RELIABILITY CENTERED MAINTENANCE (RCM)

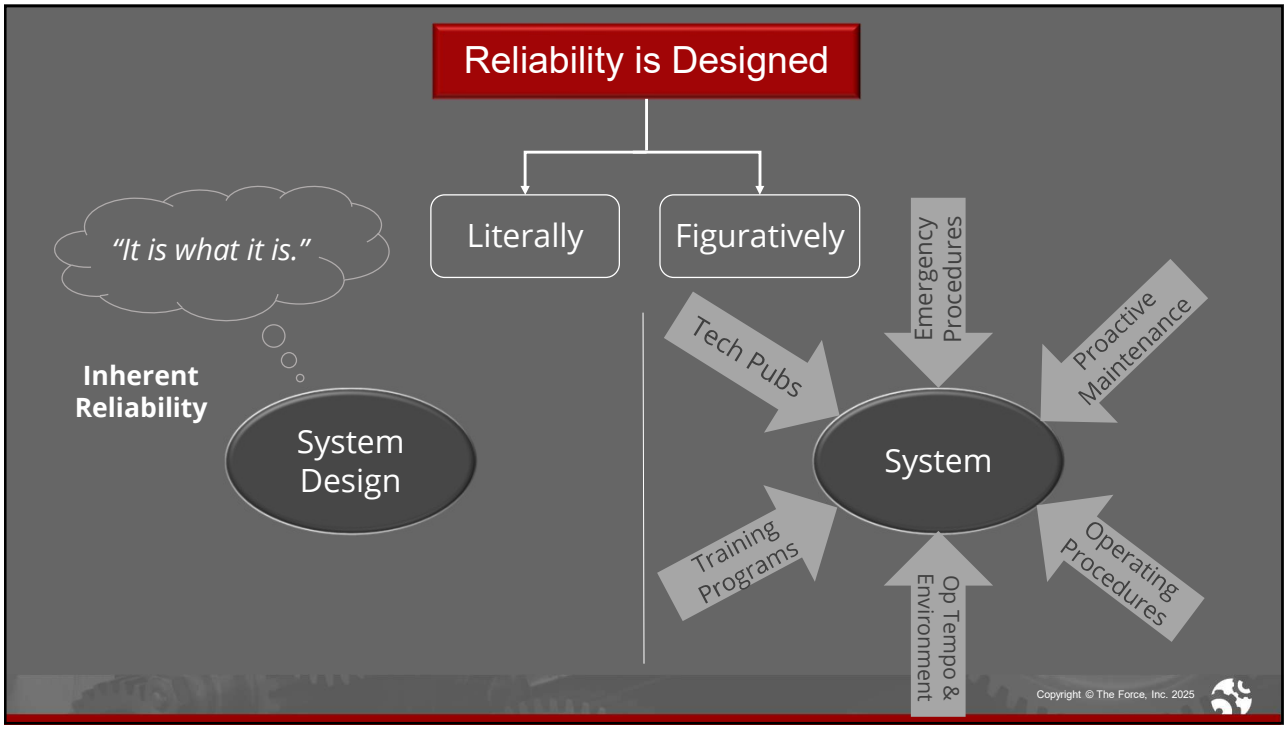
RCM Overview

Nancy Regan

1

Reliability

2


Reliability is Designed
Literally
Figuratively
"It is what it is."
Inherent Reliability
System Design
Tech Pubs
Emergency Procedures
Proactive Maintenance
System
Training Programs
Operating Procedures
Op Tempo & Environment
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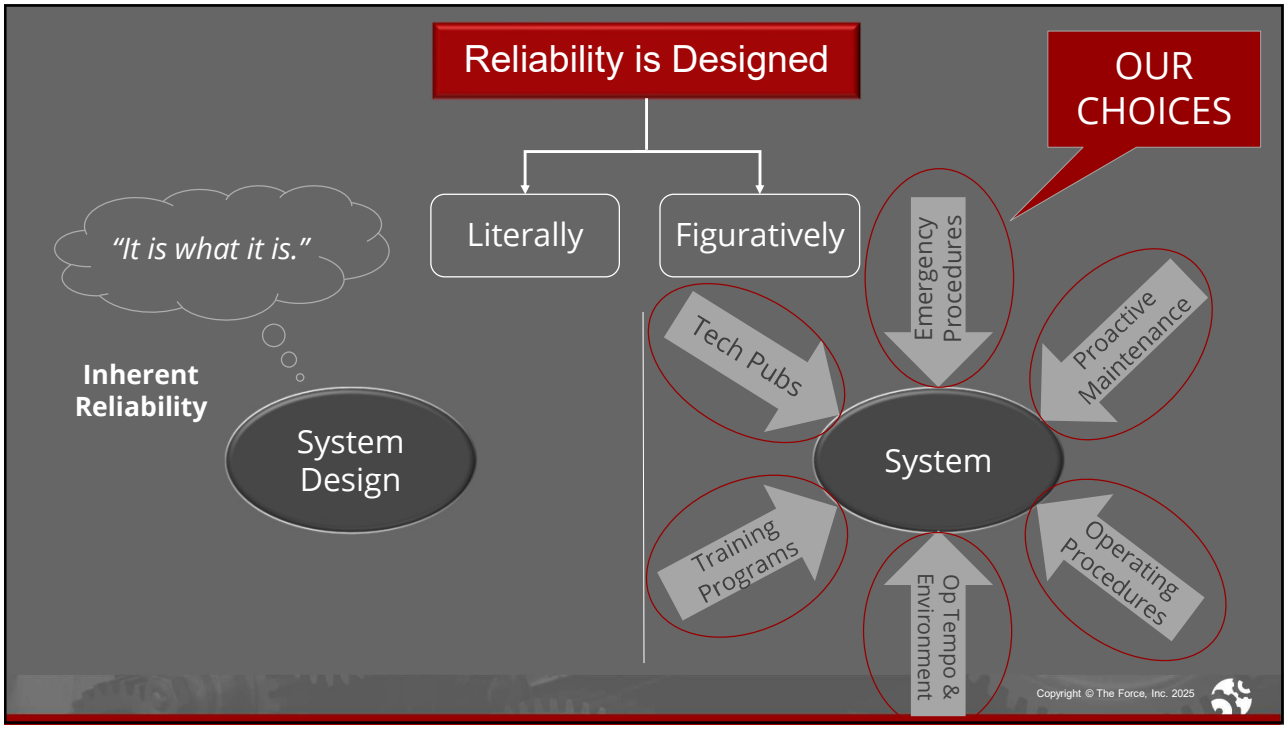
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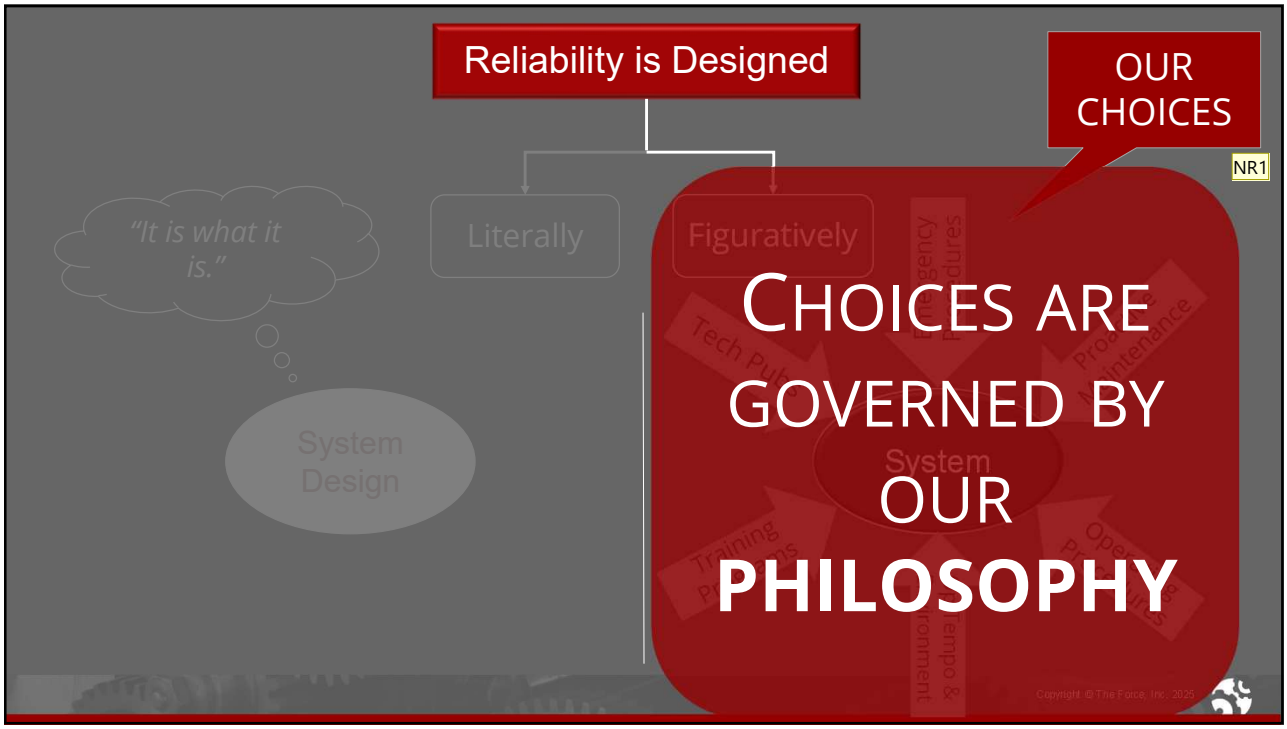

5

RCM is a Philosophy

6

Slide 5

NR1 Nancy Regan, 8/22/2021

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

7

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
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8

Functions

Function without much thought

- Deliver compressed air to tank

Writing Functions as a Matter of Routine

Properly Written Function

- To provide compressed air that is oil free, <100°F, at a minimum of 4,000 SCFM, 110 psig output pressure, to make up this compressor's portion of maintaining 14,000 [illegible] pressure to the plant.

Defining Reliability

9

Define Reliability with 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

FMEA

Failure Modes and Effects Analysis (FMEA)

Functions	Functional Failures	Failure Modes	Failure Effects
1.	A.	1.	
1.	B.	1.	
2.	A.	1.	

10

Let's debunk an RCM myth.

RCM takes too long, it's too complex, and it's too expensive.

11

FMEA: Industrial Air Compressor

	Function		Functional Failure		Failure Mode	Failure Effect
1	Deliver compressed air to the tank.					

12

FMEA: Industrial Air Compressor

	Function		Functional Failure		Failure Mode	Failure Effect
1	To provide compressed air that is oil free, <100°F, at a minimum of 4,000 SCFM, 110 psig output pressure, to make up this compressor's portion of maintaining 14,000 SCFM and 110 psig header pressure to the plant.					

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13

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14

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15

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16

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17

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18

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19

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	…and so on…			

Two Questions

1. Do all these Functions need to be listed?
2. For those we DO need to include, are they written in enough detail?

21

How to determine if a Function should be recorded

22

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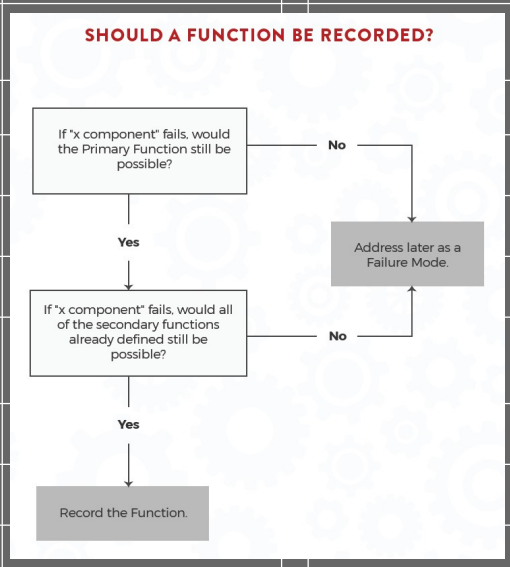

23

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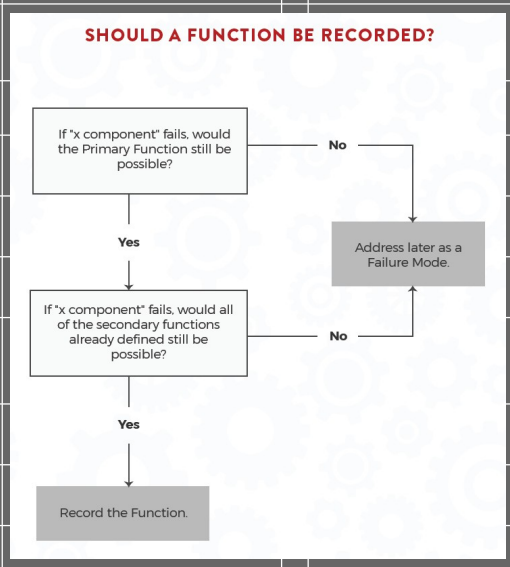

24

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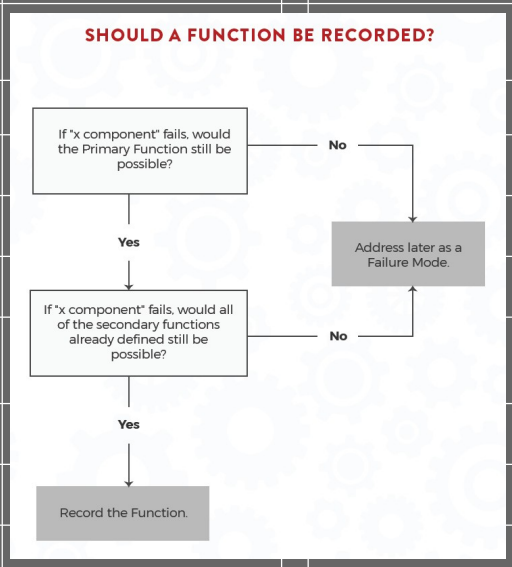

25

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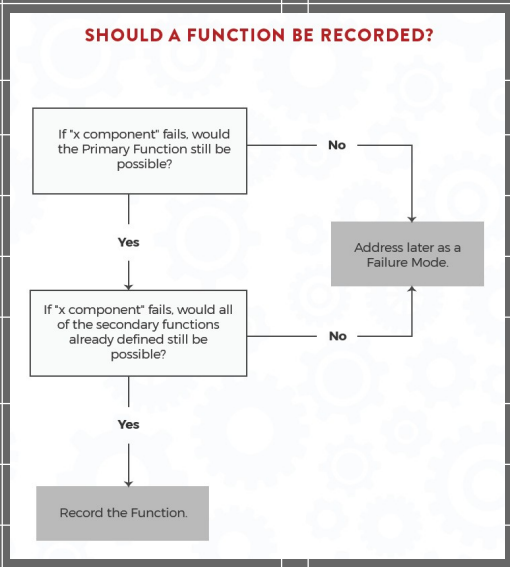

27

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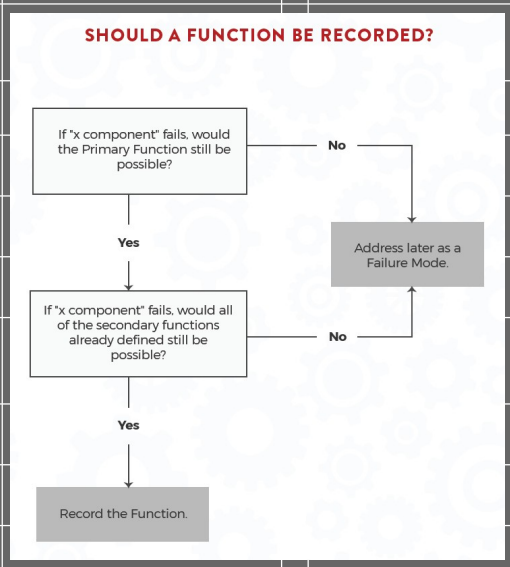

28

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29

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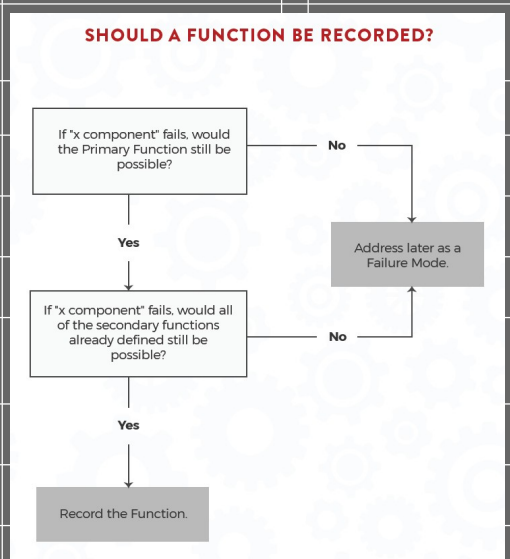

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30

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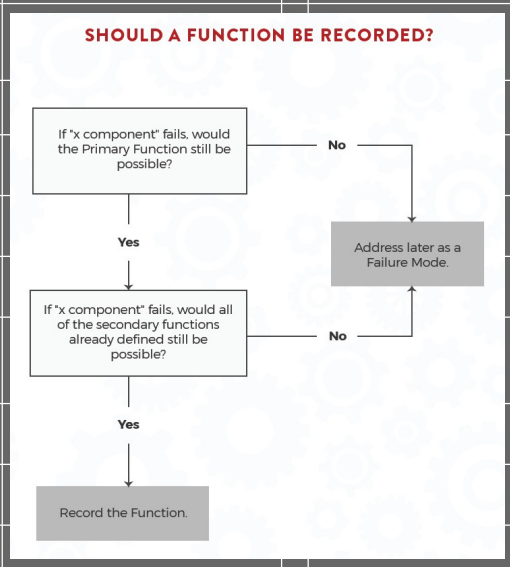

31

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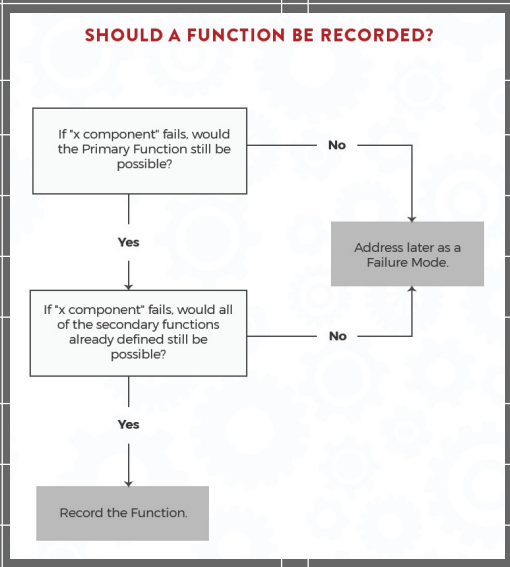

33

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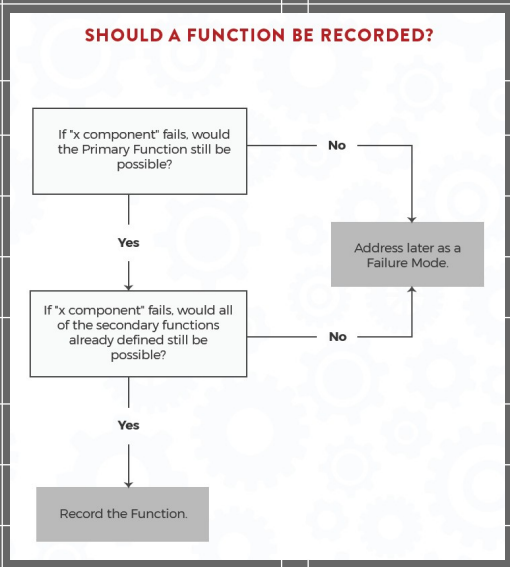

34

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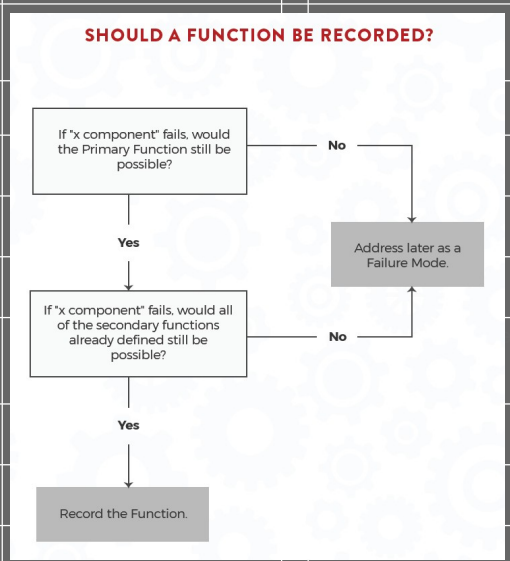

36

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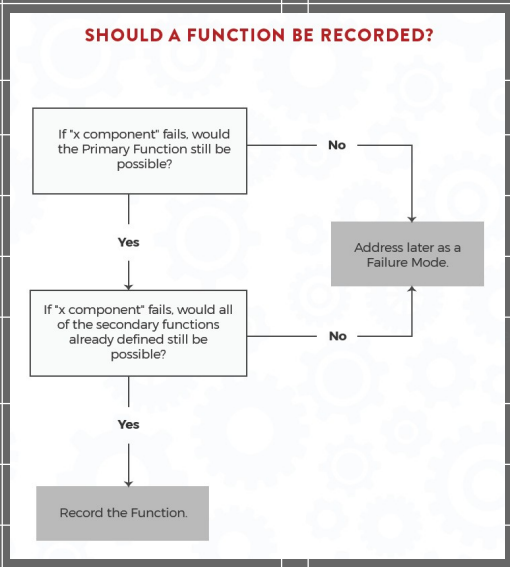

37

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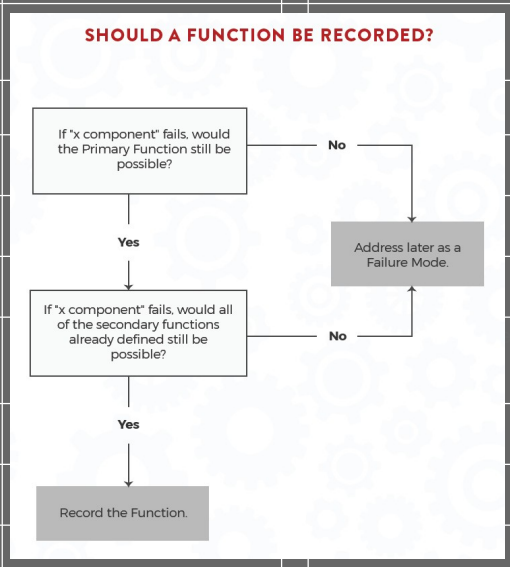
4	~~To couple the electric motor to the compressor. (main drive shaft)~~			3	Main drive shaft lubrication dissipates.	
5	~~To filter the compressor oil. (oil filter)~~			4	Oil filter clogs due to normal use.	
6	~~To filter out debris and unwanted particles from the electric motor. (electric motor intake screen)~~			5	Electric motor intake screen clogs due to normal use.	
7	To indicate the pressure drop across the oil filter. (oil filter differential pressure gauge)					
8	To visually indicate that the prelube pump is running. (prelube pump running light)					

38

FMEA: Industrial Air Compressor

	Function	Functional Failure	Failure Mode	Failure Effect
1	To provide compressed air that is oil free, <100°F, at a minimum of 4,000 SCFM, with a minimum of 5 psig rise to surge, 110 psig output pressure, to make up this compressor's portion of maintaining 14,000 SCFM and 110 psig header pressure to the plant.			
2	~~To provide force feed lubrication. (main oil pump)~~			
3	~~To power the compressor. (electric motor)~~			
4	~~To couple the electric motor to the compressor. (main drive shaft)~~			
5	~~To filter the compressor oil. (oil filter)~~			
6	~~To filter out debris and unwanted particles from the electric motor. (electric motor intake screen)~~			
7	To indicate the pressure drop across the oil filter. (oil filter differential pressure gauge)			
8	To visually indicate that the prelube pump is running. (prelube pump running light)			



39

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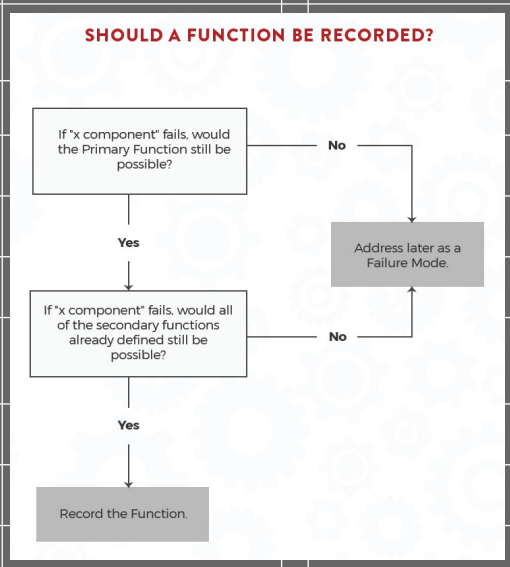
2	To indicate the pressure drop across the oil filter ***within +/- 1 psi***. (oil filter differential pressure gauge)			
8	To visually indicate that the prelube pump is running. (prelube pump running light)			



40

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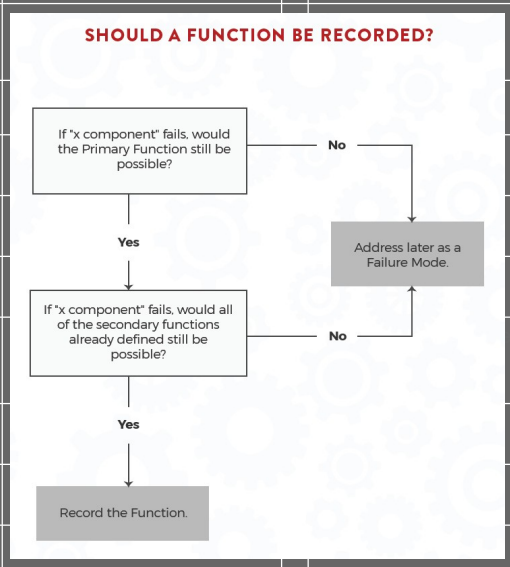

41

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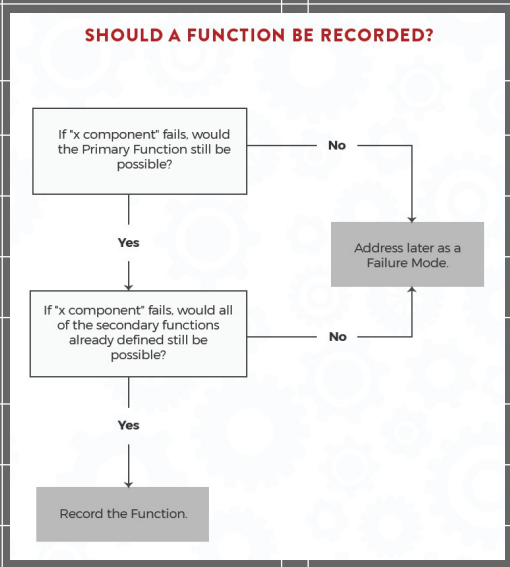

42

FMEA: Industrial Air Compressor

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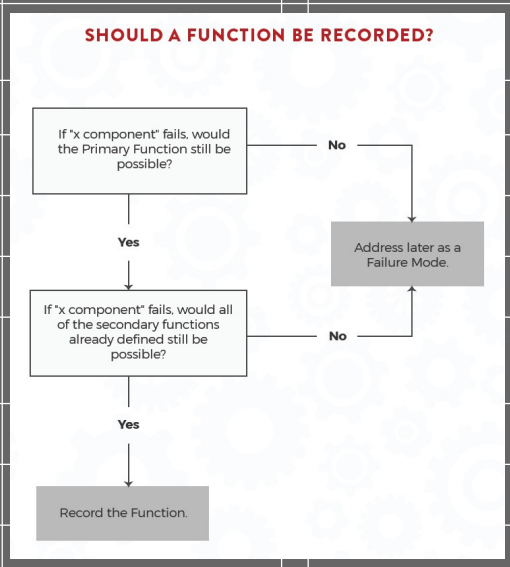


43

Failure Modes

44

Reliability Centered Maintenance

Failure Mode

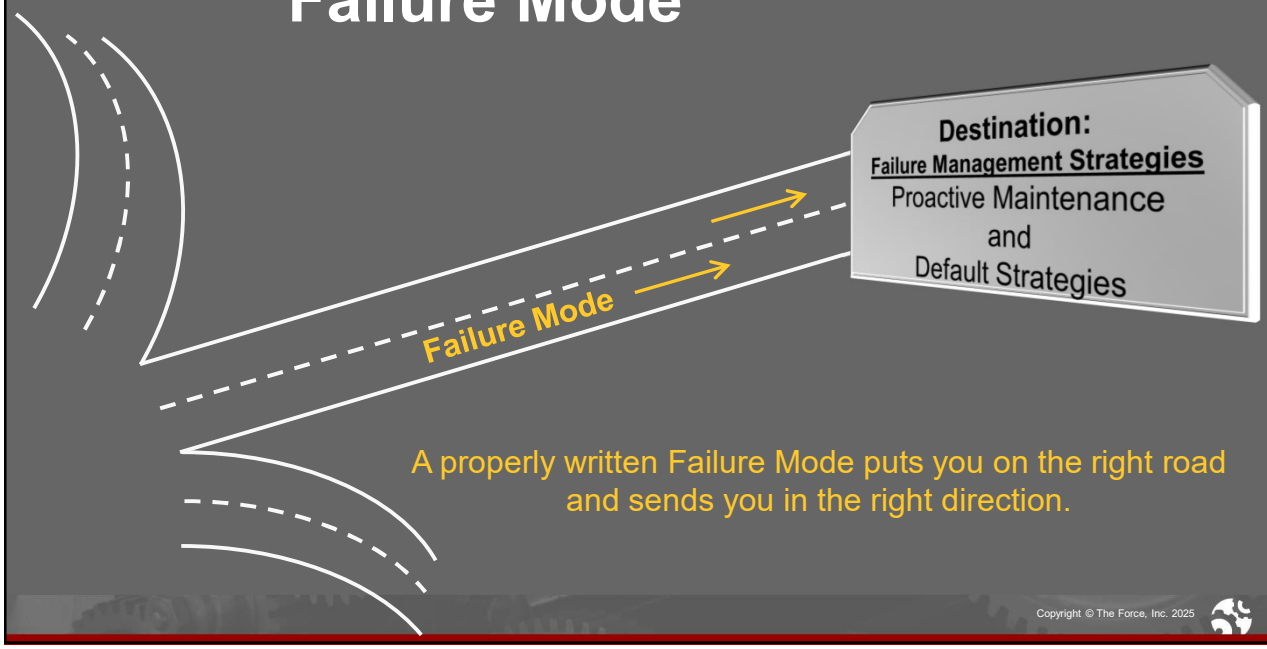
What specifically causes functional failure

RCM Process

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

45

Failure Mode



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

46

How detailed should Failure Modes be written?

Failure Modes should be written in enough detail so that an appropriate *Failure Management Strategy* can be developed.

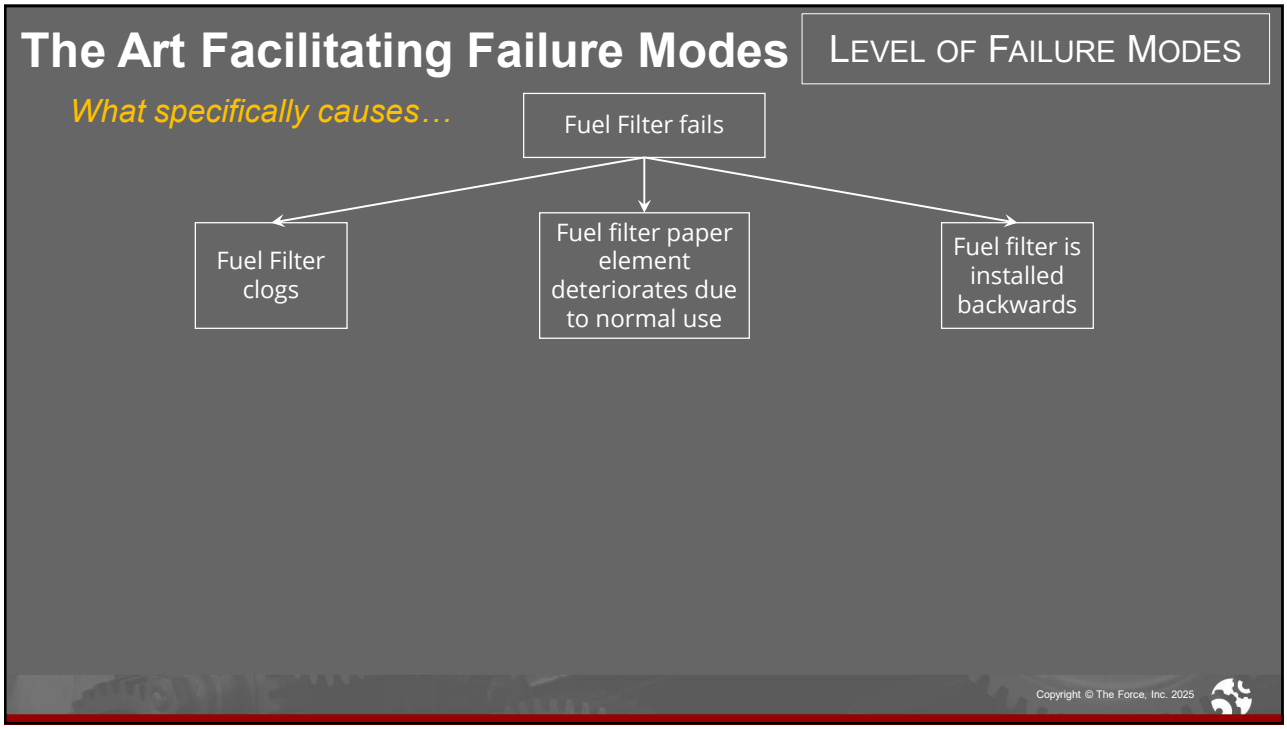
47

The Art of Writing Failure Modes

Fuel Filter fails

Is this written in enough detail so that an appropriate Failure Management Strategy can be formulated?

48


The Art Facilitating Failure Modes
LEVEL OF FAILURE MODES
What specifically causes…
Fuel Filter fails
Fuel Filter clogs
Fuel filter paper element deteriorates due to normal use
Fuel filter is installed backwards
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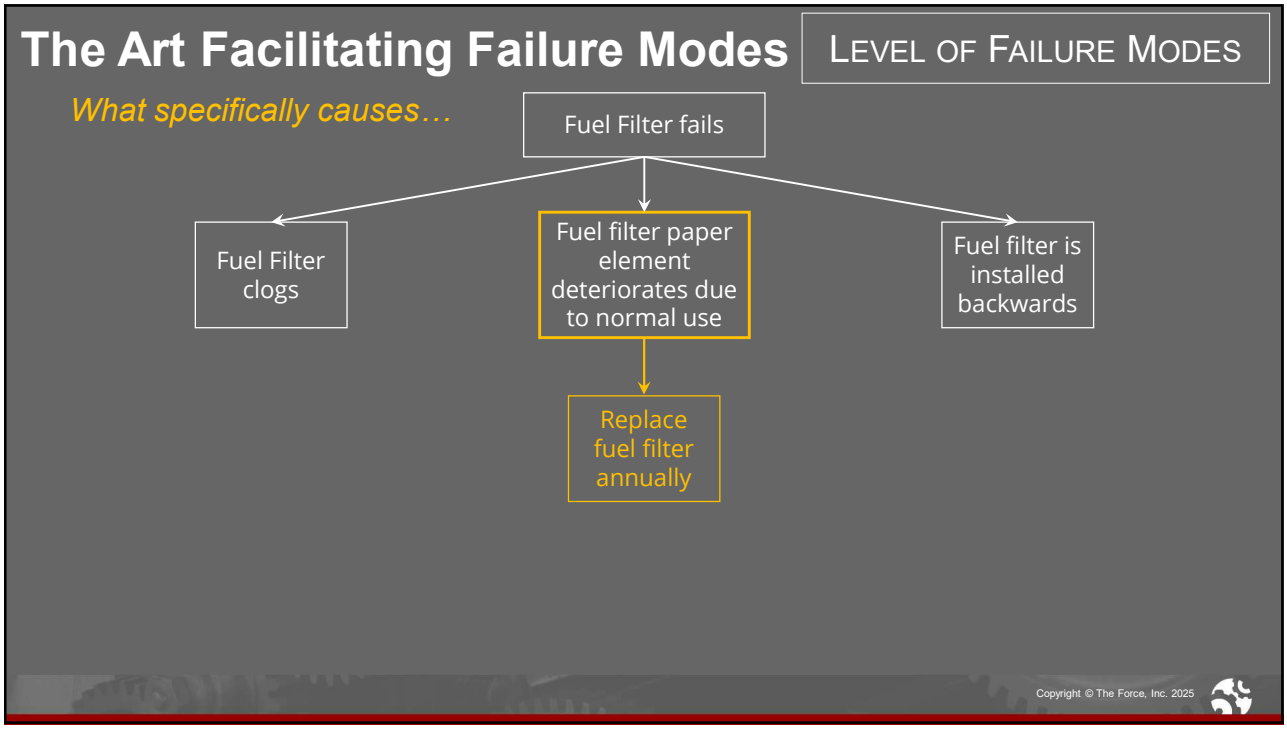
The Art Facilitating Failure Modes
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What specifically causes…
Fuel Filter fails
Fuel Filter clogs
Fuel filter paper element deteriorates due to normal use
Fuel filter is installed backwards
Replace fuel filter annually
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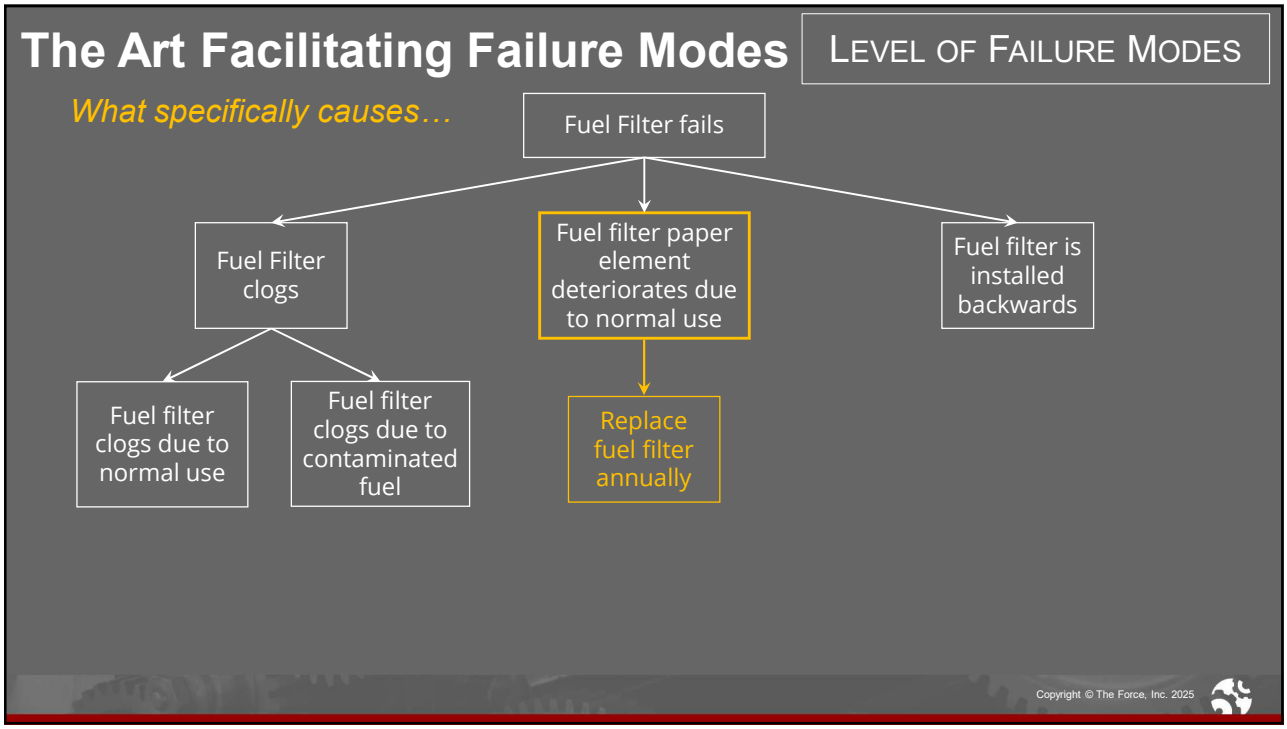
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Fuel filter paper element deteriorates due to normal use
Fuel filter is installed backwards
Fuel filter clogs due to normal use
Fuel filter clogs due to contaminated fuel
Replace fuel filter annually
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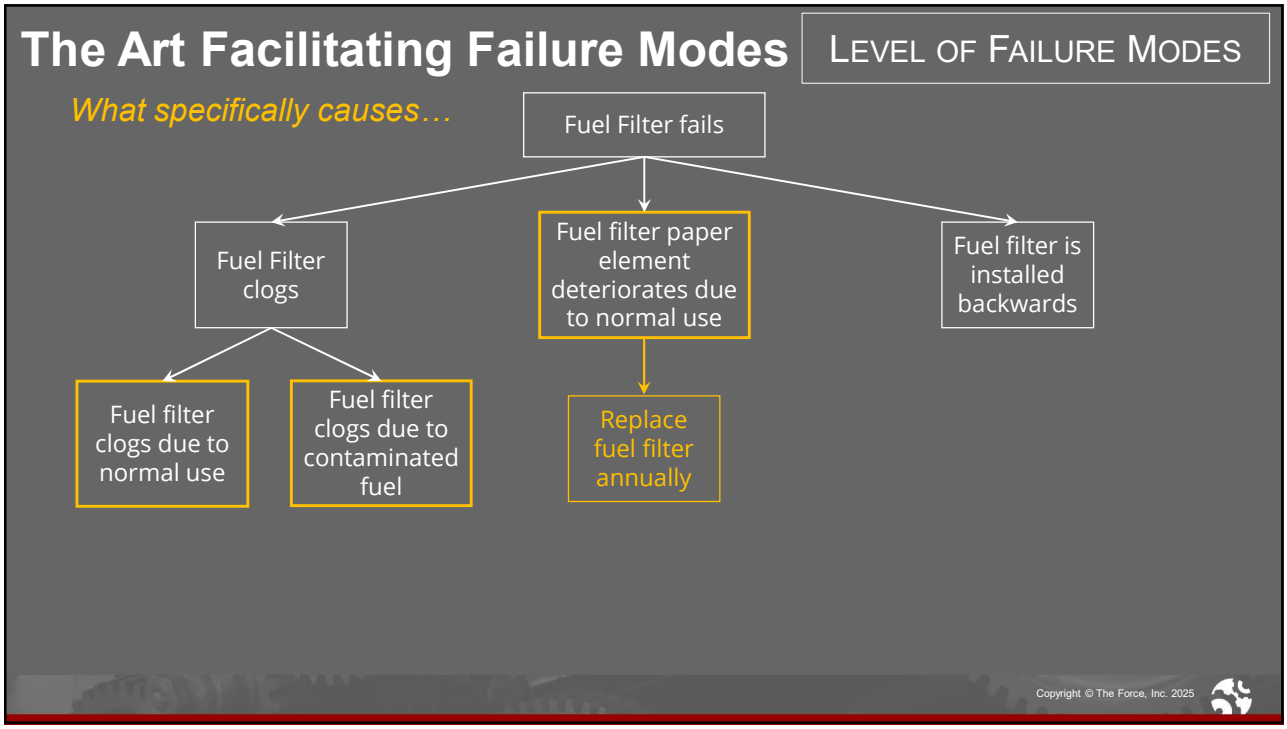
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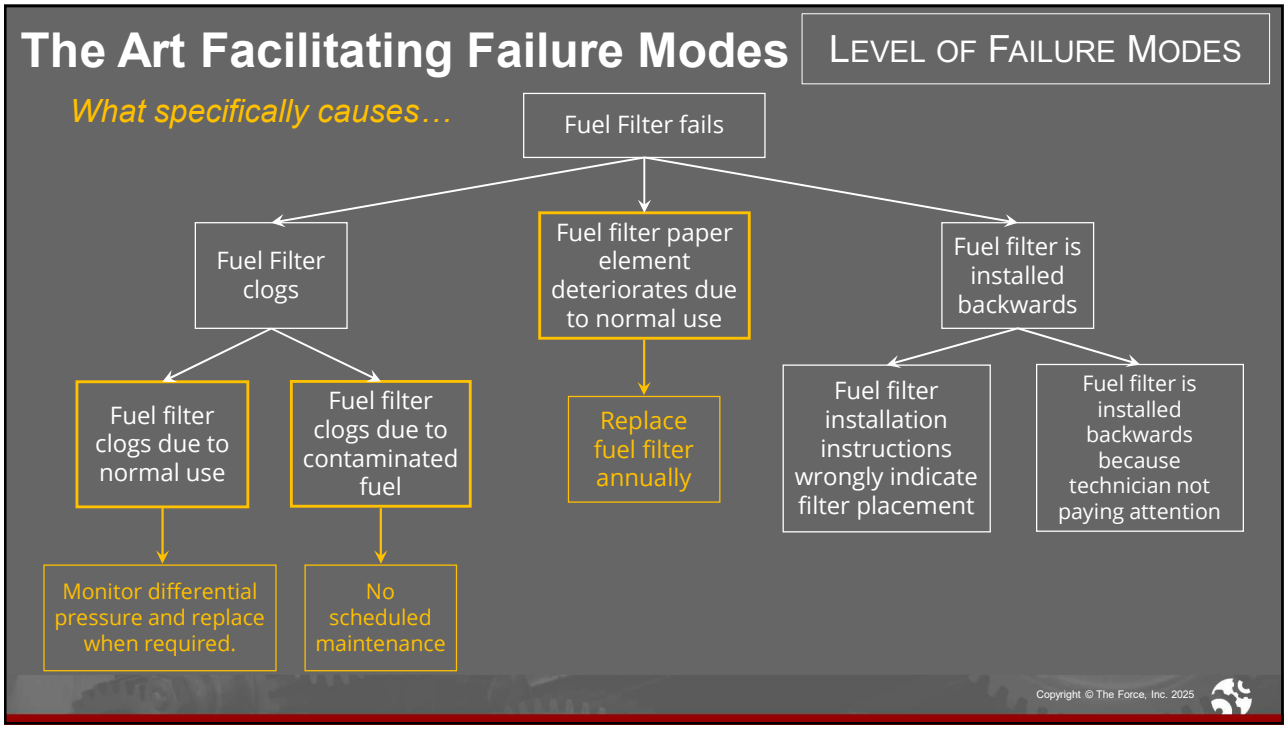
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Replace fuel filter annually
Fuel filter installation instructions wrongly indicate filter placement
Fuel filter is installed backwards because technician not paying attention
Monitor differential pressure and replace when required.
No scheduled maintenance
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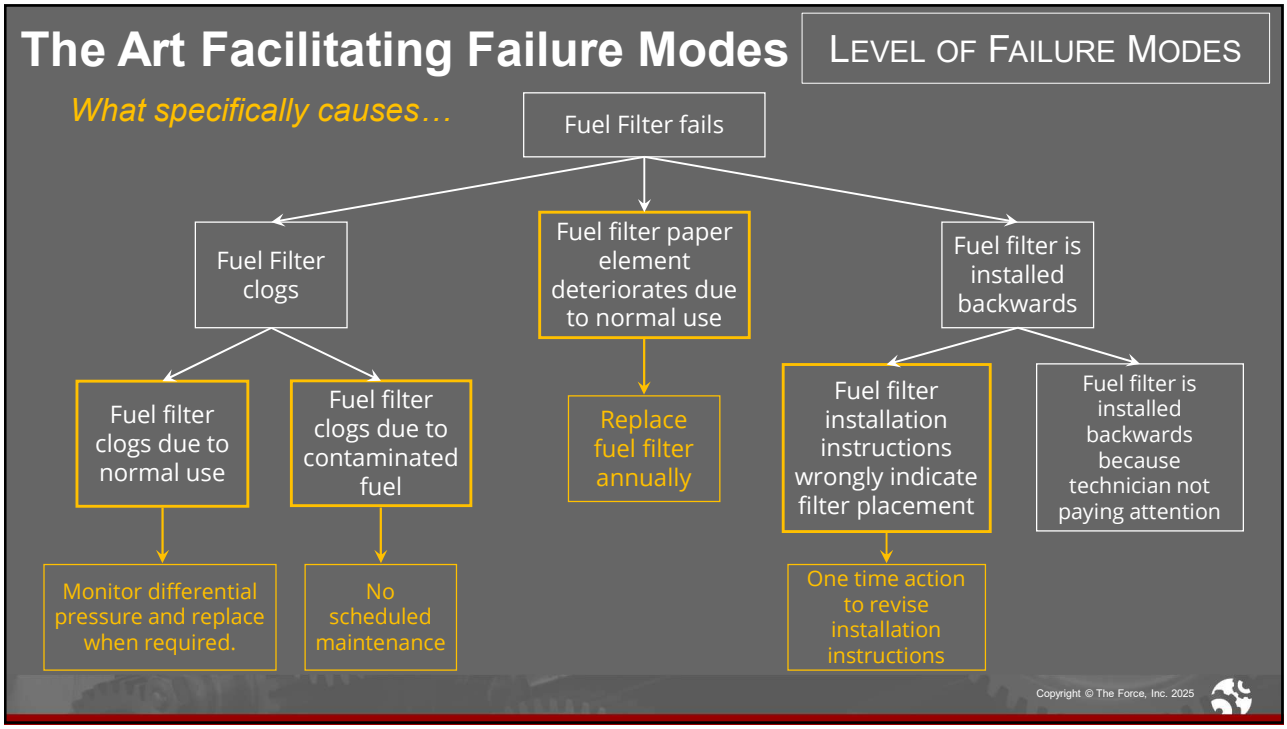
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No scheduled maintenance
One time action to revise installation instructions
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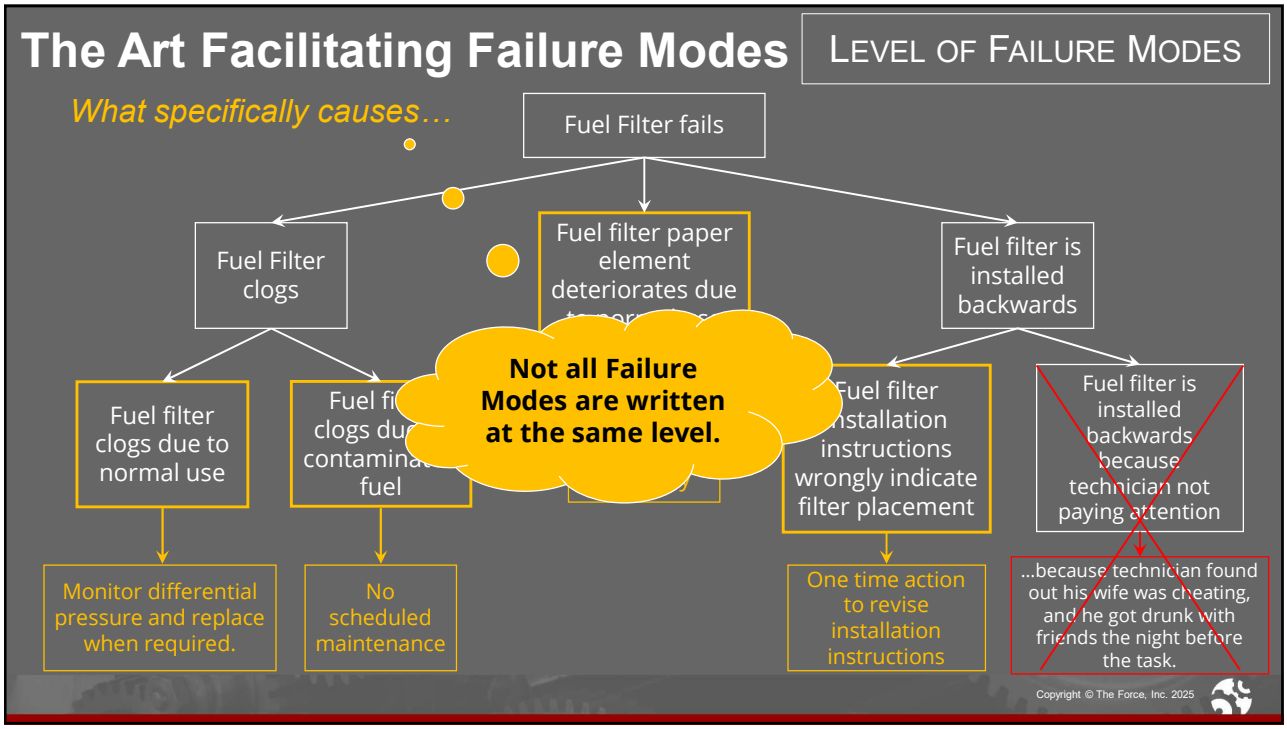
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What specifically causes…
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Fuel Filter clogs
Fuel filter paper element deteriorates due
Fuel filter is installed backwards
Fuel filter clogs due to normal use
Fuel fi
clogs du
contamina
fuel
Not all Failure Modes are written at the same level.
Fuel filter
nstallation
instructions
wrongly indicate
filter placement
Fuel filter is installed backwards because technician not paying attention
Monitor differential pressure and replace when required.
No scheduled maintenance
One time action to revise installation instructions
…because technician found out his wife was cheating, and he got drunk with friends the night before the task.
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55


DATA
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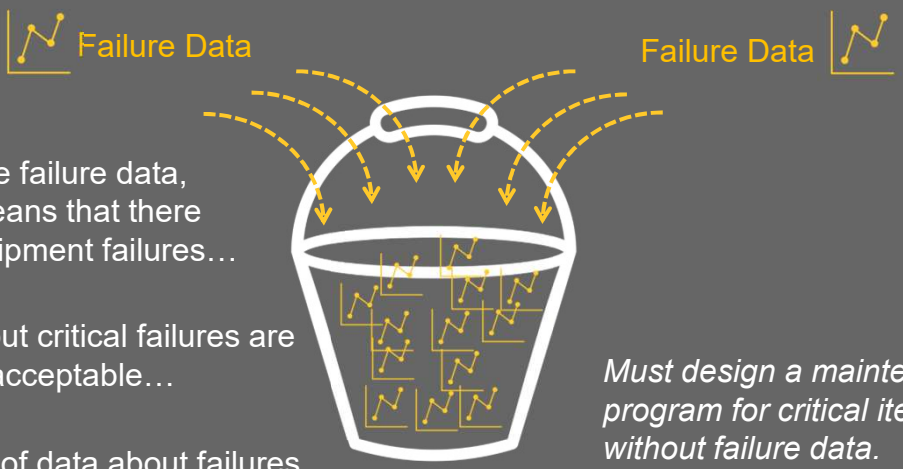
56

Resnikoff Conundrum



If we have failure data, then it means that there were equipment failures…

…but critical failures are unacceptable…

…bucket of data about failures that don't matter much.

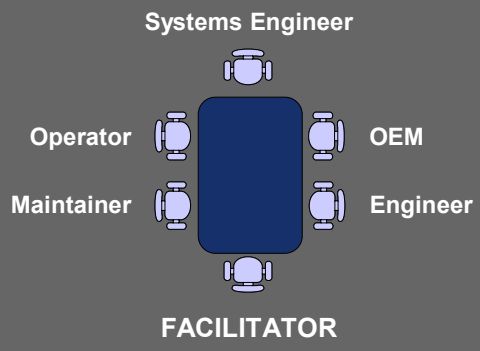
Must design a maintenance program for critical items without failure data.

57

Facilitated Working Group

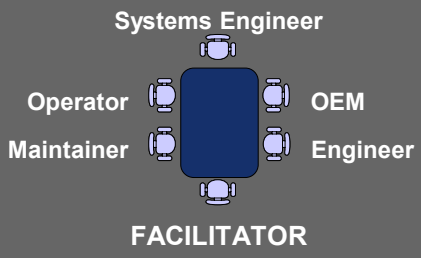
58

Augment Failure Data with Facilitated Working Group



59

Augment Failure Data with Facilitated Working Group



Significant experience and understand

- Equipment
- Operating Environment
- Operational tempo
- What is required from the machine

In the best position to know:

- What can go wrong
- What happens when something fails
- How it matters
- When asked the right questions, can determine what to do about it

60

Reliability Centered Maintenance

Failure Effect

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

61

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

62

Failure Mode: *Feedwater pump bearing lubrication dissipates.*

Lack of lubrication causes the bearing to wear abnormally. Vibration levels increase. If this goes unnoticed, eventually noise develops and just before failure, friction increases such that heat and smoke are generated. The bearing seizes, the pump stops, and feedwater is no longer supplied to the boiler. The water level in the boiler drops and is indicated on the water level sight gauge. If this goes unnoticed, eventually inadequate water is available to continue producing steam. The output steam pressure decreases such that less than 10 psi is delivered to the paper drying process. The drop in output pressure is indicated on the steam pressure gauge. When the steam supplied to the paper drying process falls below 140 psi, the low steam pressure alarm sounds. Up to 20,000 feet of paper are not thoroughly dried before the steam to the paper drying process can be stopped at a cost of $50,000. The paper is scrapped for recycle and the feedwater pump motor is replaced. Downtime to repair, 8 hours.

63

Reliability Centered Maintenance

Steps 1-4: FMEA
Failure Modes and Effects Analysis

RCM Process

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

64

Reliability Centered Maintenance

Failure Consequences

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

65

Reliability Centered Maintenance

Steps 1-4: FMEA
Failure Modes and Effects Analysis

RCM Process

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

66

Reliability Centered Maintenance

Proactive Maintenance

Scheduled Restoration
Scheduled Replacement
Condition Based Maintenance

RCM Process

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

67

Proactive Maintenance

Preventive Maintenance

Scheduled Restoration

Scheduled Replacement

Condition Based Maintenance

CBM

✓ Technically Feasible
✓ Worth Doing

68

Preventive Maintenance

69

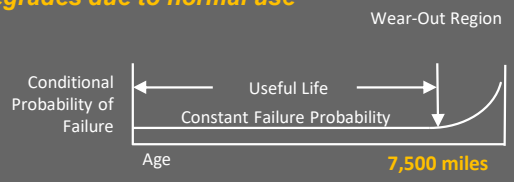
Proactive Maintenance

Preventive Maintenance

- *Scheduled Restoration*
- *Scheduled Replacement*

Failure Mode:

2014 Subaru Forester engine oil degrades due to normal use



- ✓ Technically Feasible
- ✓ Worth Doing

70

Condition Based Maintenance

71

Condition Based Maintenance (CBM)

- Most Failure Modes occur randomly

Failure Pattern E

No relationship between age and the likelihood of failure

72

Condition Based Maintenance

- Most Failure Modes occur randomly

Just because most Failure Modes occur randomly doesn't mean we can't manage them.

Most Failure Modes give us a warning that failure is in the process of occurring…there's evidence of impending failure.

Potential Failure Conditions

Illuminated warning lights
Increased vibration
Noise
Heat
Wear

73

Condition Based Maintenance

- Most Failure Modes occur randomly

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

74

Condition Based 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.)

75

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 a CBM task, let's start with what makes it technically feasible.

76

Condition Based Maintenance (CBM)

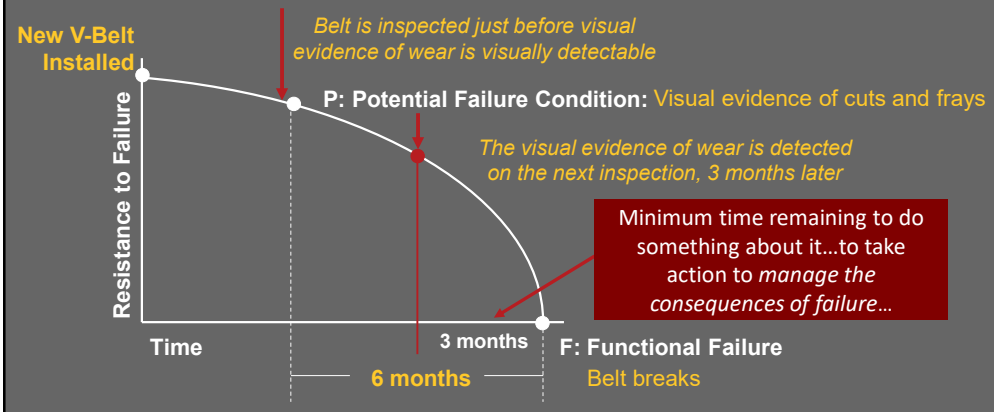
In order to determine if a CBM task is technically feasible, Potential Failure Conditions must be evaluated.

77

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.



78

How CBM task intervals are set is a widely misunderstood concept.

Four Key Points:

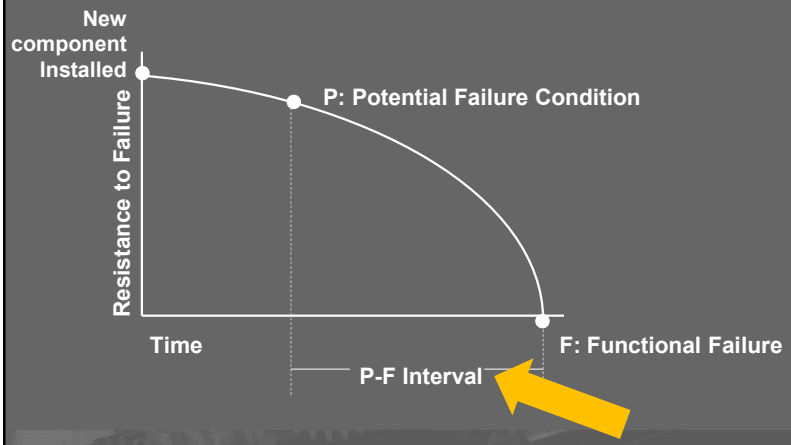
1. CBM task intervals are NOT based upon MTBF.
2. CBM task intervals are NOT based upon the *useful life* of a component.
3. CBM task intervals are NOT based upon the *criticality of the failure*.
4. CBM task intervals are based upon…

79

Condition Based Maintenance (CBM)

P-F Curve

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

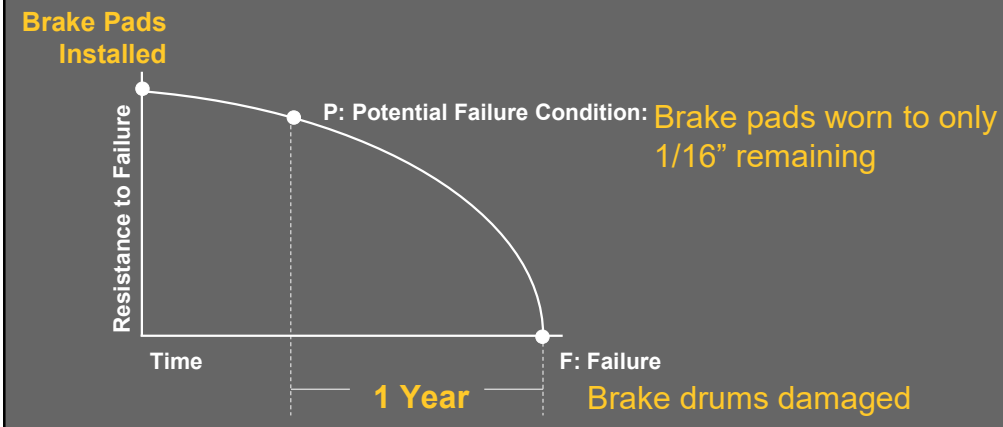


80

Condition Based Maintenance (CBM)

P-F Curve

You define what "Failure" is…not necessarily Functional Failure per the FMEA.

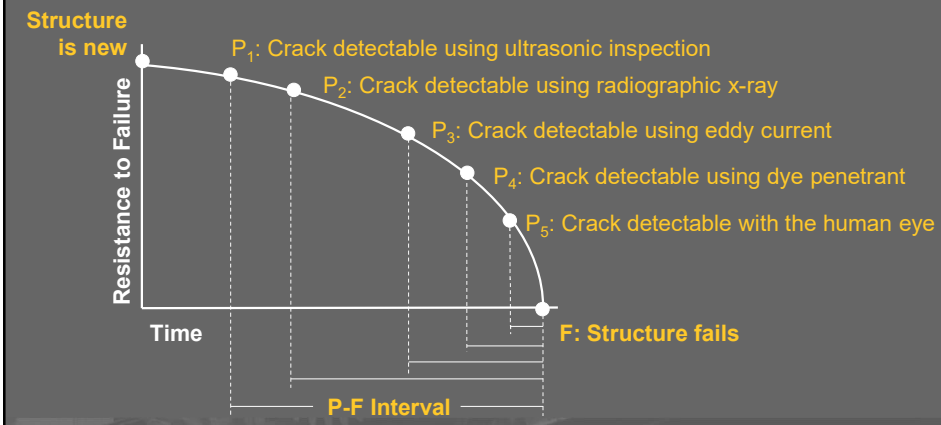


81

Condition Based Maintenance (CBM)

P-F Curve

There can be more than one Potential Failure Condition

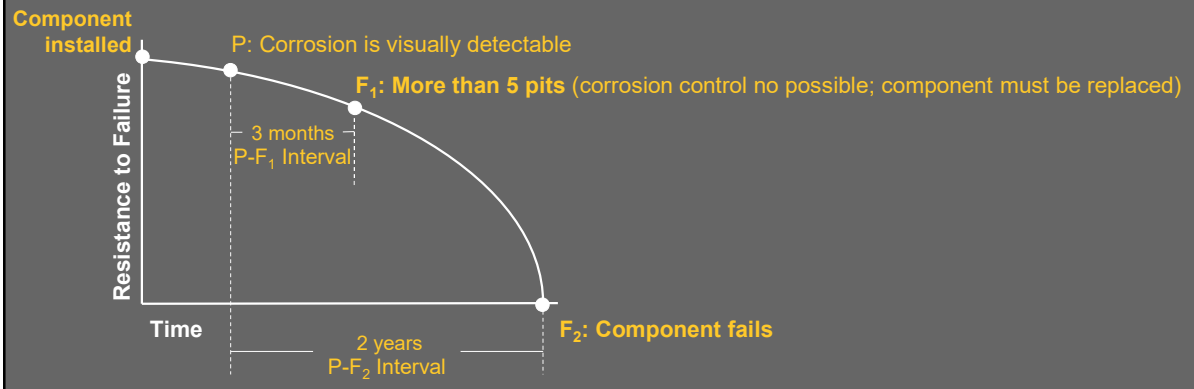


82

Condition Based Maintenance (CBM)

P-F Curve

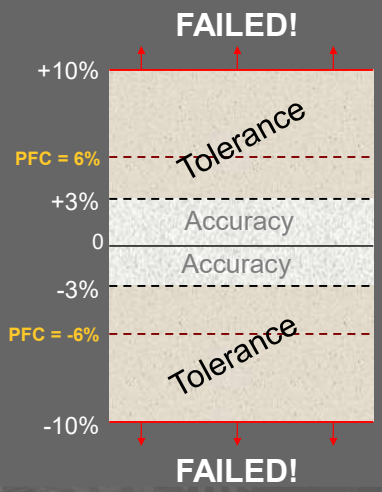
There can be more than one "Failure."

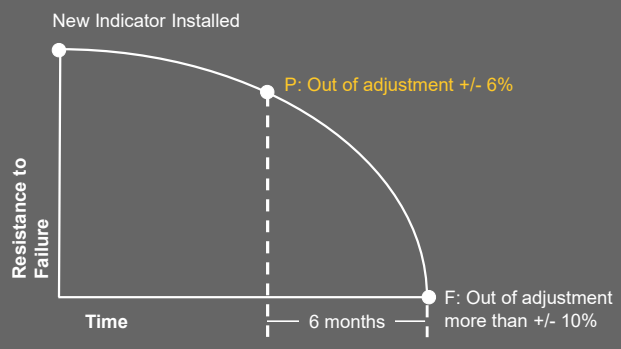


83

Accuracy and Tolerance

6. To display the quantity of fuel in the tank within +/- 10% of actual. (Fuel Level Indicator)
B. Displays the quantity of fuel in the tank to within more than +/- 10% of actual.
2. Fuel level indicator drifts out of adjustment due to normal use.





Assuming the task is worth doing, how often should the indicator be checked for proper calibration?

3 Months

84

Worth Doing

85

What do we mean by *worth doing?*

Example: Generator bearing wears due to normal use.

Doing the Maintenance	Not Doing the Maintenance (Run to Failure)
Task: Perform vibration analysis on generator bearing every 6 months **Cost to perform the task:** $200 **Cost of task over a 10 year period:** • Perform the task 20 times (20 tasks)($200 per task) = $4,000	**MTBF of the Bearing:** 5 years **Cost of Secondary Damage if run to failure:** $4,000 **Cost of running to failure over a 10 year period:** On average, over 10 years bearing will fail twice (2 bearing failures)($4,000 secondary damage) = $8,000

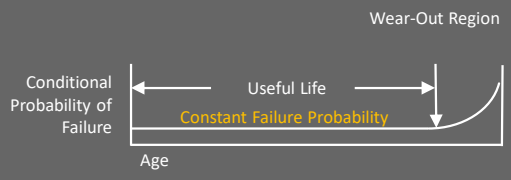
Is it "worth it" to do the maintenance? Yes!

86

Proactive Maintenance

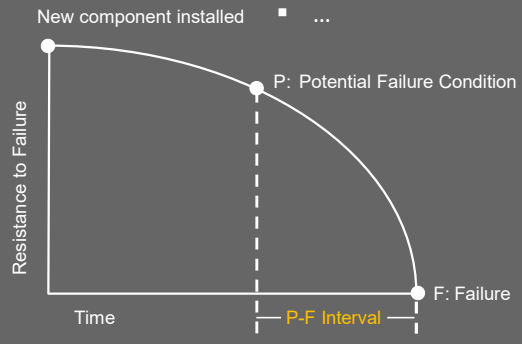
Preventive Maintenance

- *Scheduled Restoration*
- *Scheduled Replacement*



Condition Based Maintenance (CBM)

- Visual Inspections
- Infrared Technology
- Vibration Analysis
- Ultrasonic Inspection
- …



87

Reliability Centered Maintenance

Default Strategies

- Physical Redesigns
- Updates to tech pubs
- Modifications to operating procedures
- Additions to training programs
- Supply changes
- Revisions to troubleshooting procedures
- New tool
- Failure Finding Tasks
- No scheduled maintenance
- …

RCM Process

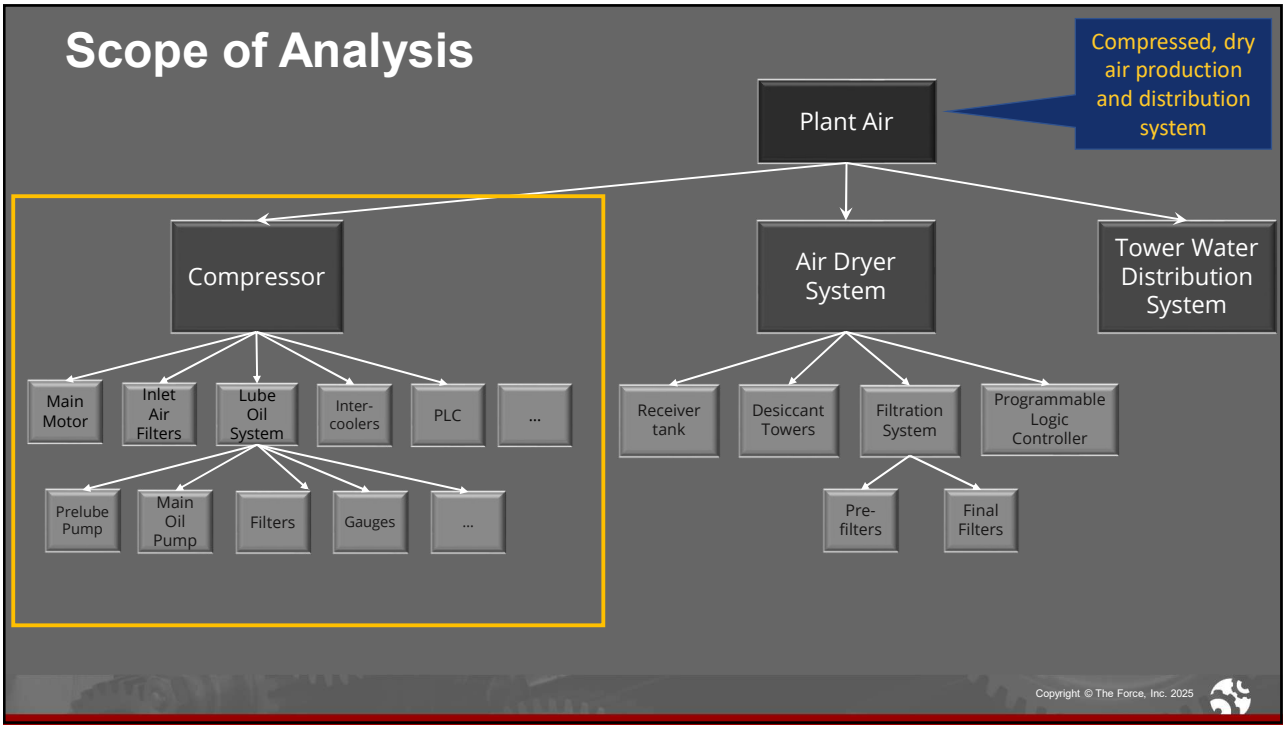
1. Functions
2. Functional Failures
3. Failure Modes
4. Failure Effects
5. Failure Consequences
6. Proactive Maintenance and Intervals
7. Default Strategies

88

On what assets do we apply RCM?

89

Scope of Analysis



90

Summary

91

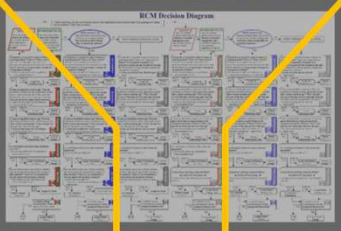
RCM Decision Diagram

One Failure Mode at a Time

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.	

RCM Decision Diagram



1) **Assess Consequences**
2) **Decisions → *How to manage each Failure Mode***
   - Proactive Maintenance
   - Default Strategy

92

Reliability Centered Maintenance *Myths*

- ☒ RCM takes too long, it's too complex, and it's too expensive.
- ☒ You must choose between FMEA or RCM.
- ☒ You must choose between CBM or RCM.
- ☒ RCM is a maintenance program.
- ☒ If you do RCM, you must do it on all assets.

93

Thank You!

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94