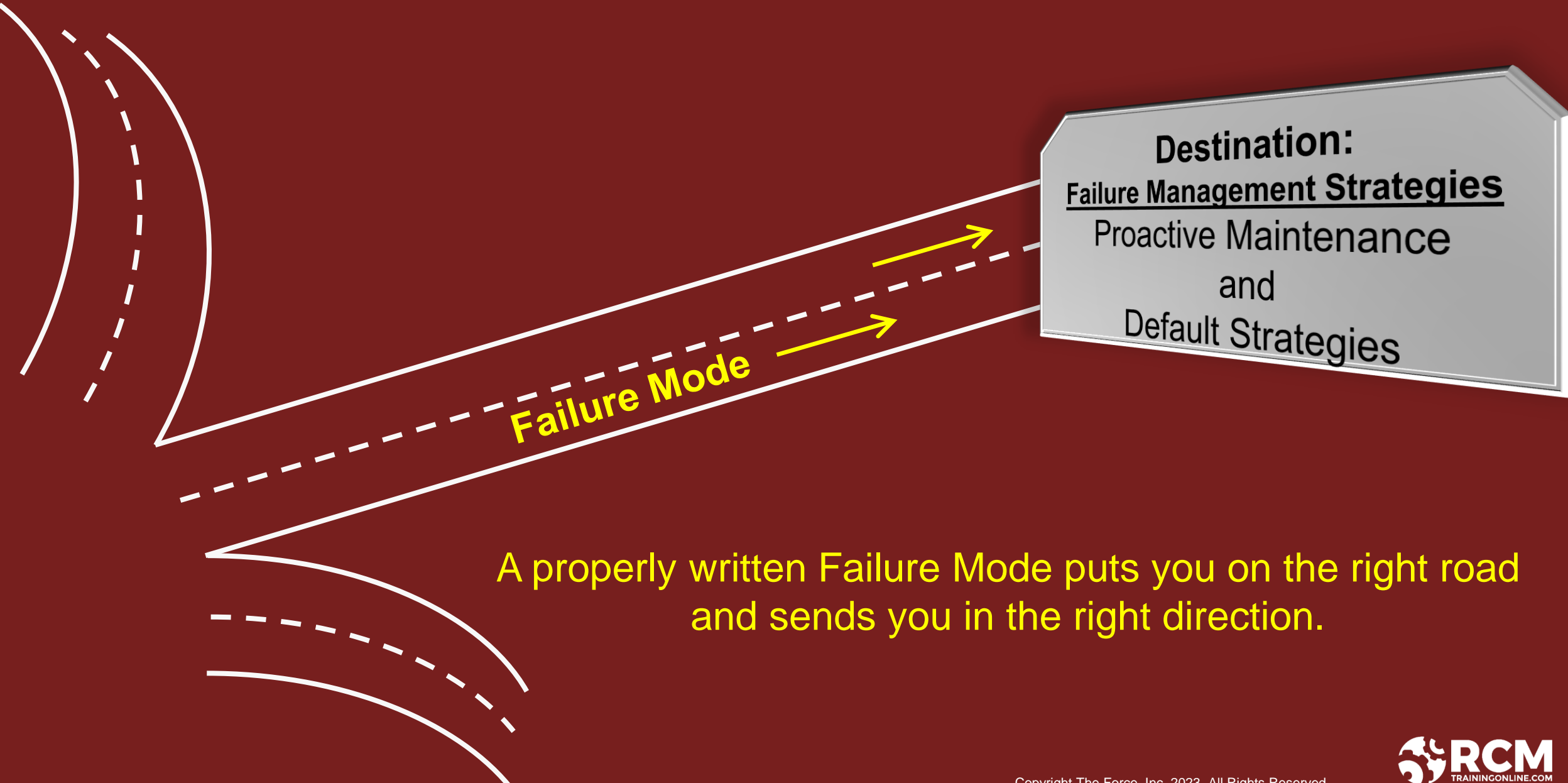
We proactively identify what could cause each Functional Failure, and then use the remaining four steps of the RCM process to figure out what (if anything at all) we should do to manage it.

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

Failure Modes

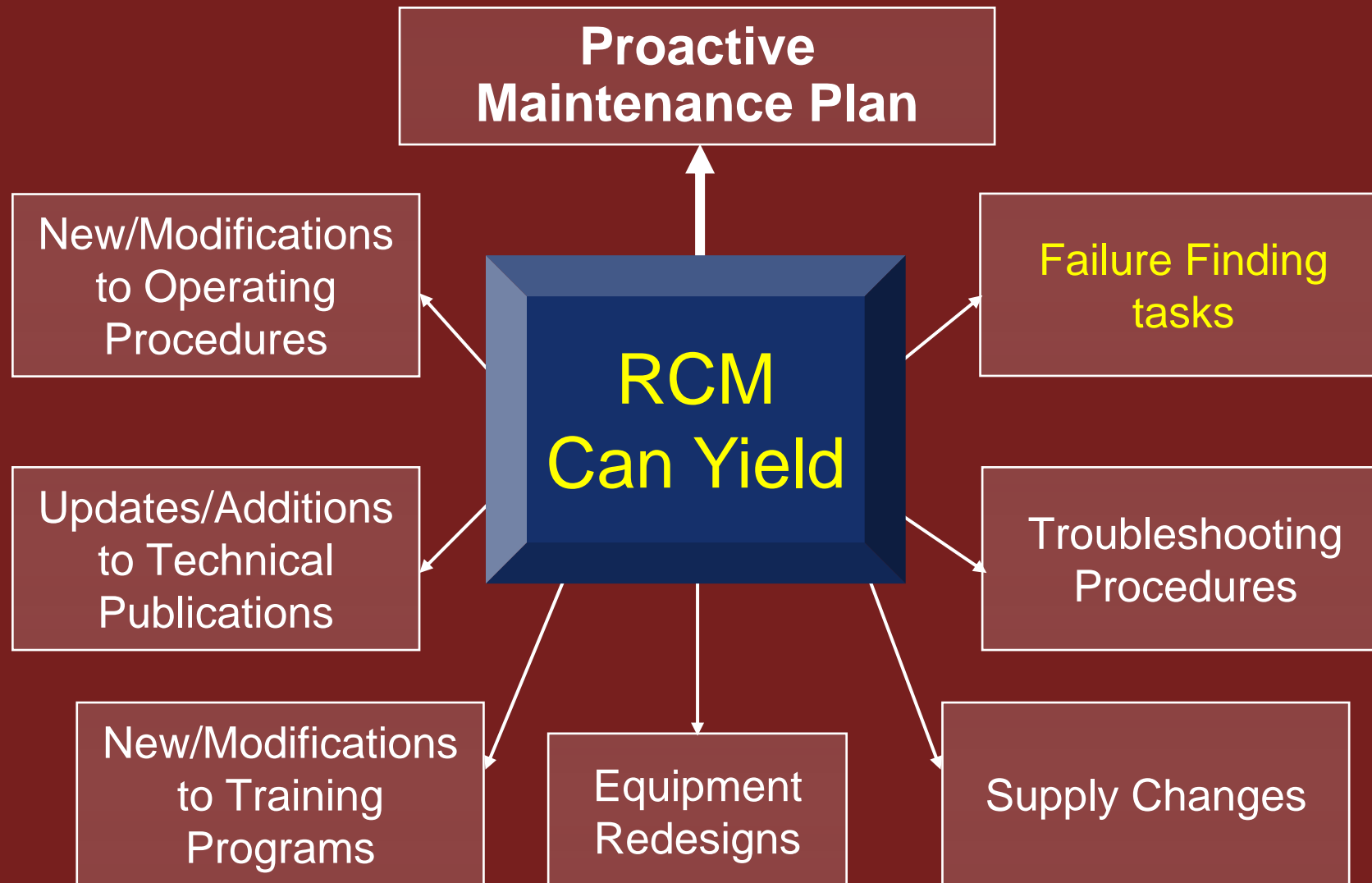


Destination:
Failure Management Strategies
Proactive Maintenance
and
Default Strategies

Failure Mode

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

Potential Products of an RCM Analysis



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

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

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**

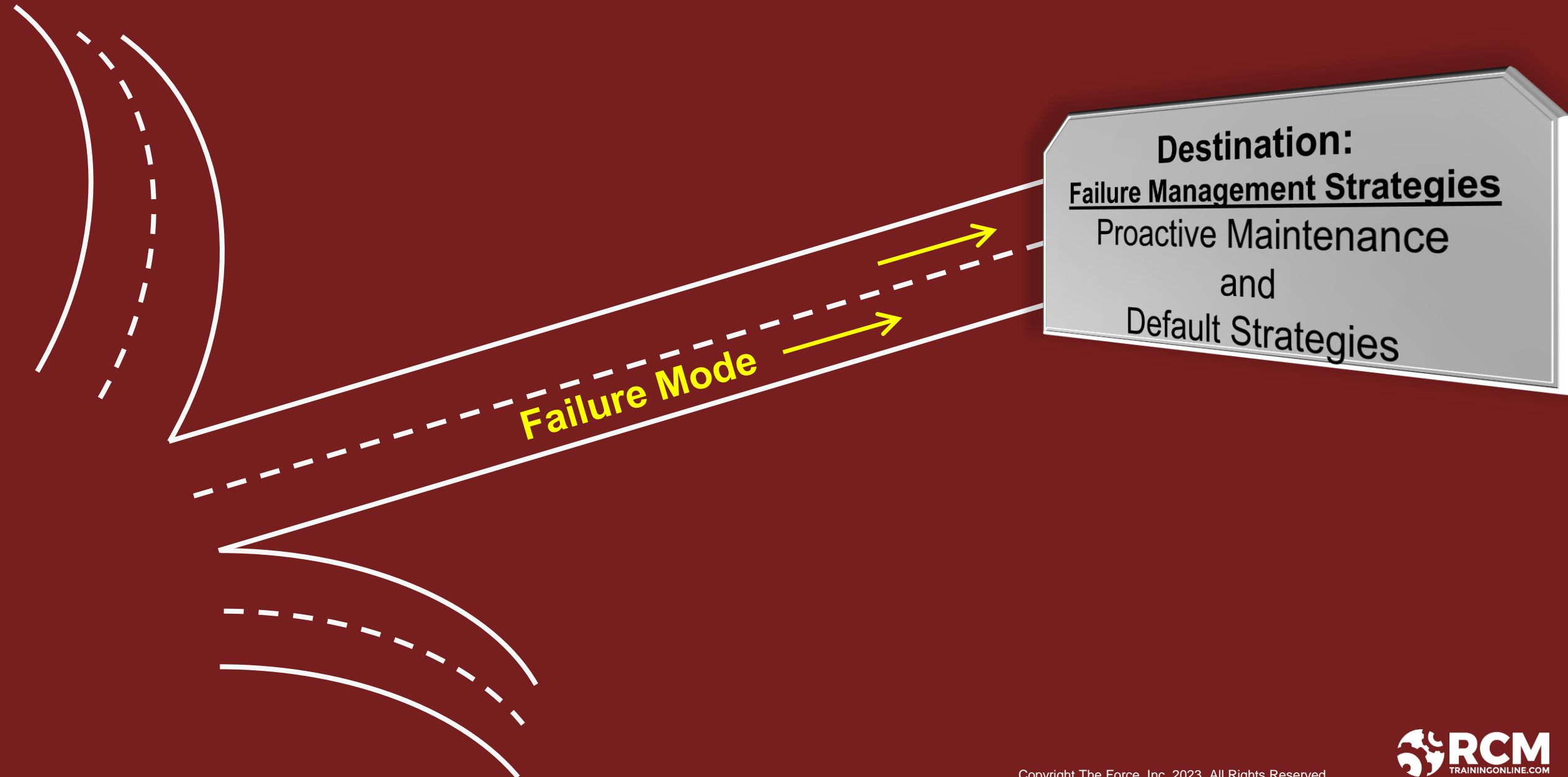
Oil filter clogs **due to normal use**

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**

Why Including Operating Context in Failure Modes Matters



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 so that hydraulic lines are routed properly.

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 so that hydraulic lines are routed properly.

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

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 engine air inlet *during flight.*

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

Failure Management Strategies

Visually inspect hydraulic line every 25 hours of operation.

Augment training program so that hydraulic lines are routed properly.

Change the oil filter after every 500 hours of operation.

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

Formulate emergency procedure for an in-flight engine failure.

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

Why Operating Context Matters in Failure Modes

Failure Modes with operating context in italics

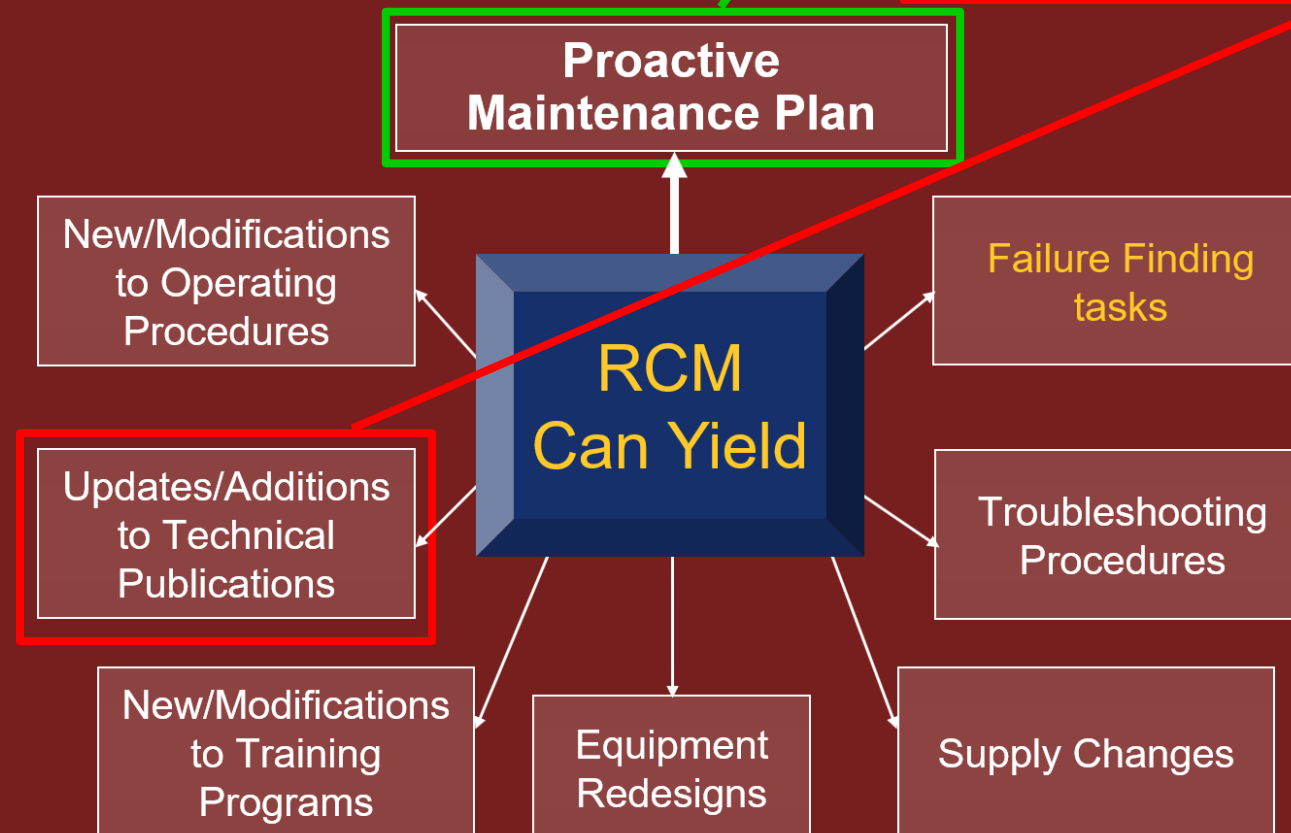
Hydraulic line chafes *due to normal equipment vibration.*

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 so that hydraulic lines are routed properly.

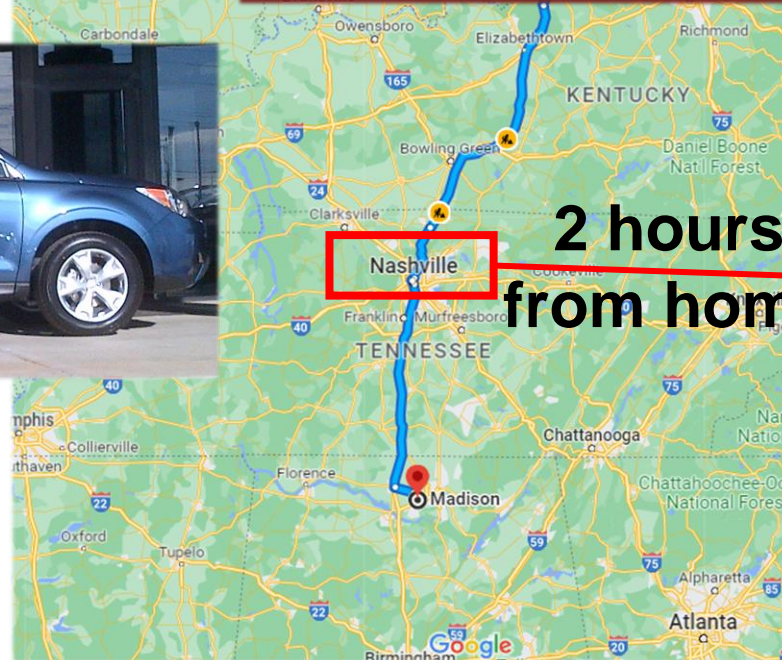


Case Study

2014 Subaru Forester Low Engine Oil Light



What specifically could cause (**Failure Modes**) the engine oil to drop to the low level limit and illuminate the LOW OIL LEVEL Light?



What specifically could cause the engine oil to drop to the low level limit and illuminate the LOW OIL LEVEL LIGHT?



1

The light could illuminate because the oil level is low **due to “normal consumption.”** In that case, I have enough oil to make it home without damaging my engine because I only had another 150 miles to go. But, it wouldn't be wise to continue driving without checking the oil level to ensure I avoid any possible engine damage.

2

The light could illuminate because the oil level is low **due to a leak in the oil system.** That's the *worst-case-scenario*. Low oil level leads to inadequate lubrication which could cause serious internal damage to engine components and possibly leave me stranded on the side of the road.

3

The light could **falsely illuminate due to a faulty circuit** (meaning the engine oil level is normal, but the light illuminates anyway). If that is the case, there is nothing I can do about it until I bring my car in for service. But between now and then, my engine will be just fine (assuming I don't ***also*** have a low oil situation in the meantime!)

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

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

Failure Modes and Effects Analysis (FMEA)

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE	FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.	A	Completely unable to transport.	1	Engine consumes oil due to normal use.	
				2	Engine oil system leaks.	

1. Engine consumes oil due to normal use.

	FUNCTION		FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the	A	Completely unable to transport.	1 Engine consumes oil due to normal use.	

Note: The Failure Mode is recorded under “Total Failure” because the light “*imposes operating restrictions as a result of the failure.*”

Engine consumes oil due to normal use.

During engine operation, the oil is gradually consumed by the engine. The decrease in oil is indicated on the dipstick. If this goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates. The driver pulls over **at the nearest service station** and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to the destination but with some delay. Downtime to repair, up to 30 minutes.



	FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)			
<p><i>To be capable of</i> visually alerting the driver <i>in the event that</i> the engine oil level decreases to the lower limit. (LOW OIL LEVEL light)</p>				



	FUNCTION		FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.	?	What specifically causes...?

Incapable of visually alerting the driver ***in the event that*** the engine oil level decreases to the lower limit.

To be capable of visually alerting the driver ***in the event that*** the engine oil level decreases to the lower limit. (LOW OIL LEVEL light)



	FUNCTION		FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.	1 LOW OIL LEVEL Light circuit fails open.	

LOW OIL LEVEL Light circuit fails open.

Incapable of visually alerting the driver *in the event that* the engine oil level decreases to the lower limit.

To be capable of visually alerting the driver *in the event that* the engine oil level decreases to the lower limit. (LOW OIL LEVEL light)



FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
LOW OIL LEVEL LIGHT circuit fails open.	the event that the oil level decreases to the lower limit.	1 LOW OIL LEVEL Light circuit fails open.	This Failure Mode only matters in the event that the engine oil level decreases to the lower limit. The driver is unaware of the low oil situation and continues to operate the

This Failure Mode only matters in the event that the engine oil level decreases to the lower limit. The driver is unaware of the low oil situation and continues to operate the vehicle. The oil level continues to drop. Engine components are not properly lubricated and start to wear abnormally. Eventually, engine oil pressure decreases and engine oil temperature increases. The OIL PRESSURE warning light and/or the CHECK ENGINE light illuminates on the dashboard. Driver must pull over and cannot get to the desired destination on time. It is likely driver can find a safe place to pull over and call a tow truck. However, worst case, driver must pull over on a busy highway or on a dark country road at night. The oil system is repaired, as required. Any secondary engine damage is repaired, as required. Worst case, engine must be replaced. Downtime to repair, 3 days to 1 month at a cost ranging from \$1,000 to \$8,000.

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.

Safety
Environmental
Operational
Non-Operational

RCM Process

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

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.

Figure out how to manage each Failure Mode

Proactive Maintenance

- *Scheduled Restoration*
- *Scheduled Replacement*
- *Condition Based Maintenance (CBM)*

Also known as:
On-Condition Maintenance
Predictive Maintenance (PdM)

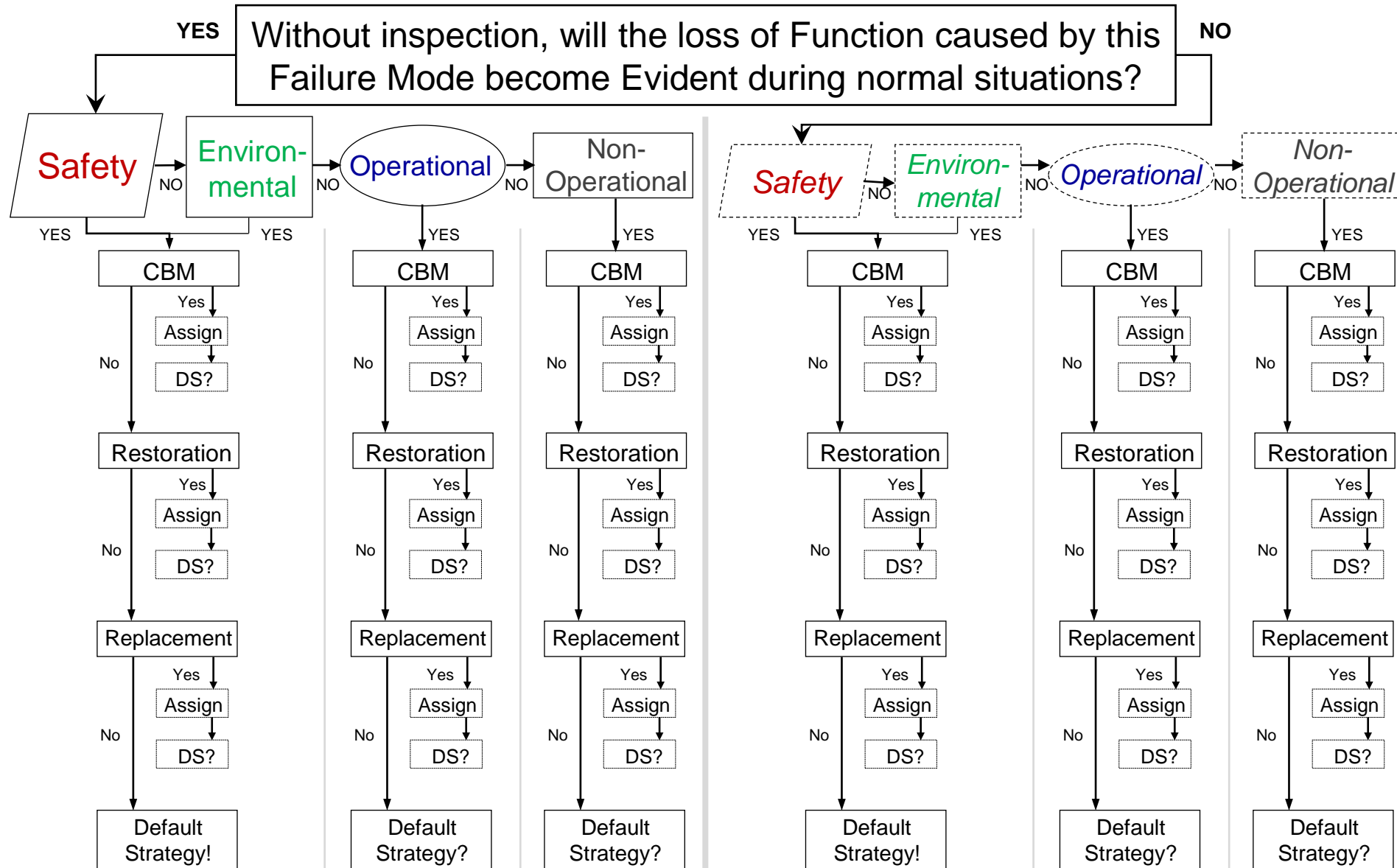
RCM Process

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

RCM Decision Diagram

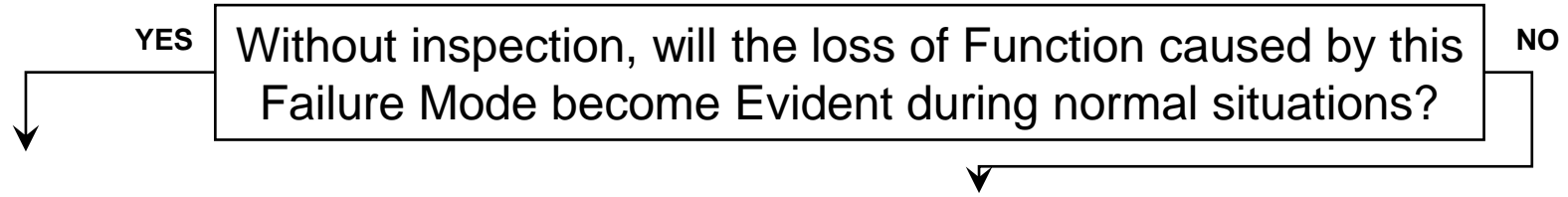
RCM Decision Diagram

EVIDENT SIDE



HIDDEN SIDE

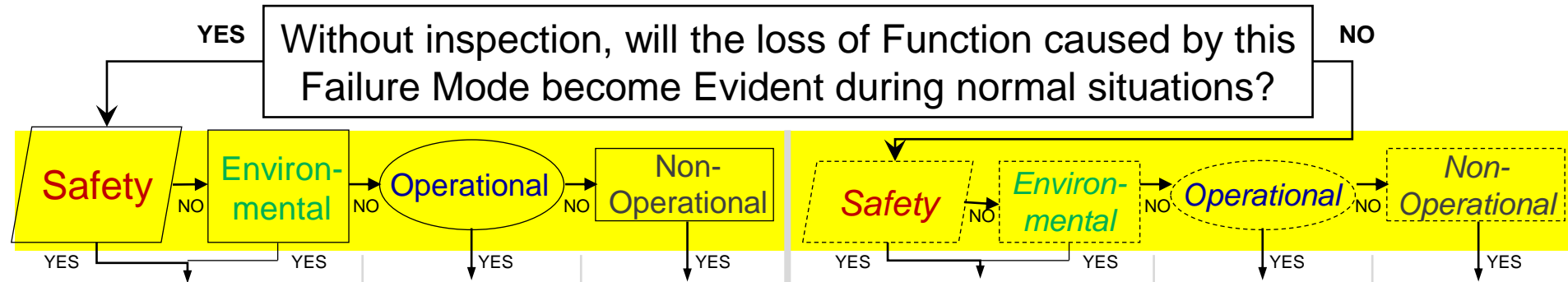
RCM Decision Diagram



EVIDENT SIDE

HIDDEN SIDE

RCM Decision Diagram



EVIDENT SIDE

HIDDEN SIDE

Safety

Environmental

Operational

Non-Operational

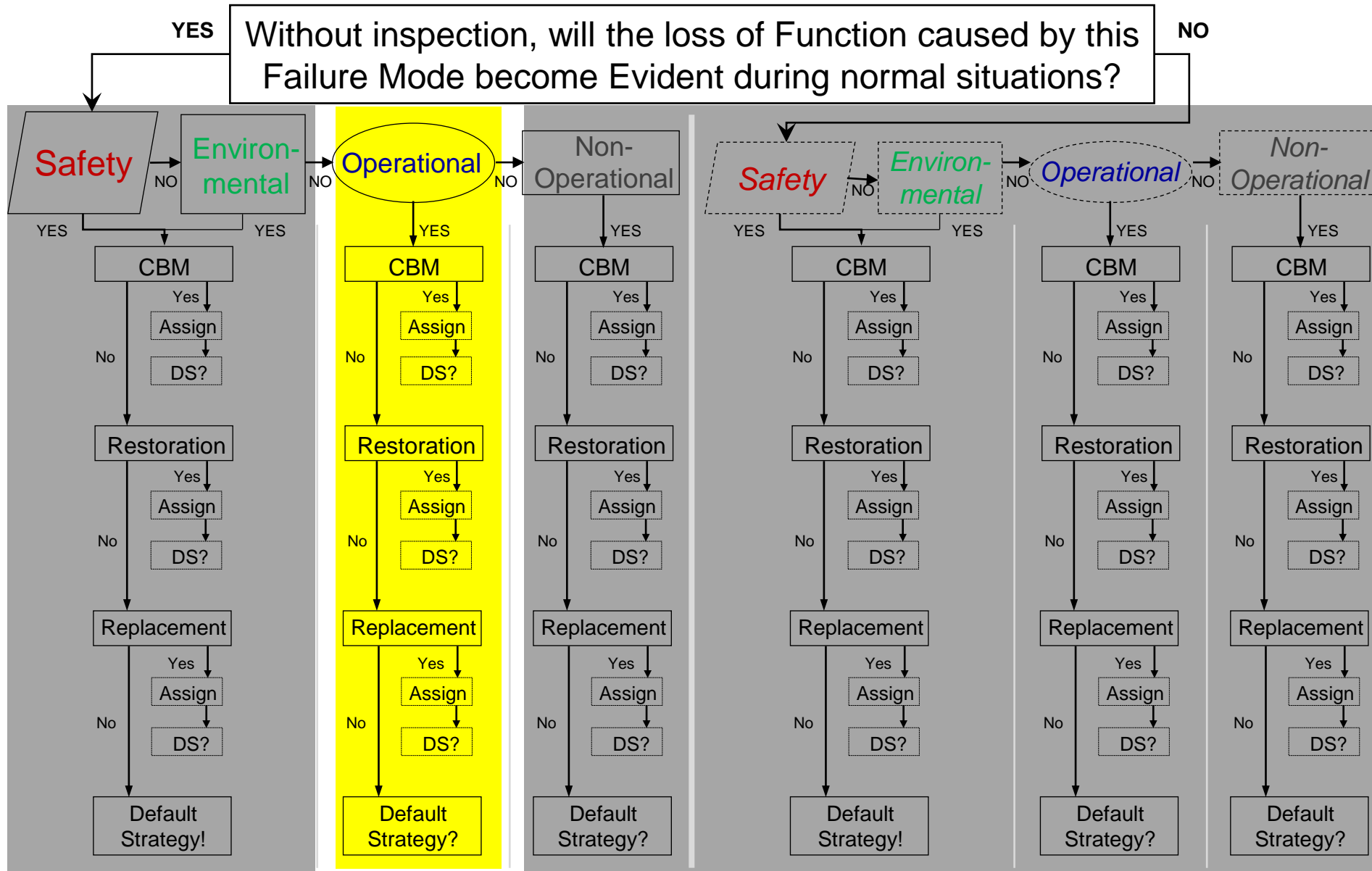
RCM Process

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

RCM Decision Diagram

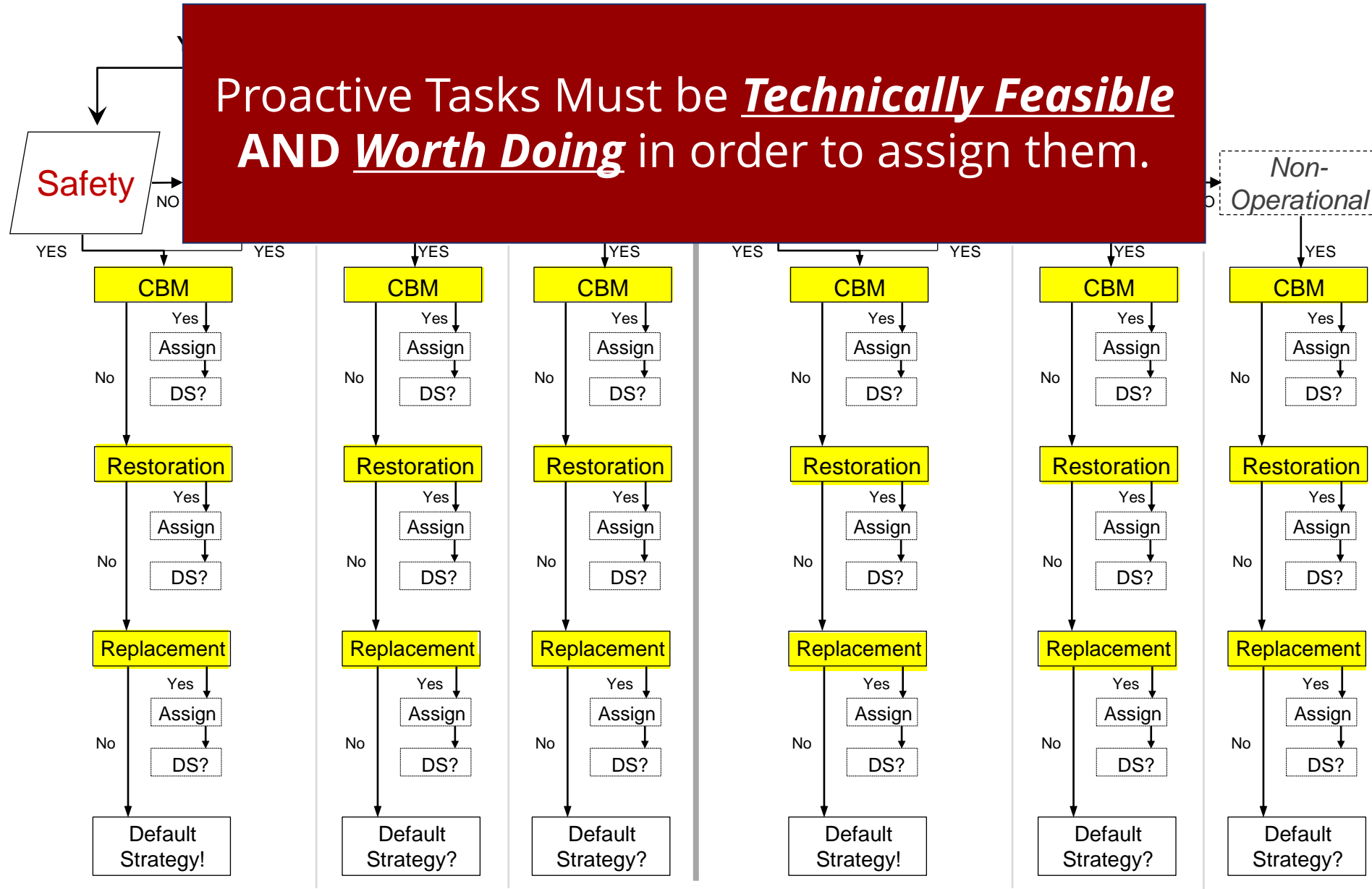
EVIDENT SIDE

HIDDEN SIDE



RCM Decision Diagram

Proactive Tasks Must be ***Technically Feasible*** AND ***Worth Doing*** in order to assign them.



EVIDENT SIDE

HIDDEN SIDE

Apply the RCM Decision Diagram

RCM INFORMATION WORKSHEET

	FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.	A Completely unable to transport	1 Engine consumes oil due to normal use.	During engine operation, the oil is gradually consumed by the engine. The decrease in oil is indicated on the dipstick. If this goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates. The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to destination but with some delay. Downtime to repair, up to 30 minutes.
			2 Engine oil system leaks.	Without warning, the system develops a leak. The leak is visually detectable on the ground. If this goes unnoticed, the oil quantity gradually decreases. The decrease in oil is indicated on the dipstick. If that goes unnoticed, eventually the engine oil drops to the point that the LOW

Engine consumes oil due to normal use.



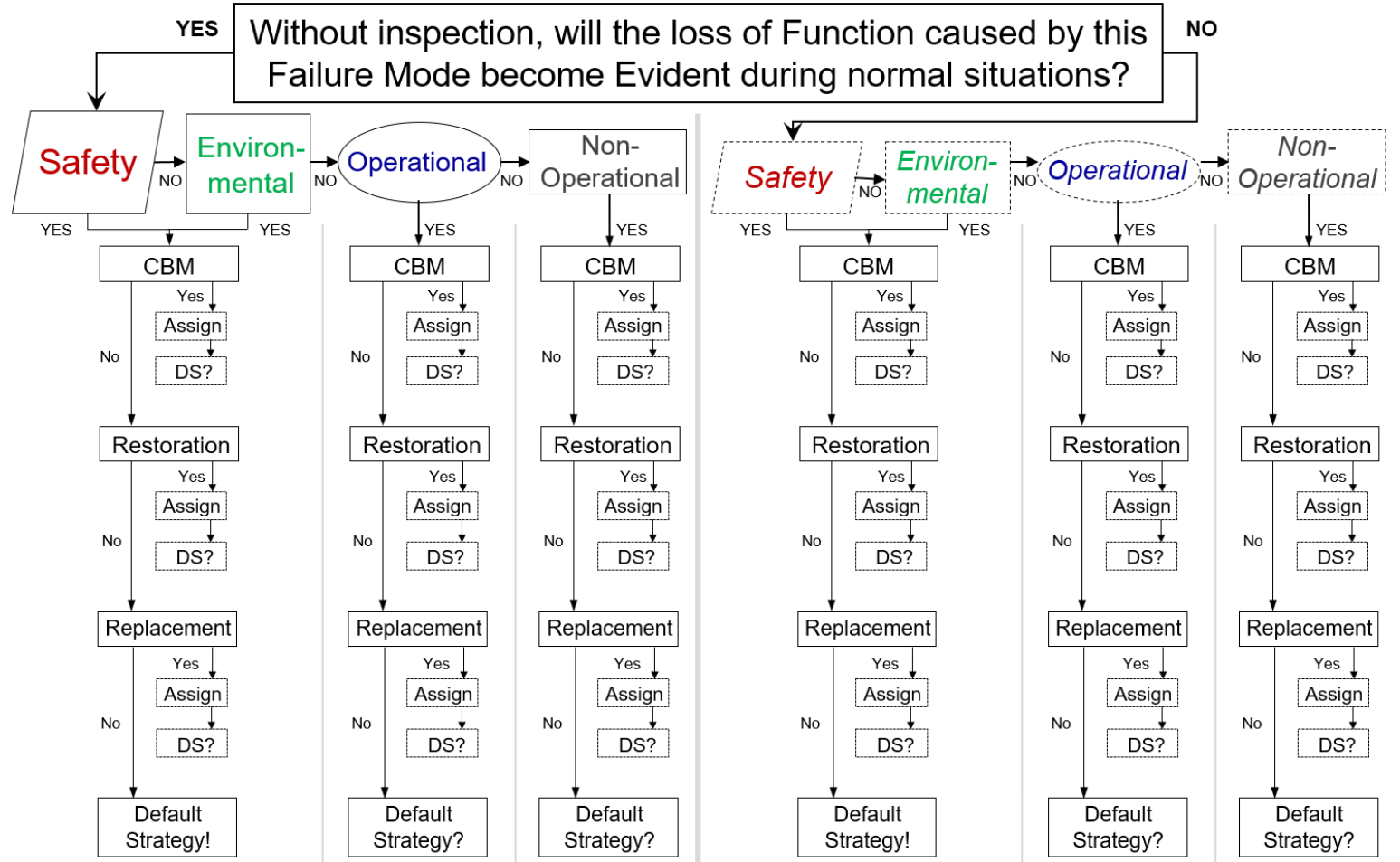
Copyright © The Force, Inc. 2017-2023 All Rights Reserved

RCM INFORMATION WORKSHEET

	FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	A Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.	1 LOW OIL LEVEL Light circuit fails open.	This Failure Mode only matters in the event that the engine oil level decreases to the lower limit. The driver is unaware of the low oil situation and continues to operate the vehicle. The oil level continues to drop. Engine components are not properly lubricated and start to wear abnormally. Eventually, engine oil pressure decreases and engine oil temperature increases. The OIL PRESSURE warning light and/or the CHECK ENGINE light illuminates on the dashboard. Driver finds a safe place to pull over and is unable to get to the desired destination. If there isn't a service station nearby, the driver needs to call the emergency service line. Worst case, the driver must pull over on the highway or in a remote, unsafe location. Vehicle is towed to the nearest Subaru dealership for repair. The oil system is repaired, as required. Engine damage is repaired. Worst case, engine must be replaced. Driver must find alternate means of transportation. Downtime to repair, 3 days to 1 month.
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	B Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.	1 Falsely illuminates the LOW OIL LEVEL Light.	While driving, the LOW OIL LEVEL Light illuminates. The driver thinks that there is a low oil situation. Driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil level is normal. The time it takes to check the oil is minimal so the driver is able to arrive at the intended destination on time. Driver schedules vehicle for service at the next available opportunity. Time to repair, 1 day.



Copyright © The Force, Inc. 2017-2023 All Rights Reserved



On-Condition Maintenance

An On-Condition task is performed at a defined interval to detect a *Potential Failure Condition* so that maintenance can be performed before the failure occurs.

On-Condition Maintenance

How can a **Potential Failure Condition** be detected?

- Using relatively simple techniques such as monitoring gauges, measuring brake linings, or feeling for vibration via Human Senses
- Employing more technically involved techniques such as thermography, frequency analysis, oil analysis, or thermal imaging
- Continuous monitoring with devices installed directly on machinery (e.g. strain gauge, accelerometer, etc.)

Two Criteria to assign a Proactive Maintenance Task

In the context of RCM, in order to assign a **Proactive Maintenance** task, two criteria must be satisfied:

1. Technically Feasible
- AND
2. Worth Doing

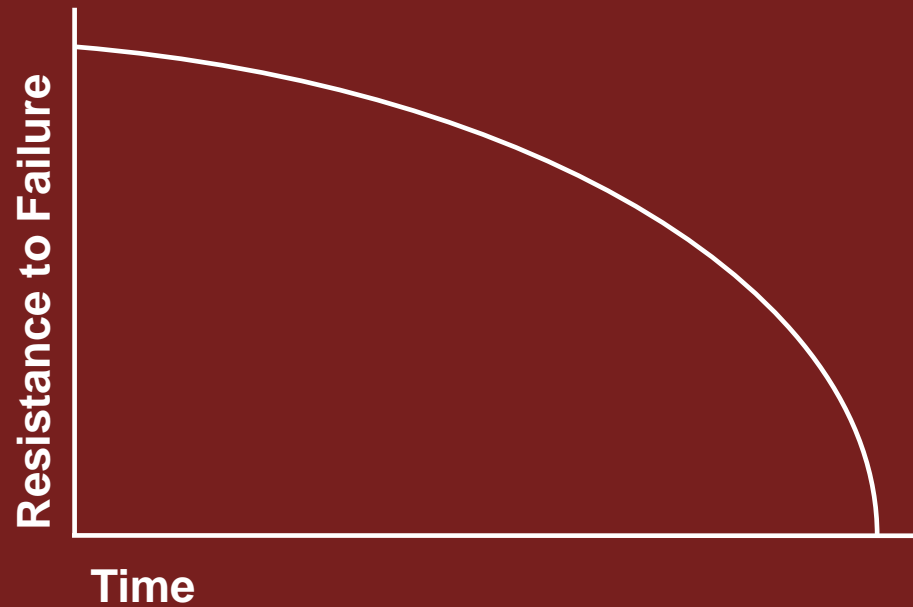
With respect to an *On-Condition* task, let's start with what makes it **Technically Feasible**.

Condition Based Maintenance (CBM)

In order to determine if an On-Condition task is technically appropriate, **Potential Failure Conditions** must be evaluated.

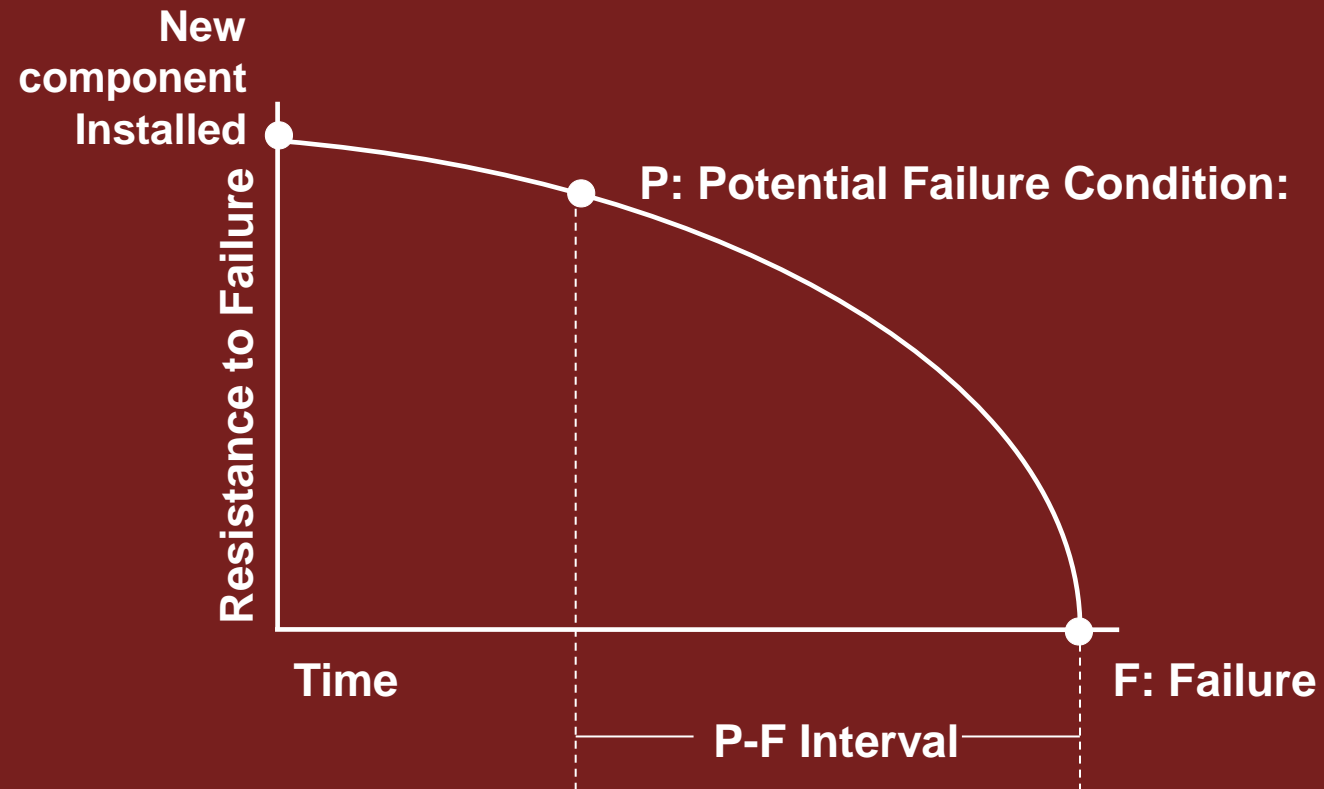
Condition Based Maintenance (CBM)

P-F Curve



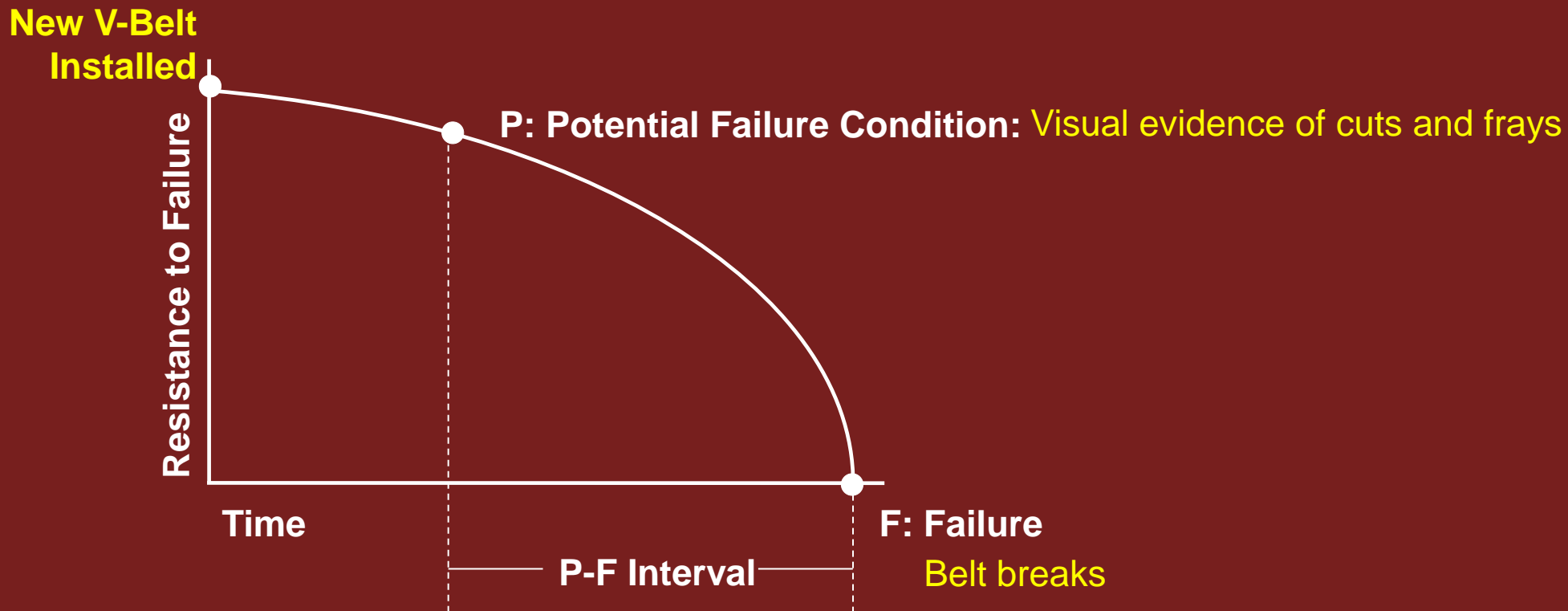
Condition Based Maintenance (CBM)

P-F Curve



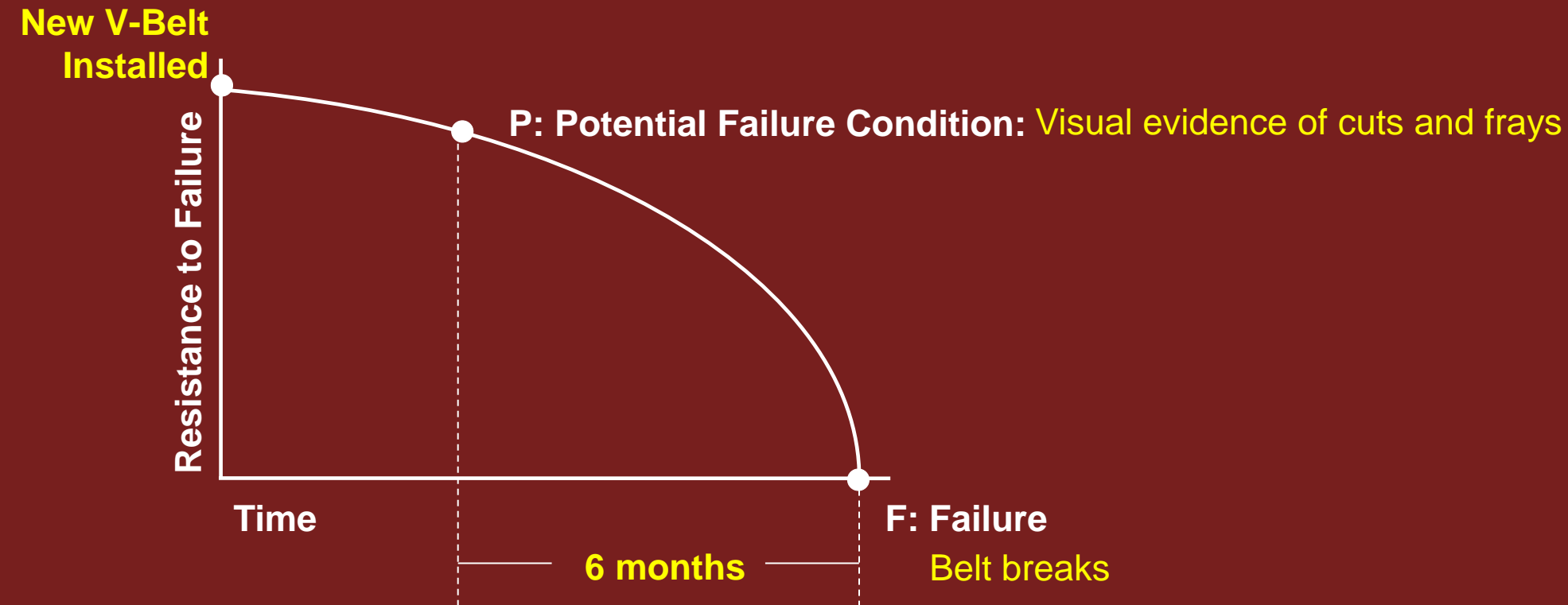
Condition Based Maintenance (CBM)

P-F Curve



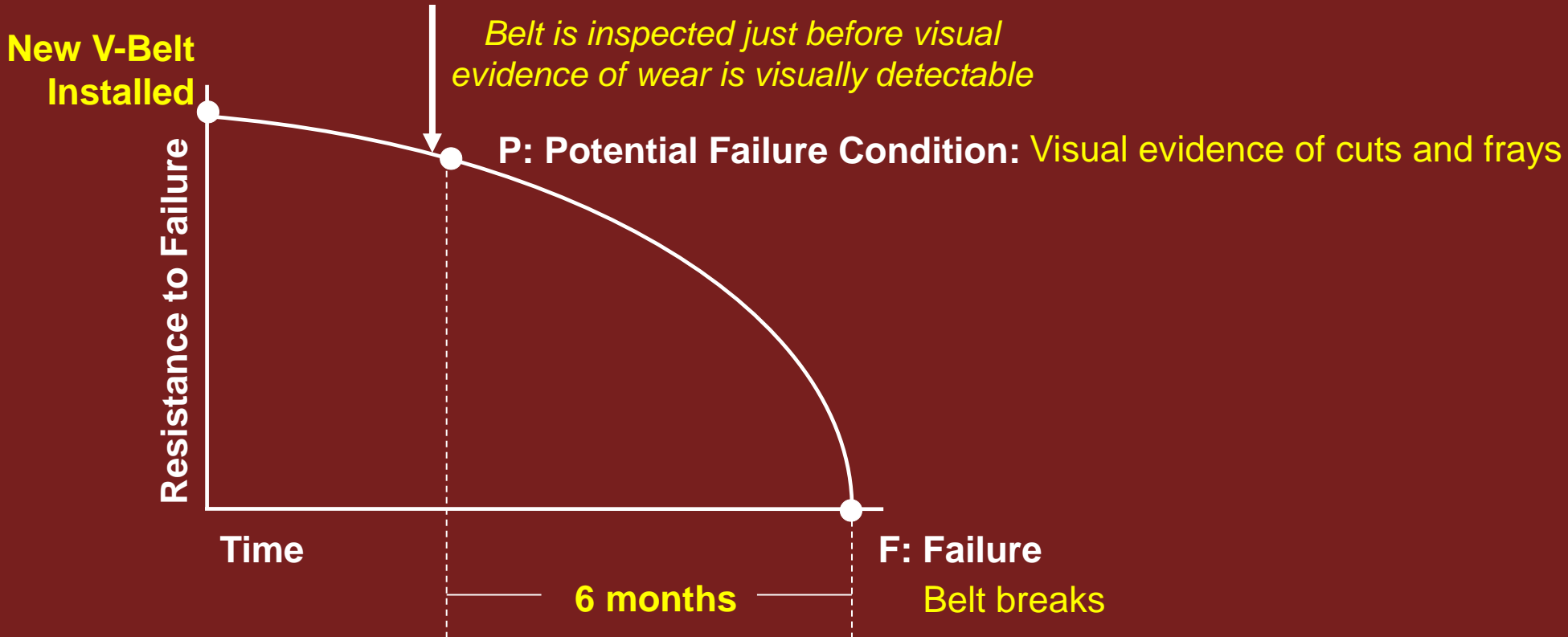
Condition Based Maintenance (CBM)

P-F Curve



Condition Based Maintenance (CBM)

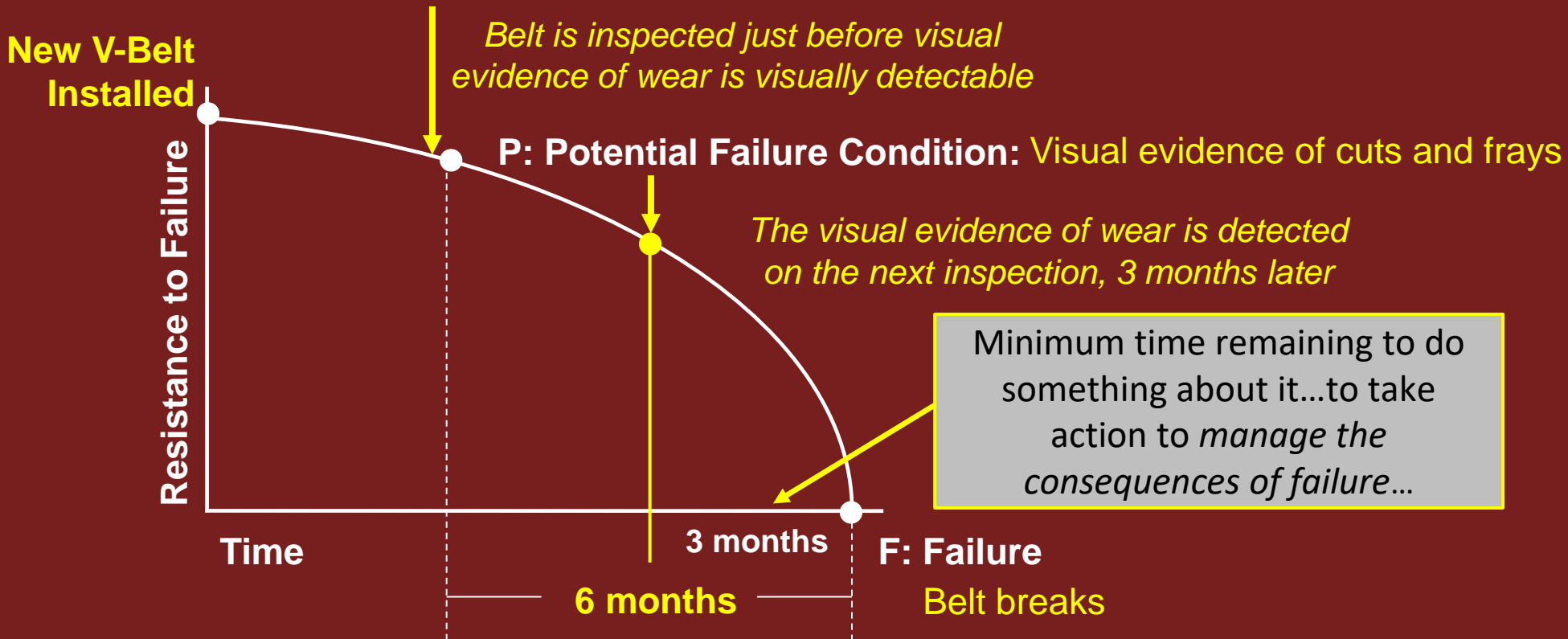
P-F Curve



Condition Based Maintenance (CBM)

P-F Curve

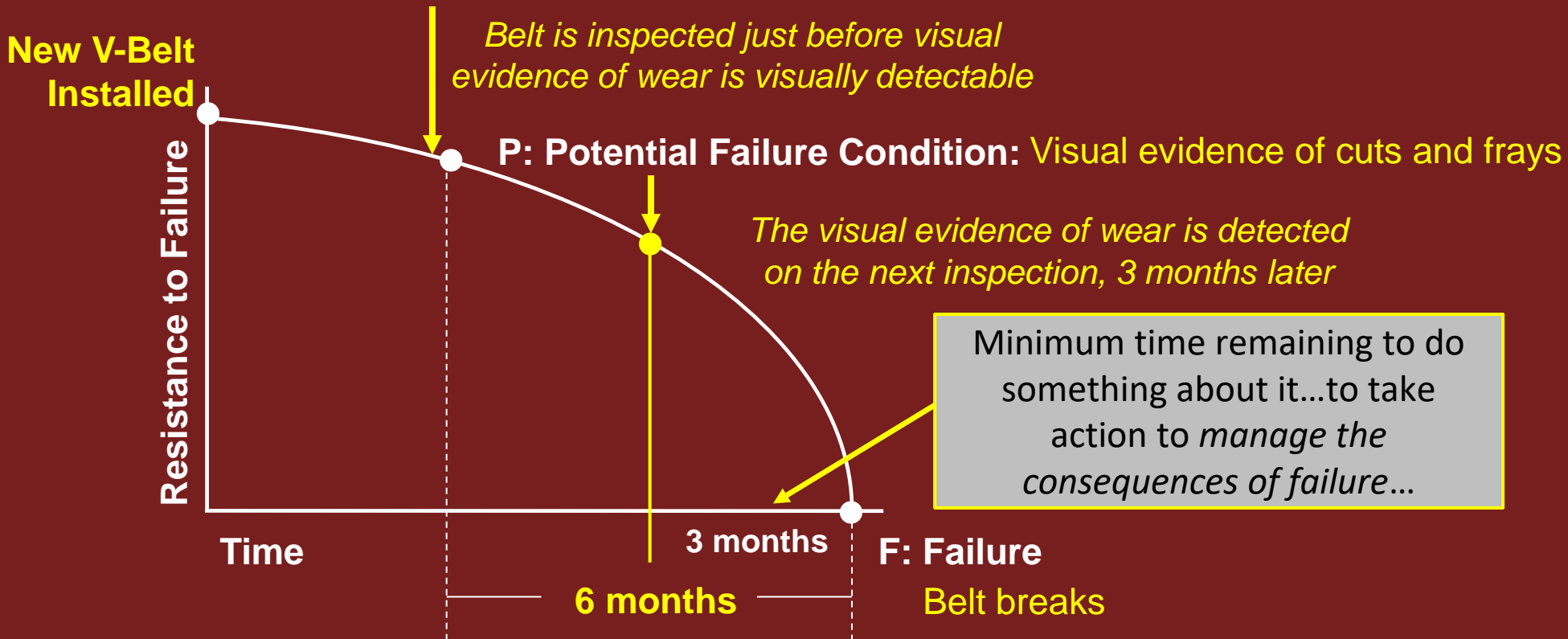
POINT: It doesn't matter how often the failure occurs. What matters is how *quickly* failure occurs once the Potential Failure Condition is detectable.



Condition Based Maintenance (CBM)

P-F Curve

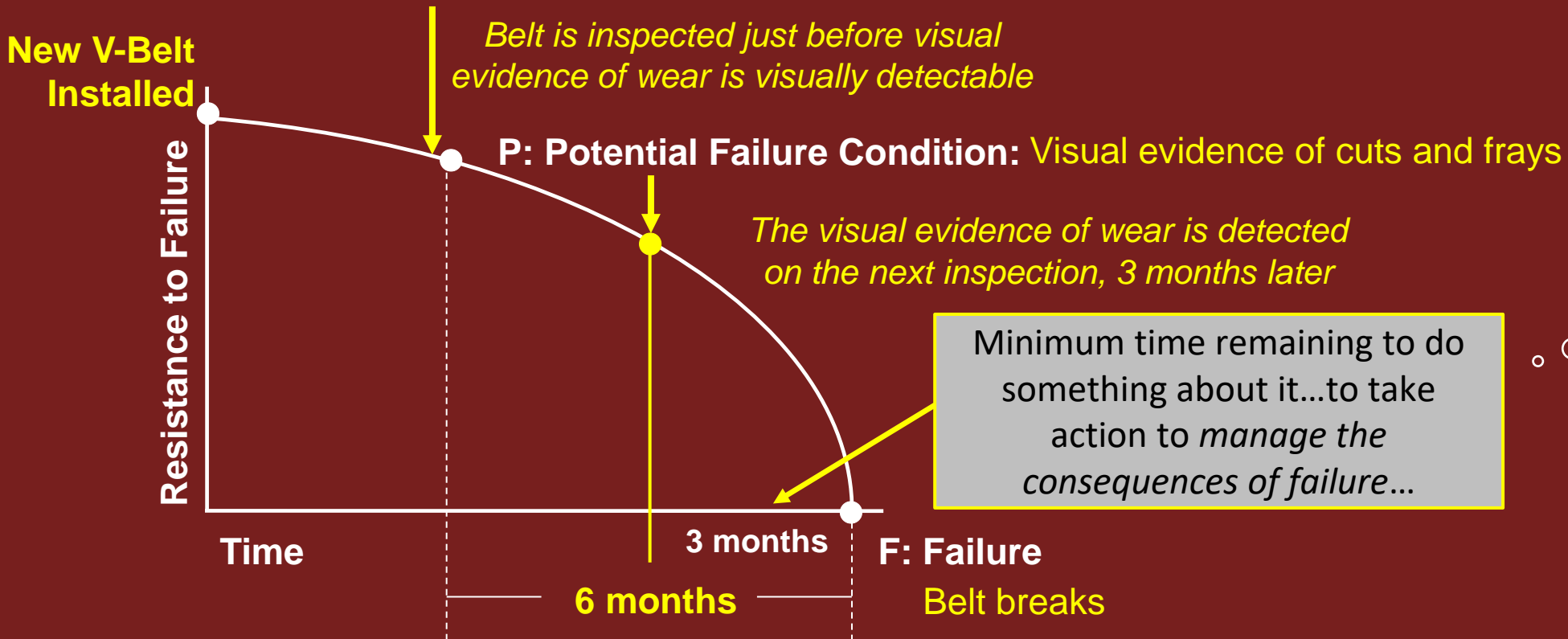
Scenario 1: Asset taken offline yearly. Can it be monitored at intervals less than the P-F Interval?



Condition Based Maintenance (CBM)

P-F Curve

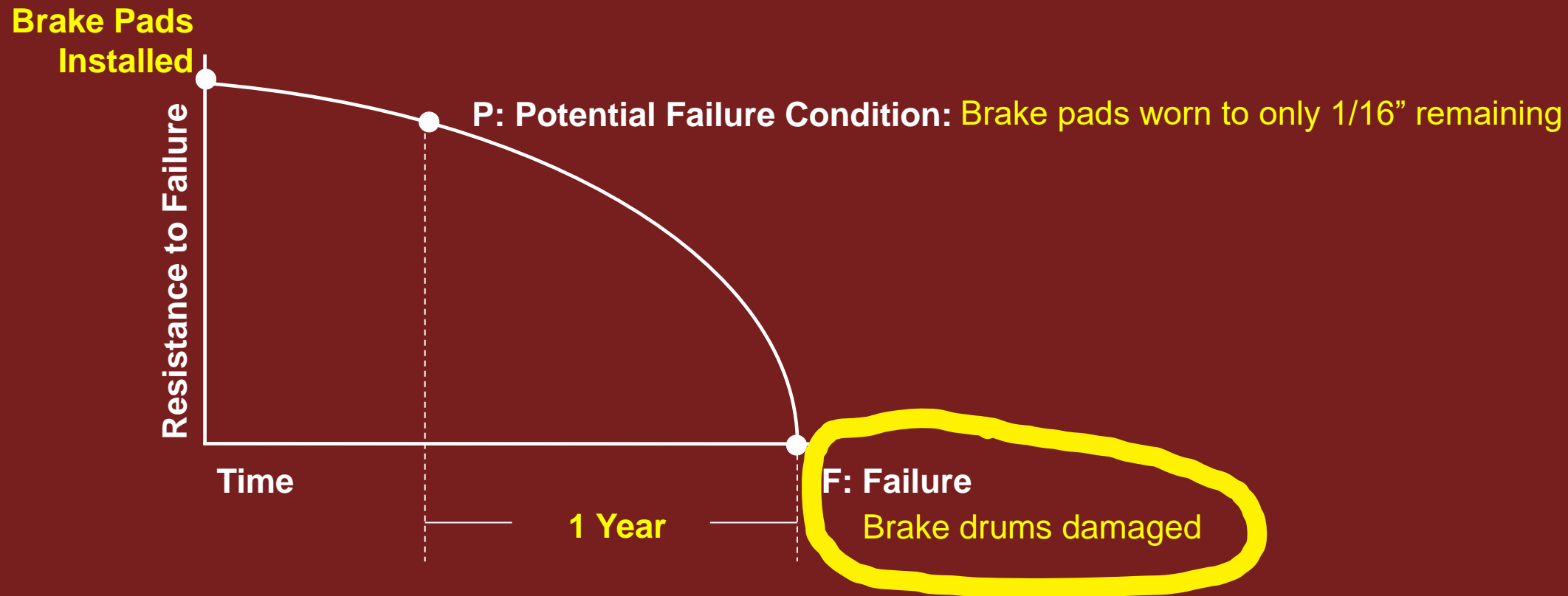
Scenario 2: Asset taken offline every month. Can it be monitored at intervals less than the P-F Interval?



Shutdown Schedules...

Condition Based Maintenance (CBM)

P-F Curve



The manner in which On-Condition task intervals are set is a widely misunderstood concept.

Four Key Points:

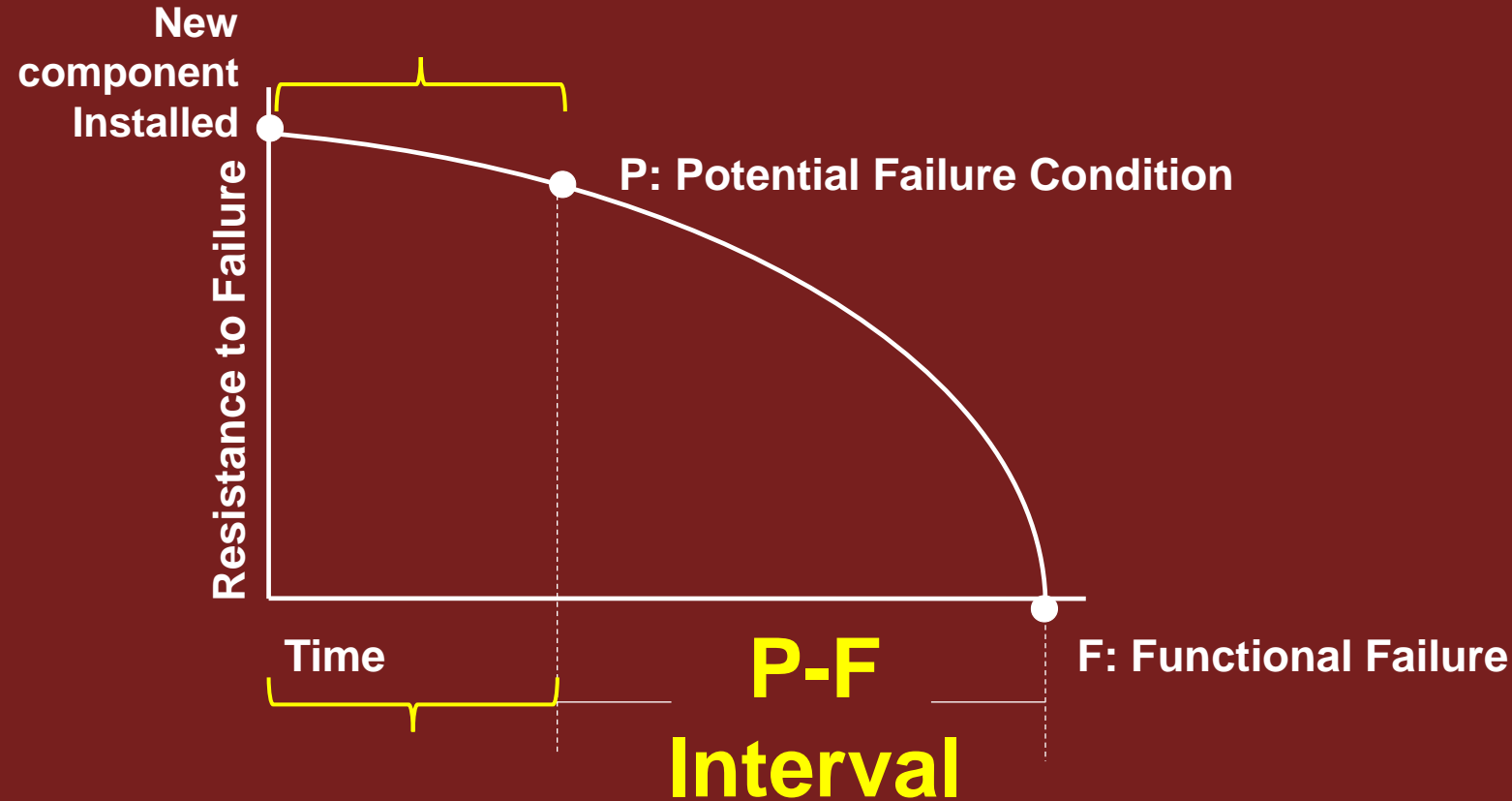
1. On-Condition maintenance task intervals are NOT based upon *MTBF*.
2. On-Condition maintenance task intervals are NOT based upon the *useful life* of a component.
3. On-Condition maintenance task intervals are NOT based upon the *criticality of the failure*.
4. On-Condition maintenance task intervals are based upon...

Condition Based Maintenance (CBM)

P-F Curve



How *QUICKLY* failure occurs once the Potential Failure Condition is detectable.



Achieve maximum useful life of components

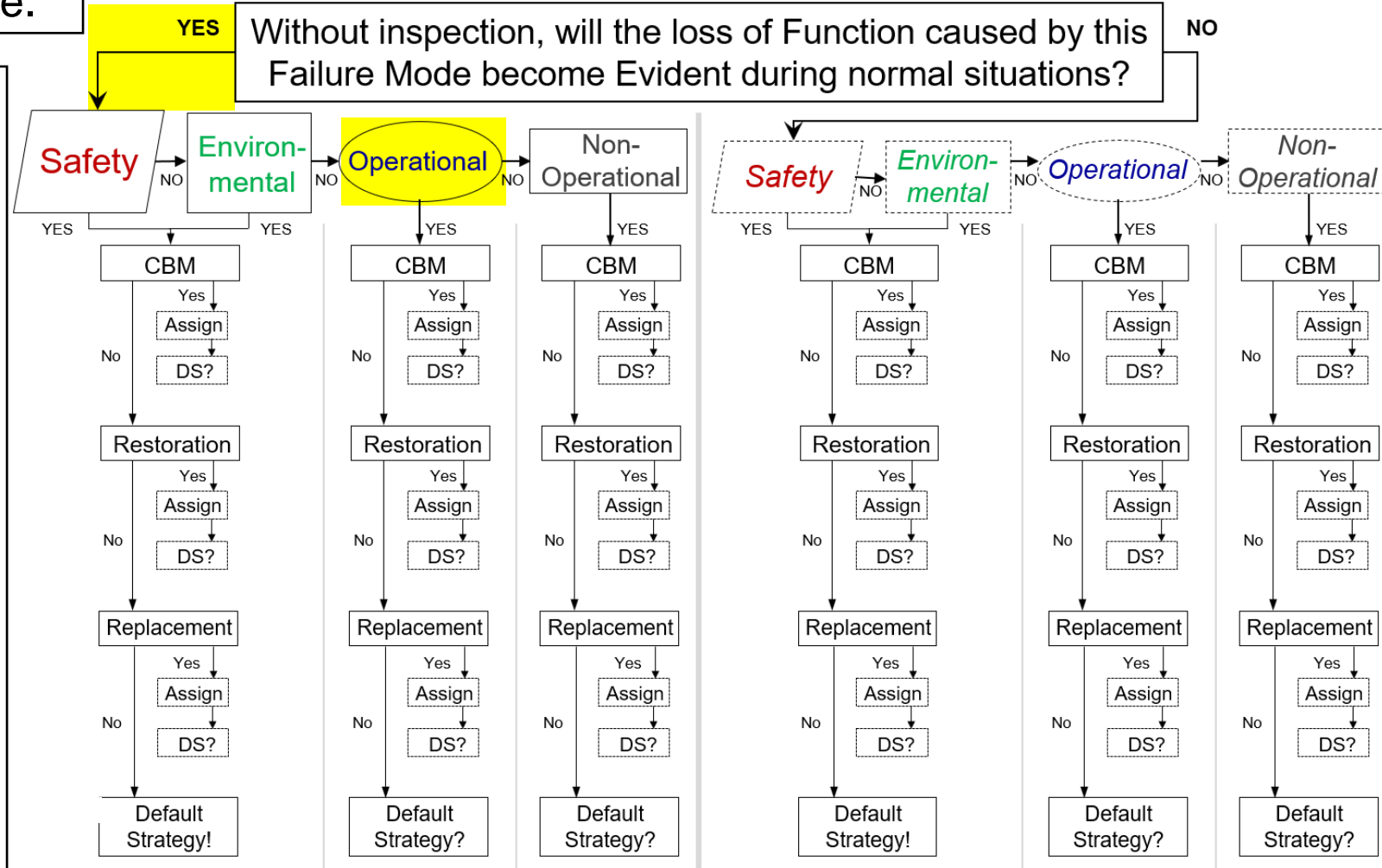
Apply the RCM Decision Diagram

Failure Mode

Engine consumes oil due to normal use.

Failure Effect

During engine operation, the oil is gradually consumed by the engine. The decrease in oil is indicated on the dipstick. If this goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates (down 2 quarts). The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to the destination but with some delay. Downtime to repair, up to 30 minutes.



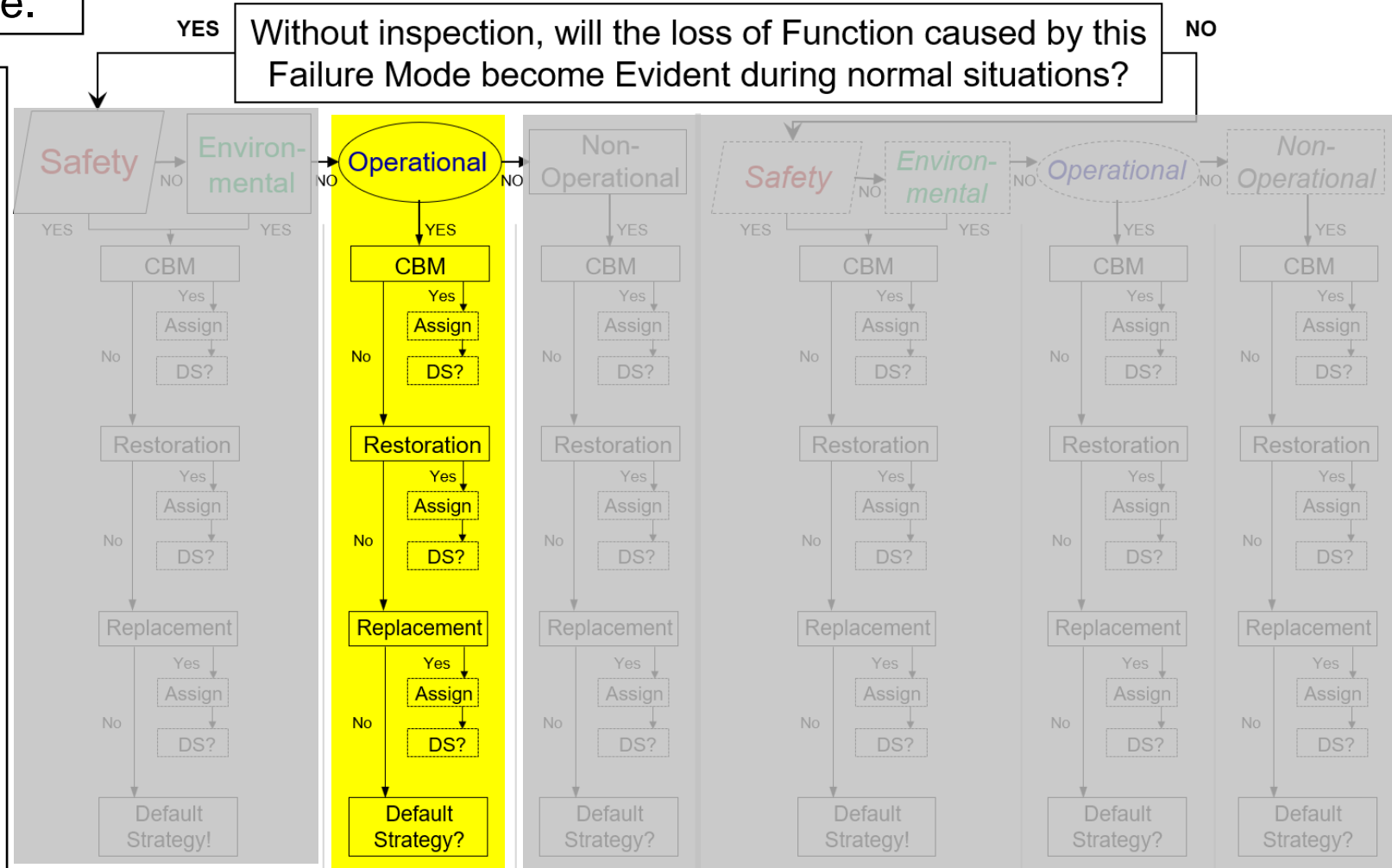
Apply the RCM Decision Diagram

Failure Mode

Engine consumes oil due to normal use.

Failure Effect

During engine operation, the oil is gradually consumed by the engine. The decrease in oil is indicated on the dipstick. If this goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates (down 2 quarts). The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to the destination but with some delay. Downtime to repair, up to 30 minutes.



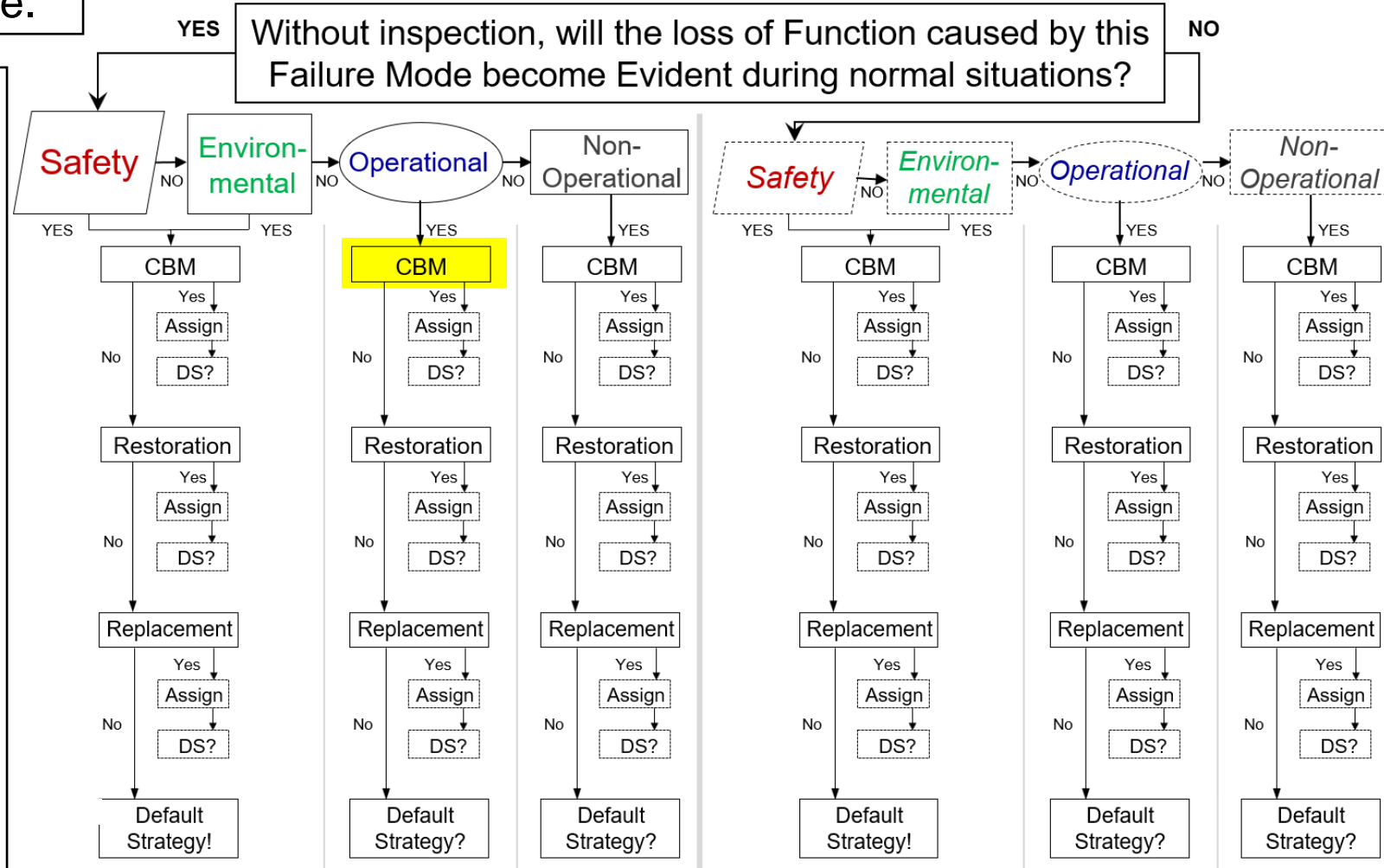
Apply the RCM Decision Diagram

Failure Mode

Engine consumes oil due to normal use.

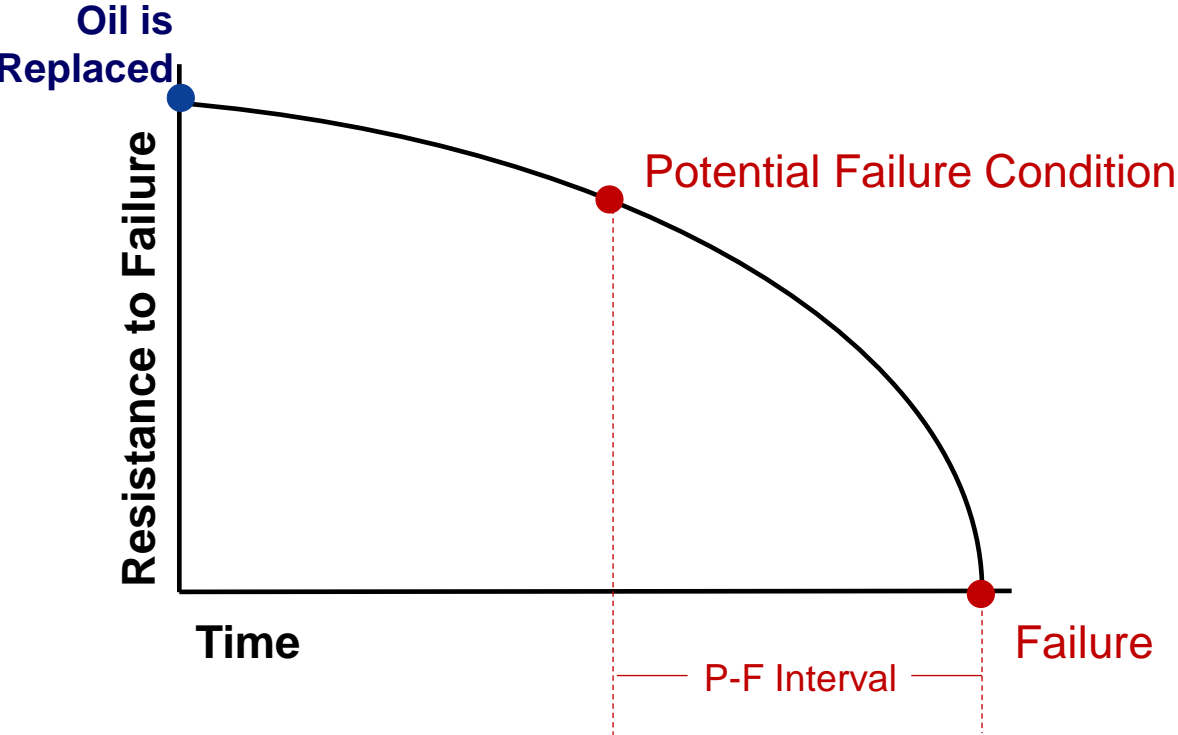
Failure Effect

During engine operation, the oil is gradually consumed by the engine. The decrease in oil is indicated on the dipstick. If this goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates (down 2 quarts). The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to the destination but with some delay. Downtime to repair, up to 30 minutes.



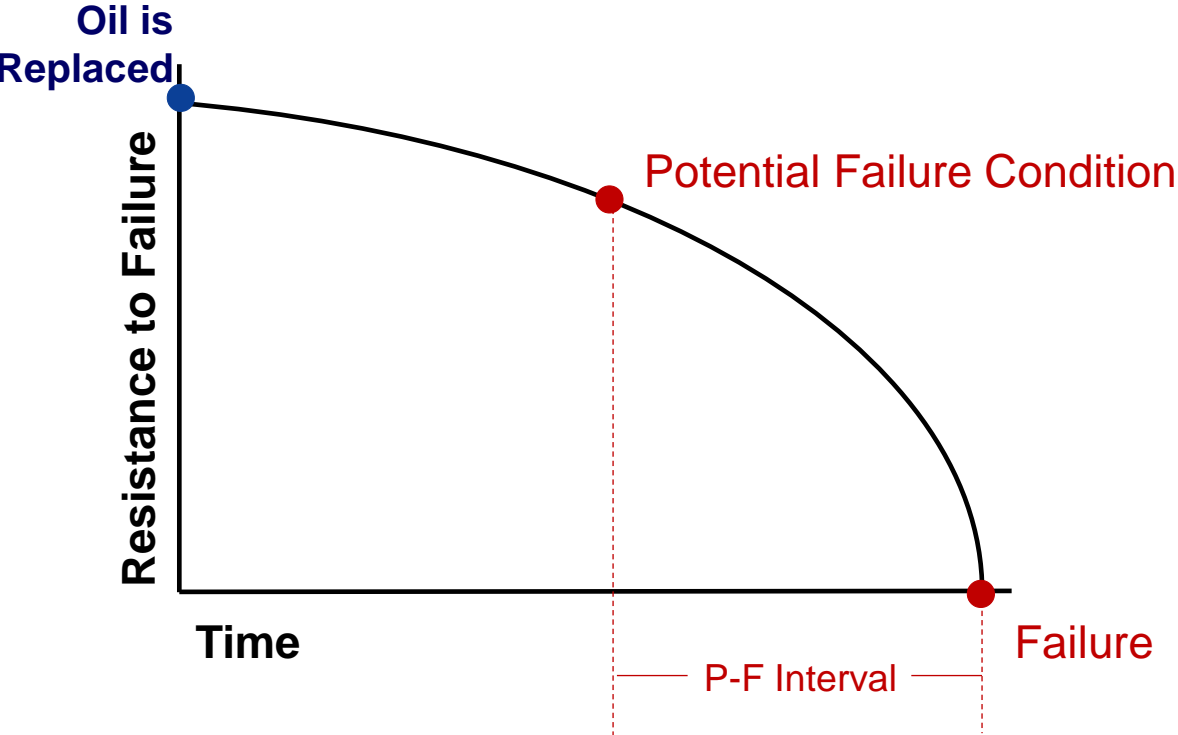
Failure Mode
Engine consumes oil
due to normal use.

P-F Curve



Failure Mode
Engine consumes oil
due to normal use.

P-F Curve



Failure Mode
Engine consumes oil
due to normal use.

P-F Curve



Oil is
Replaced

Resistance to Failure

Time

P: Oil level is 75% to the "low level"

P-F Interval

Failure

Failure Mode
Engine consumes oil
due to normal use.

P-F Curve

Oil is
Replaced

Resistance to Failure

Time



P: Oil level is 75% to the "low level"

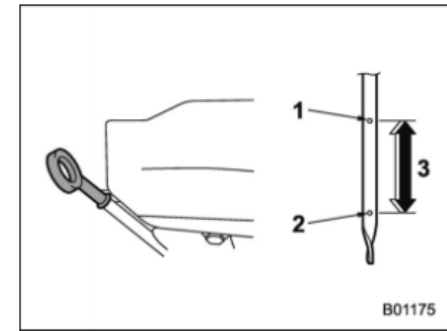
P-F Interval

F: Oil level drops to the "low level"



Failure Mode
Engine consumes oil
due to normal use.

According to my Subaru Forester manual



- 1) Full level
- 2) Low level
- 3) Approximately 1.1 US qt (1.0 liter, 0.9 Imp qt) from low level to full level

- Subaru manual states that “consuming more than 1 quart per 1,200 miles” is abnormal.
- They recommend checking the engine oil level at each fuel stop.

P-F Curve



Oil is Replaced

Resistance to Failure

Time

P: Oil level is 75% to the “low level”

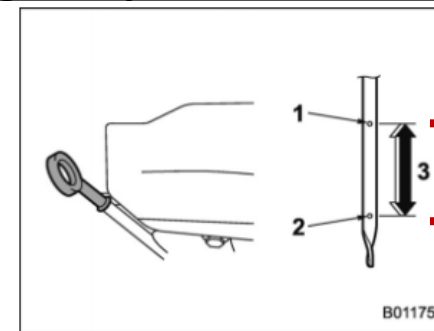
P-F Interval

F: Oil level drops to the “low level”



Failure Mode
Engine consumes oil
due to normal use.

According to my Subaru Forester manual



**<1200
Miles**

- 1) Full level
- 2) Low level
- 3) Approximately 1.1 US qt (1.0 liter, 0.9 Imp qt) from low level to full level

- Subaru manual states that “consuming more than 1 quart per 1,200 miles” is abnormal.
- They recommend checking the engine oil level at each fuel stop.

P-F Curve



Oil is Replaced

Resistance to Failure

Time

P: Oil level is 75% to the “low level”

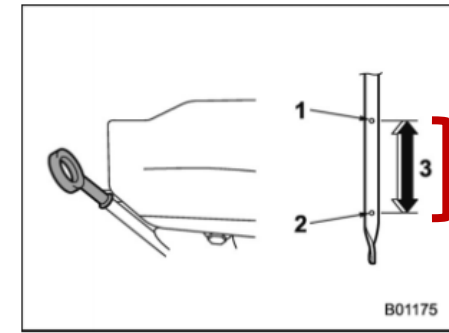
P-F Interval

F: Oil level drops to the “low level”



Failure Mode
 Engine consumes oil
 due to normal use.

According to my Subaru Forester manual



**<1200
 Miles**

- 1) Full level
- 2) Low level
- 3) Approximately 1.1 US qt (1.0 liter, 0.9 Imp qt) from low level to full level

- Subaru manual states that “consuming more than 1 quart per 1,200 miles” is abnormal.
- They recommend checking the engine oil level at each fuel stop.

P-F Curve

Oil is Replaced

Resistance to Failure

Time



P: Oil level is 75% to the “low level”

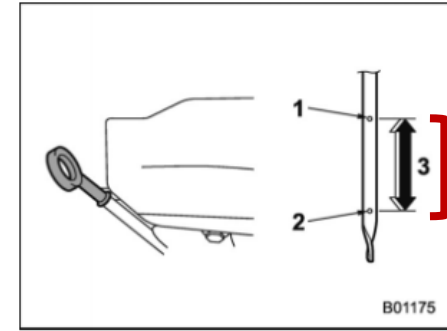
F: Oil level drops to the “low level”

P-F Interval



Failure Mode
Engine consumes oil
due to normal use.

According to my Subaru Forester manual



**<1200
Miles**

- 1) Full level
- 2) Low level
- 3) Approximately 1.1 US qt (1.0 liter, 0.9 Imp qt) from low level to full level

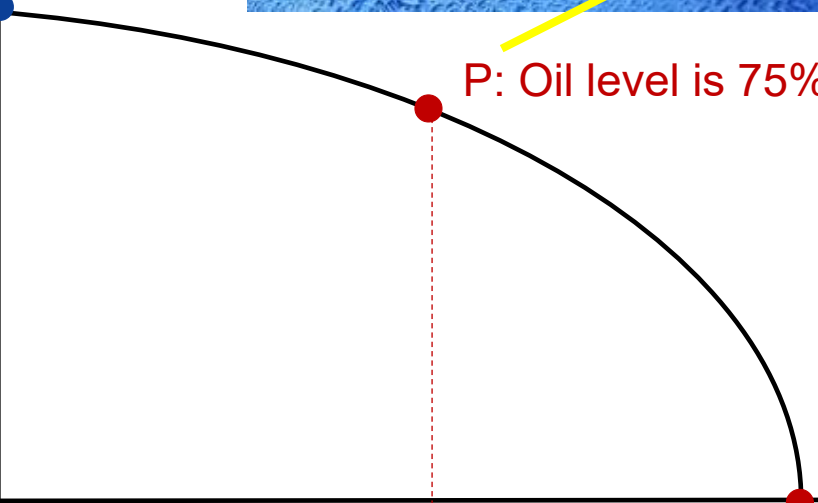
- Subaru manual states that “consuming more than 1 quart per 1,200 miles” is abnormal.
- They recommend checking the engine oil level at each fuel stop.

P-F Curve



Oil is Replaced

Resistance to Failure



P: Oil level is 75% to the “low level”

900 miles

P-F Interval

F: Oil level drops to the “low level”



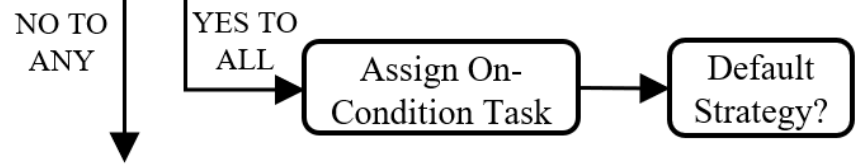
If inspected, is it possible to detect evidence of impending failure? What is it? What is the P-F Interval? Is it reasonably consistent? Is it practical to monitor the item at intervals less than the P-F interval? Is it long enough to manage the consequences of failure?

► Is the task cost effective? (Task cost vs. operational consequences + repair costs)

O
OC

On-Condition

Failure Mode
Engine consumes oil due to normal use.

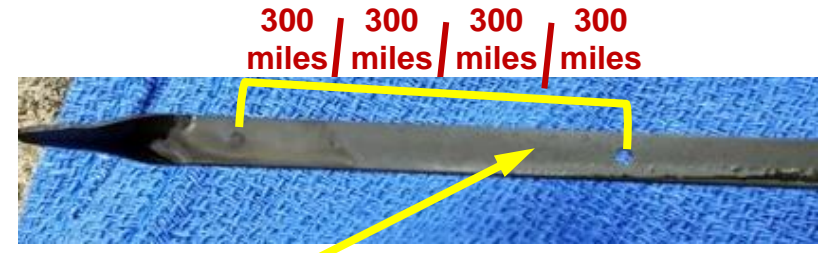


P-F Curve

Oil is Replaced

Resistance to Failure

Time



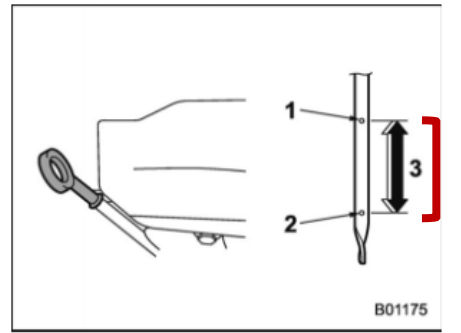
P: Oil level is 75% to the "low level"

900 miles
P-F Interval

F: Oil level drops to the "low level"



According to my Subaru Forester manual



<1200 Miles

- 1) Full level
- 2) Low level
- 3) Approximately 1.1 US qt (1.0 liter, 0.9 Imp qt) from low level to full level

- Subaru manual states that "consuming more than 1 quart per 1,200 miles" is abnormal.
- They recommend checking the engine oil level at each fuel stop.

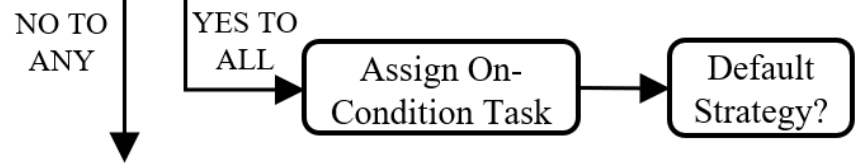
If inspected, is it possible to detect evidence of impending failure? What is it? What is the P-F Interval? Is it reasonably consistent? Is it practical to monitor the item at intervals less than the P-F interval? Is it long enough to manage the consequences of failure?

► *Is the task cost effective? (Task cost vs. operational consequences + repair costs)*

O
OC

On-Condition

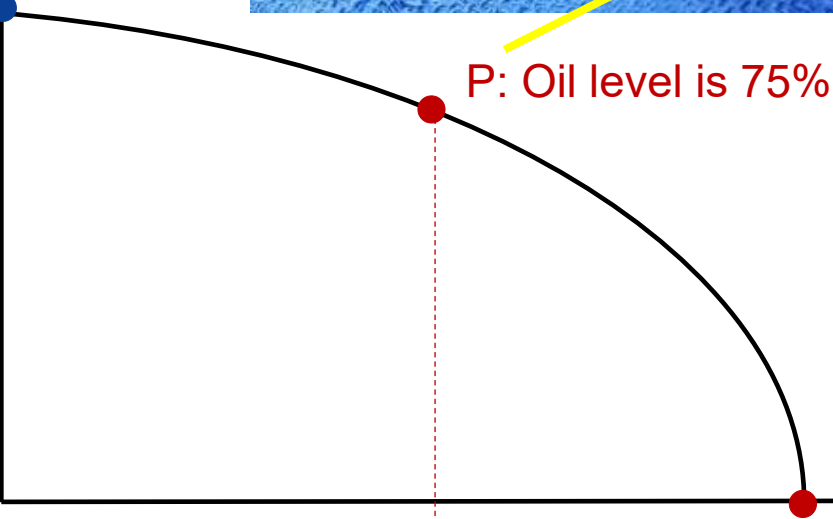
Failure Mode
Engine consumes oil due to normal use.



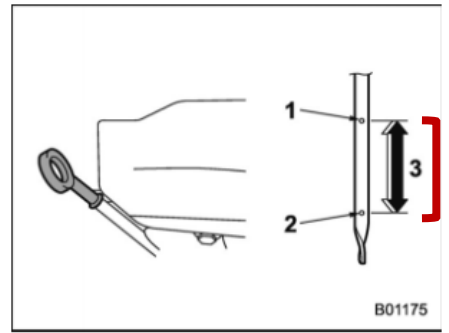
P-F Curve

Oil is Replaced

Resistance to Failure



According to my Subaru Forester manual



<1200 Miles

- 1) Full level
- 2) Low level
- 3) Approximately 1.1 US qt (1.0 liter, 0.9 Imp qt) from low level to full level

- Subaru manual states that “consuming more than 1 quart per 1,200 miles” is abnormal.
- They recommend checking the engine oil level at each fuel stop.

How far can I go on one tank of fuel?

16 gallons of fuel x 30 mpg = 480 miles



If inspected, is it possible to detect evidence of impending failure? What is it? What is the P-F Interval? Is it reasonably consistent? Is it practical to monitor the item at intervals less than the P-F interval? Is it long enough to manage the consequences of failure?

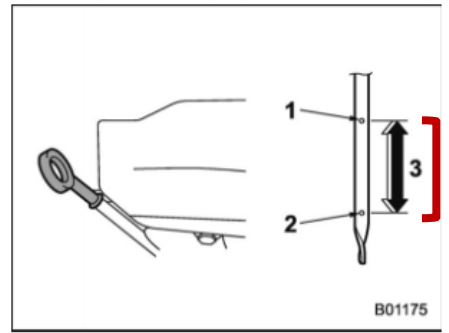
► *Is the task cost effective? (Task cost vs. operational consequences + repair costs)*

O
OC

On-Condition

Failure Mode
Engine consumes oil due to normal use.

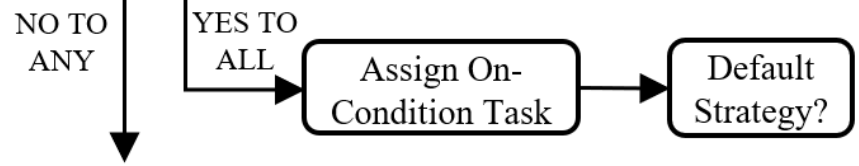
According to my Subaru Forester manual



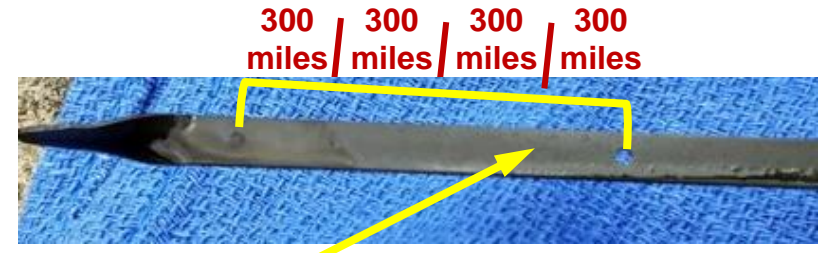
<1200 Miles

- 1) Full level
- 2) Low level
- 3) Approximately 1.1 US qt (1.0 liter, 0.9 Imp qt) from low level to full level

- Subaru manual states that “consuming more than 1 quart per 1,200 miles” is abnormal.
- They recommend checking the engine oil level at each fuel stop.

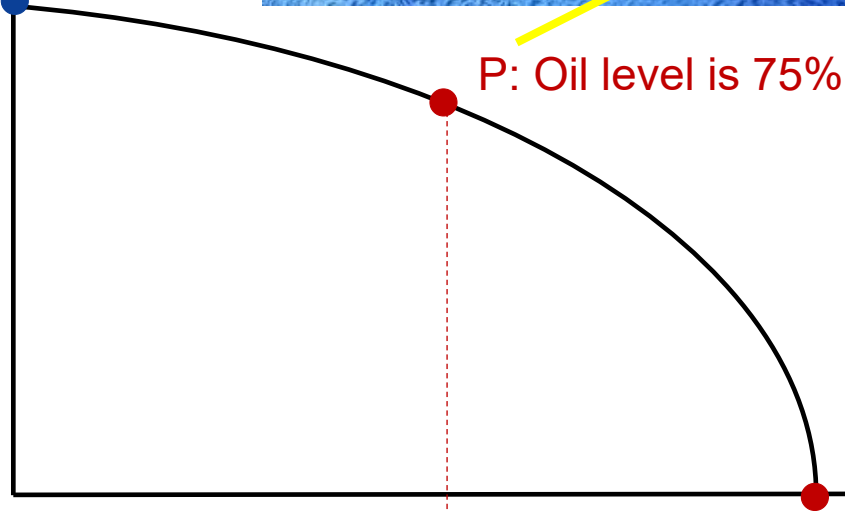


P-F Curve



Oil is Replaced

Resistance to Failure



How far can I go on one tank of fuel?
16 gallons of fuel x 30 mpg = 480 miles

If I check the oil every time I stop for gas, that would be about every 400 miles and that **IS practical**.



Apply the RCM Decision Diagram

Failure Mode

Engine consumes oil due to normal use.

If inspected, is it possible to detect evidence of impending failure? What is it? What is the P-F Interval? Is it reasonably consistent? Is it practical to monitor the item at intervals less than the P-F interval? Is it long enough to manage the consequences of failure?

► Is the task cost effective? (Task cost vs. operational consequences + repair costs)

NO TO ANY

YES TO ALL

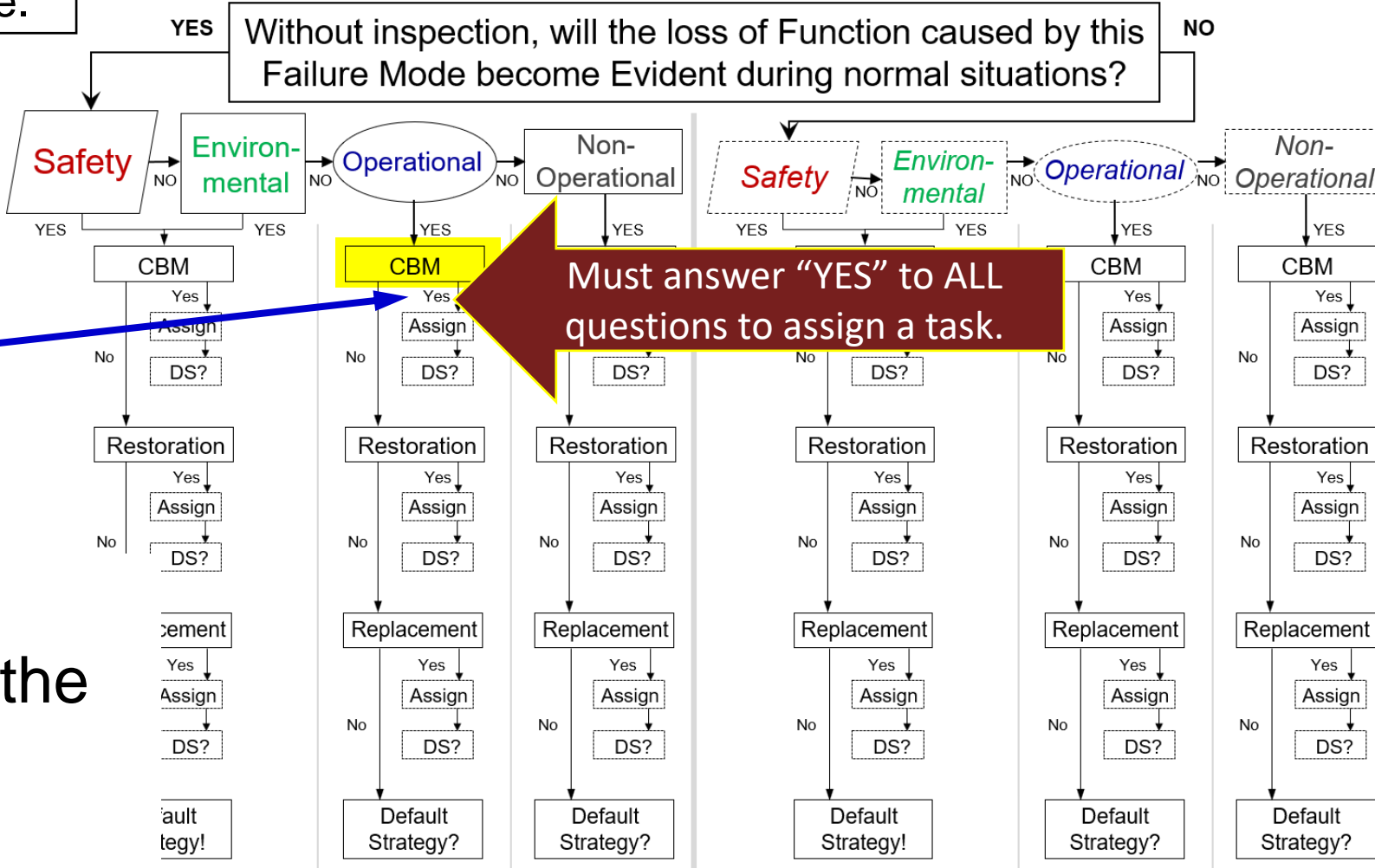
Assign On-Condition Task

Default Strategy?

On-Condition

Task:

At every fuel stop, check the engine oil level using the dipstick. Replenish the reservoir, as required.



Reliability Centered Maintenance

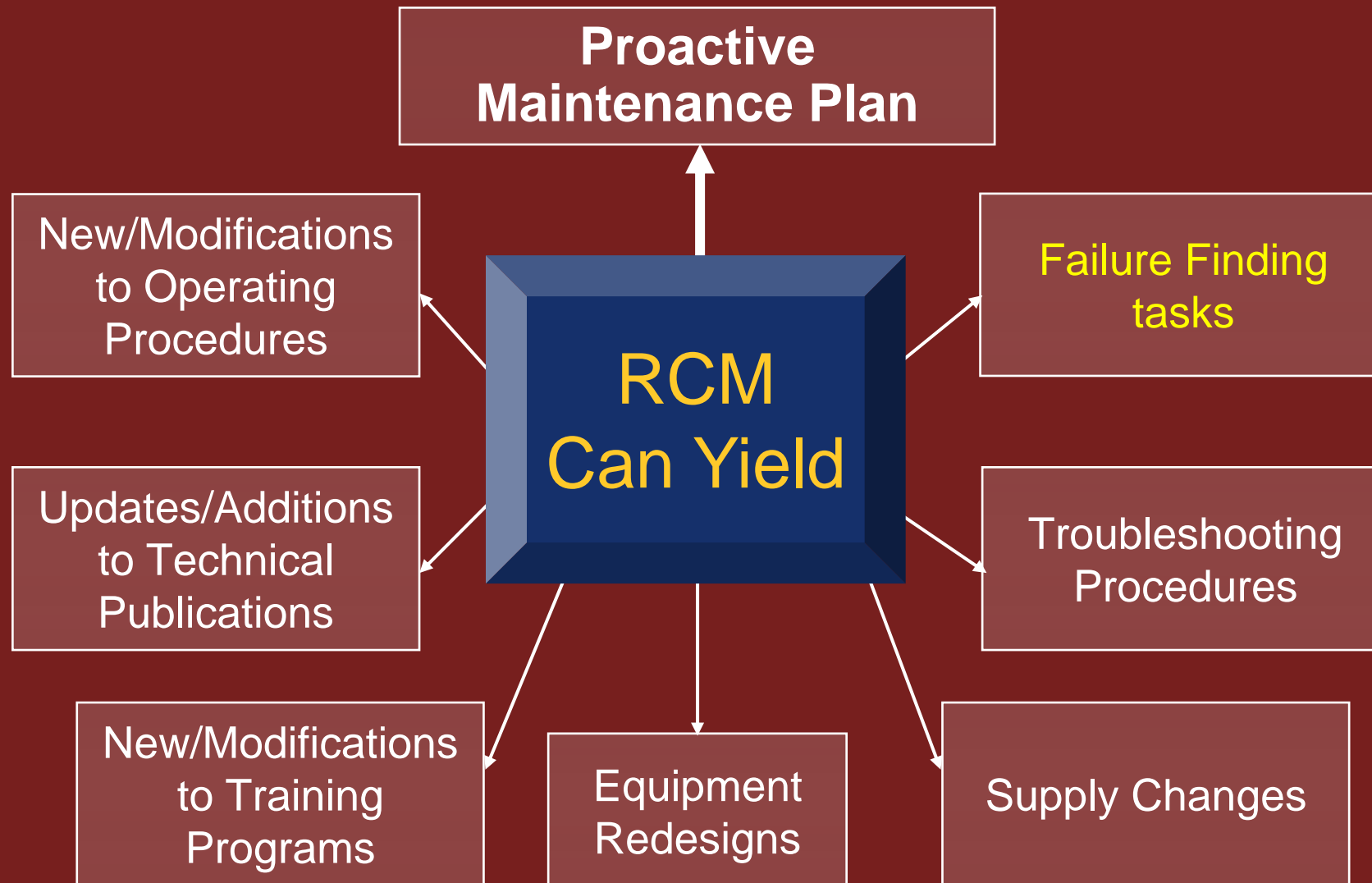
RCM is a zero-based process used to identify the Failure Management Strategies that are required to ensure an asset meets its mission requirements in its operational environment in the most safe and cost effective manner.

Figure out how to manage each Failure Mode

RCM Process

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

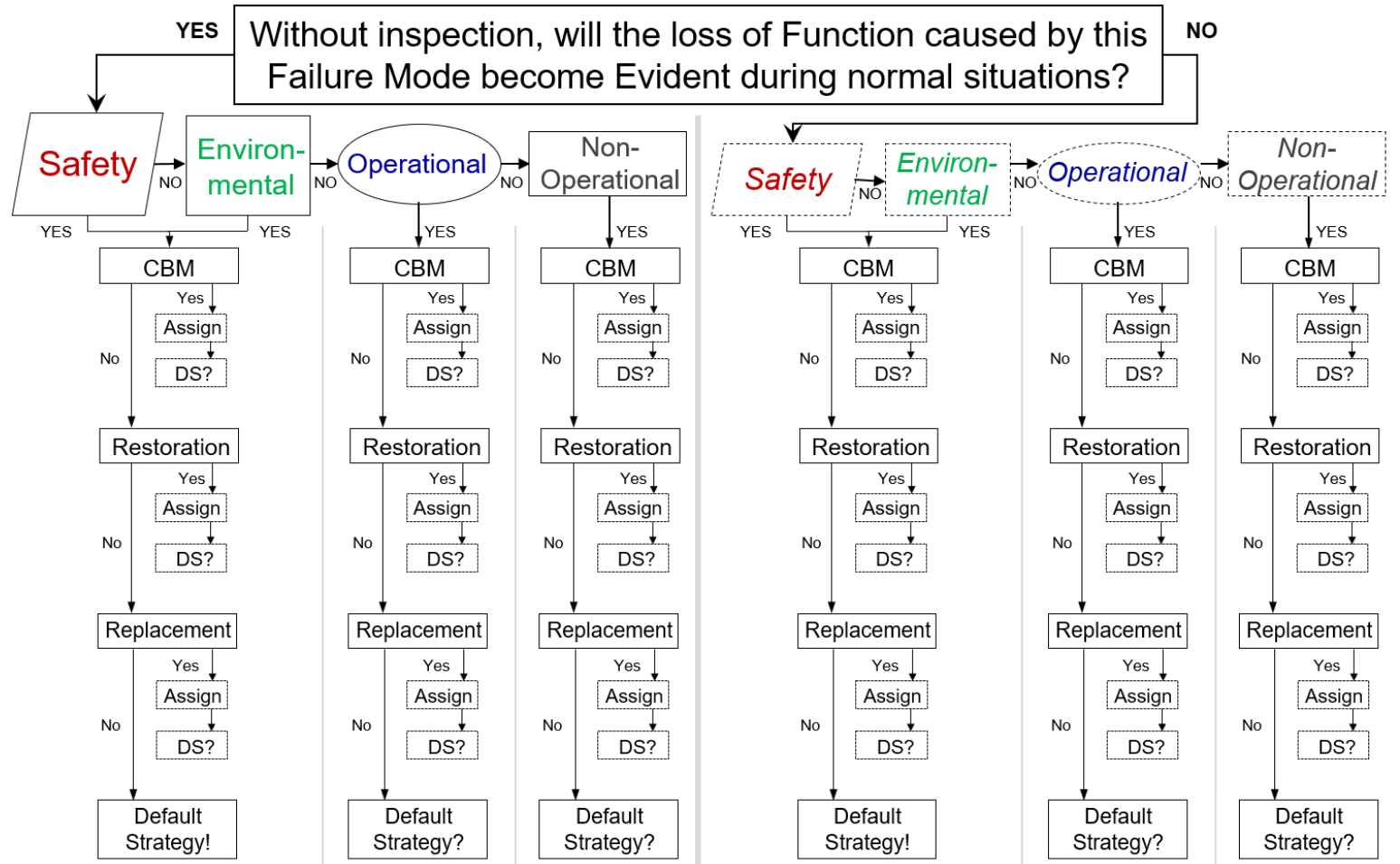
Potential Products of an RCM Analysis



Apply the RCM Decision Diagram

RCM INFORMATION WORKSHEET

FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.	A Completely unable to transport.	1 Engine consumes oil due to normal use. During engine operation, the oil is gradually consumed by the engine. The decrease in oil is indicated on the dipstick. If this goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates. The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to destination but with some delay. Downtime to repair, up to 30 minutes.
		2 Engine oil system leaks.	Without warning, the system develops a leak. The leak is visually detectable on the ground. If this goes unnoticed, the oil quantity gradually decreases. The decrease in oil is indicated on the dipstick. If that goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates. The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to the destination. Most likely, the leak is small and the driver is able to reach the destination with minimal delay. However, worst case, the leak is so extensive that the driver cannot complete the journey and must have the vehicle towed to the nearest Subaru dealership for repair. Downtime to repair, 1 day to 1 week.



Copyright © The Force, Inc. 2017-2023 All Rights Reserved

Copyright © The Force, Inc. 2017-2023 All Rights Reserved

RCM INFORMATION WORKSHEET

FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	A Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.	1 LOW OIL LEVEL Light circuit fails open. This Failure Mode only matters in the event that the engine oil level decreases to the lower limit. The driver is unaware of the low oil situation and continues to operate the vehicle. The oil level continues to drop. Engine components are not properly lubricated and start to wear abnormally. Eventually, engine oil pressure decreases and engine oil temperature increases. The OIL PRESSURE warning light and/or the CHECK ENGINE light illuminates on the dashboard. Driver finds a safe place to pull over and is unable to get to the desired destination. If there isn't a service station nearby, the driver needs to call the emergency service line. Worst case, the driver must pull over on the highway or in a remote, unsafe location. Vehicle is towed to the nearest Subaru dealership for repair. The oil system is repaired, as required. Engine damage is repaired. Worst case, engine must be replaced. Driver must find alternate means of transportation. Downtime to repair, 3 days to 1 month.
		1 Falsely illuminates the LOW OIL LEVEL Light.	While driving, the LOW OIL LEVEL Light illuminates. The driver thinks that there is a low oil situation. Driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil level is normal. The time it takes to check the oil is minimal so the driver is able to arrive at the intended destination on time. Driver schedules vehicle for service at the next available opportunity. Time to repair, 1 day.



Copyright © The Force, Inc. 2017-2023 All Rights Reserved

Copyright The Force, Inc. 2023 All Rights Reserved

Apply the RCM Decision Diagram

To be capable of visually alerting the driver **in the event that** the engine oil level decreases to the lower limit. (LOW OIL LEVEL light)

This Failure Mode only matters in the event that the engine oil level decreases beyond the lower limit. The driver is unaware of the low oil situation and continues to operate the vehicle. The oil level continues to drop. Engine components are not properly lubricated and start to wear abnormally. Eventually, engine oil pressure decreases and engine oil temperature increases. The OIL PRESSURE warning light and/or the CHECK ENGINE light illuminates on the dashboard. Driver must pull over and cannot get to the desired destination on time. It is likely that the driver can find a safe place to pull over and call a tow truck. However, worst case, driver must pull over on a busy highway or on a dark country road at night. The oil system is repaired, as required. Any secondary engine damage is repaired, as required. Worst case, engine must be replaced. Downtime to repair, 3 days to 1 month at a cost ranging from \$1,000 to \$8,000.

Incapable of visually alerting the driver **in the event that** the engine oil level decreases to the lower limit.

LOW OIL LEVEL LIGHT circuit fails open.

RCM INFORMATION WORKSHEET

	FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.	1 LOW OIL LEVEL Light circuit fails open.	This Failure Mode only matters in the event that the engine oil level decreases to the lower limit. The driver is unaware of the low oil situation and continues to operate the vehicle. The oil level continues to drop. Engine components are not properly lubricated and start to wear abnormally. Eventually, engine oil pressure decreases and engine oil temperature increases. The OIL PRESSURE warning light and/or the CHECK ENGINE light illuminates on the dashboard. Driver must pull over and cannot get to the desired destination on time. It is likely that the driver can find a safe place to pull over and call a tow truck. However, worst case, driver must pull over on a busy highway or on a dark country road at night. The oil system is repaired, as required. Any secondary engine damage is repaired, as required. Worst case, engine must be replaced. Downtime to repair, 3 days to 1 month at a cost ranging from \$1,000 to \$8,000.

Apply the RCM Decision Diagram

Failure Mode

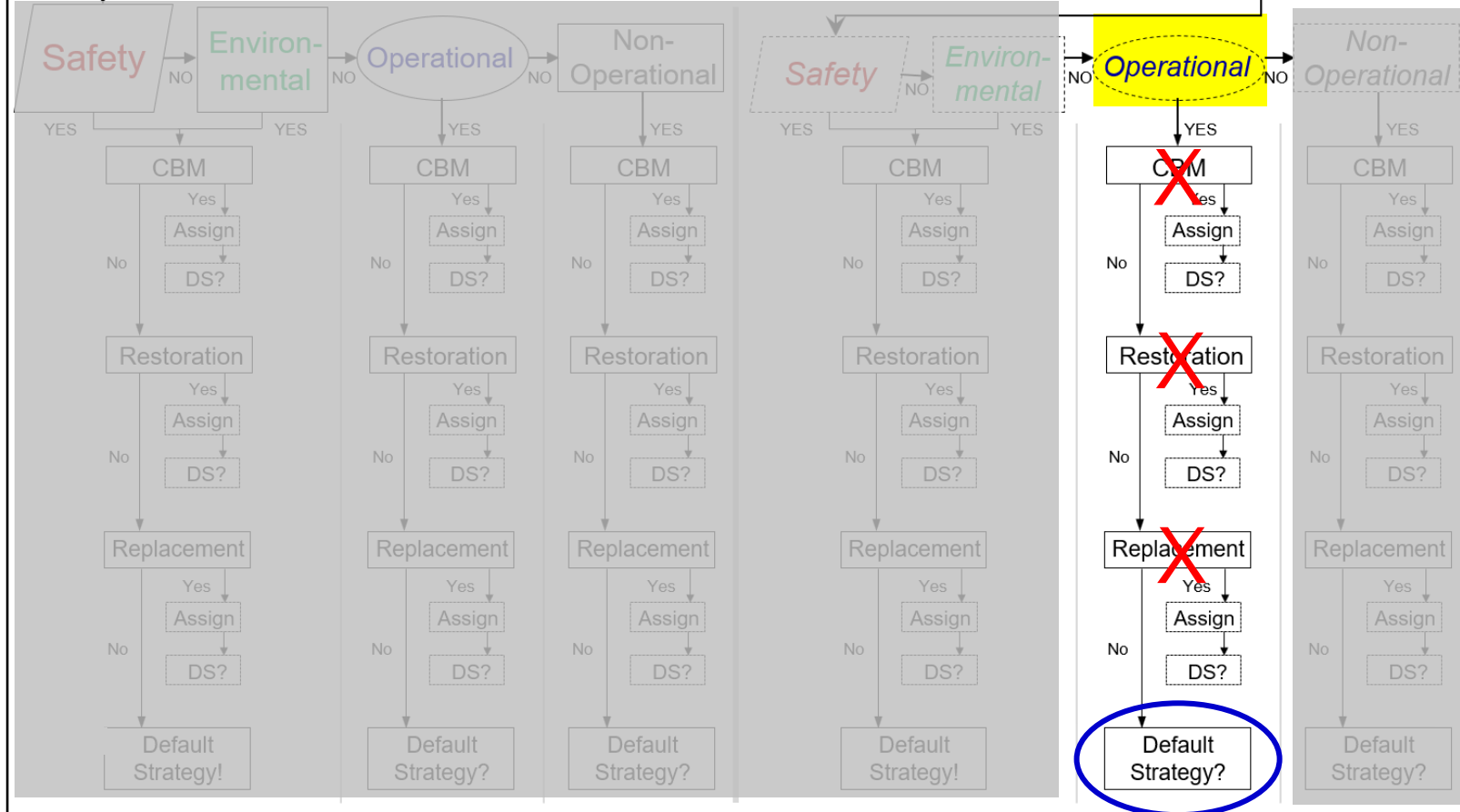
LOW OIL LEVEL LIGHT circuit fails open.

Failure Effect

This Failure Mode only matters in the event that the engine oil level decreases to the lower limit. The driver is unaware of the low oil situation and continues to operate the vehicle. The oil level continues to drop. Engine components are not properly lubricated and start to wear abnormally. Eventually, engine oil pressure decreases and engine oil temperature increases. The OIL PRESSURE warning light and/or the CHECK ENGINE light illuminates on the dashboard. Driver must pull over and cannot get to the desired destination on time. It is likely driver can find a safe place to pull over and call a tow truck. However, worst case, driver must pull over on a busy highway or on a dark country road at night. The oil system is repaired, as required. Any secondary engine damage is repaired, as required. Worst case, engine must be replaced. Downtime to repair, 3 days to 1 month at a cost ranging from \$1,000 to \$8,000.

Without inspection, will the loss of Function caused by this Failure Mode become Evident during normal situations?

NO



Reliability Centered Maintenance

RCM Process

Steps 1-4: FMEA
Failure Modes and Effects Analysis

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

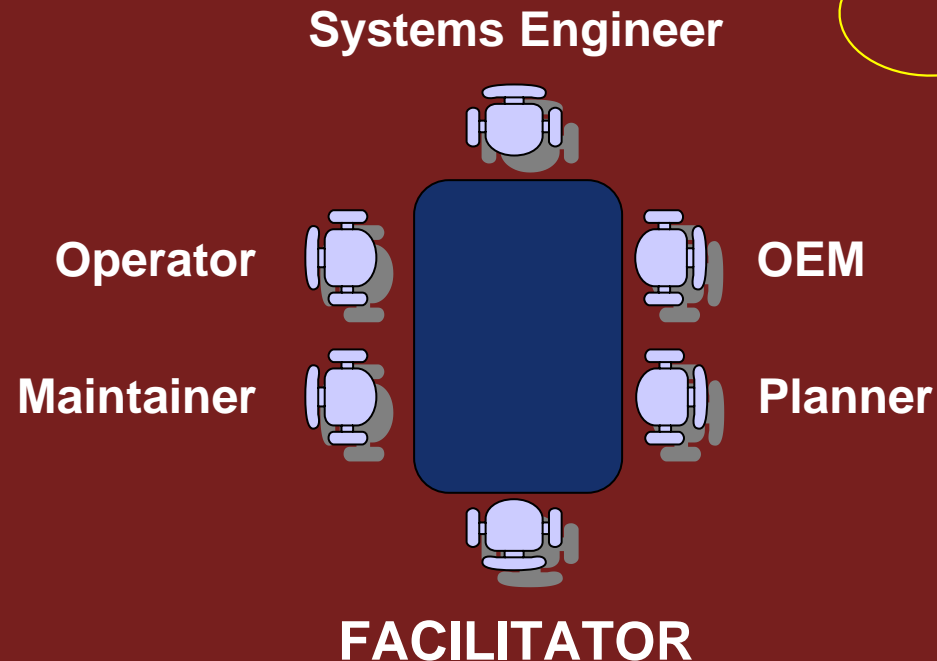
Steps 1-5: FMECA
Failure Modes, Effects, and Criticality Analysis

Augment Failure Data with a Facilitated Working Group

RCM Analysis Working Group

“Work of art watching alignment.”

Need the people managers say “I can’t afford to lose them for a week.”





CONGRESO DE
MANTENIMIENTO
& CONFIABILIDAD
C H I L E

4^a
EDICIÓN

Thank You!

Download Session Workbook:

RCMTrainingOnline.com/Chile2023



NancyReganRCM



RCM Training Online

NancyRegan@RCMTrainingOnline.com

BACKUP SLIDES ONLY

GOAL: Proactive Maintenance Plan

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.



How detailed should Failure Modes be written?

What specifically causes the diesel engine to fail?

Diesel engine fails

GOAL:
Proactive Maintenance Plan

Engine oil deteriorates due to normal use

Change the engine oil every 6 months.

Engine oil diminishes due to normal use

Check engine oil level prior to use. Replenish, as required.

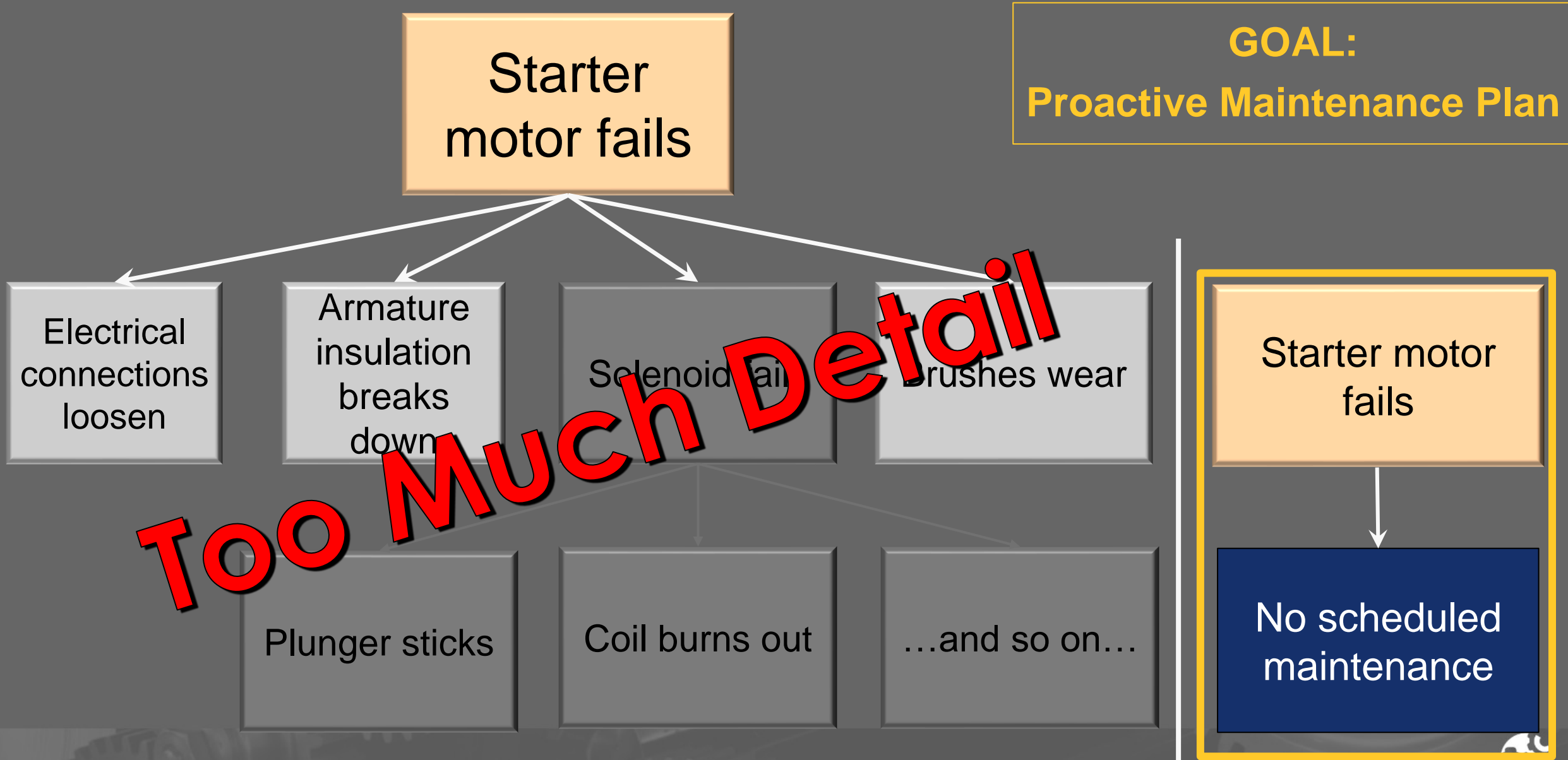
Cooling fan drive belt wears due to normal use

Visually inspect cooling fan drive belt every 500 operating hours. Replace, as required.

Starter motor fails

No scheduled maintenance

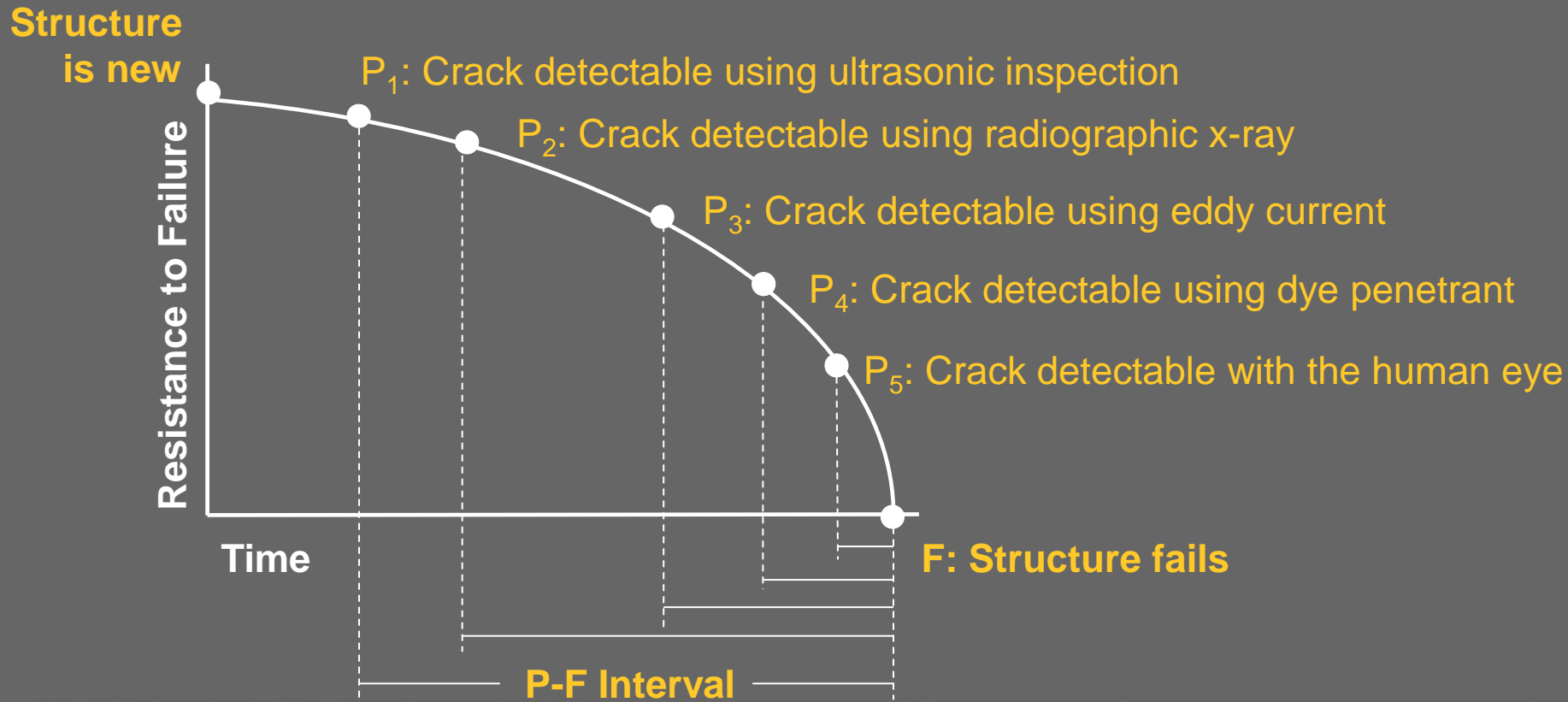
How detailed should Failure Modes be written?



Condition Based Maintenance (CBM)

P-F Curve

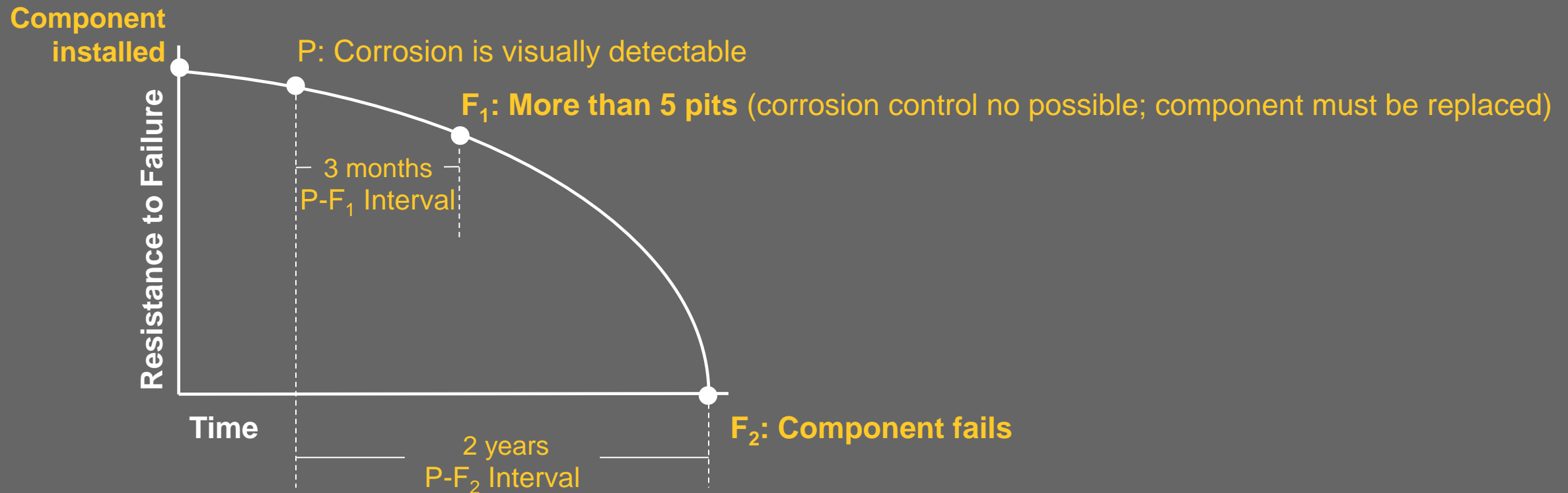
There can be more than one Potential Failure Condition



Condition Based Maintenance (CBM)

P-F Curve

There can be more than one "Failure."



Proactive Maintenance

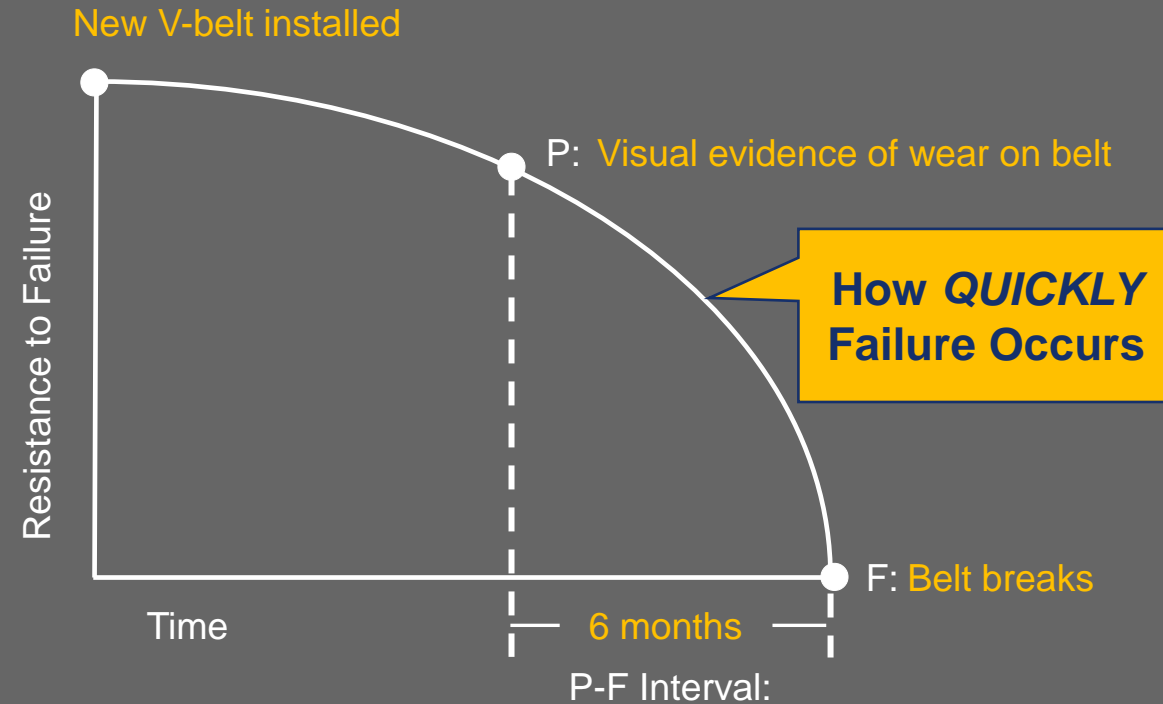
Preventive Maintenance

- *Scheduled Restoration*
- *Scheduled Replacement*



Condition Based Maintenance (CBM)

P-F Curve



Failure Mode	Function	Functional Failure	Failure Mode	Failure Effect
1A1	1. To provide compressed air that is oil free, <95F, at a minimum of 3,500 SCFM, 100 psig output pressure, with a minimum of 5 psig rise to surge to make up this compressor's portion of maintaining 10,500 SCFM and 90 psig header pressure to the plant.	A. Unable to provide compressed air.	1. Main drive shaft (coupling the motor to the compressor) lubrication dissipates.	Over time, this causes metal to metal contact which causes abnormal wear on the coupling teeth. Eventually, vibration levels increase. May cause excessive stress on the shaft, motor bearing(s), and the bullgear bearings. Vibration levels increase and are indicated on the system tab of the graphic display. Eventually, vibration levels increase such that the high vibration alarm system (from any one of the stages) produces alarm text on the INFO tab of the graphic display and illuminates the TROUBLE INDICATION light. If the text and the light go unnoticed, eventually, the vibration in one or more of the stages increases such that the high vibration trip system produces alarm text on the INFO tab, shuts down the compressor motor, energizes the prelube pump, and illuminates the PRELUBE PUMP RUNNING light. (The TROUBLE INDICATION light remains illuminated.) The inlet valve closes, and the bypass valve opens unloading the compressor. The graphic display indicates that the compressor is down. Possible internal damage to the motor, shaft, and/or the bullgear bearing. This causes low instrument air to the plant. It takes 2 days to replace the coupling but it could take weeks if the motor, shaft, and/or bullgear are damaged. Production stops for up to 2 days while an alternate means of producing instrument air is put in place.

Main drive shaft lubrication dissipates

Over time, this causes metal to metal contact which causes abnormal wear on the coupling teeth. Eventually, vibration levels increase. May cause excessive stress on the shaft, motor bearing(s), and the bullgear bearings.

Main drive shaft lubrication dissipates

Over time, this causes metal to metal contact which causes abnormal wear on the coupling teeth. Eventually, vibration levels increase. May cause excessive stress on the shaft, motor bearing(s), and the bullgear bearings. Vibration levels increase and are indicated on the system tab of the graphic display. Eventually, vibration levels increase such that the high vibration alarm system (from any one of the stages) produces alarm text on the INFO tab of the graphic display and illuminates the TROUBLE INDICATION light.

Main drive shaft lubrication dissipates

Over time, this causes metal to metal contact which causes abnormal wear on the coupling teeth. Eventually, vibration levels increase. May cause excessive stress on the shaft, motor bearing(s), and the bullgear bearings. Vibration levels increase and are indicated on the system tab of the graphic display. Eventually, vibration levels increase such that the high vibration alarm system (from any one of the stages) produces alarm text on the INFO tab of the graphic display and illuminates the TROUBLE INDICATION light. If the text and the light go unnoticed, eventually, the vibration in one or more of the stages increases such that the high vibration trip system produces alarm text on the INFO tab, shuts down the compressor motor, energizes the prelube pump, and illuminates the PRELUBE PUMP RUNNING light. (The TROUBLE INDICATION light remains illuminated.)

Main drive shaft lubrication dissipates

Over time, this causes metal to metal contact which causes abnormal wear on the coupling teeth. Eventually, vibration levels increase. May cause excessive stress on the shaft, motor bearing(s), and the bullgear bearings. Vibration levels increase and are indicated on the system tab of the graphic display. Eventually, vibration levels increase such that the high vibration alarm system (from any one of the stages) produces alarm text on the INFO tab of the graphic display and illuminates the TROUBLE INDICATION light. If the text and the light go unnoticed, eventually, the vibration in one or more of the stages increases such that the high vibration trip system produces alarm text on the INFO tab, shuts down the compressor motor, energizes the prelube pump, and illuminates the PRELUBE PUMP RUNNING light. (The TROUBLE INDICATION light remains illuminated.) The inlet valve closes, and the bypass valve opens unloading the compressor. The graphic display indicates that the compressor is down. Possible internal damage to the motor, shaft, and/or the bullgear bearing. This causes low instrument air to the plant.

Main drive shaft lubrication dissipates

Over time, this causes metal to metal contact which causes abnormal wear on the coupling teeth. Eventually, vibration levels increase. May cause excessive stress on the shaft, motor bearing(s), and the bullgear bearings. Vibration levels increase and are indicated on the system tab of the graphic display. Eventually, vibration levels increase such that the high vibration alarm system (from any one of the stages) produces alarm text on the INFO tab of the graphic display and illuminates the TROUBLE INDICATION light. If the text and the light go unnoticed, eventually, the vibration in one or more of the stages increases such that the high vibration trip system produces alarm text on the INFO tab, shuts down the compressor motor, energizes the prelube pump, and illuminates the PRELUBE PUMP RUNNING light. (The TROUBLE INDICATION light remains illuminated.) The inlet valve closes, and the bypass valve opens unloading the compressor. The graphic display indicates that the compressor is down. Possible internal damage to the motor, shaft, and/or the bullgear bearing. This causes low instrument air to the plant. **It takes 2 days to replace the coupling but it could take weeks if the motor, shaft, and/or bullgear are damaged. Production stops for up to 2 days while an alternate means of producing instrument air is put in place at a cost of \$200,000.**

Failure Modes and Effects Analysis (FMEA)

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE	FAILURE EFFECT
1	To transport up to 5 adult passengers and 3 medium-size suitcases along paved roads and highways for up to 360 miles without stopping in climates that range from 0° to 115° F (-17° to 46° C) while protecting passengers from the elements.	A	Completely unable to transport.	1	Engine consumes oil due to normal use.	During engine operation, the oil is gradually consumed by the engine. The decrease in oil is indicated on the dipstick. If this goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates. The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to destination but with some delay. Downtime to repair, up to 30 minutes.
				2	Engine oil system leaks.	Without warning, the system develops a leak. The leak is visually detectable on the ground. If this goes unnoticed, the oil quantity gradually decreases. The decrease in oil is indicated on the dipstick. If that goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates. The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to the destination. Most likely, the leak is small and the driver is able to reach the destination with minimal delay. However, worst case, the leak is so extensive that the driver cannot complete the journey and must have the vehicle towed to the nearest Subaru dealership for repair. Downtime to repair, 1 day to 1 week.

Engine oil system leaks.

Failure Modes and Effects Analysis (FMEA)

Engine oil system leaks.

Without warning, the system develops a leak. The leak is visually detectable on the ground.) If the visual leak goes unnoticed, the oil quantity gradually decreases. The decrease in oil is indicated on the dipstick. If this goes unnoticed, eventually the engine oil drops to the point that the LOW OIL LEVEL Light illuminates. The driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil is low. The driver replenishes the oil and continues to the destination but with some delay. Most likely, the leak is small and the driver is able to reach the destination with minimal delay. However, worst case, the leak is so extensive that the driver cannot complete the journey. Driver is stuck on the side of the road waiting for a tow truck. Worst case, this is at night on the highway or on a two-lane, dark country road. Downtime to repair, up to two weeks, up to \$2,000.



	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE		FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.				
<p>To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL light)</p>							
		B	?				What is another Functional Failure?



	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE		FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.				
<p>To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL light)</p>							
		B	Falsely illuminates the LOW OIL LEVEL Light.				
<p>Falsely illuminates the LOW OIL LEVEL Light.</p>							

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.			
		B	Falsely illuminates the LOW OIL LEVEL Light.		?	What specifically causes it to falsely illuminate?

Falsely illuminates the LOW OIL LEVEL Light.

?

What specifically causes it to falsely illuminate?

Failure Modes and Effects Analysis (FMEA)

	FUNCTION		FUNCTIONAL FAILURE		FAILURE MODE	FAILURE EFFECT
2	To be capable of visually alerting the driver in the event that the engine oil level decreases to the lower limit. (LOW OIL LEVEL Light)	A	Incapable of visually alerting the driver in the event that the engine oil level decreases to the lower limit.			
		B	Falsely illuminates the LOW OIL LEVEL Light.	1	LOW OIL LEVEL Light circuit fails closed.	

Falsely illuminates the LOW OIL LEVEL Light.

LOW OIL LEVEL Light circuit fails closed.

Failure Modes and Effects Analysis (FMEA)

	FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECT
2	To be capable of alerting the driver in the event that the engine oil level decreases below the lower limit. (LOW OIL LEVEL Light)			<p>While driving, the LOW OIL LEVEL Light illuminates. The driver thinks that there is a low oil situation. Driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil level is normal. The time it takes to check the oil is minimal so the driver is able to arrive at the intended destination with minimal delay. Driver schedules the vehicle for service at the next available opportunity. Time to repair, up to one day.</p>
		Falsely illuminates the LOW OIL LEVEL Light.	LOW OIL LEVEL Light circuit fails closed.	
		B Falsely illuminates the LOW OIL LEVEL Light.	1 LOW OIL LEVEL Light circuit fails closed.	<p>While driving, the LOW OIL LEVEL Light illuminates. The driver thinks that there is a low oil situation. Driver pulls over at the nearest service station and checks the oil. The dipstick indicates that the engine oil level is normal. The time it takes to check the oil is minimal so the driver is able to arrive at the intended destination on time. Driver schedules vehicle for service at the next available opportunity. Time to repair, 1 day.</p>