



SNC • LAVALIN

3 Day (6 Session version) Reliability Centred Maintenance (RCM) Foundation Course V2.1

Atkins Presentation: 18 January 2021

Presenter: Robert (Rab) Adam

Session 1 – Look Forward

- › Register and Name Cards. Domestics.
- › Introductions – Name/Job/How Long/Ice Breaker (e.g. Interesting Fact).
- › Look Forward
 - › *Course Introduction*
 - › *Changing World of Maintenance*
 - › *Traditional Views of Equipment Failure – LIFE*
 - › *Reality of Failure (6 Failure Characteristics)*
 - › *Want and Can*
 - › *New Maintenance Techniques (1st, 2nd and 3rd Generation mitigation of deterioration)*
 - › *RCM definition and Operating Context*
 - › *Define RCM (Full – 7 Questions and Structure of Course)*
 - › *Primary Functions*
 - › *Secondary Functions*



Overview/Aim

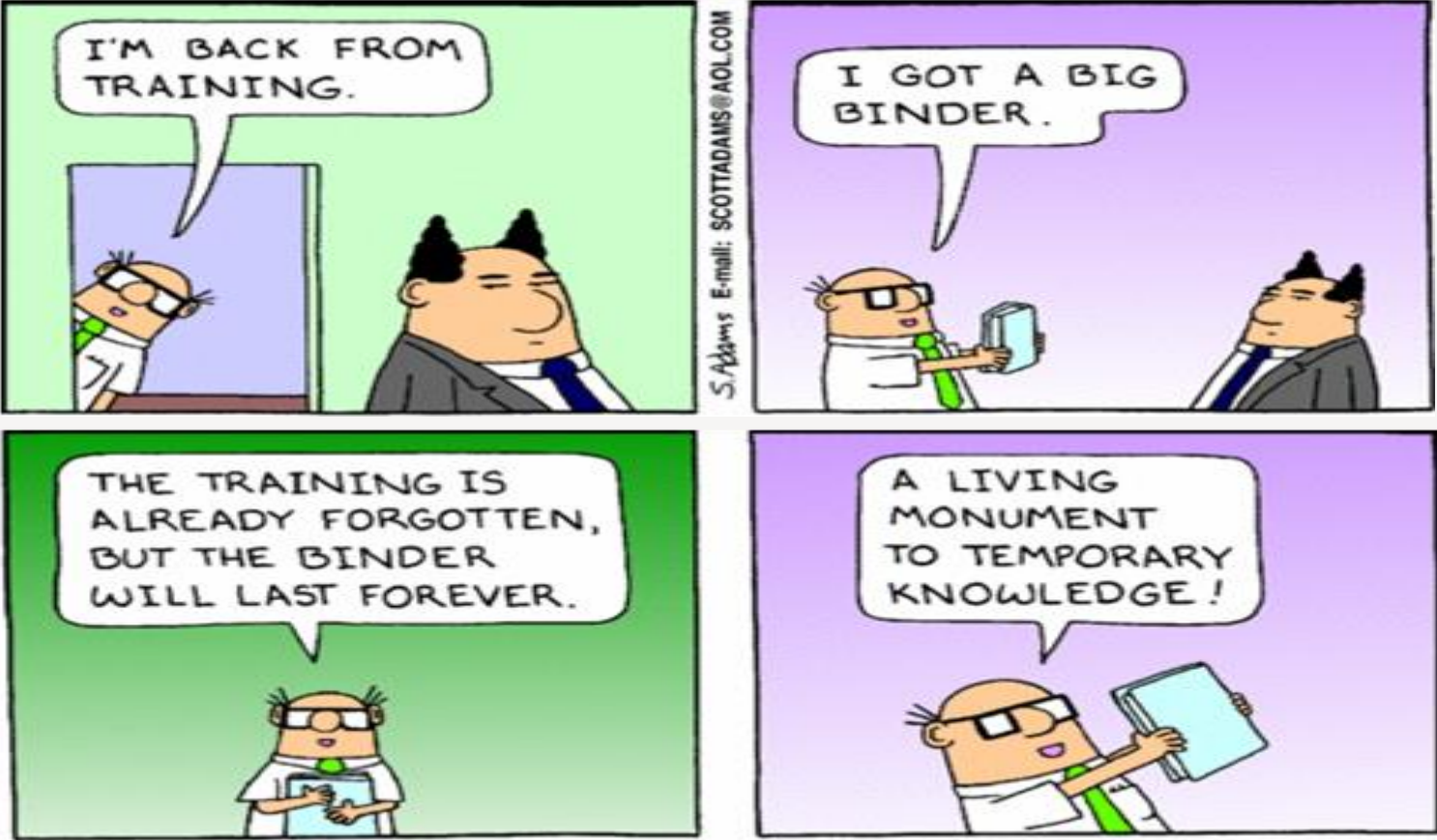
To provide attendees with sufficient knowledge and understanding of the Reliability-centred Maintenance (RCM) process to understand the approach and participate in an RCM study.

Course Objectives:

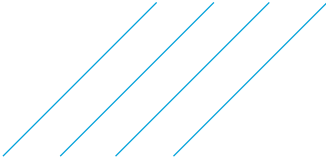
- › Understand what RCM is?
- › Why we do Maintenance?
- › Where it has come from?
- › and why RCM?



Too often training can be:



Then later - Try to avoid this!!!



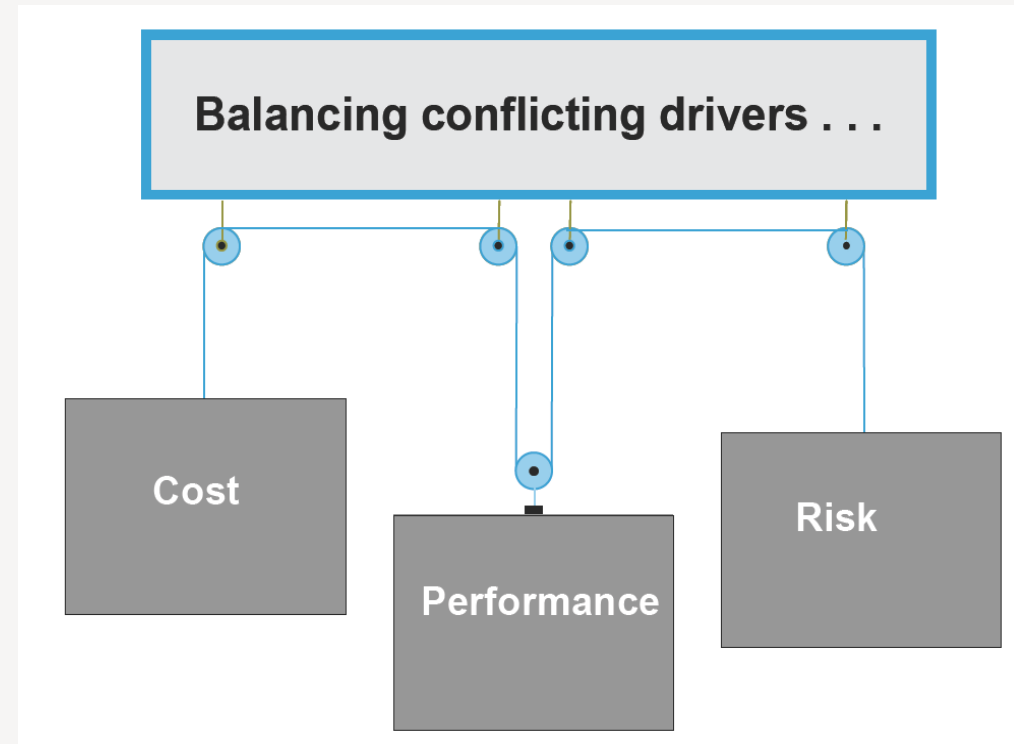
Course Outline

Session	Description	Slides
Session 1	Course introduction, history of maintenance, Changing World of Maintenance, Traditional Views, Reality of Failure Characteristics, New Maintenance Techniques, RCM definition, Operating Context, 7 Questions, Question 1 Primary and Secondary Functions and Q&A.	1-38
Session 2	Questions 2 - 4, Functional Failures, Types and Examples. Failure Modes, Failure Effects, Operational Availability, FMEA, Primary and Secondary Functions Exercises, an Introduction to the Case Study and Q&A.	39-63
Session 3	Revision of earlier stuff such in Session 1 and 2. The Study Team and the Black Hole issue. More on the Case Study and Q&A.	64-92
Session 4	Question 5, Multi-coloured Decision Logic, 6 Consequence Categories, Management of Consequences, Hidden Failures, Evident, Safety, Operational, Non-Operational. Examples Duty & Standby, Probability of multiple failure, Proactive Tasks, Case Study and Q&A.	93-126
Session 5	Q 6, Revision, Failure Management, Proactive Maintenance (OCM; SO; SR), Fixed Intervals - "LIFE", Usefulness of SD and SR, Definition of OCM, P-F Curve, Rules for task selection, Examples, Meaning of Life and Q&A.	127-145
Session 6	Q7, FF Intervals, Desired Availability vs. FF Interval as a %age of MTBF, Examples, Case Study, Equation and Derivation, Recording Decisions, Aviation Example – 1985 to 2005, Industry Examples, Pre / Post RCM, Review Aims of Course, Q&A and Feedback.	146-208

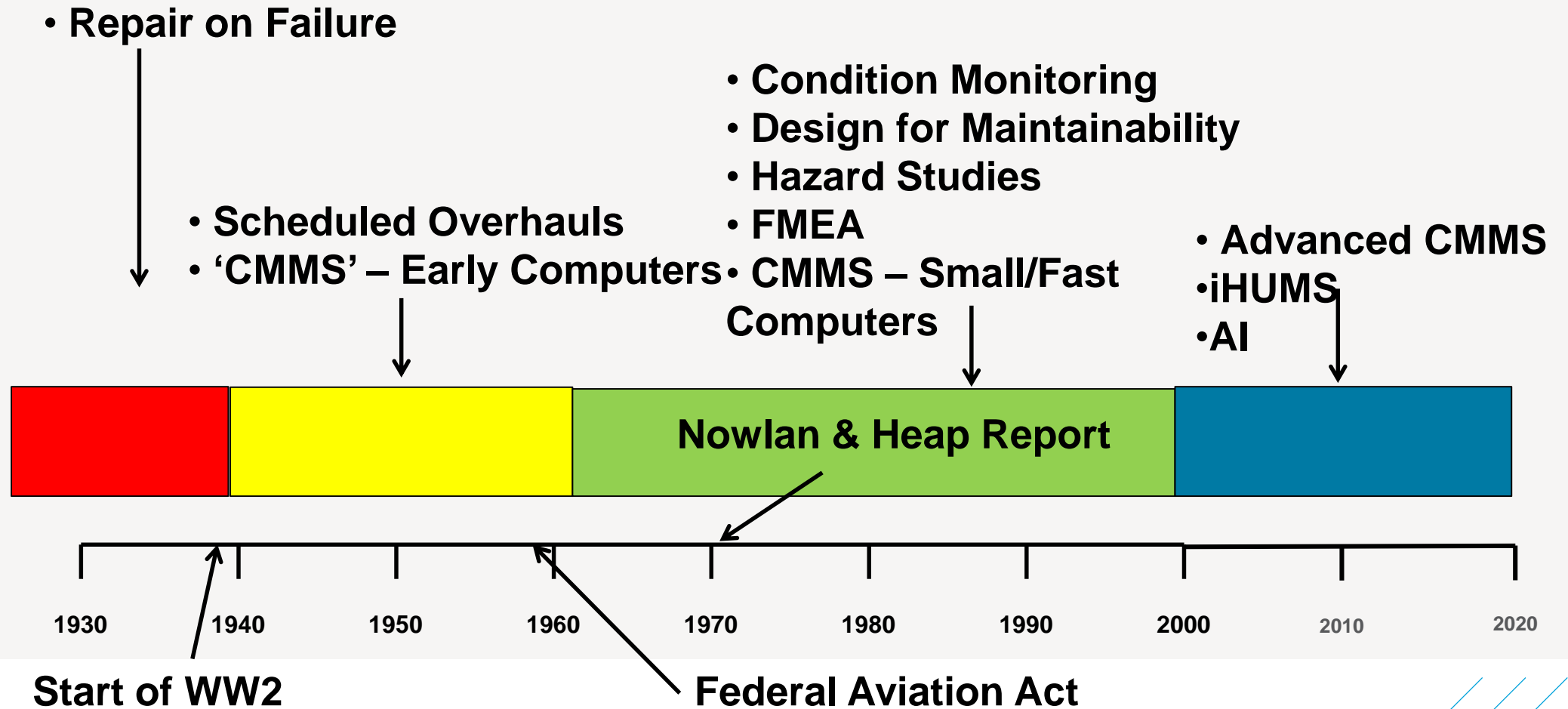


RBM (Risk Based Maintenance) programme

- What is the purpose of the RCM program of work?
 - To change the way we manage our assets, which optimally manages performance, risks and expenditures over an assets lifecycle
 - Build capability in the Business to achieve this.



The Evolution of Maintenance Techniques



Basics of Availability – Breakout Discussion

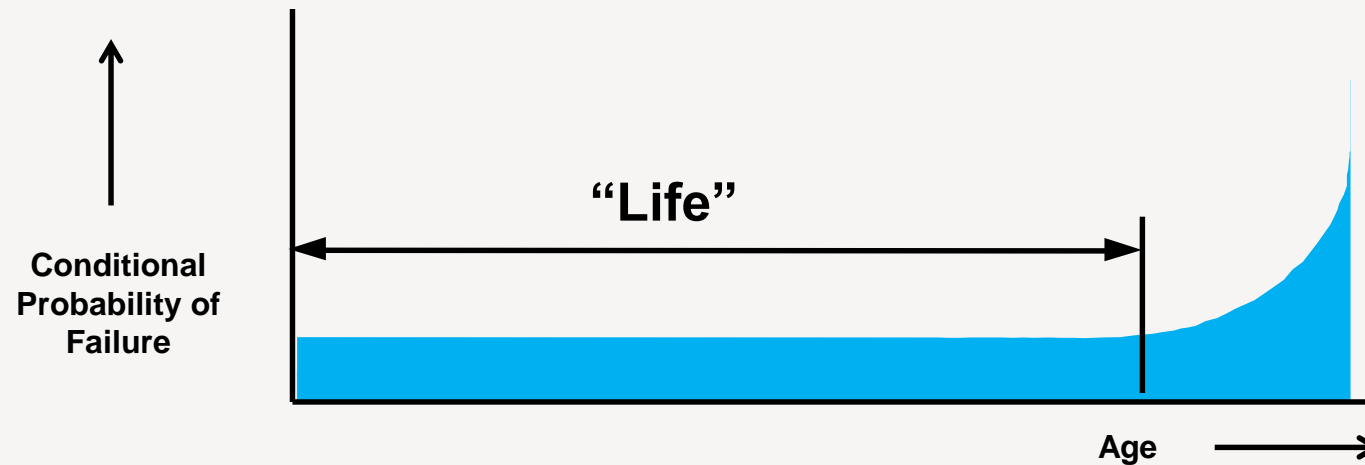
Breakout Ex – 10 Mins

$$\text{Availability} = \frac{\text{Operational Time}}{\text{Operational Time} + \text{PM Time} + \text{Failure Time}} \times 100\%$$



Traditional Views of Equipment Failure

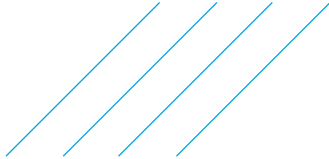
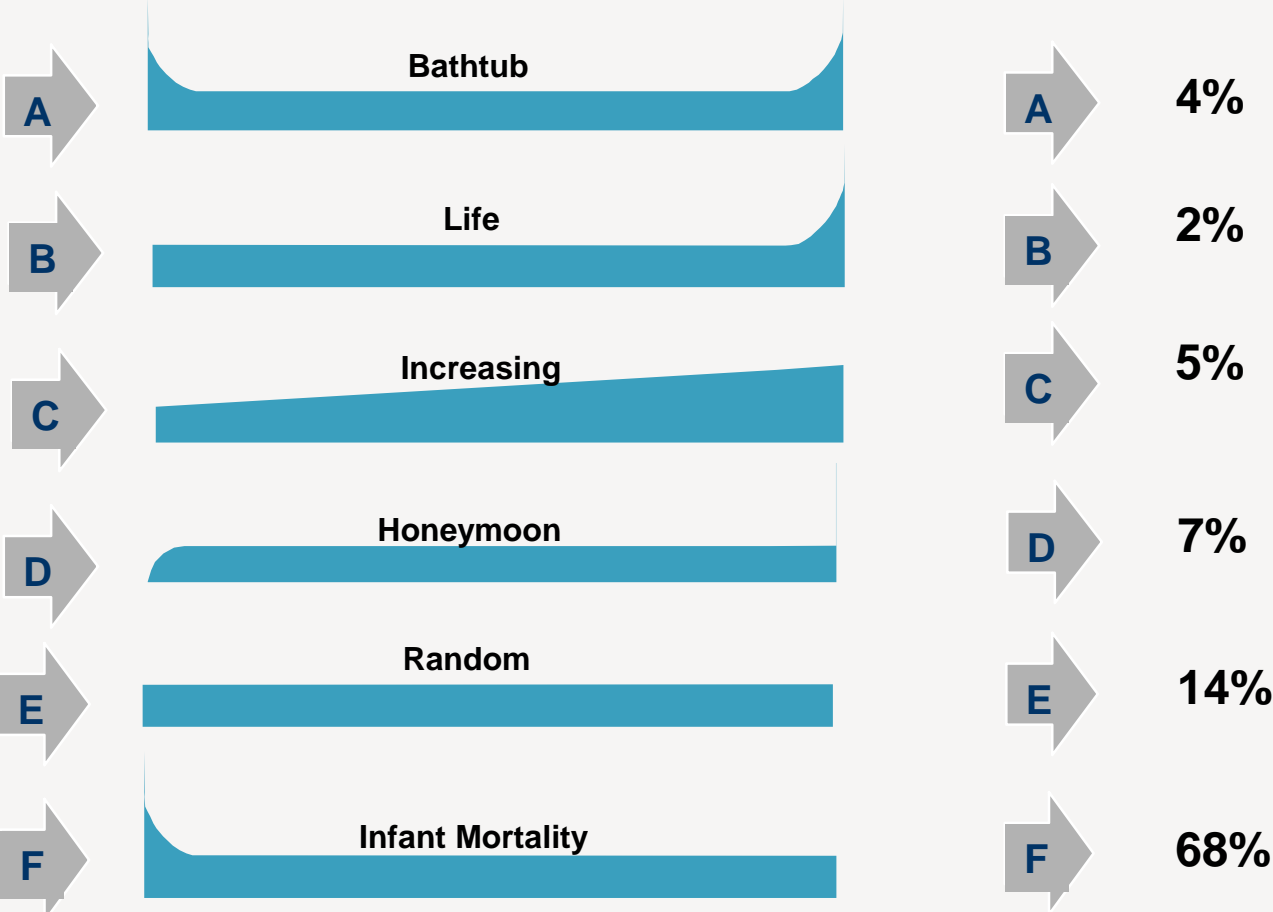
Everything has a “Life”



NB: Conditional Probability of Failure – Is the probability that any asset which has survived to the beginning of a period will fail during that period. RCM2 page 236.



The Reality of Equipment Failure



The Reality

Patterns B and F are 'Mirror Images' of each other:

What is absolutely right for Pattern B....

Is absolutely wrong for Pattern F.

Traditionally, preventive maintenance was established around Pattern B;
however:

Only 1 in 50 failures fall into Pattern B.

While 2 out of every 3 failures fall into Pattern F.



Results of the Airline Initiative

Improved Safety:

1958 – 60 crashes per million take-offs; 1998 – 1 crash per million take-offs.

Reduced Overhauls:

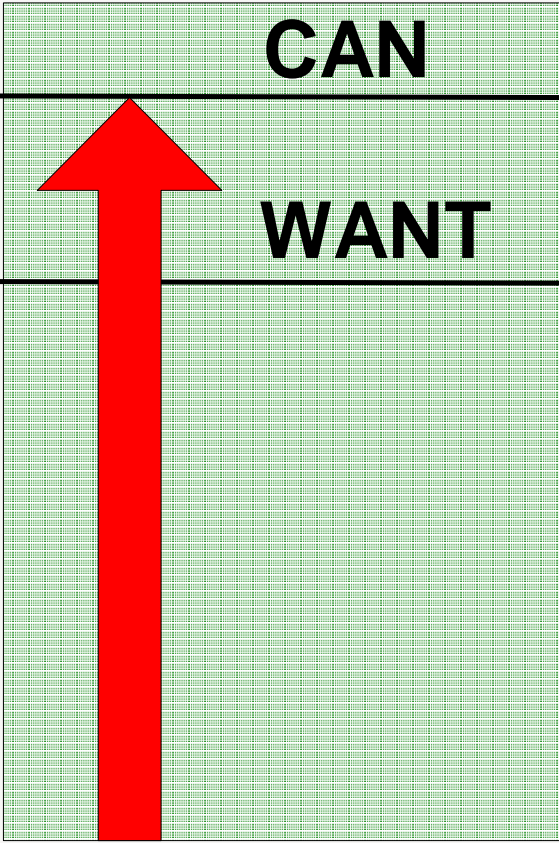
DC8 – 339 items; DC10 – only 7 items

Reduced Effort – DC8 and 747 both have major overhauls at ~ 20,000 flying hours:

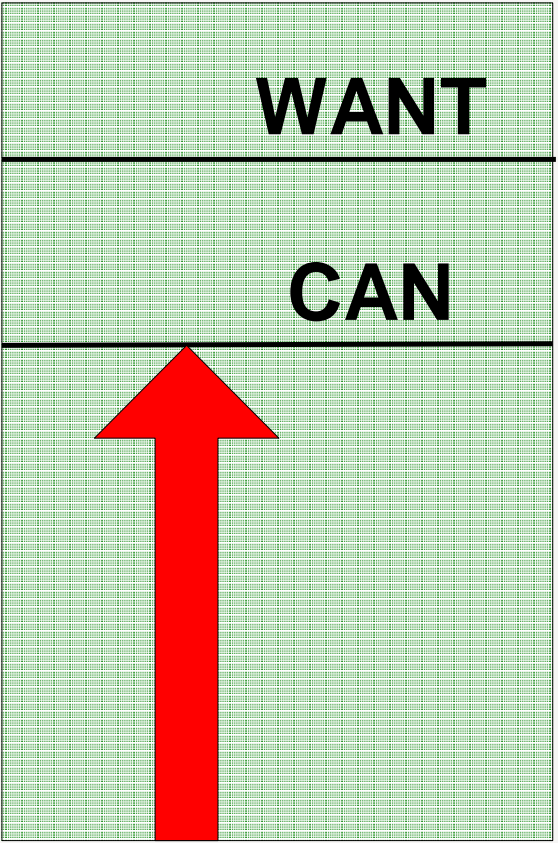
DC8 – 4 million man hours; 747 only 66,000 man hours



Want and Can



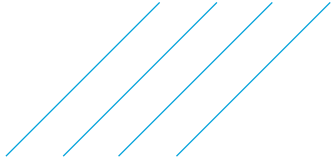
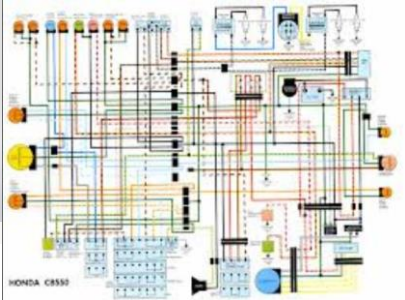
MAINTAINABLE



UNMAINTAINABLE



The Family Car – Degrades through Use/Time/Environment



Reliability Centred Maintenance (RCM)

A process used to determine what must be done to ensure that equipment fulfils its intended function in its operating context, given the failure characteristics of the equipment.



Reliability Centred Maintenance (RCM)

A **process** used to determine **what must be done** to ensure that equipment **fulfils its intended function** in its **operating context**, given **the failure characteristics** of the equipment.



Asset Definition & Operating Context

In order to identify appropriate failure management policy for any physical asset or system, we must define the asset under consideration and capture its Operating Context.

The Operating Context is the reference 'baseline' for the RCM analysis, its boundaries, any assumptions and should capture:

Brief asset description identifying where the boundaries are

Description of how and where it is used

Overall performance criteria

Safety and Environmental integrity/standards

Theatre of operations/Intensity of operations

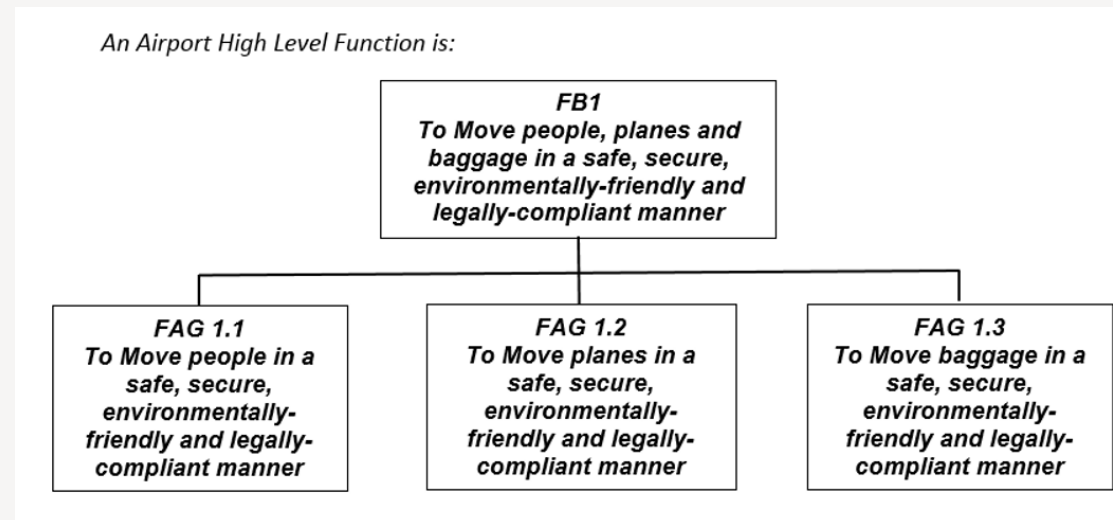
Redundancy & Spares policy



Asset Definition & Operating Context

In the case of very large or very complex systems or organisations, it might prove helpful to structure the Operating context hierarchically, starting with the mission statement of the entire organisation using the asset.

Functional Partitioning can be used to capture the overall functional hierarchy of the organisation and identify discreet and manageable RCM analyses.



Session 1 - Drinks Break 20 Minutes



Breakout – Mash Pump Scenarios

Breakout Ex – 10 Mins

Normally done in front of the class to explain the Standalone Vs Duty and Standby – Suggest Draw the Duty Stand-By and single Duty Pumps on slide and get break outs to discuss how the maintenance should look and will it be the same?



With new equipment we use manufacture's recommended maintenance; right? But is this a good approach?



Standalone

Functional role

Proposed maintenance strategy

Proactive Maintenance?



Duty

No Scheduled Maintenance?



Standby

Functional check?

3 identical assets, used in different ways, will require different maintenance to continue to do what we want them to do.

Following manufactures /suppliers recommended standard maintenance plan can only be applied to similar equipment whose operating context, functions and performance standards are the same.



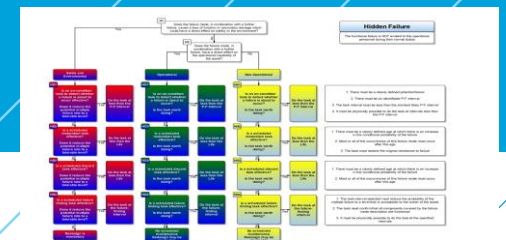
The RCM Process

The RCM process involves answering seven basic questions about the equipment for which a maintenance strategy is required:



1. What do we want the equipment to do? (Functions).
2. How can it fail to do this? (Functional Failures).
3. What causes the equipment to fail? (Failure Modes).
4. What happens when a failure occurs (Failure Effects).
5. How does the failure matter? (Failure Consequences).
6. Can the failure be predicted or prevented? (Proactive Failure Management).
7. How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).

FMEA Worksheet		Training Material	
Project: 3 Day RCM Awareness Course		Compiled By:	Date: 31 Jan 2014
System: Rolling Mill Cooling Water Supply Sys.		Approved By:	Sheet: 4 of 8
Function	Functional Failure	Failure Mode	Failure Effect
1 To supply at least 80 litres / min of cooling water to the rolling plant when required.	A Does not supply cooling water to the rolling plant at all.	1 Incoming electrical supply fails for any reason. 2 Pump A bearing lubrication degrades through normal use. 3 Pump A motor windings degrade due to age (contaminants, vibration). 4 Pump A coupling degrades through normal use (wear and tear).	Analysed separately (Outside the boundaries of this analysis). Friction increases as the lubrication degrades and wear rates will increase. Eventually the bearing will seize and the motor will trip on overload. Cooling water supply to the mill will cease. The Operator will receive a 'low flow rate alarm' and immediately panic call to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting minor damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000. The current to the motor increases as the winding degrades. Eventually an earth fault will occur and the motor will trip. Cooling water supply to the mill will cease. The Operator will receive a 'low flow rate alarm' and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000. There will be visible signs of degradation on the coupling surfaces. Identify the coupling wear/tear. The motor will continue to rotate but no pumping will take place. The Operator will receive a 'low flow rate' alarm and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000.



RCM Process – Recording the analysis

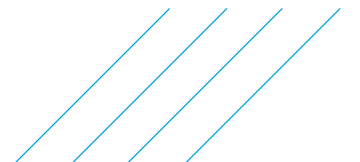
The RCM process and the outcomes are recorded on two worksheets:

The answers to questions 1 to 4 are recorded on a Failure Modes and Effects Analysis (FMEA) worksheet.

The answers to questions 5 to 7 are determined using the decision logic algorithm and recorded on Maintenance task Selection worksheet.

The process presented during this 3-day course is compliant with the Society of Automotive Engineers (SAE) JA1011 Standard for the Evaluation Criteria for RCM Processes.

A brief word about RCM2. Mention Blue Book and John Moubray.



Defining Functions – Q1

Example – Marine Engine:

To power the main gearbox at varying speeds up to a maximum of 1700 CRPM and 708 BkW.

List all functions associated with the system.

Describe the minimal acceptable performance criteria rather than the design capacity.

Wherever possible, performance standards should be quantified

The 'want' must not exceed the 'can'.

Distinguish between “To do....” and “To be....”



Types of Function

Functions can be split into two different categories:

- *Primary*
- *Secondary*



Primary Functions

Breakout Ex – 10 Mins

The reason why the equipment exists.

Normally identified by the name, e.g.:

Power Pack – To Power;

Pump – To Pump;

Drier – To Dry.

Suggest the Primary Function of the 'Mash' Transfer Pump – Also Handout Primary Examples sheet and get Groups to record their answers.



Primary Functions - Exercise

Technical Specification:

Stylish silver cordless rapid-boil jug kettle with chrome detailing and gloss paint finish.

Acceptable Performance – Boil a full kettle of room temperature tap water within 3 minutes.

360 degree swivel base and stainless steel concealed element.

220 – 240 Voltage @ 50 MHz.

3 kW power and 1.7 Litre water capacity.

3-level safety protection: auto shut-off when boiled or lifted and thermal cut-off.

Removable, washable scale filter and non-slip feet.

Breakout Ex – 10 Mins



Secondary Functions

Checklist:

Environmental Integrity

Safety/Structural Integrity

Control/Containment/Comfort

Appearance

Protection

Economy/Efficiency

Superfluous

E – S – C – A – P – E – S



Secondary Functions - Examples

Marine Engine:

To indicate engine speed to within +/- 5% actual speed.

To contain lubricating oil.

To support ancillary equipment.

To remove particulates of size greater than 10 micron from the fuel.



Secondary Functions - Exercise

Breakout Ex – 10 Mins

Technical Specification:

Stylish silver cordless rapid-boil jug kettle with chrome detailing and gloss paint finish.

360 degree swivel base and stainless steel concealed element.

3 kW power and 1.7 Litre water capacity.

3-level safety protection: auto shut-off when boiled or lifted and thermal cut-off.

Removable, washable scale filter and non-slip feet.



Protective Functions

- To draw attention of the operators to abnormal conditions (e.g. track circuits, alarms, etc.).
- To shut down equipment in the event of failure.
- To eliminate or relieve abnormal conditions that follow a failure (e.g. fuse, circuit breaker, etc.).
- To take over from a function that has failed (e.g. standby 'Mash' Transfer Pump).
- To prevent dangerous situations from arising in the first place (e.g. signage, interlocks, etc.).



Protective Functions - Examples

Marine Engine:

To annunciate an alarm in the event of high exhaust temperature >750 deg C.

To isolate the fuel supply in the event that engine speed exceeds 2,000 CRPM.

To vent the fuel supply tank in the event of internal pressure rising above 15 psi.



Protective Functions - Exercise

Breakout Ex – 10 Mins

Technical Specification:

Stylish silver cordless rapid-boil jug kettle with chrome detailing and gloss paint finish.

360 degree swivel base and stainless steel concealed element.

3 kW power and 1.7 Litre water capacity.

3-level safety protection: auto shut-off when boiled or lifted and thermal cut-off.

Removable, washable scale filter and non-slip feet.



Superfluous Functions

Equipment that has been modified several times over a period of years may now contain legacy components/functions that are no longer used/required.

New equipment that has been over specified may contain functions that are not used/required.

It is important to be aware of these 'superfluous' functions as they still have the propensity to fail and, as such, may reduce overall system safety, reliability and cost of ownership.



Question & Answer Session (1)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. What is the aim of this course?
2. Why take a risk based approach to maintenance?
3. What is the main lesson from the six Failure Patterns Nowlan & Heap uncovered?
4. In RCM what are the two types of Functions?
5. What acronym is used to ensure all types of Secondary Function are covered?

1.



Question & Answer Session (1)

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3. What is the main lesson from the six Failure Patterns Nowlan & Heap uncovered?
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1. *To provide attendees with sufficient knowledge and understanding of the Reliability-centred Maintenance (RCM) process to understand the approach and the benefits of an RCM study.*
2. To change the way we manage our assets, which optimally manages performance, risks and expenditures over an assets lifecycle.
3. That the traditional failure patterns only equate to a very small percentage of all failure. Most are random.
4. Primary and Secondary.
5. ESCAPES.



Look Back

- › *Course Introduction*
- › *Changing World of Maintenance*
- › *Traditional Views of Equipment Failure – LIFE*
- › *Reality of Failure (6 Failure Characteristics)*
- › *Want and Can*
- › *New Maintenance Techniques (1st, 2nd and 3rd Generation mitigation of deterioration)*
- › *RCM definition and Operating Context*
- › *Define RCM (Full – 7 Questions and Structure of Course)*
- › *Types of Function*
- › *Primary Functions*
- › *Secondary Functions*



Session 2

Session 2 – Look Forward

- › Look Forward
 - › *Functional Failures Types and Examples*
 - › *Failure Modes*
 - › *Failure Effects*
 - › *Operational Availability*
 - › *FMEA*
 - › *Introduction to Case Study*



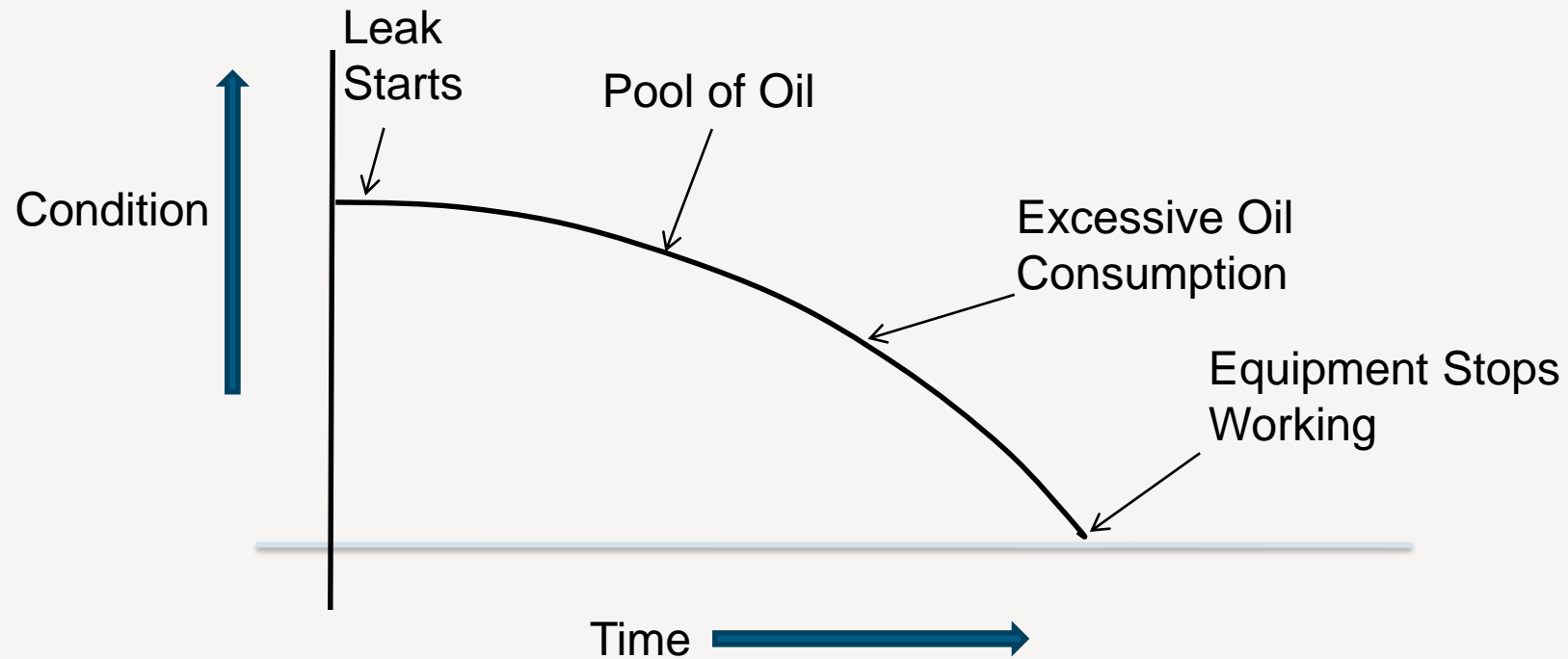
The RCM Process – Q2

- What do we want the equipment to do? (Functions).
- How can it fail to do this? (Functional Failures).
- What causes the equipment to fail? (Failure Modes).
- What happens when a failure occurs (Failure Effects).
- How does the failure matter? (Failure Consequences).
- Can the failure be predicted or prevented? (Proactive Failure Management).
- How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).



Failures and Performance Standards

'Mash' Transfer Pump:



Defining Functional Failures

Even for the most complex functional descriptions, defining functional failures should be a straightforward process; however, the importance of this step should not be overlooked.

Functional Failures can be described in simple terms as:

Not at all;

Too little (depends on performance standards);

Too much (depends on performance standards).



Functional Failures - Examples

Suggest Functional Failures for the following Functions:

To power the main gearbox at varying speeds up to a maximum of 1700 CRPM and 708 BkW.

To indicate engine speed to within +/- 5% of actual speed.

To contain lubricating oil.

To annunciate an alarm in the event of high exhaust temperature >750 deg C.

To isolate the fuel supply in the event that engine speed exceeds 2,000 CRPM.



Functional Failures - Exercise

Breakout Ex – 10 Mins

Technical Specification:

Stylish silver cordless rapid-boil jug kettle with chrome detailing and gloss paint finish.

360 degree swivel base and stainless steel concealed element.

3 kW power and 1.7 Litre water capacity.

3-level safety protection: auto shut-off when boiled or lifted and thermal cut-off.

Removable, washable scale filter and non-slip feet.



The RCM Process – Q3

What do we want the equipment to do? (Functions).

How can it fail to do this? (Functional Failures).

What causes the equipment to fail? (Failure Modes).

What happens when a failure occurs (Failure Effects).

How does the failure matter? (Failure Consequences).

Can the failure be predicted or prevented? (Proactive Failure Management).

How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).



Describing Failure Modes

A Functional Failure is a “failed state” whereas a Failure Mode is an ‘event’ that causes the Functional Failure. For example:

- Bearing misaligned (human error).
- Pipe corrodes.
- Pipe erodes.
- Pipe accidentally damaged.
- Drive belt wears.

Note that similar equipment items may experience different Failure Modes depending on the operating context. For example – the duty and standby ‘Mash’ Transfer Pumps.



How Far Do We Go?

Pump stolen.

Pump struck by a meteorite.

Failure Modes must be credible:

- Events that have occurred before.

- Events that may not have occurred but are considered credible (including those being prevented by the current maintenance schedules).

- Events that are considered less likely to occur in the future but will have very severe consequences if they do.



How Much Detail?

This will, to a large extent, depend on the level at which Preventive Maintenance is carried out – e.g. “PCB fails” will be sufficient if the only course of action is to replace the PCB for a like-for-like unit.

The root cause of the failure (as opposed to the symptom) should be recorded – e.g. “Leakage” is an effect of a failure mode (root cause). Root Cause Analysis - Make sure you use Why? Why? Why? To get to root cause.



Failure Modes - Examples

Suggest Failure Modes for the following Functional Failures:

Does not power at all.

Does not indicate engine speed to within +/- 5% of actual speed.

Does not contain lubricating oil.

Does not alarm in the event of high exhaust temperature >750 deg C.

Does not isolate the fuel supply in the event that engine speed exceeds 2,000 CRPM.



Failure Modes - Exercise

Breakout Ex – 10 Mins

Technical Specification:

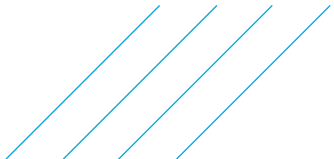
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3-level safety protection: auto shut-off when boiled or lifted and thermal cut-off.

Removable, washable scale filter and non-slip feet.



The RCM Process – Q4

What do we want the equipment to do? (Functions).

How can it fail to do this? (Functional Failures).

What causes the equipment to fail? (Failure Modes).

What happens when a failure occurs (Failure Effects).

How does the failure matter? (Failure Consequences).

Can the failure be predicted or prevented? (Proactive Failure Management).

How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).



Session 2 - Drinks Break 20 Minutes



Describing Failure Effects

Failure Effects are described as if nothing is being done to detect or prevent the Failure Mode. These can be written as:

- A story
- A series of bullet points.
- Local, next higher level (System), End Effects (Operational).



What To Include?

Failure Effects should cover/include:

Any evidence that the failure is about to occur (e.g. heat, noise, vibration, etc.)

Any evidence that the failure has occurred (e.g. engine stops, alarms, etc.)

Any action taken by the operator to isolate or mitigate the failure

Ways in which the failure may threaten safety or the environment

Ways in which the failure may threaten production/operation

Any secondary damage caused by the failure and estimate of costs.

The repair action and downtime required to repair the failure (estimated costs).



Ao – Uptime / Uptime + Downtime

Explain difference between downtime and repair time:

Realisation time.

Time to shutdown.

Time to find repair team.

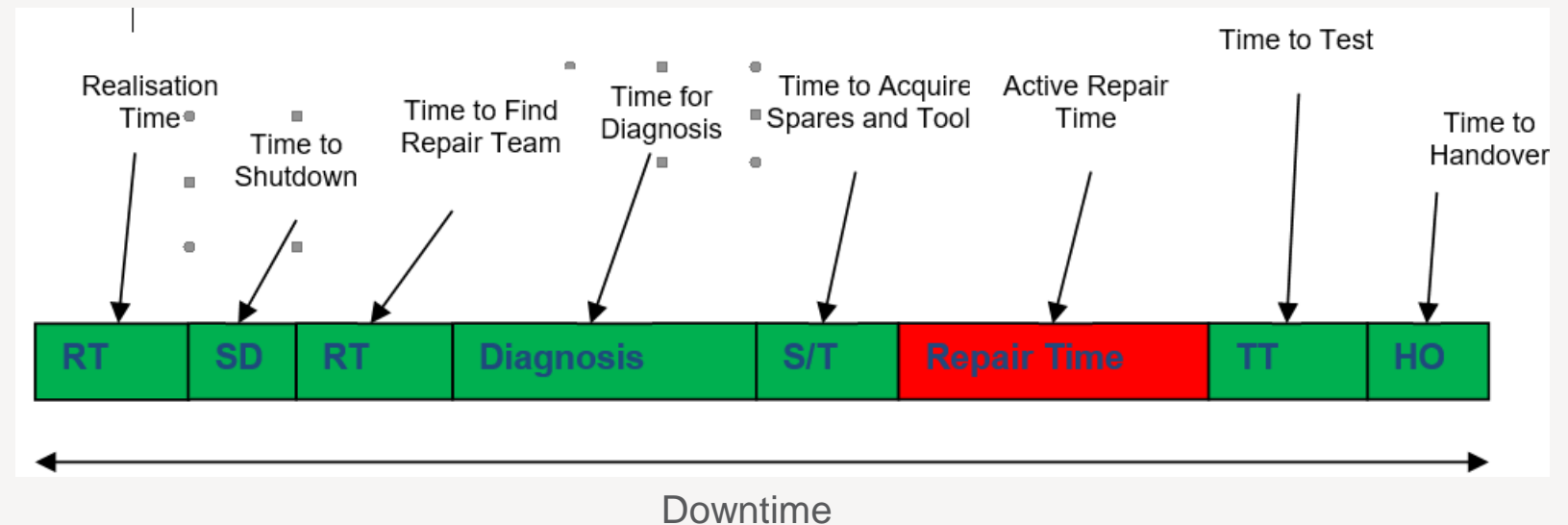
Time for diagnosis.

Time to acquire spares and tools.

Time to repair.

Time to test.

Time to handover.



Failure Effects - Examples

Suggest Failure Effects for the following Failure Modes:

Engine big-end bearing lubrication degrades.

Engine speed sensor drifts out of calibration.

Oil tank corrodes (leading to loss of containment).

High exhaust temperature alarm fails open circuit.



Failure Effects - Exercise

Breakout Ex – 10 Mins

Technical Specification:

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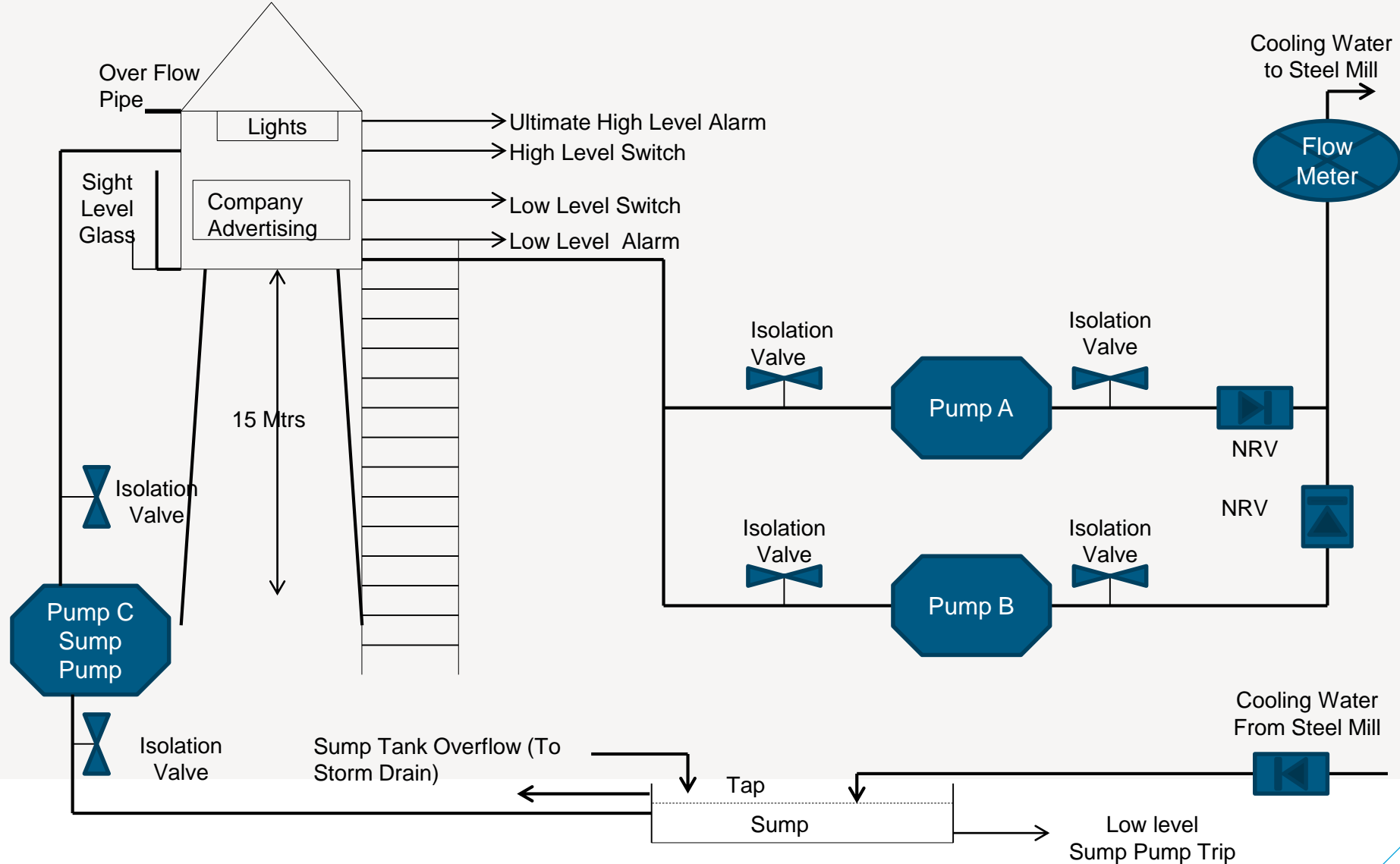
FMEA Worksheet

The answers to questions 1, 2, 3 and 4 are recorded in a worksheet similar to that shown below:

FMEA Worksheet				Sheet of		
Date:		Project:			System/Process:	
	Function		F. Failure		F. Mode	Failure Effects
1	To heat up to 1.7l of water from ambient temperature to boiling point within 3 minutes (+/-10 secs).	A	Does not heat at all.	1	Element fails open circuit.	'Power On' status light is lit but kettle fails to boil. Failure becomes apparent after a few minutes when operator notices that kettle hasn't boiled. Fails in a safe condition. Operator discards failed kettle and purchases replacement when convenient. In the meantime Operator can revert to a saucepan and the gas hob to boil water but process takes longer and will cost slightly more in energy consumption.



Case Study – Rolling Mill Cooling System



Question & Answer Session (1)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. In RCM what are the three types of Functional Failures?
2. In RCM what are Failure Modes?
3. How do we get to the root cause of failures?
4. Why is it important to record Failure Effects in reasonable detail?
5. What is the document called that capture the first 4 Qs of RCM?

1.



Question & Answer Session (1)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. In RCM what are the three types of Functional Failures?
 1. Complete failure (At all), Partial (Too Little) and sometimes too much.
2. In RCM what are Failure Modes?
 - . Failure Modes are the root cause of failure which is important as that is what will need addressing! So engine seizes due to lack of oil is not the root cause. The reasons why there is less oil than needed is the root cause (gasket leaks, bolts left loose by Maintainer etc etc). They must be credible (happened before on similar kit etc).
3. How do we get to the root cause of failures?
 3. By asking why is there insufficient oil; why has it leaked out; why were the bolts loose? Etc. By asking the Why Q up to 5 times we usually get to the root cause.
4. Why is it important to record Failure Effects in reasonable detail?
 4. The Effects are recorded in the FMEA to help the Study Team make the right decisions in the rest of the RCM analysis. They will be reviewed by the Auditor to ensure they are credible and cover whether Hidden, Safety/Environmental or Operational decisions were justified!
5. What is the document called that captures the first 4 Qs of RCM?
 5. FMEA.



Look Back

Functional Failures (FF)

FF Examples

Failure Modes (FM) & Credibility / Root Causes NOT Symptoms

FM Examples

How Much Detail – When to Stop?

Past (History); Present (FMs Prevented); Real Possibilities in the Future; Severe Consequences

Different FMs in Different Context

Failure Effects

Example – Electric Kettle

FMEA

Case Study Op Context



Session 3

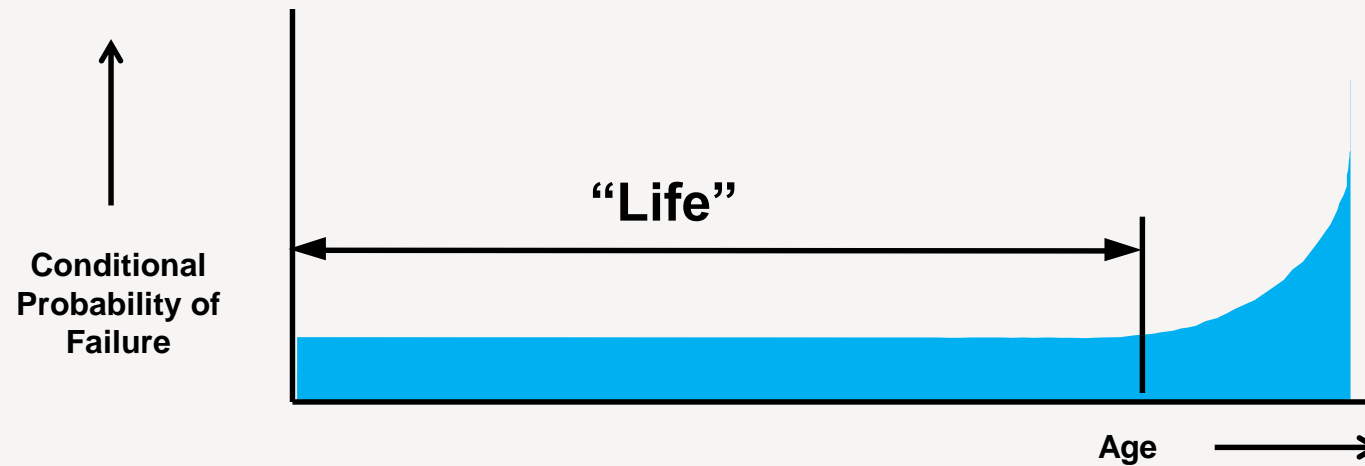
Session 3 – Look Forward

- › Look Forward
 - › *Revision of earlier stuff 66-86;*
 - › *Evolution of Maintenance Techniques*
 - › *Lessons learnt from Airline Initiative*
 - › *RCM and 7 Qs*
 - › *Primary and Secondary Functions*
 - › *Functional Failures*
 - › *Failure Modes and Effects*
 - › *How far do we go.*
 - › *Introduction to Case Study*
- › The Study Team and the Black Hole issue



Traditional Views of Equipment Failure

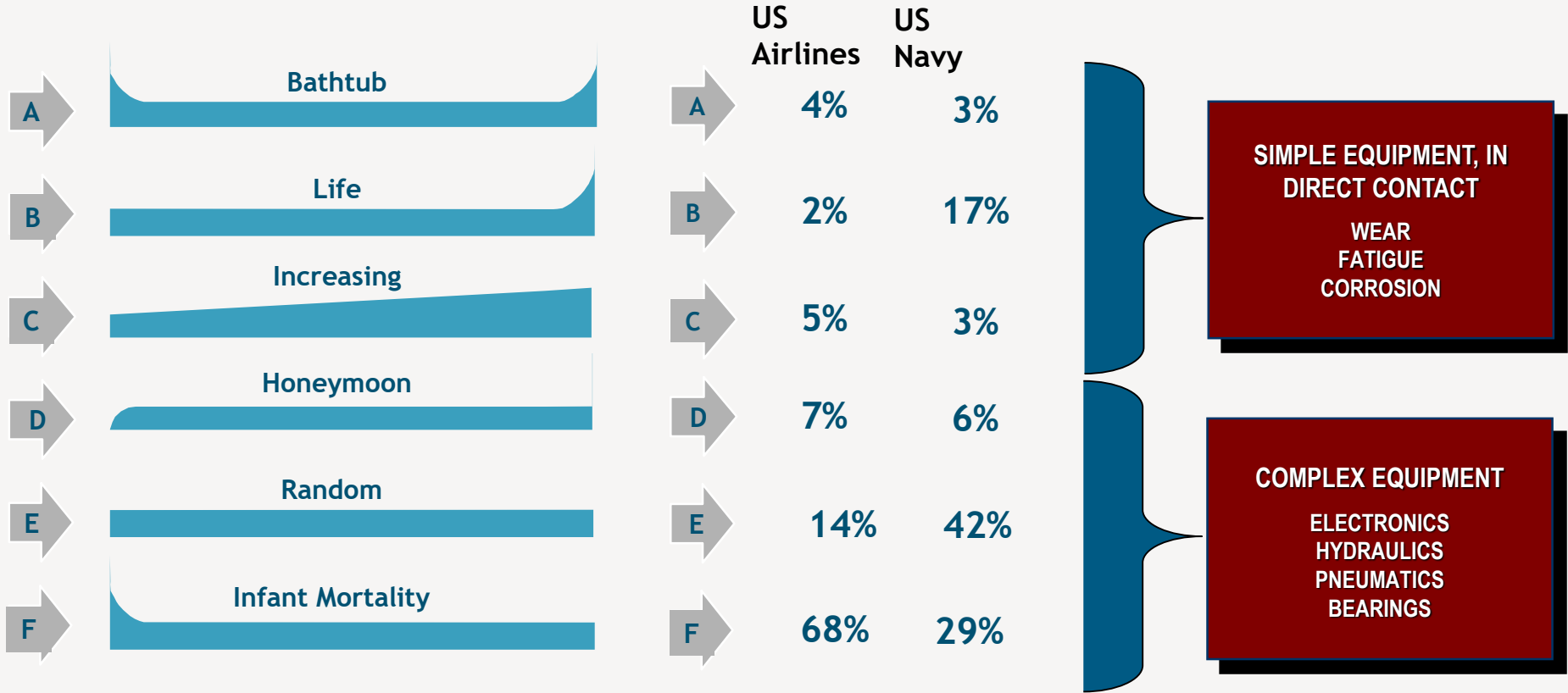
Everything has a “Life”



NB: Conditional Probability of Failure – Is the probability that any asset which has survived to the beginning of a period will fail during that period. RCM2 page 236.



The Reality of Equipment Failure



The Reality

Patterns B and F are 'Mirror Images' of each other:

What is absolutely right for Pattern B....

Is absolutely wrong for Pattern F.

Traditionally, preventive maintenance was established around Pattern B;
however:

Only 1 in 50 failures fall into Pattern B.

While 2 out of every 3 failures fall into Pattern F.



Results of the Airline Initiative

Improved Safety:

1958 – 60 crashes per million take-offs; 1998 – 1 crash per million take-offs.

Reduced Overhauls:

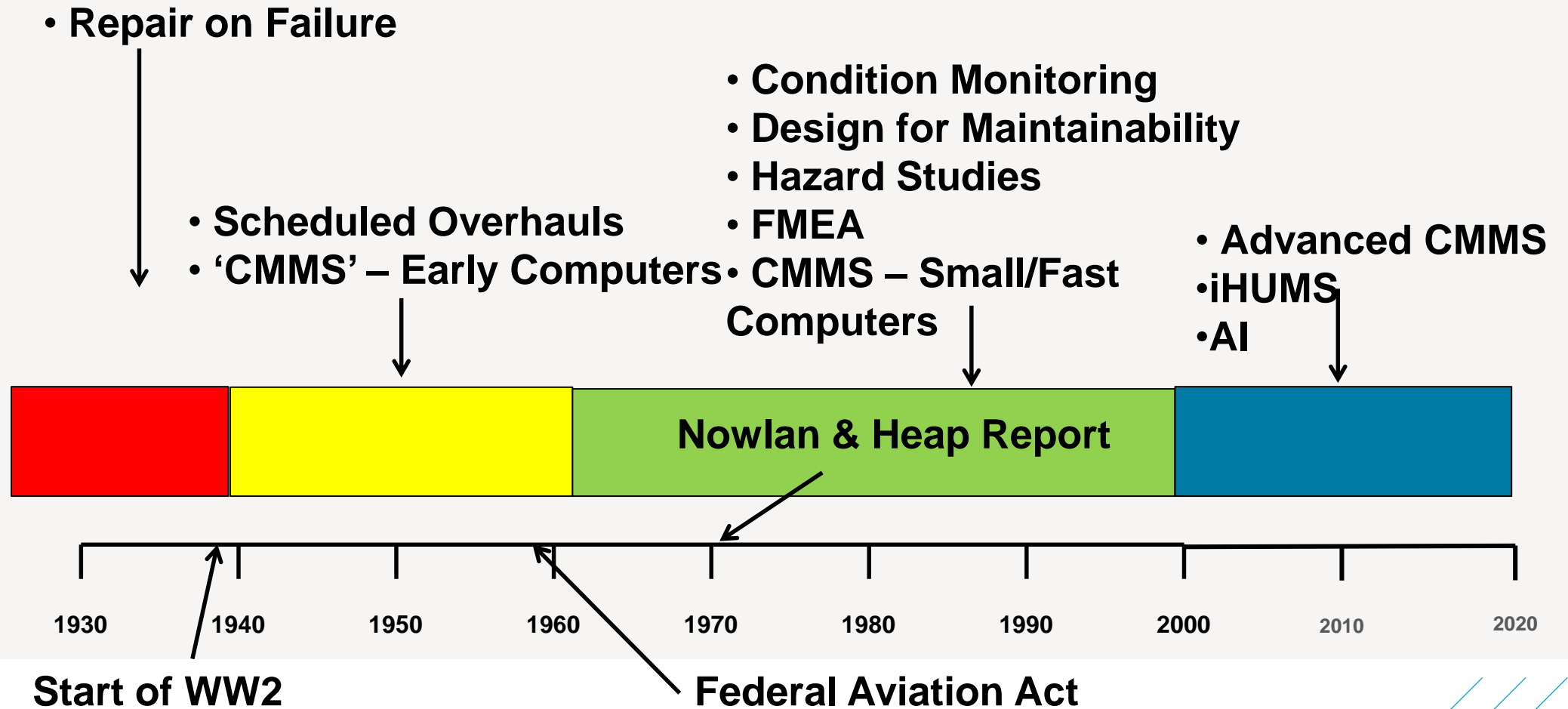
DC8 – 339 items; DC10 – only 7 items

Reduced Effort – DC8 and 747 both have major overhauls at ~ 20,000 flying hours:

DC8 – 4 million man hours; 747 only 66,000 man hours



The Evolution of Maintenance Techniques



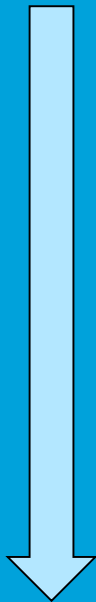
Reliability Centred Maintenance (RCM)

A process used to determine what must be done to ensure that equipment fulfils its intended function in its operating context, given the failure characteristics of the equipment.



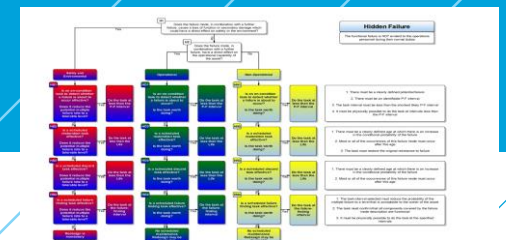
The RCM Process

The RCM process involves answering seven basic questions about the equipment for which a maintenance strategy is required:



1. What do we want the equipment to do? (Functions).
2. How can it fail to do this? (Functional Failures).
3. What causes the equipment to fail? (Failure Modes).
4. What happens when a failure occurs (Failure Effects).
5. How does the failure matter? (Failure Consequences).
6. Can the failure be predicted or prevented? (Proactive Failure Management).
7. How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).

FMEA Worksheet		Training Material	
Project: 3 Day RCM Awareness Course		Compiled By:	Date: 31 Jan 2014
System: Rolling Mill Cooling Water Supply Sys.		Approved By:	Sheet: 4 of 8
Function	Functional Failure	Failure Mode	Failure Effect
1 To supply at least 80 litres / min of cooling water to the rolling plant when required.	A Does not supply cooling water to the rolling plant at all.	1 Incoming electrical supply fails for any reason. 2 Pump A bearing lubrication degrades through normal use. 3 Pump A motor windings degrade due to age (contaminants, vibration). 4 Pump A coupling degrades through normal use (wear and tear).	Analysed separately (Outside the boundaries of this analysis). Friction increases as the lubrication degrades and wear rates will increase. Eventually the bearing will seize and the motor will trip on overload. Cooling water supply to the mill will cease. The Operator will receive a 'low flow rate alarm' and immediately panic call to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting minor damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000. The current to the motor increases as the winding degrades. Eventually an earth fault will occur and the motor will trip. Cooling water supply to the mill will cease. The Operator will receive a 'low flow rate alarm' and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000. There will be visible signs of degradation on the coupling surfaces. Identify the coupling wear/tear. The motor will continue to rotate but no pumping will take place. The Operator will receive a 'low flow rate' alarm and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000.



Defining Functions – Q1

Example – Marine Engine:

To power the main gearbox at varying speeds up to a maximum of 1700 CRPM and 708 BkW.

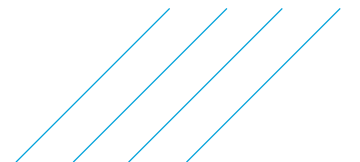
List all functions associated with the system.

Describe the minimal acceptable performance criteria rather than the design capacity.

Wherever possible, performance standards should be quantified

The 'want' must not exceed the 'can'.

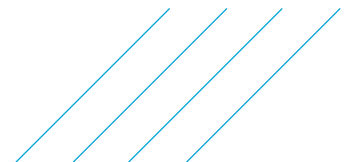
Distinguish between “To do....” and “To be....”



Types of Function

Functions can be split into two different categories:

- *Primary*
- *Secondary*



Primary Functions

The reason why the equipment exists.

Normally identified by the name, e.g.:

Power Pack – To Power;

Pump – To Pump;

Drier – To Dry.

Suggest the Primary Function of the 'Mash' Transfer Pump



Secondary Functions

Environmental Integrity

Safety/Structural Integrity

Control/Containment/Comfort

Appearance

Protection

Economy/Efficiency

Superfluous

E – S – C – A – P – E – S



Secondary Functions - Examples

Marine Engine:

To indicate engine speed to within +/- 5% actual speed.

To contain lubricating oil.

To support ancillary equipment.

To remove particulates of size greater than 10 micron from the fuel.



Protective Functions

- To draw attention of the operators to abnormal conditions (e.g. track circuits, alarms, etc.).
- To shut down equipment in the event of failure.
- To eliminate or relieve abnormal conditions that follow a failure (e.g. fuse, circuit breaker, etc.).
- To take over from a function that has failed (e.g. standby 'Mash' Transfer Pump).
- To prevent dangerous situations from arising in the first place (e.g. signage, interlocks, etc.).



Defining Functional Failures

Even for the most complex functional descriptions, defining functional failures should be a straightforward process; however, the importance of this step should not be overlooked.

Functional Failures can be described in simple terms as:

Not at all;

Too little (depends on performance standards);

Too much (depends on performance standards).



Describing Failure Modes

A Functional Failure is a “failed state” whereas a Failure Mode is an ‘event’ that causes the Functional Failure. For example:

Bearing misaligned (human error).

Pipe corrodes.

Pipe erodes.

Pipe accidentally damaged.

Drive belt wears.

Note that similar equipment items may experience different Failure Modes depending on the operating context. For example – the duty and standby ‘Mash’ Transfer Pumps.



How Far Do We Go?

Pump stolen.

Pump struck by a meteorite.

Failure Modes must be credible:

- › Events that have occurred before.
- › Events that may not have occurred but are considered credible (including those being prevented by the current maintenance schedules).
- › Events that are considered less likely to occur in the future but will have very severe consequences if they do.

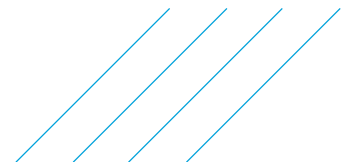


Session 3 - Drinks Break 20 Minutes



The RCM Process Q4

What happens when a failure occurs (Failure Effects).



How Much Detail?

This will, to a large extent, depend on the level at which Preventive Maintenance is carried out – e.g. “PCB fails” will be sufficient if the only course of action is to replace the PCB for a like-for-like unit.

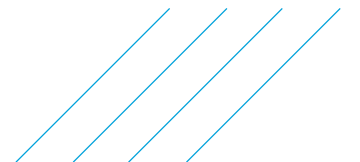
The root cause of the failure (as opposed to the symptom) should be recorded – e.g. “Leakage” is an effect of a failure mode (root cause). Make sure you use Why? Why? Why? To get to root cause.



Describing Failure Effects

Failure Effects are described as if nothing is being done to detect or prevent the Failure Mode. These can be written as:

- › A story
- › A series of bullet points.
- › Local, next higher level (System), End Effects (Operational).



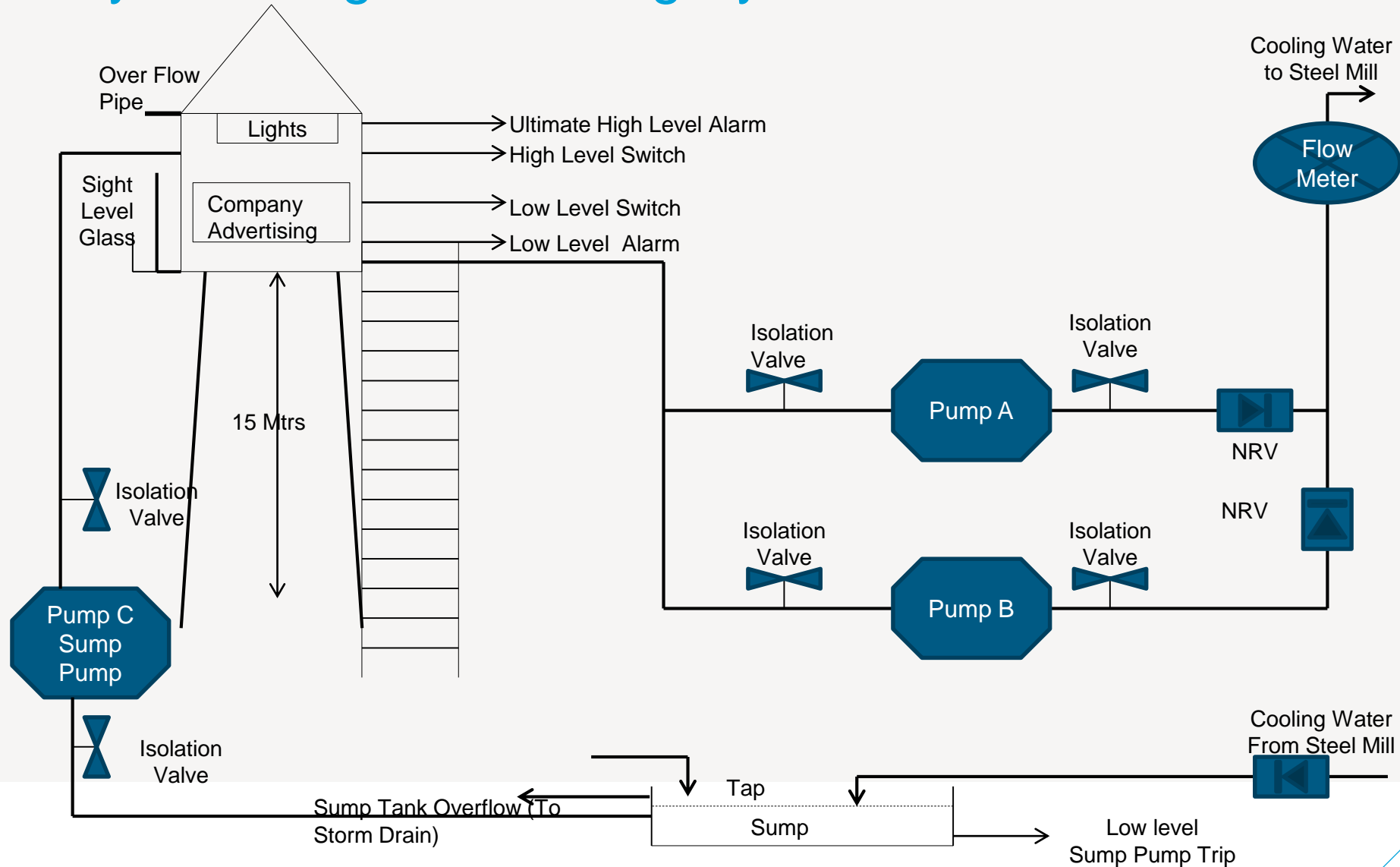
What To Include?

Failure Effects should cover/include:

- › Any evidence that the failure is about to occur (e.g. heat, noise, vibration, etc.)
- › Any evidence that the failure has occurred (e.g. engine stops, alarms, etc.)
- › Any action taken by the operator to isolate or mitigate the failure
- › Ways in which the failure may threaten safety or the environment
- › Ways in which the failure may threaten production/operation
- › Any secondary damage caused by the failure and estimate of costs.
- › The repair action and downtime required to repair the failure (estimated costs).



Case Study – Rolling Mill Cooling System



Tutor Led FMEA Activity

Back to FMEA worksheets for Case Study going through the FMs and Effects.

Explain use of non-industry specific case study.

Avoids temptation to delve into the weeds.

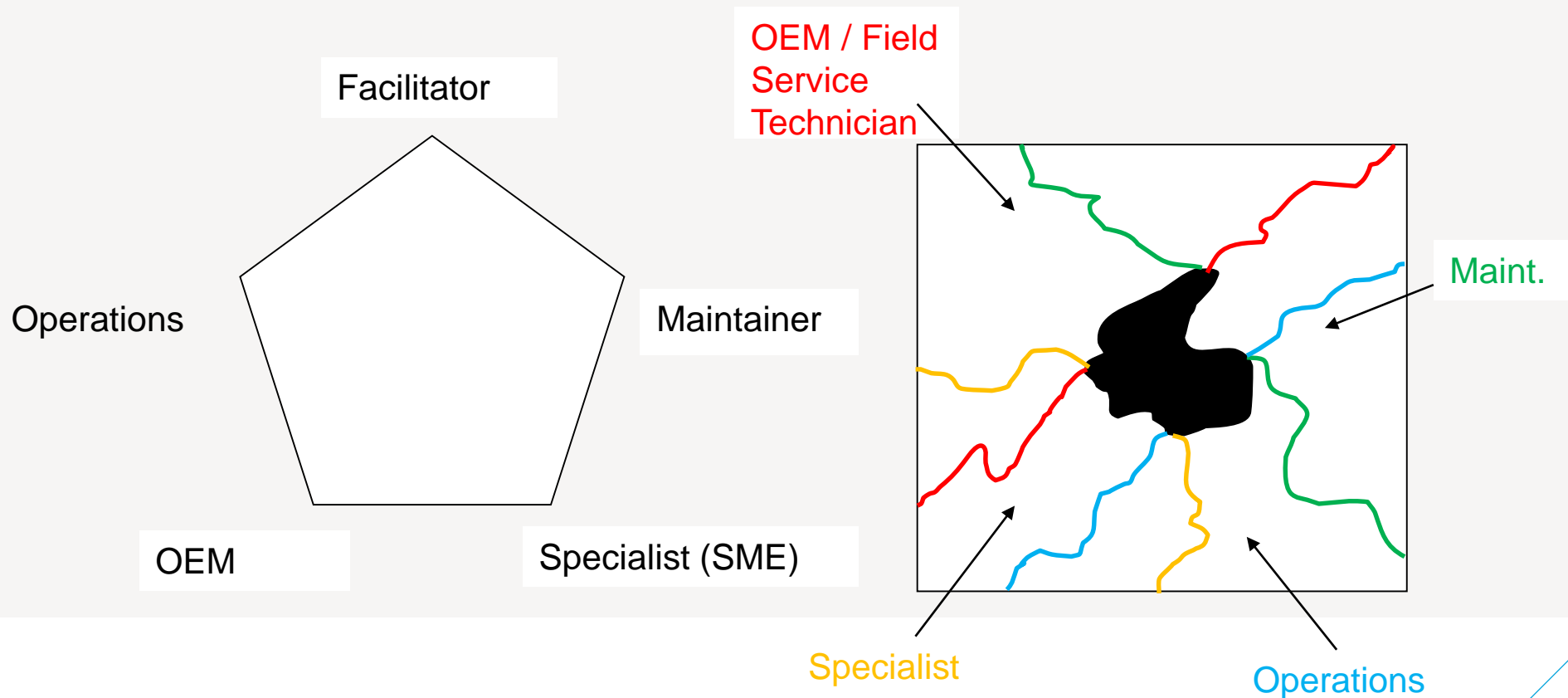
Allows the trainer to move the goalposts as necessary to clarify key points.

Demonstrates the size of the “Black Hole” and the importance of group facilitation.



RCM Working Group

Diversity is key to a successful RCM study as it reduces the knowledge, “Black Hole”:



Question & Answer Session (1)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. Where did the RCM methodology originate?
2. Who are recognized as the founders?
3. Who make up the standard RCM Analysis Group?
4. Explain why recognizing the Black Hole in knowledge is key?
5. What is recorded in a FMEA?

1.



Question & Answer Session (2)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. Where did the RCM methodology originate?
1. FAA review of failure patterns and what should be done about it in late 1960s / early 1970s.
2. Who are recognized as the founders?
2. Authors of FAA Report in 1973 were Stan Nowlan and Howard Heap.
3. Who make up the standard RCM Analysis Group?
3. RCM Facilitator, Maintainers, Operators, OEM Design, Specialists as needed.
4. Explain why recognizing the Black Hole in knowledge is key?
4. What is the Black Hole of knowledge and how do you recognise when you have one?
5. What is recorded in a FMEA?
5. Functions, Functional Failures, Failure Modes and Failure Effects.



Look Back

- › Traditional View vs. Reality
- › Way Forward – 7 Questions
- › RCM Definition
- › Functions
- › Functional Failures
- › Failure Modes
- › Failure Effects
- › Case Study
- › RCM Study Group



Session 4

Session 4 – Look Forward

- › Look Forward
 - › *Question 5*
 - › *Multi-coloured Decision Logic*
 - › *6 Consequence Categories (H/D (x3) and S/E; O; Non-O)*
 - › *Worth Doing? – Management of Consequences*
 - › *Hidden Failures*
 - › *Evident - S/E – Probability/Risk*
 - › *Evident – O – Economic / Non-O – Economic*
 - › *Example of Non-O Using Duty/Standby*
 - › *Probability of multiple failure*
 - › *Proactive Tasks*
 - › *Case Study*



The RCM Process – Q5

What do we want the equipment to do? (Functions).

How can it fail to do this? (Functional Failures).

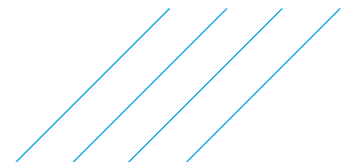
What causes the equipment to fail? (Failure Modes).

What happens when a failure occurs (Failure Effects).

How does the failure matter? (Failure Consequences).

Can the failure be predicted or prevented? (Proactive Failure Management).

How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).



Dealing with Failure Consequences

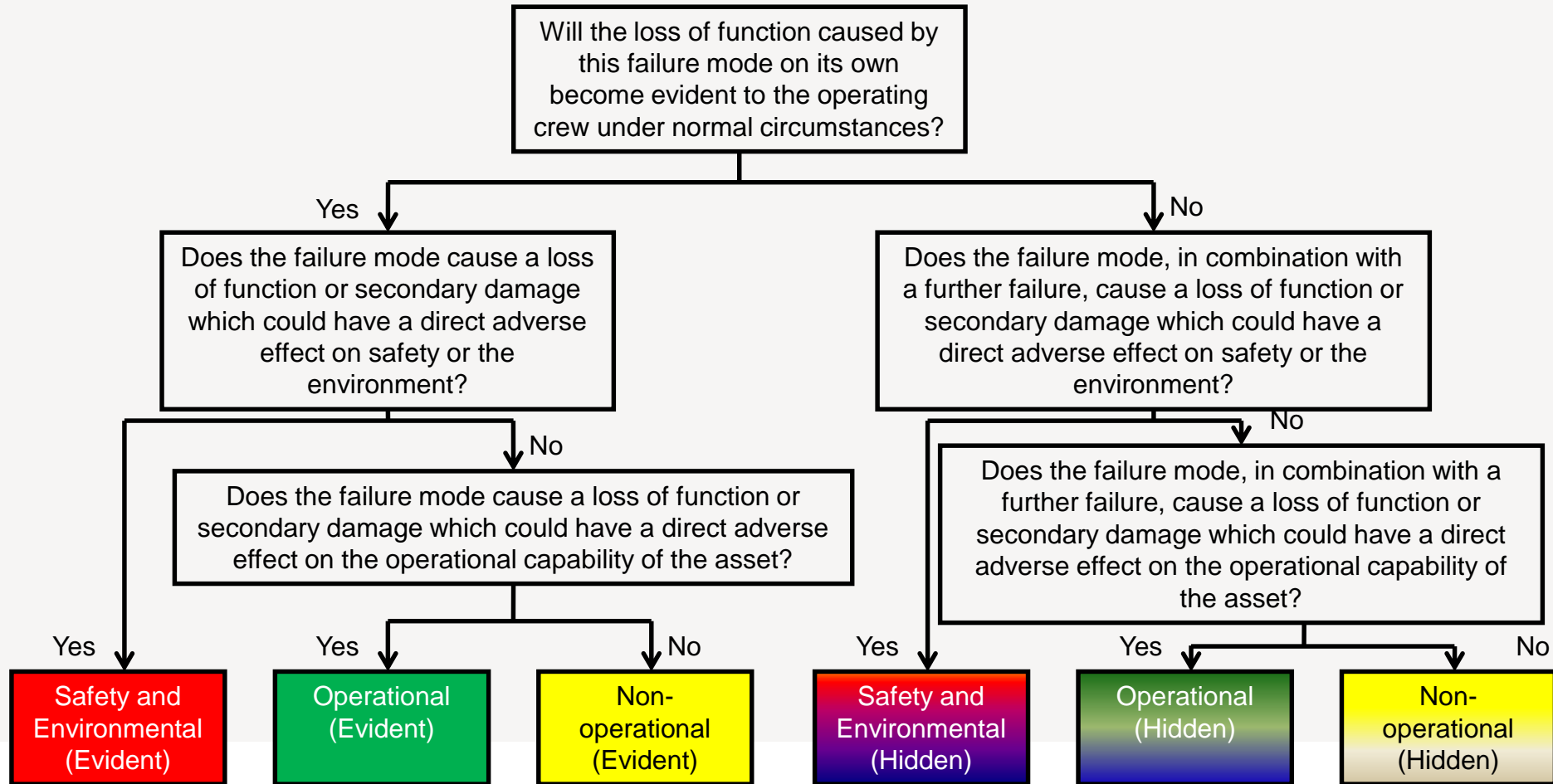
Failure management is more to do with understanding the consequences of failure and if appropriate preventing the failure occurring.

Therefore, any preventive action is only worth doing if it deals successfully with the consequences of failure.

Therefore, an assessment of the consequences of each failure is necessary to provide a basis for determining whether or not any preventive action is worth doing.



RCM Decision Logic – Level 1



Failure Consequence Categories

Using the RCM decision logic will yield one of 6 Failure Consequence categories for each failure that is considered:

Evident:

Safety and Environmental

Operational

Non-operational.

Hidden:

Safety and Environmental

Operational

Non-operational.



Safety and Environmental Consequences

A Failure Mode has Safety Consequences if the resulting loss of function could cause harm, injury or death.

A Failure Mode has Environmental Consequences if the resulting loss of function could result in the failure to comply with legislative or environmental standards.

For Failure Modes with Safety and Environmental Consequences, preventive actions are only worth doing if they are effective and reduce the probability of failure to a tolerable level.



Operational Consequences

A Failure Mode has Operational Consequences if it has a direct adverse impact on operational capability (i.e. it will incur direct or indirect costs). For example:

Zero/reduced output.

Quality issues.

Poor customer service.

Increased operating costs (energy consumption, conversion efficiency, etc.).

For Failure Modes with Operational Consequences, preventive actions are only worth doing if they are effective and their overall costs are less than the overall cost of the failures they are designed to prevent.

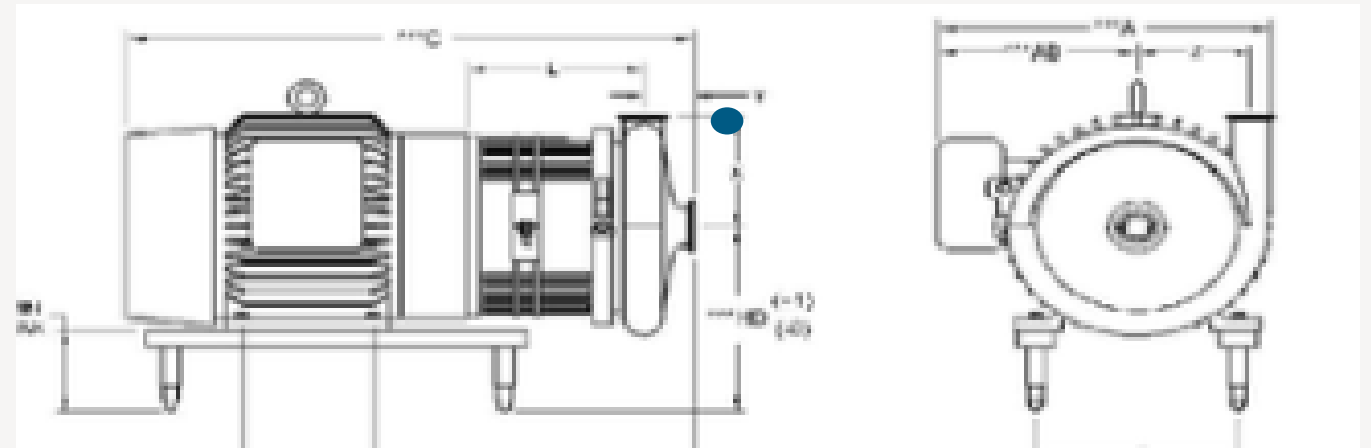
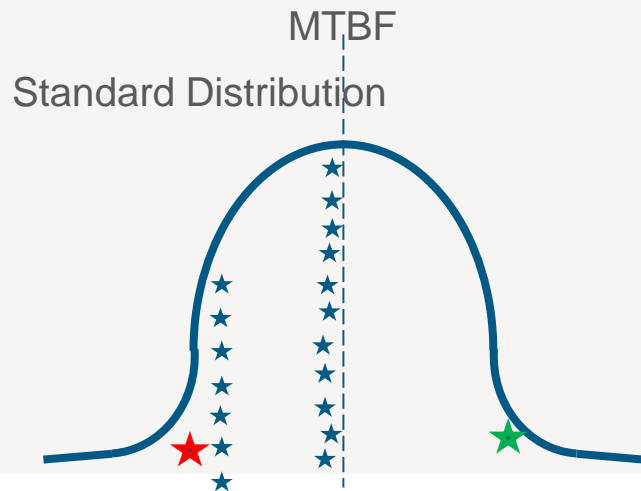


Operational Consequences – Duty Mash Pump

Example cost calculation to demonstrate how viability of operational consequence tasks are assessed. How do I work out if its worthwhile?? But is MTBF useful?

‘Mash’ Transfer Pump main bearing example.

Explain concept of MTBF and it’s usefulness (or lack of it).



Non-operational Consequences

If a Failure Mode has no Safety, Environmental or Operational Consequences the only consequence is the cost of repair.

For Failure Modes with Non-operational Consequences, preventive actions are only worth doing if they are effective and their overall costs are less than the cost of repairing the failures they are designed to prevent.



White-Board/Flip-Chart

Example - Cost calculation of 'Mash' Transfer Pump but add a second standby pump so that there are no operational consequences.

Explain that calculation could be made more complicated by, for example:

Considering the failure to start probability of the standby pump.

Knock-on failure effects and associated additional costs

Etc.



Hidden Failure Consequences

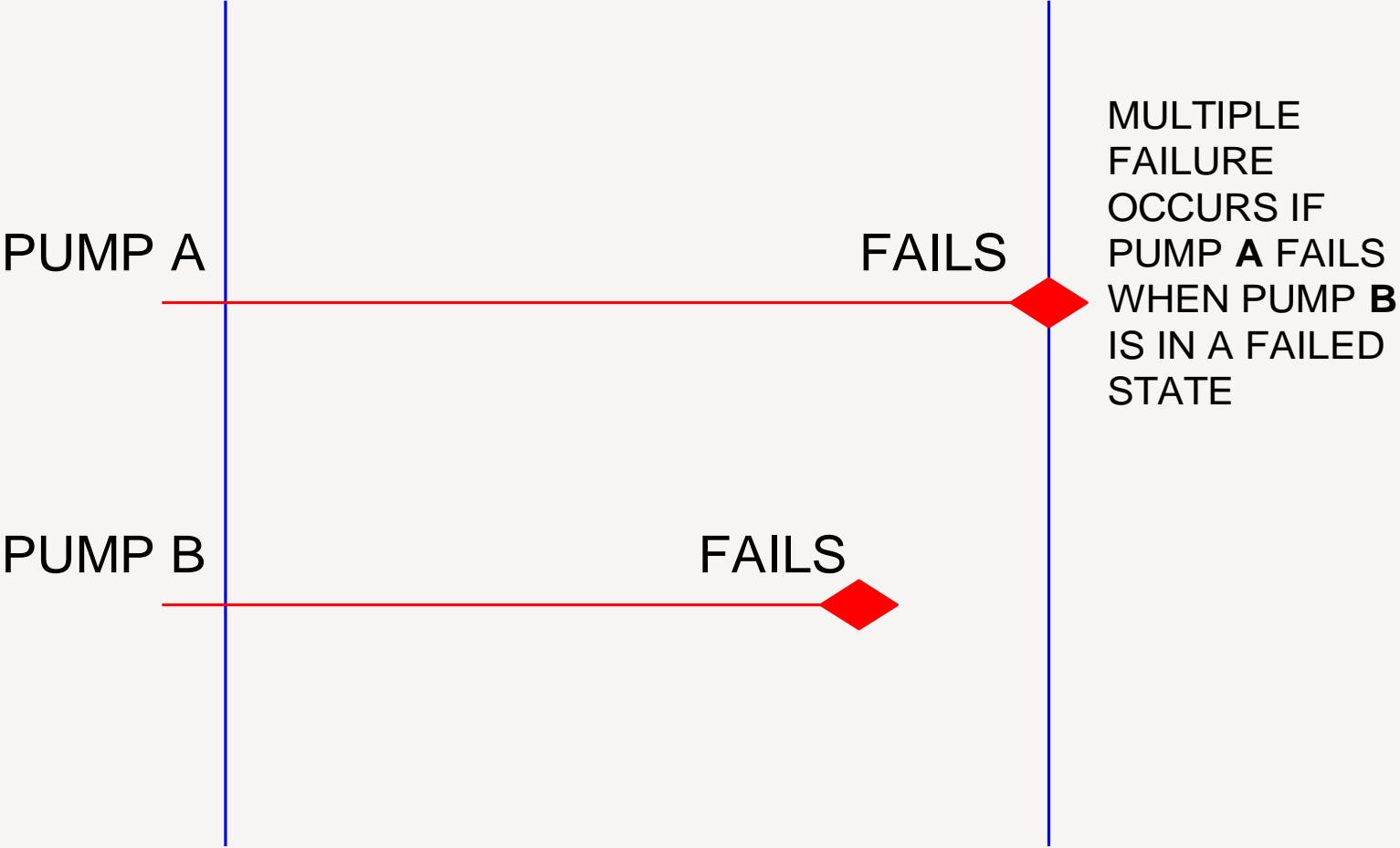
The consequences of a Hidden Failure will not become apparent to the operator during normal operation.

The consequences of a Hidden Failure will only become apparent after another failure or unusual event has occurred (in the absence of conducting a fault finding task).

For Failure Modes with Hidden Consequences, preventive actions are only worth doing if they are effective and reduce the probability of the multiple failure to a tolerable level.



Hidden Failure Example



White-Board – Hidden Failures

Use example of a motor car to demonstrate hidden failures:

- › Brake lights on a 2CV (i.e. No dashboard indication) – Hidden
- › Fuel line – Evident
- › Spare tyre – Hidden

Hand out hidden failures exercise sheet.

Go through hidden failures solutions and ask attendees to ‘facilitate’ if there are any disagreements.



Probability of Multiple Failure

Use 'Mash' Transfer Pump example to demonstrate probability of multiple failure:

- › If duty pump (protected function) has MTBF 4 years, probability of failure = $\frac{1}{4}$ per year.
- › If standby pump (protective device) has an availability of 66%, probability of being in a failed state = $\frac{1}{3}$.
- › Probability of the multiple failure = $\frac{1}{12}$.

However, if prepared to accept $\frac{1}{1000}$, there are several ways of upping the figure:

- › More reliable protected function (PM).
- › More available protective device (PM).
- › More layers of protection.

Task only worth doing if we achieve $\frac{1}{1000}$ – If Safety then Probability of failure will be as per Safety Management Matrix.



Is It Worth Doing?

Safety and Environmental Consequences:

Must reduce the probability of failure to a tolerable level.

Operational Consequences:

The cost of the activity must be less than the overall cost of failure.

Non-operational Consequences:

The cost of the activity must be less than the cost of repair.

Hidden Consequences:

Must reduce the probability of the multiple failure to a tolerable level and be cost effective for failures with Operational and Non-operational consequences.



Failure Consequences Exercise / Flip-Chart

Breakout Ex – 10 Mins

Hand out failure consequences exercise sheet.

Go through failure consequence solutions and ask attendees to 'facilitate' if there are any disagreements.



Session 4 - Drinks Break 20 Minutes



The RCM Process – Q6

What do we want the equipment to do? (Functions).

How can it fail to do this? (Functional Failures).

What causes the equipment to fail? (Failure Modes).

What happens when a failure occurs (Failure Effects).

How does the failure matter? (Failure Consequences).

Can the failure be predicted or prevented? (Proactive Failure Management).

How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).



Proactive Failure Management Tasks

The type of task eventually selected (and the chosen interval) will not only depend on the Failure Consequences, but also the failure characteristics of the Failure Mode.

Therefore, an assessment of the characteristics of each Failure Mode is necessary to determine whether or not any preventive action will be appropriate and effective.



Proactive Failure Management - Options

There are three categories of proactive maintenance activities:

On-condition Maintenance (OCM). Equipment is 'checked' at fixed, regular intervals to determine if a condition exists that indicates the equipment is in the process of 'failing'.

Scheduled Restoration (SR). Equipment is 'restored' (e.g. overhauled) at fixed intervals, **regardless** of condition.

Scheduled Discard (SD). Equipment is 'discarded' (i.e. replaced) at fixed intervals, **regardless** of condition.



Exercise - Use White-Board/Flip-Chart

Ask for examples of each type of task, related to some everyday object – e.g. Motor car:

- › OCM: Fluid levels, tyre tread, break pads, pump wear, bearing wear etc.
- › SR: Wheel Alignment, Oil filled Air Filter, Ride height.
- › SD: Timing belt, spark plugs, filters.

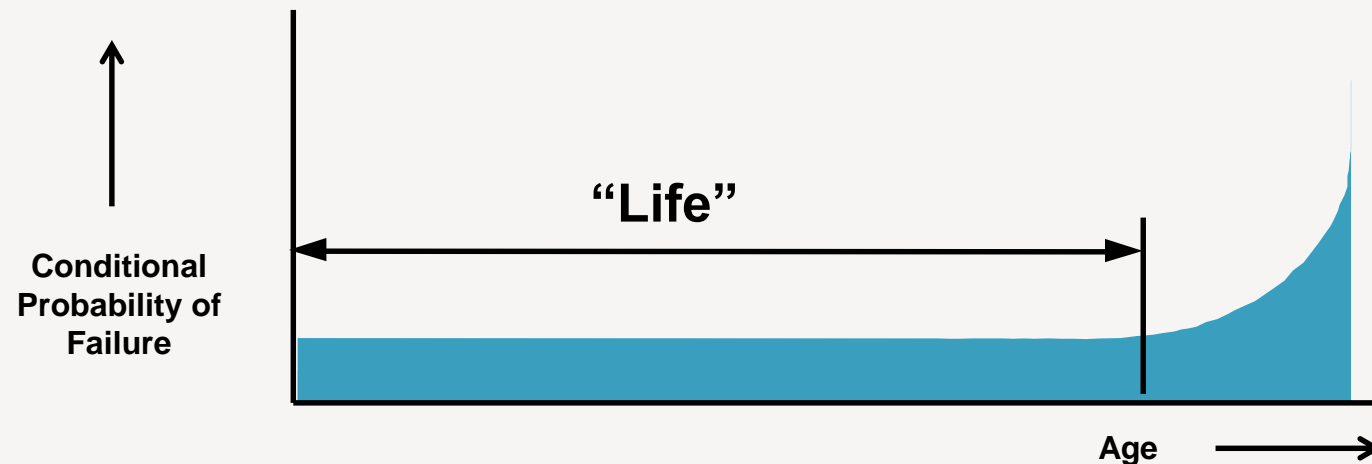
But will the chosen task be effective and worthwhile? For instance - old spark plugs used to be cleaned, smoothed and reset and so it was just time of a mechanic to do the SR that had to be costed; however now we understand that plugs degrade with age and so given they are relatively cheap and they do degrade they are now SD.



Scheduled Discard Tasks

For a Scheduled Discard Task to be effective there are 2 'rules' that must be satisfied:

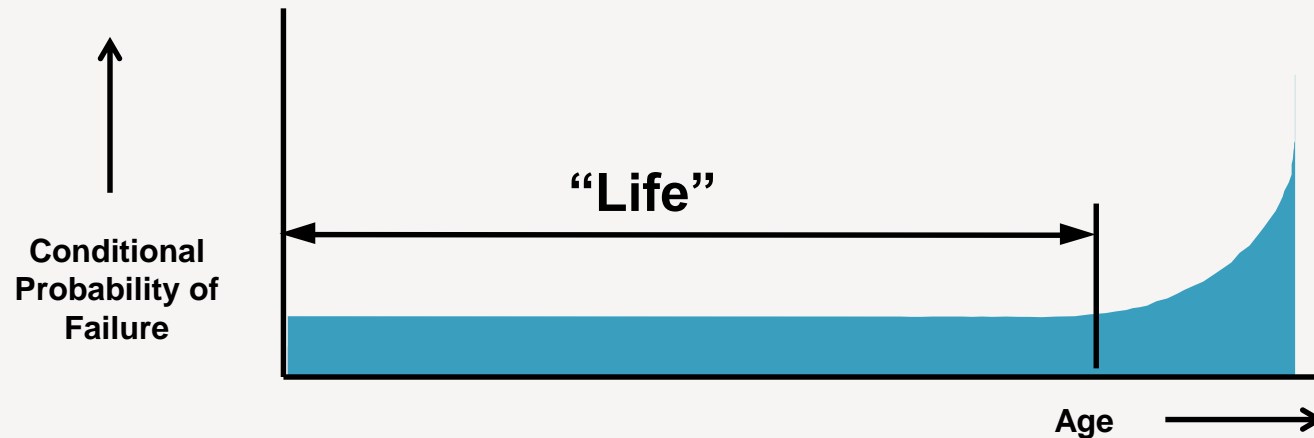
- › There has to be an age at which there is a marked increase in the conditional probability of failure.
- › This age has to be consistent across a sample of items such that the majority of items survive to this age. However, for failures with Safety (or Environmental) Consequences, all items have to survive to this age.



Scheduled Restoration Tasks

For a Scheduled Restoration Task to be effective there are **3** 'rules' that must be satisfied:

- › There has to be an age at which there is a marked increase in the conditional probability of failure.
- › This age has to be consistent across a sample of items such that the majority of items survive to this age. However, for failures with Safety (or Environmental) Consequences, all items have to survive to this age.
- › The restoration task has to restore the item to its original condition.

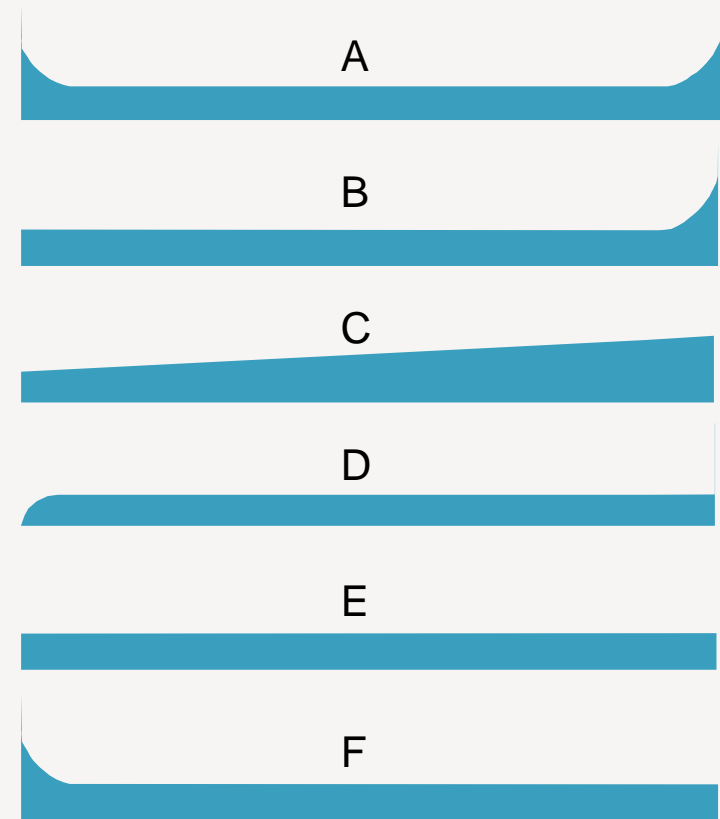


Limitations of SR and SD Tasks

According to the first 'rule' for SR and SD tasks, they will only be effective where the failure pattern exhibits a marked increase in the conditional probability of failure.

This is only true for failure patterns A, B and C, which, in turn, represent only a small percentage of equipment failures (~11% in the aviation industry).

How, therefore, do we prevent the vast majority of equipment failures that exhibit failure patterns D, E and, in particular, F?



OCBM – P-F Duration

OCM is used instead – looks for warnings of failure or the emergence of ‘potential’ failure conditions.

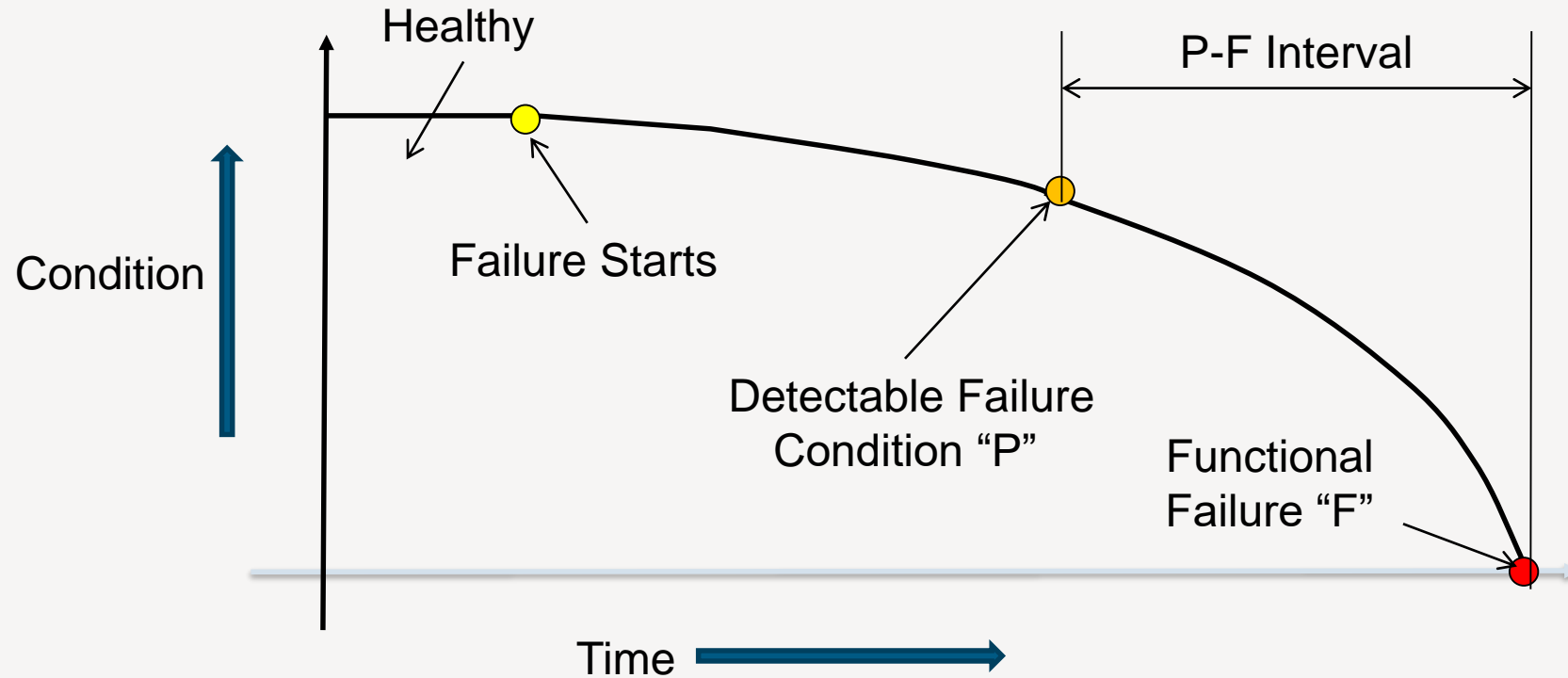
Draw P-F curve for ‘Mash’ Transfer Pump bearing failure showing several failure conditions and associated P-F intervals:

- › Vibration – 2 months.
- › Noise – 2 weeks.
- › Temperature – 2 days.
- › Flames – 2 minutes.

If we decide to check for noise, we must return within 2 weeks to be certain of catching the onset of failure or 2 days if we decide to check temperature.



The Potential Failure Curve



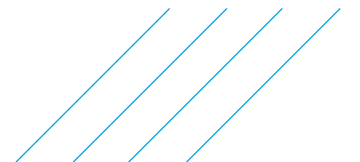
On-condition tasks can apply to any of the 6 failure consequence categories and are not related to the age of the equipment



On-condition Tasks

For an On-condition Task to be effective there are 4 'rules':

- › There has to be a clear condition (potential failure) that can be checked/monitored.
- › The P-F interval has to be sufficient to allow appropriate action to be taken.
- › The P-F interval has to be consistent.
- › The On-condition Task can/has to be done at intervals less than the P-F interval. (For Safety/Environmental appropriate factors are applied e.g. 1/2 or 1/3 P-F interval).



On Condition Based Maintenance (OCBM)

Discuss examples that illustrate the use of the 4 OC Task 'rules':

- › Oil samples that have to be sent away for analysis and the results returned later that week.
- › Looking for bearing degradation through metal in oil. P-F interval is very short but continuous monitoring may make the task worthwhile – i.e. an emergency shutdown prevents significant secondary damage.
- › Domestic light bulb (old style) – monitored continuously but P-F is not long enough to be of use.

The difficult part is assessing the P-F interval – e.g. would car drivers continue with their journey if they detected vibration in the front wheel bearing? Would the same be true if they detected a knocking noise coming from the big-end bearing?



Techniques - On Condition Based Monitoring

Types of OCBM:

Vibrational Analysis

Thermography (Mechanical and Electrical)

Oil Analysis

Electrical current analysis

Pressure / Pressure Differential Monitoring

Ultrasonics

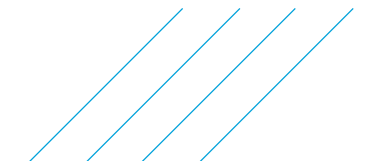
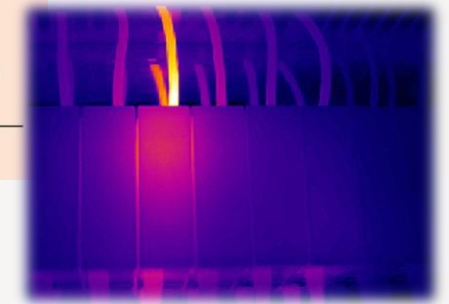
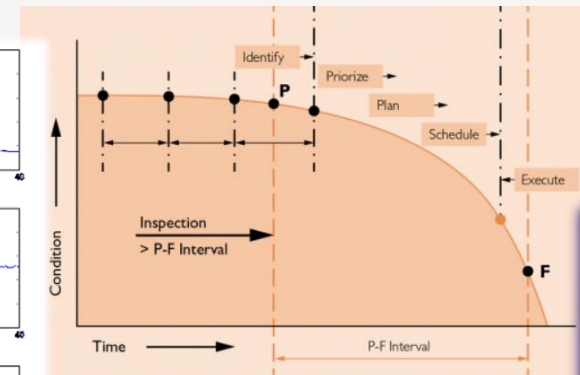
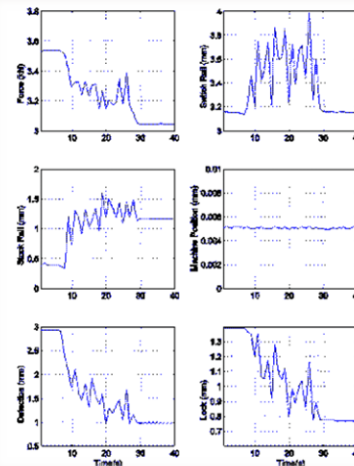
Laser Alignment

Crack detection

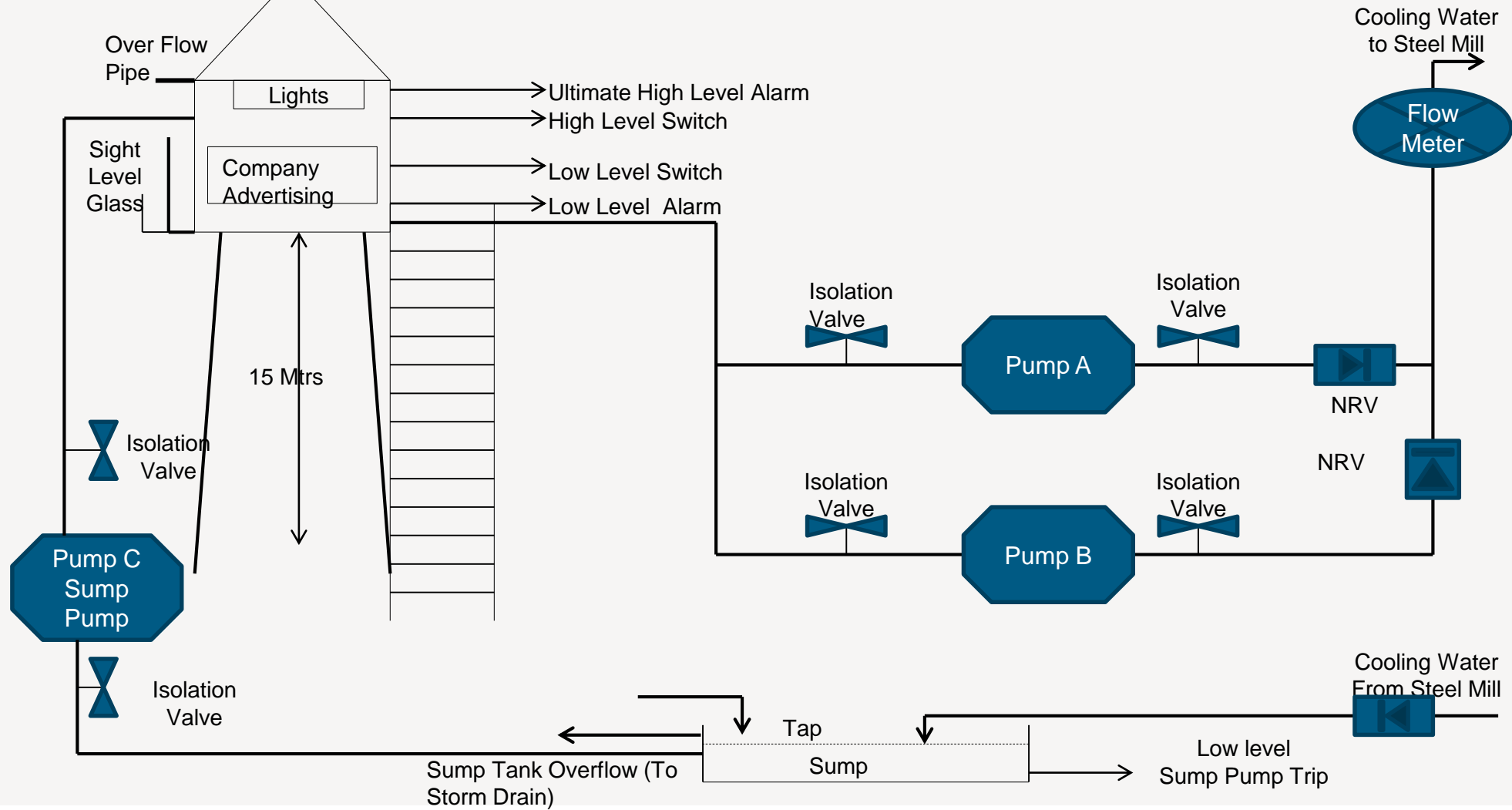
Optical – Ultra-fast Imaging

Human senses (i.e. look, listen, feel, smell) which, although highly subjective, do come as a complete package.

NB: Refer to Appendix 4 of RCM2 Blue Book (page 348 onwards).



Case Study – Rolling Mill Cooling System



Question & Answer Session (1)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. Explain what is meant by the term Hidden Failure in RCM terms? 1.
2. What consequences are regarded as Safety or Environmental in RCM terms?
3. Name three methods of OCBM?
4. What is the main limitation of hard time tasks such as SR/SD?
5. Name two of the rules that apply to setting an OCBM Task such as checking oil condition or Differential Pressure (DP)?



Question & Answer Session (2)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. Explain what is meant by the term Hidden Failure in RCM terms?
1. It will only become evident with a second failure or event. On its own you might not know until another event happens and then it might be too late?
2. What consequences are regarded as Safety or Environmental in RCM terms?
2. It will depend on your organisations definition, but generally anything that causes injury or death is a Safety consequence and any failure that will breach Environmental legislation is regarded as a Environmental consequence.
3. Name three methods of OCBM?
3. Heat monitoring, Pump output or DP, measuring wear, Vibrational analysis, electrical motor current analysis etc .
4. What is the main limitation of hard time tasks such as SR/SD?
4. In sophisticated systems such as Aircraft it can only represent 2% of all failure patterns!! Most are random failures so cant set useful life?
5. Name two of the rules that apply to setting an OCBM Task such as checking oil condition or Differential Pressure (DP)?
5. It must be consistent and give you enough time to do something about the potential failure. For safety related failures you must apply a suitable factored interval.



Add Look Back

Question 5

Multi-colored Decision Logic (6 Options)

Worth Doing? – Management of Consequences

Evident - S/E , O – Economic

Example of O Using Data – MTBF vs. Break Even MTBF

Evident – Non-O – Economic

Hidden Failures Consequences and example

Exercise on Hidden

Probability of a Multiple failure (Protective and Protected)

Proactive Tasks

Case Study Task Selection.



Session 5

Session 3 – Look Forward

- › Q 6
- › Revision
- › Failure Management/Proactive Maintenance
- › OCM; SO; SR – 3 Types of Proactive Task
- › Definition of SO and SR
- › Fixed Intervals Regardless
- › Interval – “LIFE”
- › Usefulness of SO and SR – Not for Random Failures
- › Definition of OCM
- › Draw P-F Curve with Bearing Conditions and Explain
- › Apply to Any Failure Curve; Not Related to Age
- › Interval of OCM Tasks – Less Than P-F Interval
- › Four Rules for OCM Plus Examples
- › Meaning of Life



The RCM Process – Q6

What do we want the equipment to do? (Functions).

How can it fail to do this? (Functional Failures).

What causes the equipment to fail? (Failure Modes).

What happens when a failure occurs (Failure Effects).

How does the failure matter? (Failure Consequences).

Can the failure be predicted or prevented? (Proactive Failure Management).

How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).



Proactive Failure Management Tasks

The type of task eventually selected (and the chosen interval) will not only depend on the Failure Consequences, but also the failure characteristics of the Failure Mode.

Therefore, an assessment of the characteristics of each Failure Mode is necessary to determine whether or not any preventive action will be appropriate and effective.



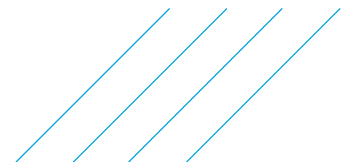
Proactive Failure Management - Options

There are three categories of proactive maintenance activities:

On-condition Maintenance (OCM). Equipment is 'checked' at fixed, regular intervals to determine if a condition exists that indicates the equipment is in the process of 'failing'.

Scheduled Restoration (SR). Equipment is 'restored' (e.g. overhauled) at fixed intervals, **regardless** of condition.

Scheduled Discard (SD). Equipment is 'discarded' (i.e. replaced) at fixed intervals, **regardless** of condition.



Exercise - Use White-Board/Flip-Chart

Ask for examples of each type of task, related to some everyday object – e.g. Motor car:

- › OCM: Fluid levels, tyre tread, break pads, pump wear, bearing wear etc.
- › SR: Wheel Alignment, Oil filled Air Filter, Ride height.
- › SD: Timing belt, spark plugs, filters.

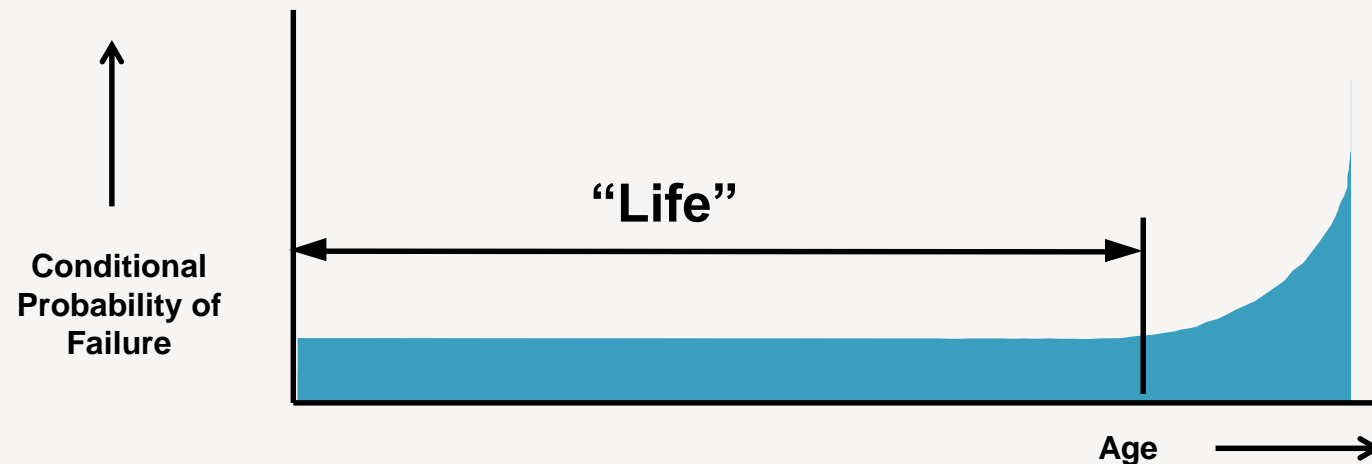
But will the chosen task be effective and worthwhile? For instance - old spark plugs used to be cleaned, smoothed and reset and so it was just time of a mechanic to do the SR that had to be costed; however now we understand that plugs degrade with age and so given they are relatively cheap and they do degrade they are now SD.



Scheduled Discard Tasks

For a Scheduled Discard Task to be effective there are 2 'rules' that must be satisfied:

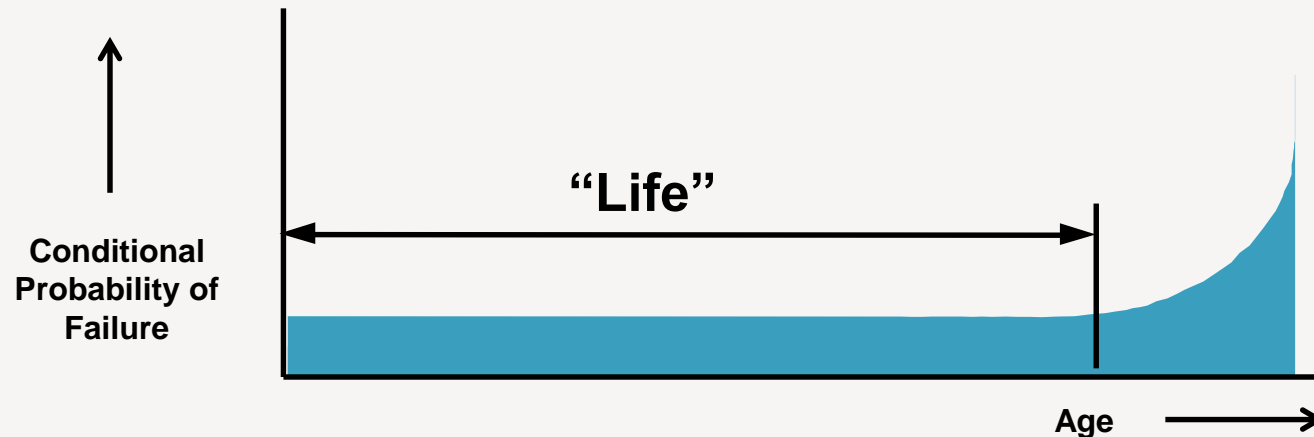
- › There has to be an age at which there is a marked increase in the conditional probability of failure.
- › This age has to be consistent across a sample of items such that the majority of items survive to this age. However, for failures with Safety (or Environmental) Consequences, all items have to survive to this age.



Scheduled Restoration Tasks

For a Scheduled Restoration Task to be effective there are **3** 'rules' that must be satisfied:

- › There has to be an age at which there is a marked increase in the conditional probability of failure.
- › This age has to be consistent across a sample of items such that the majority of items survive to this age. However, for failures with Safety (or Environmental) Consequences, all items have to survive to this age.
- › The restoration task has to restore the item to its original condition.

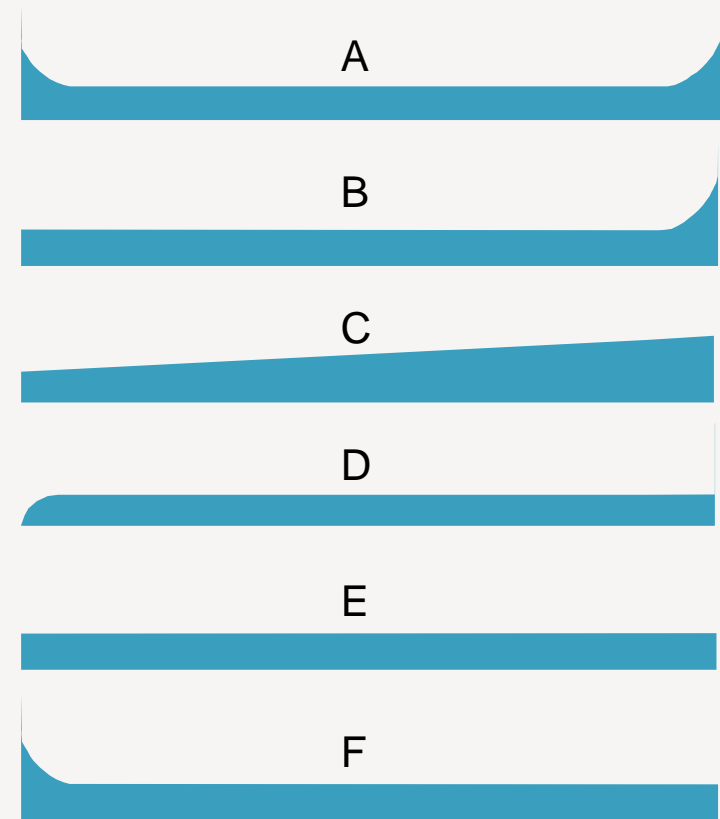


Limitations of SR and SD Tasks

According to the first 'rule' for SR and SD tasks, they will only be effective where the failure pattern exhibits a marked increase in the conditional probability of failure.

This is only true for failure patterns A, B and C, which, in turn, represent only a small percentage of equipment failures (~11% in the aviation industry).

How, therefore, do we prevent the vast majority of equipment failures that exhibit failure patterns D, E and, in particular, F?



OCBM – P-F Duration

OCM is used instead – looks for warnings of failure or the emergence of ‘potential’ failure conditions.

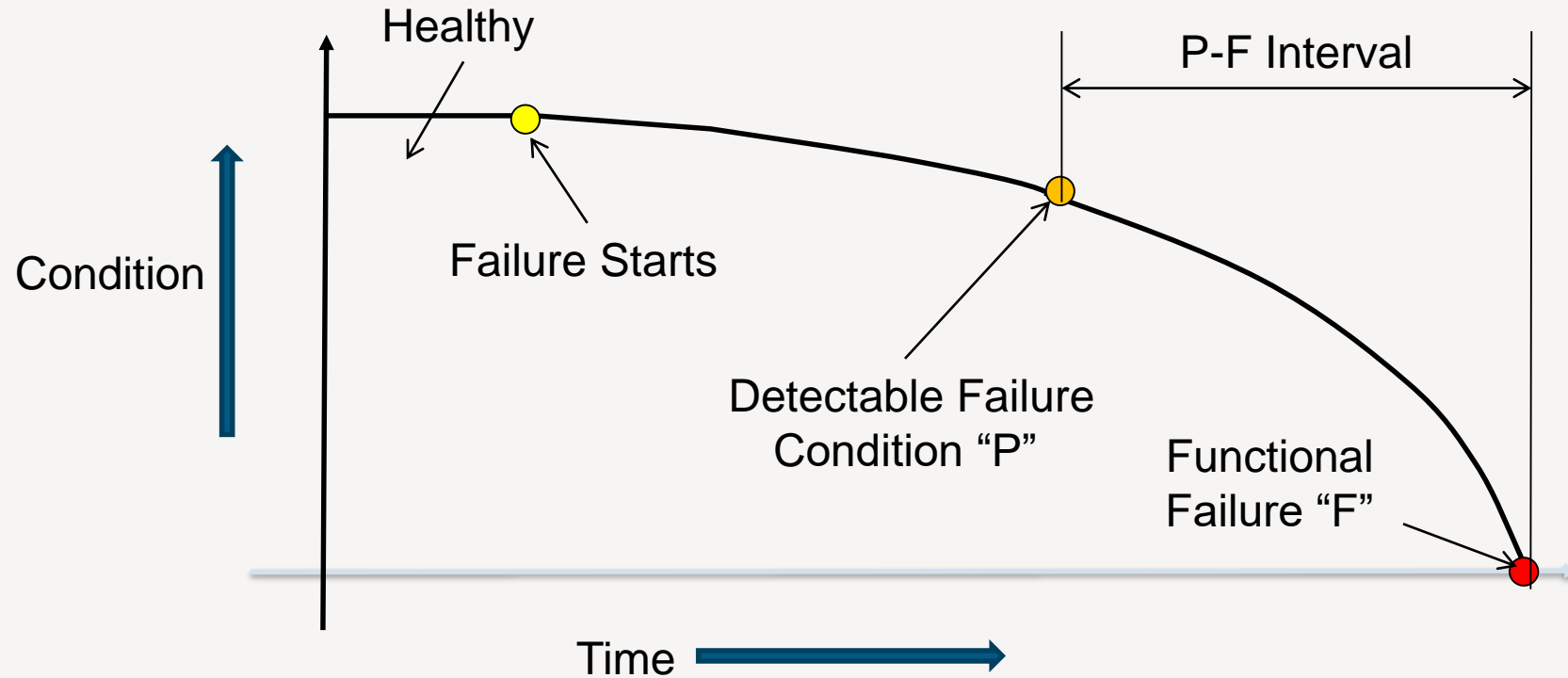
Draw P-F curve for ‘Mash’ Transfer Pump bearing failure showing several failure conditions and associated P-F intervals:

- › Vibration – 2 months.
- › Noise – 2 weeks.
- › Temperature – 2 days.
- › Flames – 2 minutes.

If we decide to check for noise, we must return within 2 weeks to be certain of catching the onset of failure or 2 days if we decide to check temperature.



The Potential Failure Curve



On-condition tasks can apply to any of the 6 failure consequence categories and are not related to the age of the equipment



On-condition Tasks

For an On-condition Task to be effective there are 4 'rules':

- › There has to be a clear condition (potential failure) that can be checked/monitored.
- › The P-F interval has to be sufficient to allow appropriate action to be taken.
- › The P-F interval has to be consistent.
- › The On-condition Task can/has to be done at intervals less than the P-F interval. (For Safety/Environmental appropriate factors are applied e.g. 1/2 or 1/3 P-F interval).



On Condition Based Maintenance (OCBM)

Discuss examples that illustrate the use of the 4 OC Task 'rules':

- › Oil samples that have to be sent away for analysis and the results returned later that week.
- › Looking for bearing degradation through metal in oil. P-F interval is very short but continuous monitoring may make the task worthwhile – i.e. an emergency shutdown prevents significant secondary damage.
- › Domestic light bulb (old style) – monitored continuously but P-F is not long enough to be of use.

The difficult part is assessing the P-F interval – e.g. would car drivers continue with their journey if they detected vibration in the front wheel bearing? Would the same be true if they detected a knocking noise coming from the big-end bearing?



Types of On Condition Based Monitoring

Types of OCBM:

Vibrational Analysis

Thermography (Mechanical and Electrical)

Oil Analysis

Electrical current analysis

Pressure / Pressure Differential Monitoring

Ultrasonics

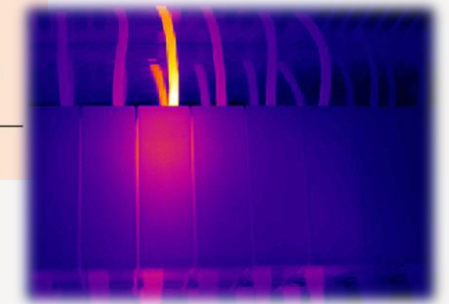
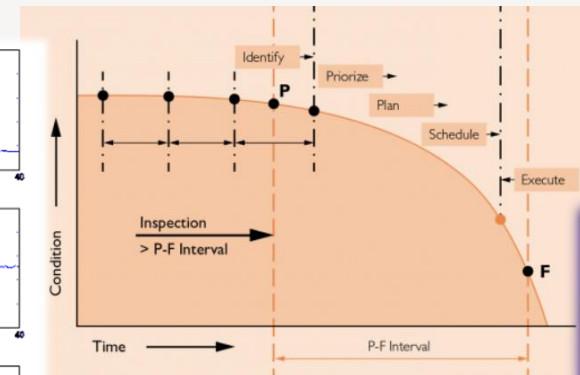
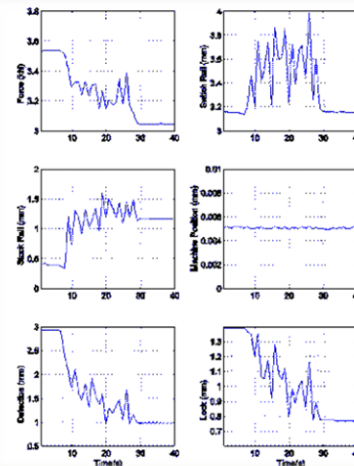
Laser Alignment

Crack detection

Optical – Ultra-fast Imaging

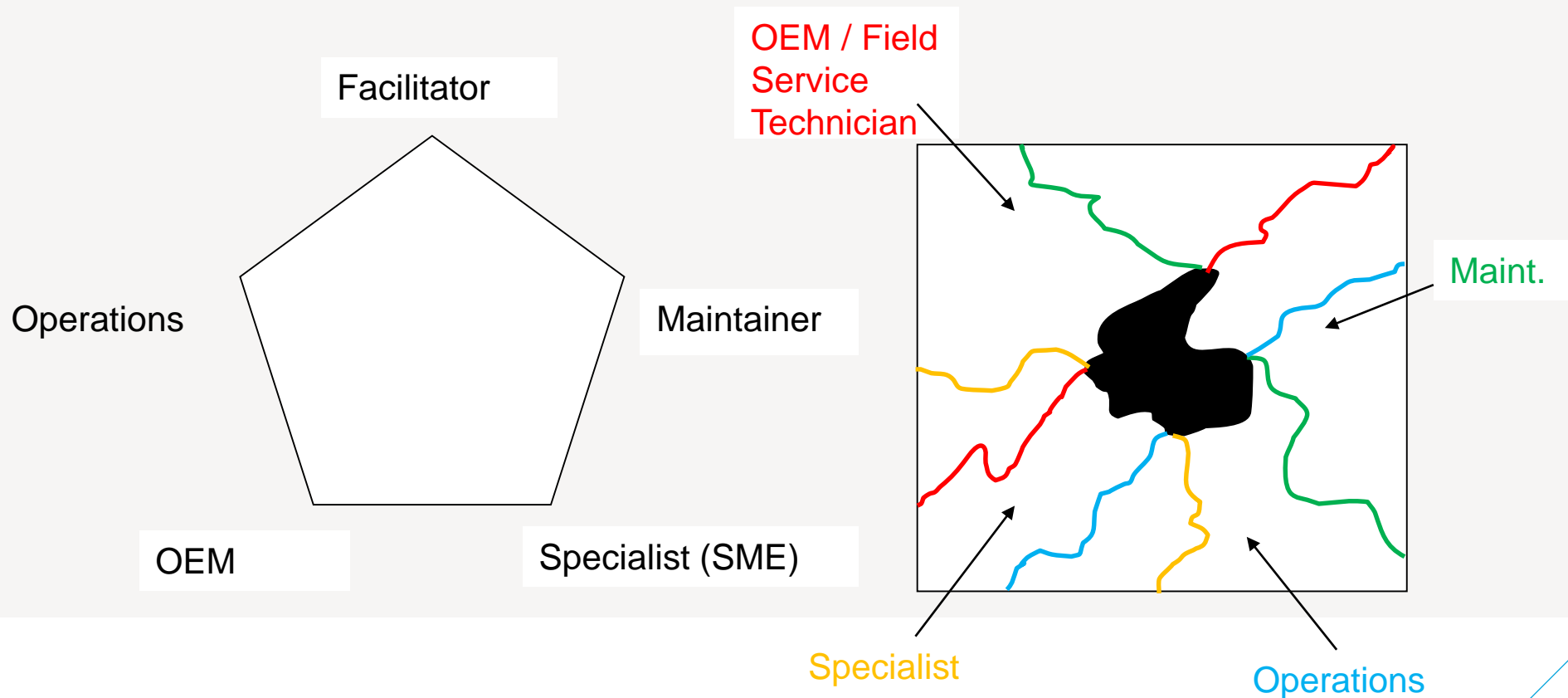
Human senses (i.e. look, listen, feel, smell) which, although highly subjective, do come as a complete package.

NB: Refer to Appendix 4 of RCM2 Blue Book (page 348 onwards).



RCM Working Group

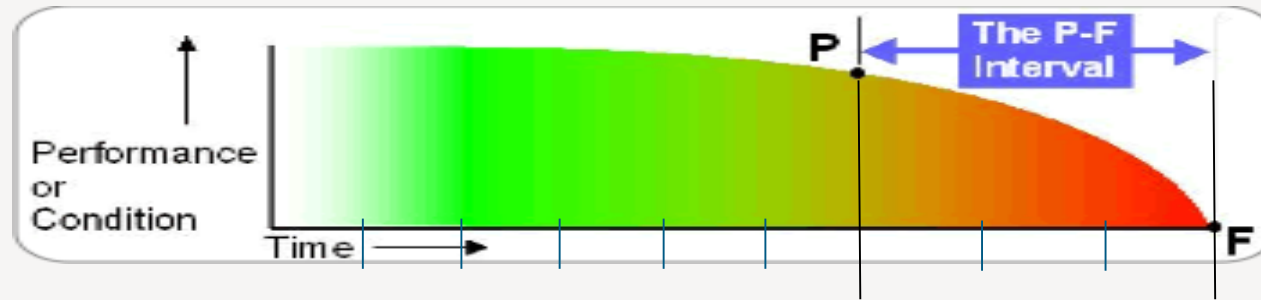
Diversity is key to a successful RCM study as it reduces the knowledge, “Black Hole”:



Use White-Board/Flip-Chart

Demonstrate the importance of carrying out OCM Tasks at intervals less than the P-F interval using the 'extended' P-F curve. Explain that this is the fundamental reason why OCM 'doesn't work'.

Introduce the concept of 'Delayed Onset of OCM' – e.g. checking of car tyres.



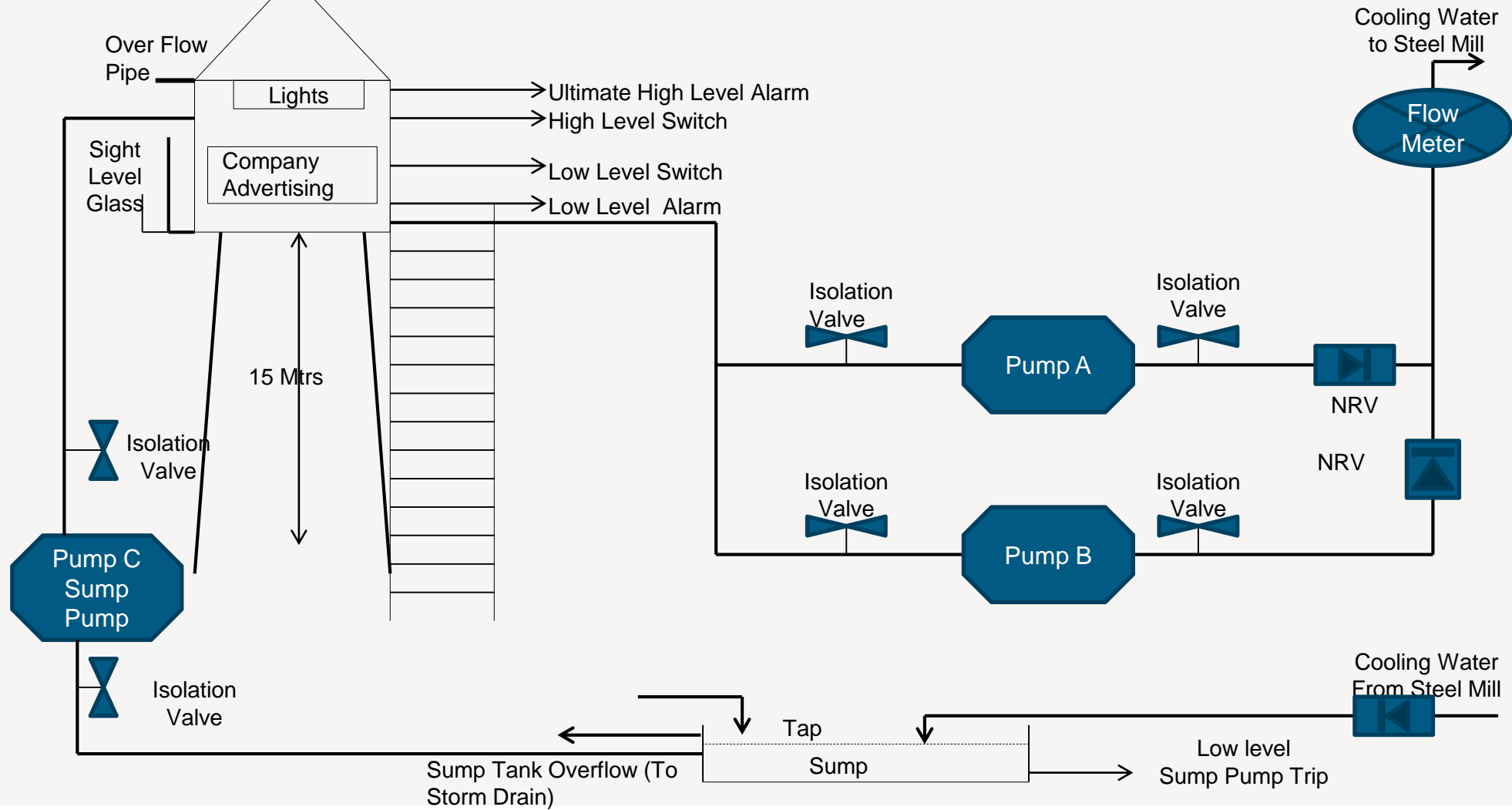
Intervals = >2 opportunities to find deteriorating Incipient condition.



Session 5 - Drinks Break 20 Minutes



Case Study – Rolling Mill Cooling System



Scheduled vs. On-condition

Scheduled (SR/SD)

For failures with safety consequences, probability of failure before “Life” has to be zero.

Life estimates are usually conservative to ‘guarantee’ that wear-out zone is avoided.

- Therefore, On-condition tasks are safer and (generally) less expensive than SR/SD tasks. They are also less intrusive.
- Similarly SR tasks are (generally) less expensive than SD tasks.
- Hence the order (OCM – SR – SD) in the RCM decision logic diagram.

On-condition

Will identify ‘premature’ failures and is therefore the safer option.

Doesn’t “waste” residual “Useful Life” and, therefore, reduces the amount of re-introduced “Burn-in”.



Revision Slides

The Way Forward - RCM

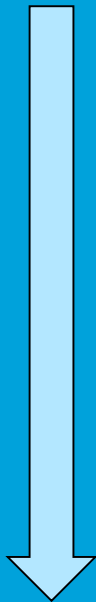
Reliability-centred Maintenance (RCM):

A process used to determine what must be done to ensure that equipment fulfils its intended function in its operating context, given the failure characteristics of the equipment.



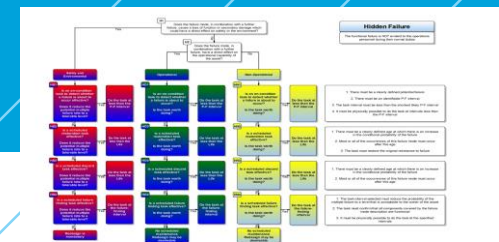
The RCM Process

The RCM process involves answering seven basic questions about the equipment for which a maintenance strategy is required:



1. What do we want the equipment to do? (Functions).
2. How can it fail to do this? (Functional Failures).
3. What causes the equipment to fail? (Failure Modes).
4. What happens when a failure occurs (Failure Effects).
5. How does the failure matter? (Failure Consequences).
6. Can the failure be predicted or prevented? (Proactive Failure Management).
7. How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).

FMEA Worksheet		Training Material	
Project: 3 Day RCM Awareness Course		Compiled By:	Date: 31 Jan 2014
System: Rolling Mill Cooling Water Supply Sys.		Approved By:	Sheet: 4 of 8
Function	Functional Failure	Failure Mode	Failure Effect
1 To supply at least 80 litres / min of cooling water to the rolling plant when required.	A Does not supply cooling water to the rolling plant at all.	1 Incoming electrical supply fails for any reason. 2 Pump A bearing lubrication degrades through normal use.	Analysed separately (Outside the boundaries of this analysis). Friction increases as the lubrication degrades and wear rates will increase. Eventually the bearing will seize and the motor will trip on overload. Cooling water supply to the mill will cease. The Operator will receive a 'low flow rate alarm' and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 2 minutes with resulting minor damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000.
		3 Pump A motor windings degrade due to age (contaminants, vibration).	The current to the motor increases as the winding degrades. Eventually an earth fault will occur and the motor will trip. Cooling water supply to the mill will cease. The Operator will receive a 'low flow rate alarm' and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 2 minutes with resulting damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000.
		4 Pump A coupling degrades through normal use (wear and tear).	There will be visible signs of degradation on the coupling surfaces. Initially the coupling will 'click'. The motor will continue to rotate but no pumping will take place. The Operator will receive a 'low flow rate' alarm and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 2 minutes with resulting damage to the rolled steel. Downtime = 3 mins. Production loss = £3,000.



Defining Functions – Q1

Example – Marine Engine:

To power the main gearbox at varying speeds up to a maximum of 1700 CRPM and 708 BkW.

List all functions associated with the system.

Describe the minimal acceptable performance criteria rather than the design capacity.

Wherever possible, performance standards should be quantified

The 'want' must not exceed the 'can'.

Distinguish between “To do....” and “To be....”



Types of Function

Functions can be split into two different categories:

- › Primary
- › Secondary



Primary Functions

The reason why the equipment exists.

Normally identified by the name, e.g.:

- › Power Pack – To Power;
- › Pump – To Pump;
- › Drier – To Dry.

Suggest the Primary Function of the 'Mash' Transfer Pump



Secondary Functions

Environmental Integrity

Safety/Structural Integrity

Control/Containment/Comfort

Appearance

Protection

Economy/Efficiency

Superfluous

E – S – C – A – P – E – S



Defining Functional Failures

Even for the most complex functional descriptions, defining functional failures should be a straightforward process; however, the importance of this step should not be overlooked.

Functional Failures can be described in simple terms as:

- › Not at all;
- › Too little (depends on performance standards);
- › Too much (depends on performance standards).



Describing Failure Modes

A Functional Failure is a “failed state” whereas a Failure Mode is an ‘event’ that causes the Functional Failure. For example:

- › Bearing misaligned (human error).
- › Pipe corrodes.
- › Pipe erodes.
- › Pipe accidentally damaged.
- › Drive belt wears.

Note that similar equipment items may experience different Failure Modes depending on the operating context. For example – the duty and standby ‘Mash’ Transfer Pumps.



Describing Failure Effects

Failure Effects are described as if nothing is being done to detect or prevent the Failure Mode. These can be written as:

A story

A series of bullet points.

Local, next higher level (System), End Effects (Operational).



What To Include?

Failure Effects should cover/include:

- › Any evidence that the failure is about to occur (e.g. heat, noise, vibration, etc.)
- › Any evidence that the failure has occurred (e.g. engine stops, alarms, etc.)
- › Any action taken by the operator to isolate or mitigate the failure
- › Ways in which the failure may threaten safety or the environment
- › Ways in which the failure may threaten production/operation
- › Any secondary damage caused by the failure and estimate of costs.
- › The repair action and downtime required to repair the failure (estimated costs).



RCM Decision Worksheet - Example

Training Material

FMEA Worksheet

Project: 3 Day RCM Awareness Course	Compiled By:	Date: 31 Jan 2014
System: Rolling Mill Cooling Water Supply Sys	Approved By:	Sheet of 8

Function		Functional Failure		Failure Mode		Failure Effect	
1	To supply at least 80 litres / min of cooling water to the rolling plant when required.	A	Does not supply cooling water to the rolling plant at all.	1	Incoming electrical supply fails for any reason.	Analysed separately (Outside the boundaries of this analysis).	
				2	Pump A bearing lubrication degrades through normal use.	Friction increases as the lubrication degrades and wear rates will increase. Eventually the bearing will seize and the motor will trip on overload. Cooling water supply to the mill will cease. The Operator will receive a 'low flow rate' alarm and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting minor damage to the rolled steel. Downtime – 3 mins Production loss - £3,000.	
				3	Pump A motor windings degrade due to age (contaminants, vibration).	The current to the motor increase as the winding degrade. Eventually an earth fault will occur and the motor will trip. Cooling water supply to the mill will cease. The Operator will receive a 'low flow rate' alarm and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting damage to the rolled steel. Downtime – 3 mins Production loss - £3,000.	
				4	Pump A coupling degrades through normal use (wear and tear).	There will be visible signs of degradation on the coupling surfaces. Eventually the coupling will shear. The motor will continue to rotate but no pumping will take place. The Operator will receive a 'low flow rate' alarm and immediately switch over to the standby pump and call Maintenance. Water cooling to the mill will be lost for approximately 3 minutes with resulting damage to the rolled steel. Downtime – 3 mins Production loss - £3,000.	



Failure Consequence Categories

Using the Network Rail RCM decision logic will yield one of 6 Failure Consequence categories for each failure that is considered:

Evident:

Safety and Environmental

Operational

Non-operational.

Hidden:

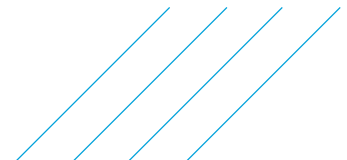
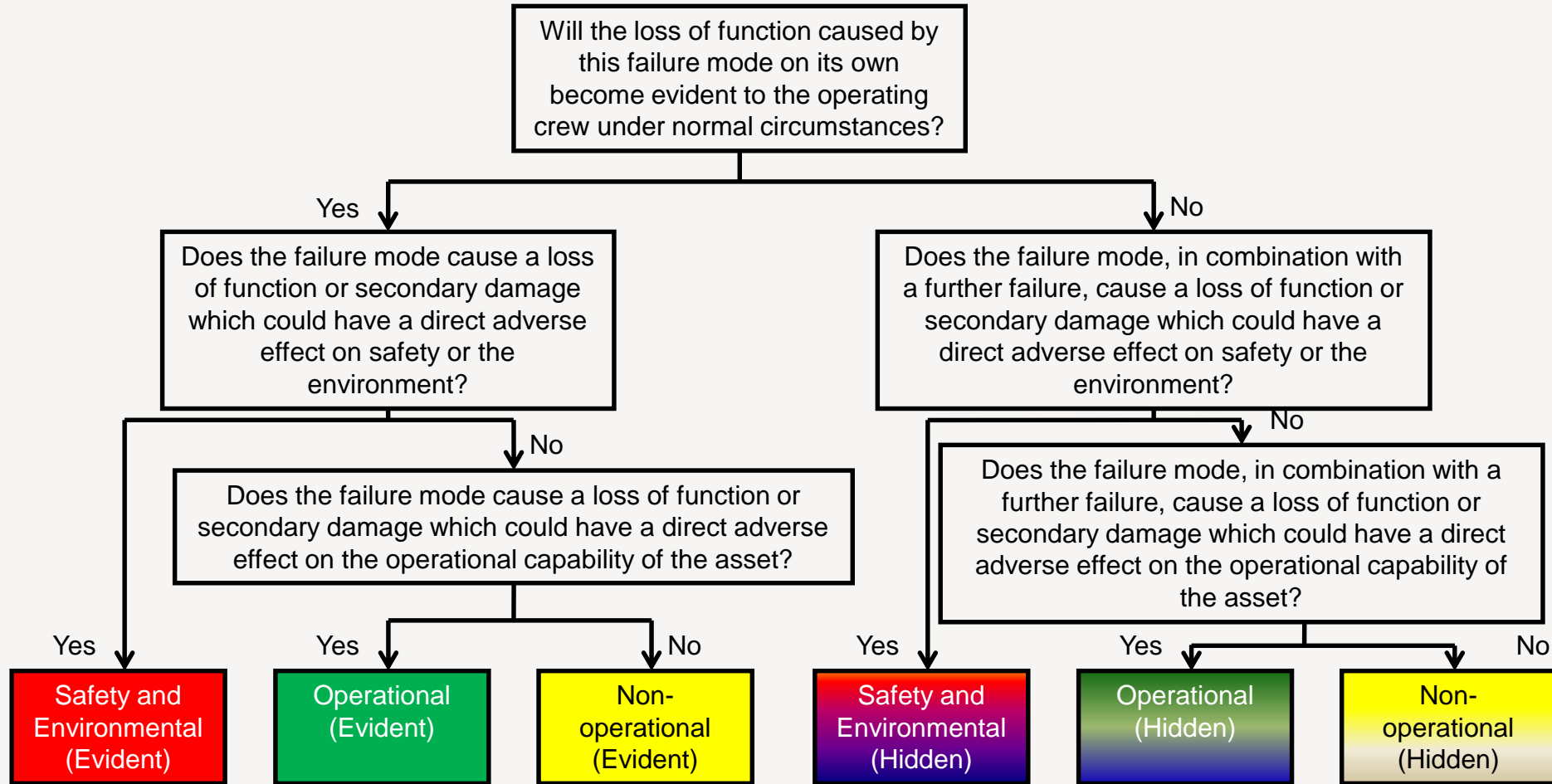
Safety and Environmental

Operational

Non-operational.



RCM Decision Logic – Level 1



Safety and Environmental Consequences

A Failure Mode has Safety Consequences if the resulting loss of function could cause harm, injury or death.

A Failure Mode has Environmental Consequences if the resulting loss of function could result in the failure to comply with legislative or environmental standards.

For Failure Modes with Safety and Environmental Consequences, preventive actions are only worth doing if they are effective and reduce the probability of failure to a tolerable level.



Operational Consequences

A Failure Mode has Operational Consequences if it has a direct adverse impact on operational capability (i.e. it will incur direct or indirect costs). For example:

Zero/reduced output.

Quality issues.

Poor customer service.

Increased operating costs (energy consumption, conversion efficiency, etc.).

For Failure Modes with Operational Consequences, preventive actions are only worth doing if they are effective and their overall costs are less than the overall cost of the failures they are designed to prevent.



Non-operational Consequences

If a Failure Mode has no Safety, Environmental or Operational Consequences the only consequence is the cost of repair.

For Failure Modes with Non-operational Consequences, preventive actions are only worth doing if they are effective and their overall costs are less than the cost of repairing the failures they are designed to prevent.



Hidden Failure Consequences

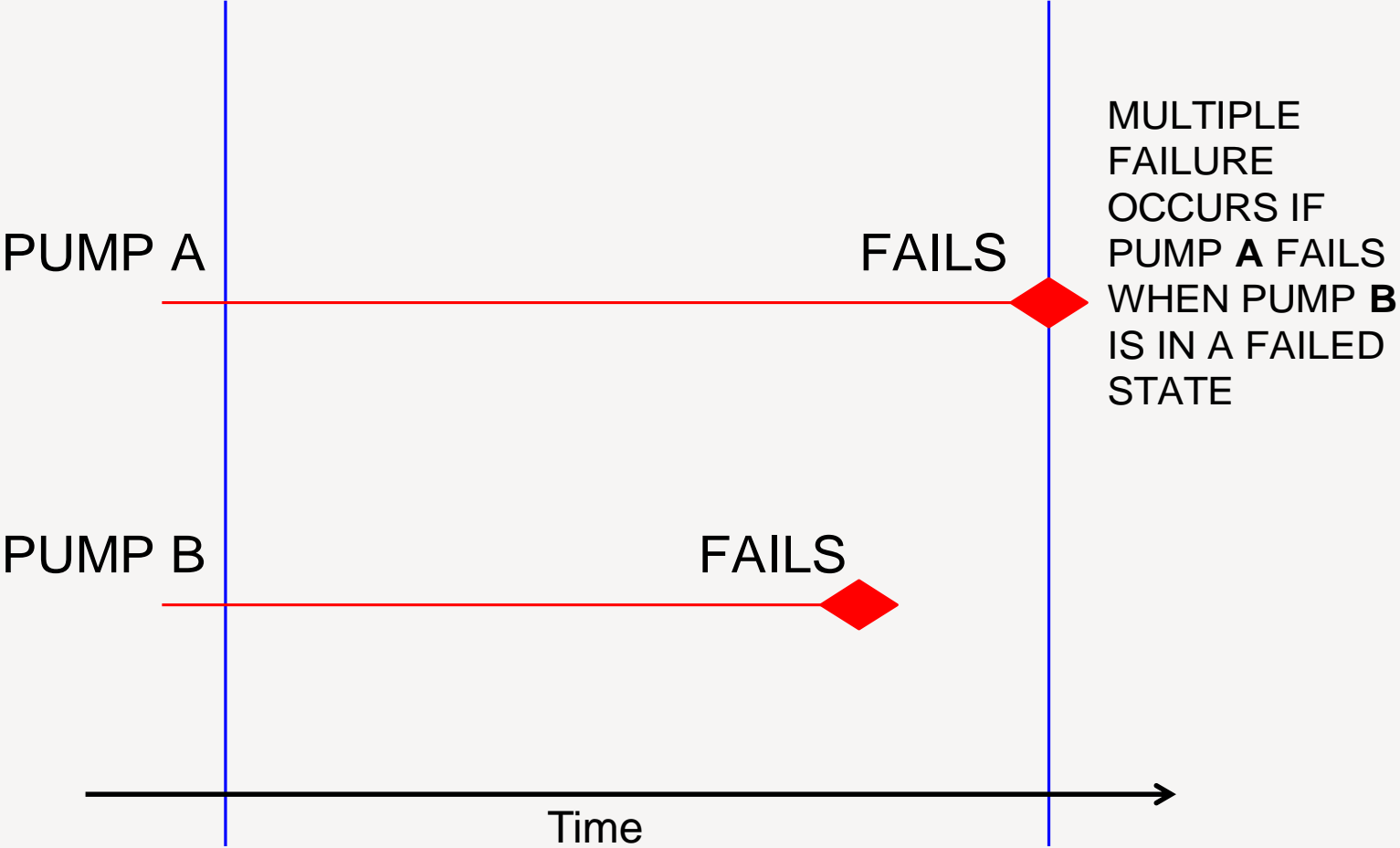
The consequences of a Hidden Failure will not become apparent to the operator during normal operation.

The consequences of a Hidden Failure will only become apparent after another failure or unusual event has occurred (in the absence of conducting a fault finding task).

For Failure Modes with Hidden Consequences, preventive actions are only worth doing if they are effective and reduce the probability of the multiple failure to a tolerable level.



Hidden Failure Example



Proactive Failure Management Tasks

The type of task eventually selected (and the chosen interval) will not only depend on the Failure Consequences, but also the failure characteristics of the Failure Mode.

Therefore, an assessment of the characteristics of each Failure Mode is necessary to determine whether or not any preventive action will be effective.



Proactive Failure Management - Options

There are three categories of proactive maintenance activities:

On-condition Maintenance (OCM). Equipment is 'checked' at fixed, regular intervals to determine if a condition exists that indicates the equipment is in the process of 'failing'.

Scheduled Restoration (SR). Equipment is 'restored' (e.g. overhauled) at fixed intervals, **regardless** of condition.

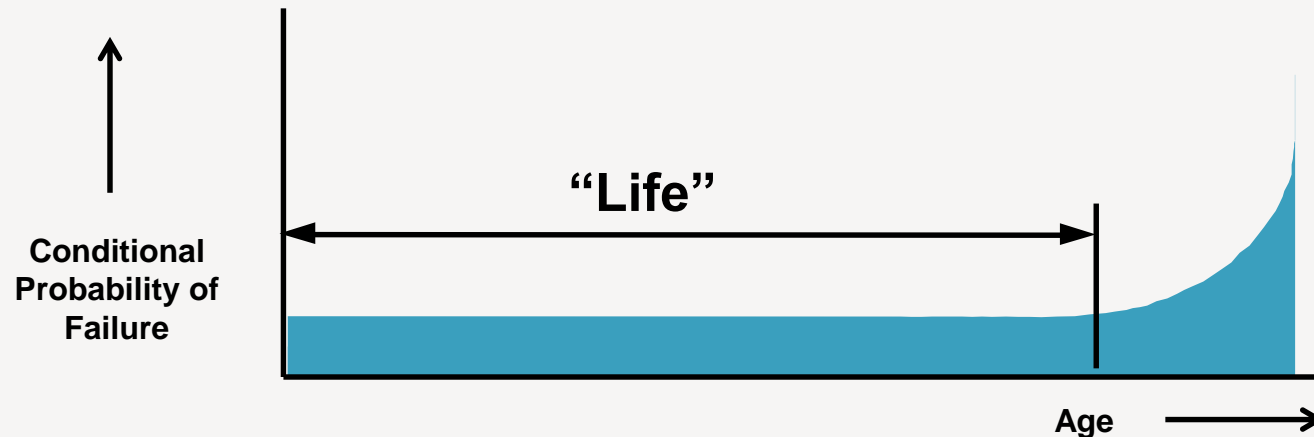
Scheduled Discard (SD). Equipment is 'discarded' (i.e. replaced) at fixed intervals, **regardless** of condition.



Scheduled Restoration Tasks

For a Scheduled Restoration Task to be effective there are **3** 'rules' that must be satisfied:

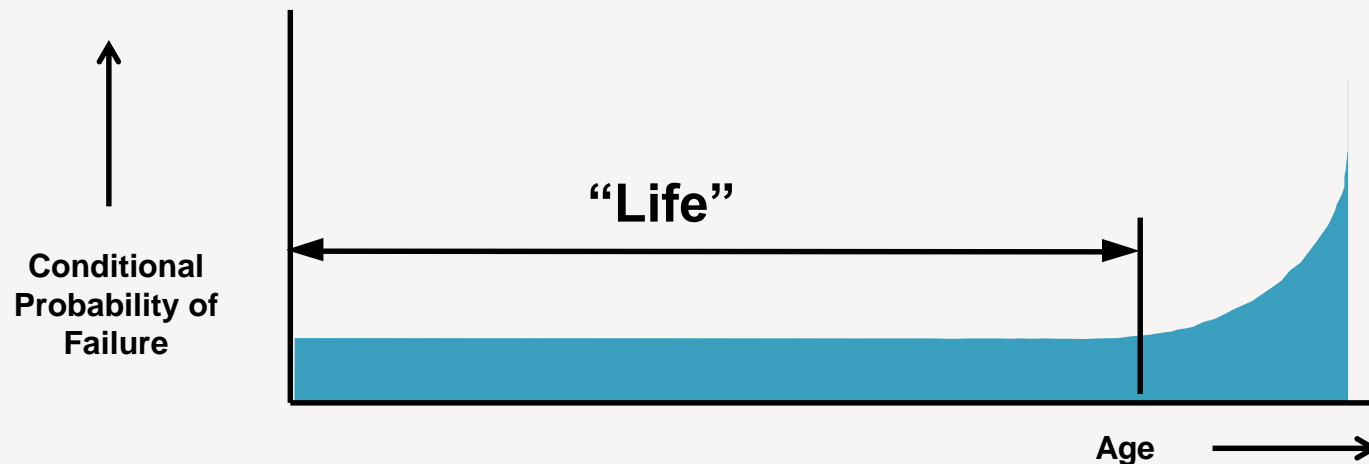
- There has to be an age at which there is a marked increase in the conditional probability of failure.
- This age has to be consistent across a sample of items such that the majority of items survive to this age. However, for failures with Safety (or Environmental) Consequences, **all** items have to survive to this age.
- The restoration task has to restore the item to its original condition.



Scheduled Discard Tasks

For a Scheduled Discard Task to be effective there are **2** 'rules' that must be satisfied:

- There has to be an age at which there is a marked increase in the conditional probability of failure.
- This age has to be consistent across a sample of items such that the majority of items survive to this age. However, for failures with Safety (or Environmental) Consequences, **all** items have to survive to this age.

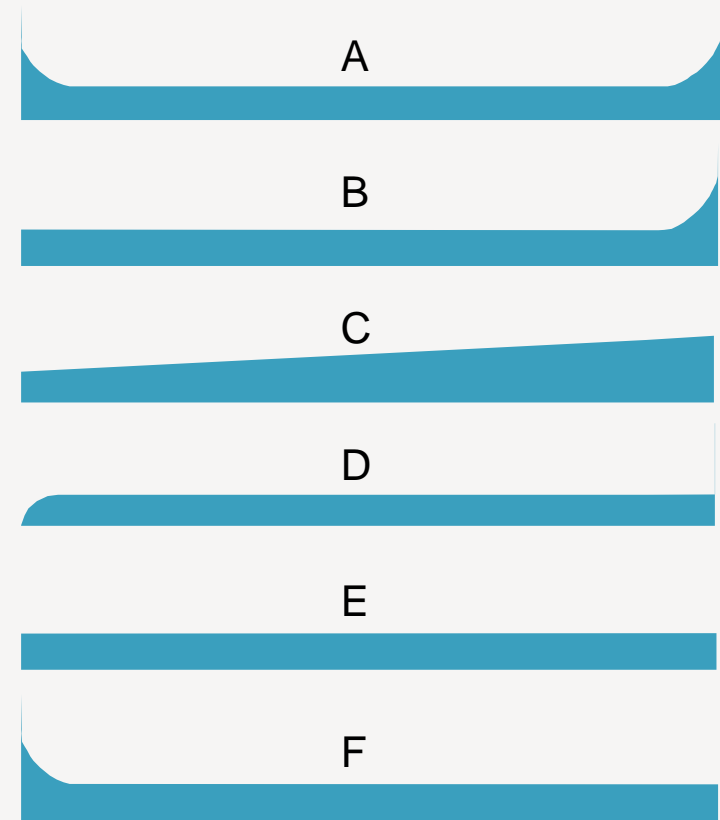


Limitations of SR and SD Tasks

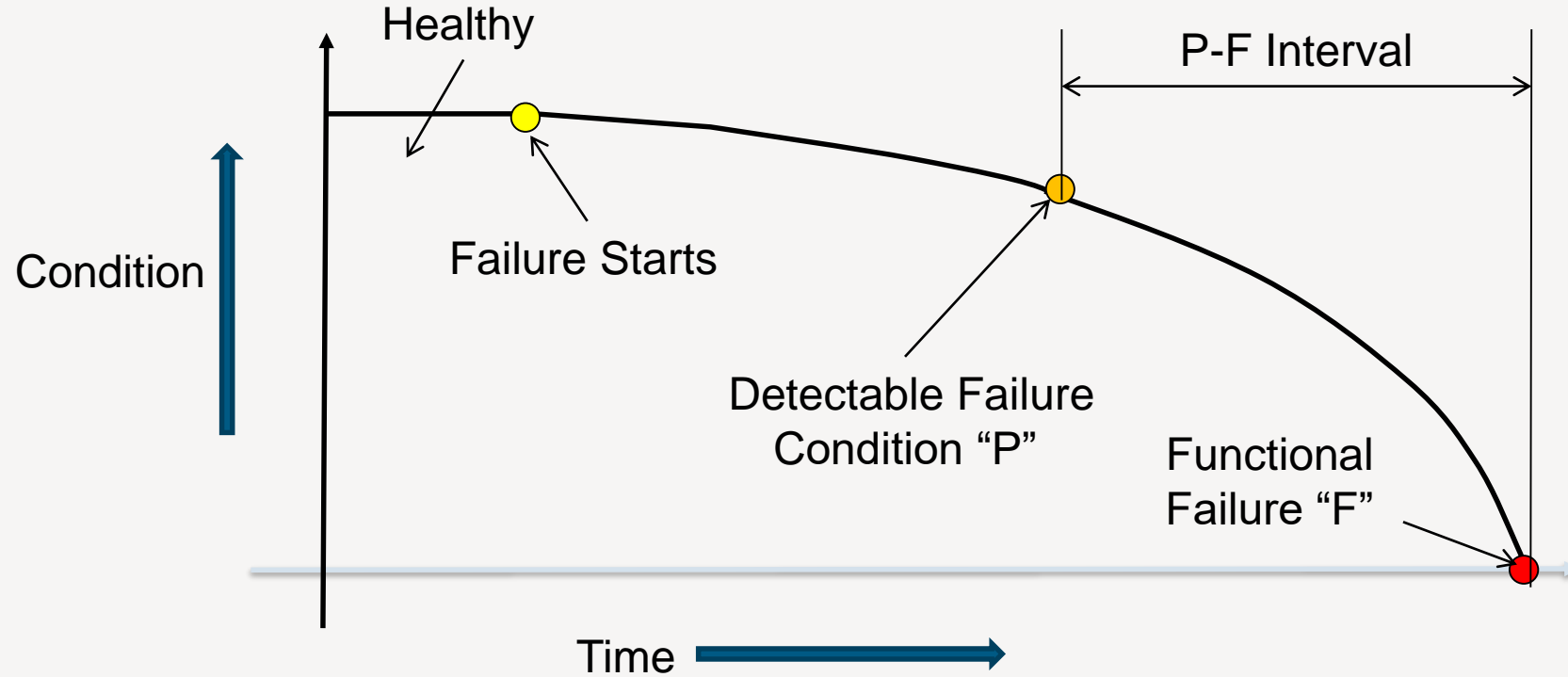
According to the first 'rule' for SR and SD tasks, they will only be effective where the failure pattern exhibits a marked increase in the conditional probability of failure.

This is only true for failure patterns A, B and C, which, in turn, represent only a small percentage of equipment failures (~11% in the aviation industry).

How, therefore, do we prevent the vast majority of equipment failures that exhibit failure patterns D, E and, in particular, F?



The Potential Failure Curve



On-condition tasks can apply to any of the 6 failure consequence categories and are not related to the age of the equipment



On-condition Tasks

For an On-condition Task to be effective there are 4 'rules':

- › There has to be a clear condition (potential failure) that can be checked/monitored.
- › The P-F interval has to be sufficient to allow appropriate action to be taken.
- › The P-F interval has to be consistent.
- › The On-condition Task can/has to be done at intervals less than the P-F interval. (For Safety/Environmental appropriate factors are applied e.g. 1/2 or 1/3 P-F interval).

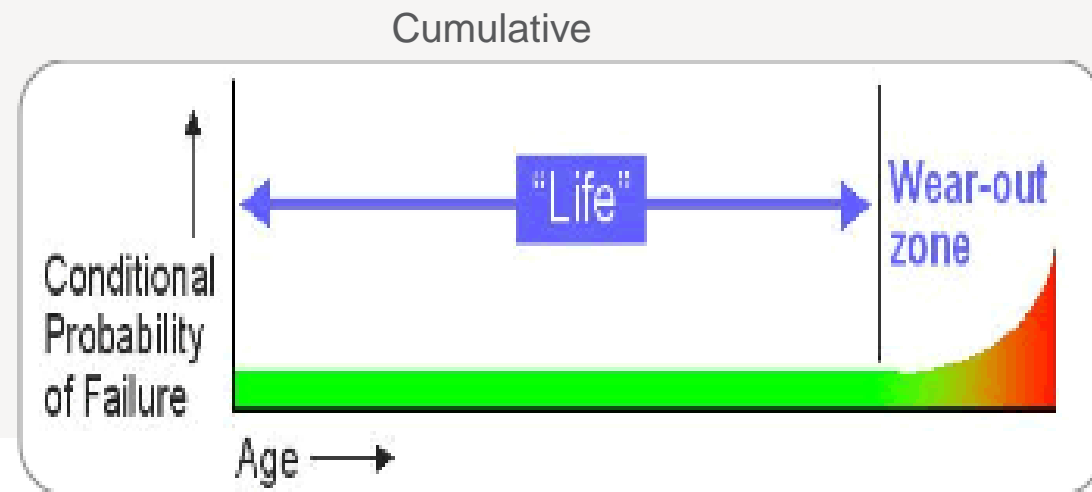
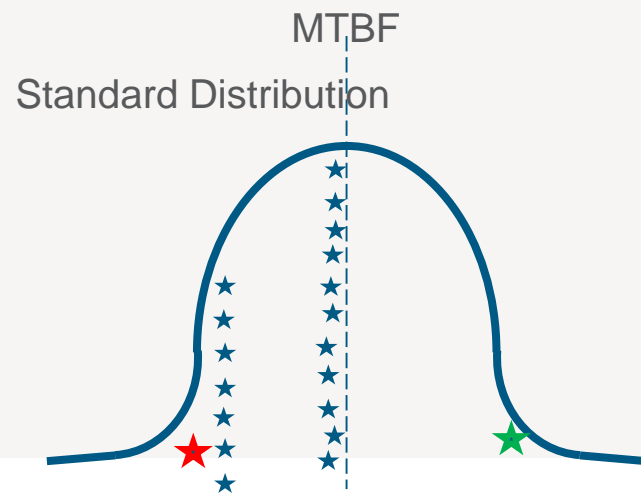


The Meaning of Life

Talk about the “Meaning of Life” and how it is ‘related’ to MTBF.

MTBF is not the same as life:

Does MTBF tell/guide you when next failure is about to occur? How useful is it as a measure. Usually the only measure available?

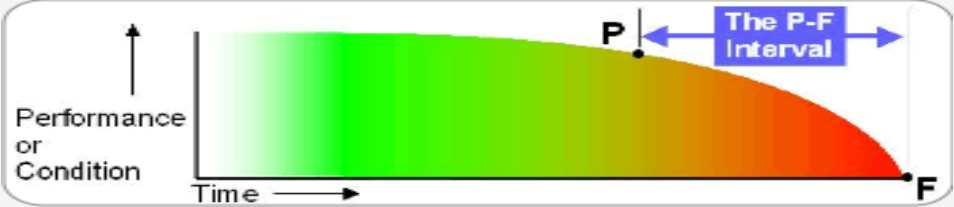


Proactive Failure Management Task Selection

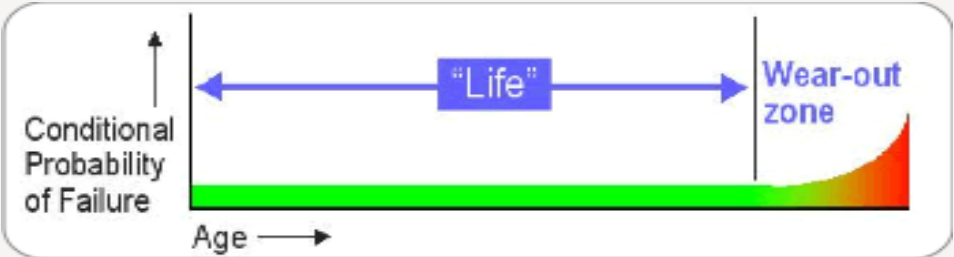
On condition

Scheduled Restoration / Discard

Failure-finding (hidden failures only)



'Predictability'



'Durability'

Required availability for the hidden function, %	99.99	99.95	99.9	99.5	99	98	95
FFI (as a % of the MTBF)	0.02	0.1	0.2	1	2	4	10

'Reliability'



Question & Answer Session (1)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. Name three proactive tasks?
2. What type of task is a P-F Interval used to set the interval on?
3. What does Life mean?
4. What does Safe Life Mean?
5. Why is MTBF not very useful when setting hard time tasks?

1.



Question & Answer Session (2)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. Name three proactive tasks?
2. What type of task is a P-F Interval used to set the interval on?
3. What does Useful Life mean?
4. What does Safe Life Mean?
5. Why is MTBF not very useful when setting hard time tasks?

1. SR, SD and OCBM Tasks.

2. P-F is used to help set OCBM tasks on incipient conditions such as wear, heat, Differential Pressure, oil condition etc etc.

3. Useful Life is a period of time/cycles/usage when the probability of failure increases rapidly based on failure data or experience.

4. Safe Life is a period less than life that is agreed as having no failures to that point. Can be ½ or 1/3 of Useful Life.

5. MTBF is a statistical Mean and so is not accurate. Your asset could fail very early or very late, but the margin for error is high as you don't know where in the Weibull Curve your asset will be?



Look Back

- › Question 6
- › Proactive Failure Management Tasks
- › Proactive Tasks SD, SR and OCBM
- › Scheduled vs. On-condition
- › RCM Working Group
- › Revision
- › The Meaning of Life
- › Case Study
- › Q&A.



Session 6

Session 3 – Look Forward

- › Q7
- › FF Intervals
- › Desired Availability vs. FF Interval as a %age of MTBF
- › Examples from Third Stage Separation Case Study Using Given MTBFs
- › Difference Between “Failing” and “Failed”
- › Weakness – Desired Availability
- › Equation and Derivation
- › Recap Task Interval Selection
- › Recording Decisions
- › Aviation Example – 1985 to 2005
- › Industry Examples
- › Pre / Post RCM
- › Review Aims of Course.



The RCM Process Q7

What do we want the equipment to do? (Functions).

How can it fail to do this? (Functional Failures).

What causes the equipment to fail? (Failure Modes).

What happens when a failure occurs (Failure Effects).

How does the failure matter? (Failure Consequences).

Can the failure be predicted or prevented? (Proactive Failure Management).

How should the failure be managed if prediction or prevention is not a viable option? (Other Failure Management Options).



Default Strategies

If a technically feasible **AND** worth doing proactive task cannot be found, there are a number of default strategies available depending on the consequences of failure:

- › Carry out a combination of proactive tasks (i.e. a combination of OCM, SR and SD tasks).
- › ‘No Scheduled Maintenance’ (i.e. allow the equipment to fail).
- › Redesign to either eliminate or mitigate the consequences of failure.
- › If Hidden, carry out a Failure Finding task.



Combination Tasks

Only applicable (worth doing) if the failure has Safety and/or Environmental Consequences.

If individual proactive tasks on their own are not worth doing or effective, carrying them out in combination may be sufficient to avoid a “Redesign”.



No Scheduled Maintenance

If it is not possible to identify applicable or effective proactive tasks and the failure has Operational or Non-operational Consequences, allowing the equipment to fail may be the only alternative.

'No Scheduled Maintenance' appears at the bottom of the legs of the logic diagram and is only arrived at after other options have been considered and rejected.

It is not possible (nor sensible) to operate on the basis that all failures can be prevented. RCM works on the basis of managing (ideally preventing) all failures that matter.

A 'No Scheduled Maintenance' strategy is not permissible for failures with Safety and/or Environmental Consequences.



Redesign

Redesign is compulsory for failures that have Safety and/or Environmental consequences if nothing else can be done (including a combination of proactive tasks).

The action “Redesign” can take a number of different forms:

- › Redesigning the equipment (to eliminate the failure) or the ‘system’ (to eliminate or reduce the consequences - e.g. through the provision of standby equipment).
- › Redesigning the equipment to make it ‘maintainable’ (i.e. ensuring a proactive task is applicable and effective).
- › Providing training to operators.
- › Introducing new procedures or modifying existing ones.
- › Putting up new warning notices/fencing off danger zones.



Failure Finding (Hidden)

Failure Finding Tasks are only applicable to failure modes whose consequences are Hidden.

The purpose of a Failure Finding Task is to check the function of a protective device to see if it is still operational.

This will reduce the probability of the multiple failure to a tolerable level by increasing the availability of the protective device.



Failure Finding Tasks

For a Failure Finding Task to be effective there are **3** 'rules':

- It has to be possible to carry out the task without 'destroying' the protective device (e.g. one-shot devices such as fuses, frangible bulbs, air-bags, etc.).

- It has to be possible to carry out the task without increasing the risk of the multiple failure (e.g. ramping up the pressure in an enclosed vessel to check that the PRV operates correctly).

- It has to be practical to carry out the task at the required interval.

This last question is the most difficult of all the RCM questions to answer.



Use White-Board/Flip-Chart

Q - What, failure finding tasks are likely to be carried out in the Mining industry.

Illustrate how the failure finding task improves the availability of the protective device:

Example: Break lights on a car fail 3 months after MOT and not checked again until next MOT, etc.



Failure Finding Task Intervals

Failure Finding Task Intervals are a function of:

The desired availability of the hidden function (protective device) which will be derived from the tolerable probability of the multiple failure.

The reliability of the protective device.

$$FF \text{ Task Interval} = 2 \times U_{tive} \times M_{tive}$$

It is possible to use this expression to generate a look-up table of the desired availability of the protective device against the Failure Finding Task interval expressed as the percentage of the MTBF of the protective device.

NB: Refer to RCM2 (Page 178)



Use White-Board/Flip-Chart

Compile look up table. For example:

$A = 99.99\%$; $FFTI = 0.02\% \times MTBF$

$A = 99.5\%$; $FFTI = 1\% \times MTBF$

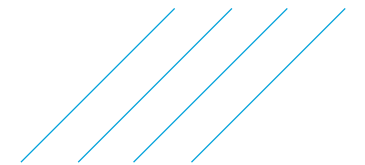
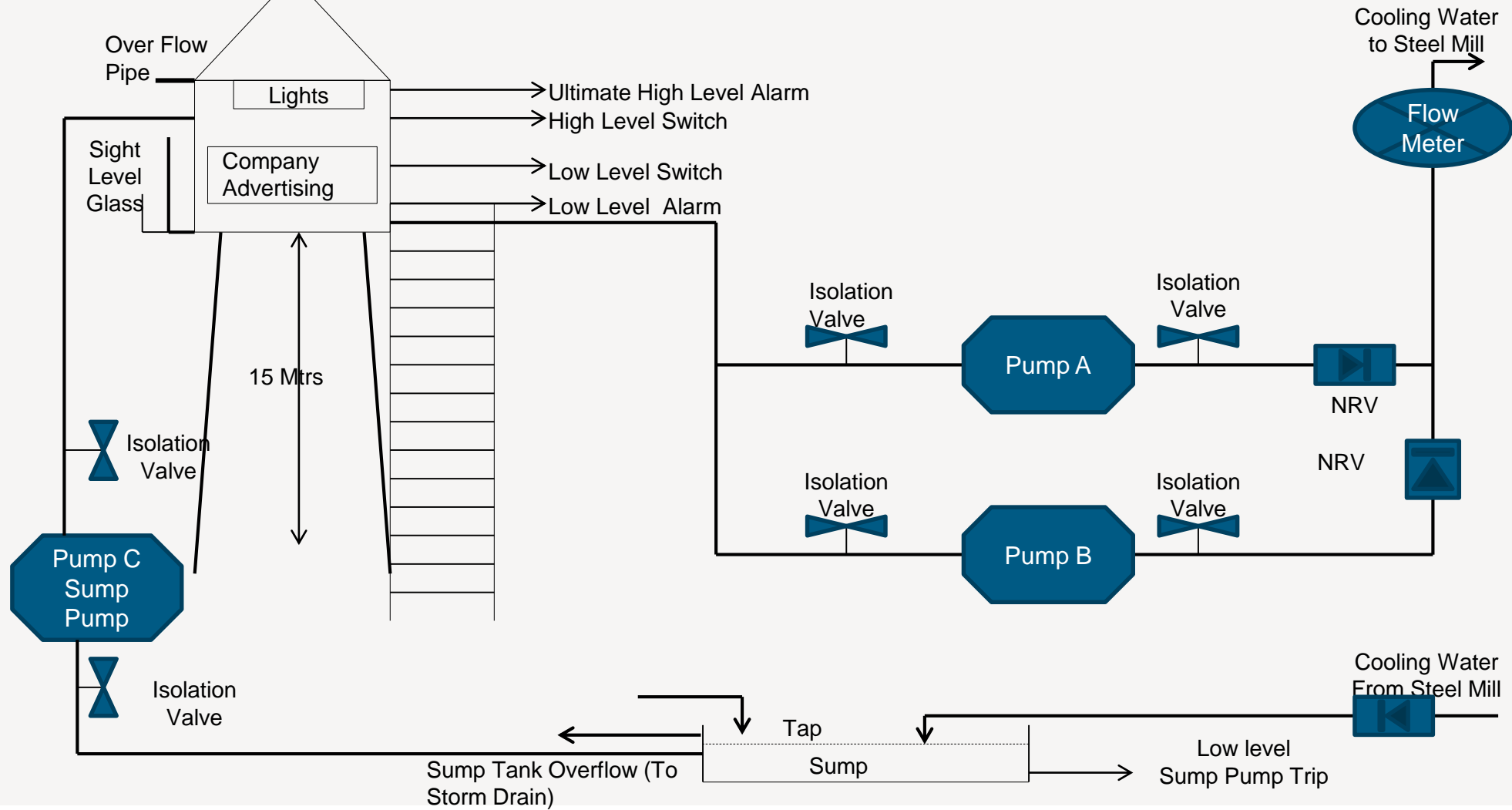
$A = 95\%$; $FFTI = 10\% \times MTBF$

i.e. $FFTI \approx [2 \times (1 - A)] \times 100\% \times MTBF$

For example, a device with an MTBF of 10 years should be tested once per year to achieve an availability of 95% but approximately once every 17.5 hours to achieve an availability of 99.99%



Case Study – Rolling Mill Cooling System



Use White-Board/Flip-Chart

Depending on time available, select specific failure mode references for attendees to work through:

- Select FMs that have hidden failures and provide appropriate MTBFs when requested so that task intervals can be calculated.

- Throw in one or two 'curved balls' – e.g. protective devices where failures are not necessarily hidden and a proactive task may be appropriate.



Limitations of Failure Finding Task Interval

As demonstrated by the examples and Case Study, it is all too easy to decide on a desired level of availability for the hidden failure and then 'back-track' if the resulting Failure Finding Task Interval is not 'acceptable'.

The process for determining Failure Finding Task Intervals has to be rigorous.

A more rigorous, risk-based method can also be used to determine Failure Finding Task Intervals:

$$FF \text{ Task Interval} = 2 \times M_{tve} \times M_{ted} / M_{mf}$$



Risk-based Failure Finding Task Intervals

$$FF \text{ Task Interval} = 2 \times M_{tive} \times M_{ted} / M_{mf}$$

Decide on what is an acceptable probability of occurrence for the multiple failure (e.g. once in 1,000 years). - M_{mf}

Determine how often the protected function is likely to fail – i.e. the demand rate for the protective device (e.g. once every 10 years – MTBF = 10 years). - M_{ted}

Determine the reliability for the protective device (e.g. MTBF is 25 years). – M_{tive}

$$FF \text{ Task Interval} = 2 \times 25 \times 10 / 1000$$
$$= 0.5 \text{ years}$$



Summary of Task Interval Selection Criteria

On-Condition Tasks:

Carried out at intervals less than the P-F interval.

Scheduled Restoration and Scheduled Discard Tasks:

Carried out at intervals determined by the “Life” of the Failure Mode.

Failure Finding Tasks:

Carried out at intervals determined by the desired availability and reliability of the protective device.



RCM Decision Worksheet - Example

Task Selection Worksheet

Project: 3 Day RCM Awareness Course	Compiled By:	Date: 31 Jan 2014
System: Rolling Mill Cooling Water Supply Sys	Approved By:	Sheet of 3

FMEA Ref.	Consequences			Task Type			Default Tasks		Task Description	Task Interval	Task Done By
	E0	E1 H1	E2 H2	E/H S1 E/HO1 E/HN1	E/H S2 E/HO2 E/HN2	E/H S3 E/HO3 E/HN3	E S4	H S4 HO4 HN4			
1A1									Not considered further.		
1A2	Y	N	Y	N	N	Y			Re-grease Pump A bearings.	6 months	Maintainer
1A3	Y	N	Y	Y					Check earth resistance of Pump A motor windings.	3 months	Maintainer
1A4	Y	N	Y	Y					Inspect Pump A coupling for visible signs of cracking/degradation.	3 months	Maintainer
1A5	Y	N	Y	N	N	Y			Renew Pump A coupling.	5 years	Maintainer
1A6	Y	N	Y	N	N	Y			Re-grease Pump C bearings.	6 months	Maintainer
1A7	Y	N	Y	Y					Check Earth resistance of Pump C motor windings.	3 months	Maintainer
1A8	Y	N	Y	Y					Inspect Pump C coupling for visible signs of cracking/degradation.	3 months	Maintainer
1A9	Y	N	Y	N	N	Y			Renew Pump C coupling.	5 years	Maintainer
1B1	Y	N	Y	Y					Inspect Flow meter rate for flow rate >105 litres/min.	Daily	Operator
2A1	N	N	Y	N	N	Y			Re-grease Pump B bearings.	1 year	Maintainer
2A2	N	N	Y	Y					Check earth resistance of Pump B motor windings.	1 week	Maintainer
2A3	N	N	Y	N	Y				Swap to Pump B and run on-line for at least 15 minutes.	1 month	Maintainer
2A4	N	N	Y	N	N	Y			Renew Pump B coupling.	5 years	Maintainer
2A5	N	N	Y	N	N	N	Y		Functionally test standby pump B (Aligned to 2A3).	1 month	Maintainer
2A6	N	N	Y	N	Y				Cycle/Unsieze Pump B NRV.	1 month	Maintainer
3A1	Y	Y		Y					Inspect Water Tower support structure for paint condition and corrosion (P = visual corrosion and F = Structure fails) (P-F is at least 1 year).	6 months	Maintainer
3A2								Y	Not considered plausible.		



Role of the Facilitator - White-Board/Flip-Chart

Explain the role of the facilitator in ensuring that task intervals are established in a rigorous manner and meet all the relevant rules and criteria that includes:

- › Probability of failure is at a tolerable level for failures with Safety and Environmental Consequences.
- › The cost of doing the task over a period of time will be less than the cost of failure and repair for failures with Operational Consequences and the cost of repair for failures with Non-operational Consequences.
- › Probability of the multiple failure is at a tolerable level for failures with Hidden Consequences.
- › Don't WAG / SWAG it!



Session 6 - Drinks Break 20 Minutes



The Benefits of RCM

The reasons for adopting RCM varies from industry to industry:

Improve safety.

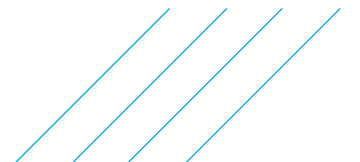
Improve availability/reliability.

Improve throughput/efficiency.

Improve effectiveness of resources.

Reduce costs.

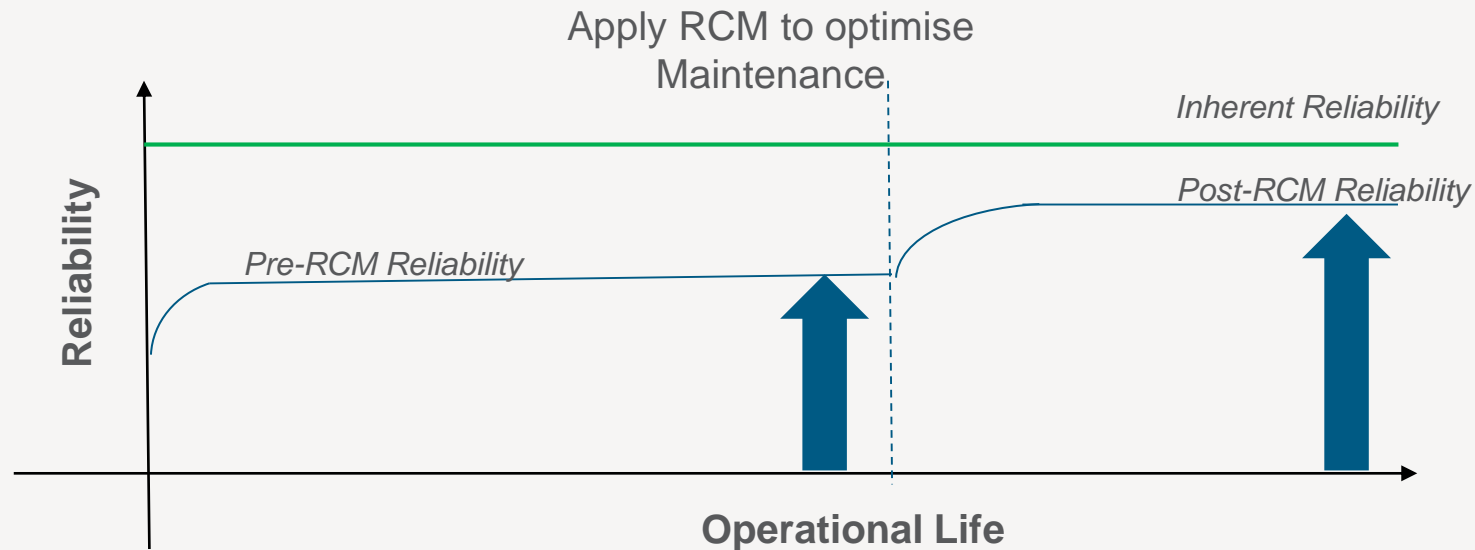
RCM achieves all of the above (and more) as an integrated package.



Pre / Post RCM View

What RCM can achieve – Explain below Time vs. Operational Reliability for both ‘before’ and ‘after’ and show how this ‘closes the gap’ towards achieving inherent equipment reliability.

Show inherent Reliability curve and designed reliability and show RCM can close the gap.



Examples from Industry (1)

Airline Industry.

A global oil company adopted RCM following Piper Alpha as their principal response to addressing the safety issues raised and then achieved up to 30% reduction in maintenance man hours on offshore oil and gas installations as an aside.

A nuclear power generator adopted RCM as part of the assurance process necessary to retain its operating license and was able to reduce the value of its critical spares holdings by over 70%.

A global Swiss-based cigarette manufacturer bought over 20 (largely government owned) failing manufacturing plants in Russia and Eastern Europe and used (predominantly) RCM to turn them into efficient, highly profitable concerns.



Examples from Industry (2)

The old Trebor Basset Mint Creams production facility in Kent was threatened with closure due to falling sales and declining margins. RCM was used to refocus the maintenance effort and resources to meet the changing needs of the ageing process line equipment. The facility turned itself around, was acquired by a French company and relocated to Paris 18 months later.

RCM was used by a pharmaceutical facility in the North West to refocus its maintenance resources from one area of production to another, more profitable area. Margins soared and the company was able to invest in the previously 'neglected' areas.

Network Rail – the next success story? RCM is not a tick box exercise – unless embraced as a Change Management initiative and applied in a intelligent way it can just be a waste of money.



Discussion - RCM

- › How is RCM2 'different' from MSG3?
- › Mention the RCM Desktop software again.
- › The Roles in carrying out RCM (Management, Maintenance Management, Facilitator, Study Team, Auditor/Reviewers and SMEs).
- › 3 Day Course – sound basis - however, unless anyone has been earmarked as a Facilitator, none of this should be of concern. Everyone in the room now has sufficient knowledge and understanding in the principles of RCM to enable them to make more than an effective contribution to any future RCM studies.



Recap: Course Goals and Objectives

To provide attendees with sufficient knowledge and understanding of the Reliability-centred Maintenance (RCM) process to enable them to make a valued and effective contribution to future RCM studies.

The purpose of the course is not to tell the attendees how they should be maintaining their assets but to change their perception of how maintenance is viewed and assessed.



Aviation Example – 1985 to 2005



Engine renewals

When the B747 entered service the engine service and change regime left the engines routinely **replaced every 18 months**. (an overhauled engine costs **£4.3M**) Through effective asset leadership and management, using RCM and risk based evaluations, the engines average life on wing is now **5.8 years**.

Through the course of the life of an airframe this asset leadership approach saves 14.8 engine overhauls....or £66.6M per aircraft. British Airways has 56, B747 in its fleet giving an averaged fleet saving of roughly £120M per year

Maintenance Regimes

BA Engineering teams took the unit cost of maintenance down from £45.00 in 1985, to today's highly competitive figure of £21.50.

Understanding and planning maintenance more effectively using long term scheduling and work based planning techniques reduced the heavy-maintenance inputs.

Meaning the Operations, Maintenance and Renewals costs are reduced and the aircraft are available to route much more.



**Safety record in this period
IMPROVED**



Question & Answer Session (1)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. What is RCM?
2. Why apply RCM?
3. Where did it come from?
4. Explain what consequence driven means?
5. Why is Operating Context important?



Question & Answer Session (2)

Points are 5 points for correct, 3 points for nearly correct, 0 points for incorrect

Answers

1. What is RCM?
2. Why apply RCM?
3. Where did it come from?
4. Explain what consequence driven means?
5. Why is Operating Context important?

1. RCM is a process used to determine what must be done to ensure that equipment fulfils its intended function in its operating context, given the failure characteristics of the equipment.

2. A Risk based approach to optimising maintenance.

3. FAA sponsored analysis and report (Nowlan & Heap) in early 70s.

4. Taking each FM and assuming that nothing is done we assess the probably consequences (Zero based Analysis). Hidden, Safety/Environmental, Operational and Non-Operational).

5. Operating Context is the environment and regime that applied to your Assets. A manufacturer understands how his OEM Asset fails and its MTBF from data he holds but doesn't know how it is used in your system, maintained or spared? These all affect how an asset should be maintained.



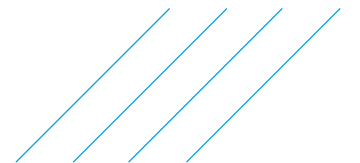
Look Back

- › Q7
- › FF Intervals
- › Desired Availability vs. FF Interval as a %age of MTBF
- › Examples from Third Stage Separation Case Study Using Given MTBFs
- › Difference Between “Failing” and “Failed”
- › Weakness – Desired Availability
- › Equation and Derivation
- › Recap Task Interval Selection
- › Recording Decisions
- › Aviation Example – 1985 to 2005
- › Industry Examples
- › Pre / Post RCM
- › Review Aims of Course
- › Q&As.



Training Feedback

Please complete the training feedback / SurveyMonkey to ensure we learn from your experience.



Thank you!