FAILURE MODES AND EFFECT ANALYSIS (FMEA)

INTRODUCTION

While defining the functions and desired standards of performance of an asset, the objectives of maintenance with respect to that asset are defined. Defining functional failures enables us to spell out exactly what we mean by 'failed'. These two issues were addressed by the first two questions of the RCM process. The next two questions seek to identify the failure modes which are reasonably likely to cause each functional failure, and to ascertain the failure effects associated with each failure mode. This is done by performing a Failure modes and effect analysis (FMEA) for each functional failure.

WHAT IS A FAILURE MODE?

A failure mode is any event, which causes a functional failure.

The best way to show the connection and the distinction between failed states and the events which could cause them, is to list functional failures first and then to record the failure modes which could cause each functional failure, as shown below:

RCM (Reliability Centered Maintenance) INFORMATION WORKSHEET

System: Cooling Water Pumping System

Sub-system:

Function	Functional Failure (Loss of function)	Failure Mode (Cause of failure)
1.To transfer water from tank X to tank Y at not less than 800 ltrs/min	A.Unable to transfer any water at all	1. Bearing seizes 2.**Impeller comes adrift** 3**. Impeller jammed by foreign object** 4. Coupling hub shears due to fatigue 5. Motor burns out 6. Inlet valve jams/closed.. etc
	B.Transfers less than 800 litres/ minute	1. **Impeller worn** 2. Partially blocked suction line ……etc

The worksheet above indicates, a description of a failure mode, which should consist of a noun and a verb. The description should contain enough detail, so that it will be possible to select an appropriate failure management strategy, but not so much detail that excessive amounts of time are wasted on the analysis process itself.

WHY ANALYSE FAILURE MODES?

A single machine can fail for dozens of reasons. A group of machines or system such as a production line can fail for hundreds of reasons. For an entire plant, the number can rise into the thousands or even tens of thousands.

Most Engineers/Managers shudder at the thought of the time and efforts likely to be involved in identifying all these failure modes. Many decide that this type of analysis is just too much work, and abandon the whole idea entirely. While doing so, they forget that on a day to day basis, maintenance is really managed at the failure mode level.

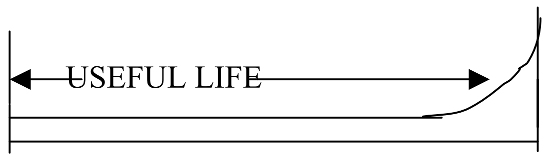
In too many cases, these failure modes are discussed, recorded or otherwise dealt with after they have occurred, which are known as **reactive maintenance.**

Proactive maintenance, on the other hand deals with events before they occur,- or at least, deciding how they should be dealt with, if they were to occur. The **events** in this context are failure modes. For an asset, we must try to identify all the **failure modes,** which are likely to affect that asset in a proactive maintenance.

Once each failure mode has been identified, it then becomes possible to consider what happens when it occurs, to assess its consequences and to decide what (if anything) should be done to anticipate, prevent, detect or correct it- or even to design it out.

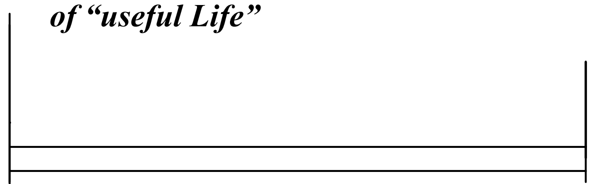
The example given at 'RCM information work sheet', has the pump which is a direct-coupled single-stage back-pull-out end-suction volute pump sealed by a mechanical seal. In this example, we look more closely at the three failure modes which are likely to effect the impeller only:

- ***Impeller worn out***



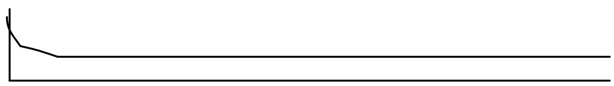
Manage this failure by changing impellers before end of "useful Life"

- ***Impeller jammed:***



: Manage this failure by: installing screen in suction line?

- ***Impeller adrift:***



Manage this failure by training people to fit impellers correctly ?

This example reinforces the point that the level at which we manage the maintenance of any asset is not at the level of the asset as a whole (in this case the pump) and not even at the level of any component (in this case the impeller), but at the level of each failure mode. So, before we can develop a systematic, proactive maintenance management strategy for any asset, we must identify what these failure modes are.

This example also suggests that one of the failure mode could be eliminated by a design change and another by improving training or procedures. So, not every failure mode is dealt with by scheduled maintenance.
Identification of failure mode is one of the most important steps in the development of any program intended to ensure that any asset continues to fulfil its intended functions. In practice, depending on the complexities of the item, its operating context and the level at which it is being analysed, between one and thirty failure modes are usually listed per functional failure.

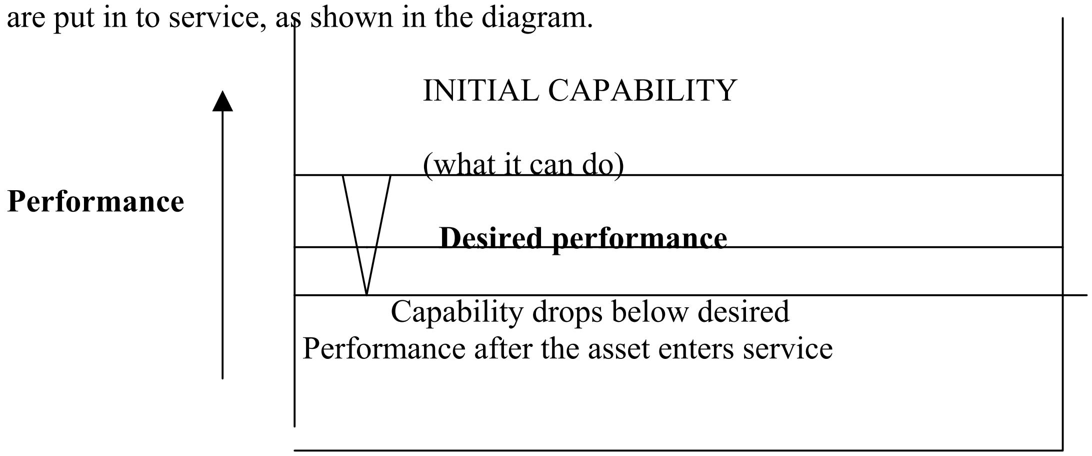
CATEGORIES OF FAILURE MODES

Failure modes can be classified in to three groups:

- When capability falls below desired performance
- When desired performance rises above initial capability
- When the asset is not capable of doing what is wanted from the outset.

Falling Capability:

The first category of failure modes covers situations where capability is above desired performance to begin with, but then drops below desired performance after the asset are put in to service, as shown in the diagram.



FAILURE MODE CATEGORY I

The five principal causes of reduced capabilities are listed below:

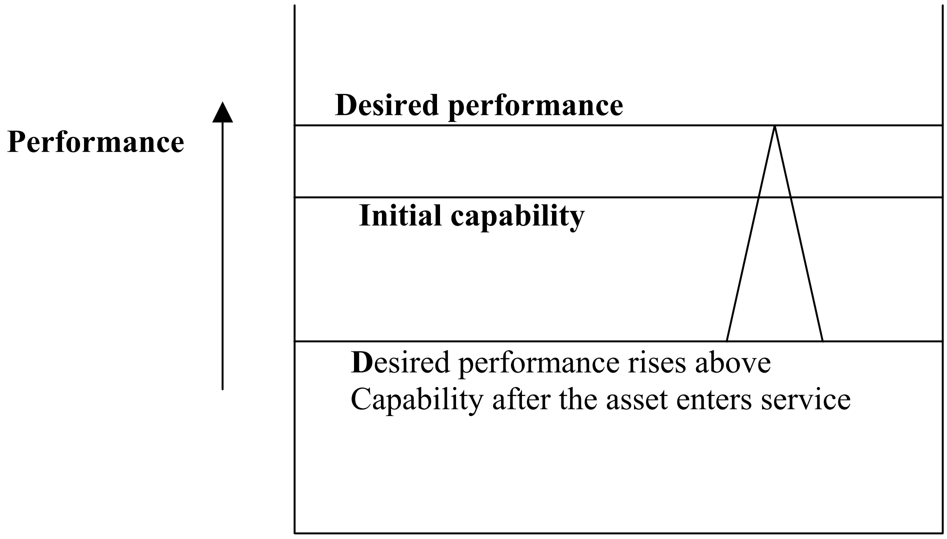
- Deterioration
- Lubrication failure
- Dirt
- Disassembly
- ‘Capability reducing ‘ human errors.

Increase in desired performance

In this category, the desired performance is within the envelope of the capability of the asset when it is first put in to service, but then the desired performance increases until it falls outside the capability envelope. The asset could fail in two ways:

- The desired performance rises until the asset can no longer deliver it, or
- The increase in stress causes deterioration to accelerate to the extent that the asset becomes so unreliable that it is effectively useless.

Example one: the user of the pump were to increase the off take from the tank to 1050 litres per minute (as against delivery capacity of 1000 litres per minute). In this case, the users have simply opened a valve bit wider somewhere else in the system. Example two: if the owner of a motor car whose engine is redlined at 6000 rpm persists in reviving the motor to 7000 rpm. This causes the engine to deteriorate more quickly than if the user keeps the revolutions within the prescribed limits, so it fails more often.



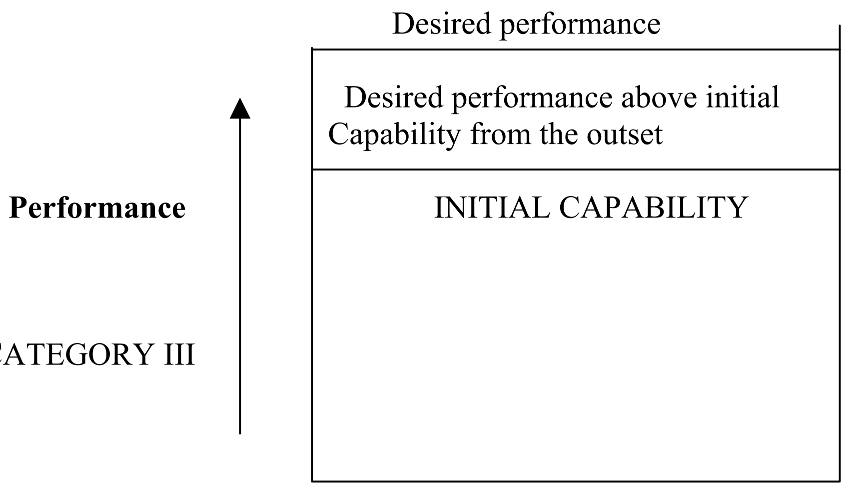
FAILURE MODE CATEGORY II

This phenomenon occurs for four reasons, the first three of which embody some kind of human error:

- Sustained, deliberate overloading
- Sustained, unintentional overloading
- Sudden, unintentional overloading
- Incorrect process material.

Initial incapability

In this case the desired performance is outside the envelope of the initial capability right from the outset, as shown in the figure below: This incapability problem seldom affects entire assets. It usually affects just one or two functions of one or two components, but these weak links upset the operation of the whole chain. The first step towards rectifying design problems of this nature is to list them as failure modes in an FMEA.



FAILURE MODE CATEGORY III

HOW MUCH DETAIL?

Failure modes should be described in enough detail to assist in selecting an appropriate failure management strategy, but not so much detail that excessive amounts of time are wasted on the analysis process itself.

Failure modes should be defined in enough detail for it to be possible to select a suitable failure management policy.

Too little detail and/or too few failure modes lead to superficial and sometimes dangerous analyses. Too many failure modes and/or too much detail causes the entire RCM process to take much longer than it needs to. Therefore it is essential to try and strike a balance and some of the factors, which are required to be considered, are as under:

- Causation- could be root causes and/or human error
- Probability: failures occurred before, failure modes under proactive maintenance, and any other possible failure modes.
- Consequences
- Causes vs Effect
- Failure modes and the operating context

FAILURE EFFECTS

The fourth step in RCM review is: listing out of what happens when each failure modes occurs. These are known as failure effects.

'***Failure effects describe what happens when a failure mode occurs'***

(Note: failure effects are not same as failure consequences. Failure effect = what happens, and, Failure consequences = how does it matters?)

While describing the effects of a failure, the followings should be recorded:

- What evidence that the failure has happened/occurred?
- In what way it poses a threat to safety or the environment?
- In what way it affects production or operation?
- What physical damage is caused by the failure?
- What must be done to repair the failure?

Evidence of Failure:

Failure effects should be described in a way, which enables the team doing the RCM analyses to decide whether the failure will become evident to the operating crew under normal conditions.

For example: the description should state whether the failure causes warning lights to come on or alarms to sound (or both), and whether the warning is given on a local panel or in a central control room (or both).

Also, the description should state whether the failure is accompanied or preceded by obvious physical effects such as loud noises, fire, smoke, escaping steam, unusual smells or pools of liquid on the floor, and whether the machine shots down as a result of the failure.

Safety and Environmental Hazards:
If there is a possibility that someone could get injured or killed as a direct result of the failure, or an environmental standard or regulation could be breached, the failure effect should describe how this could happen. For example:

- Increased risk of fire and explosions
- The escape of hazardous chemicals (gases, liquids or solids)
- Pressure bursts
- The collapse of structures
- ………..Etc

Secondary Damage and Production Effects
Failure effect descriptions should also help with decisions about operational and non-operational failure consequences. They should indicate how long the production is affected giving the downtime associated with each failure. As indicated below the down time is much longer than the repair time.

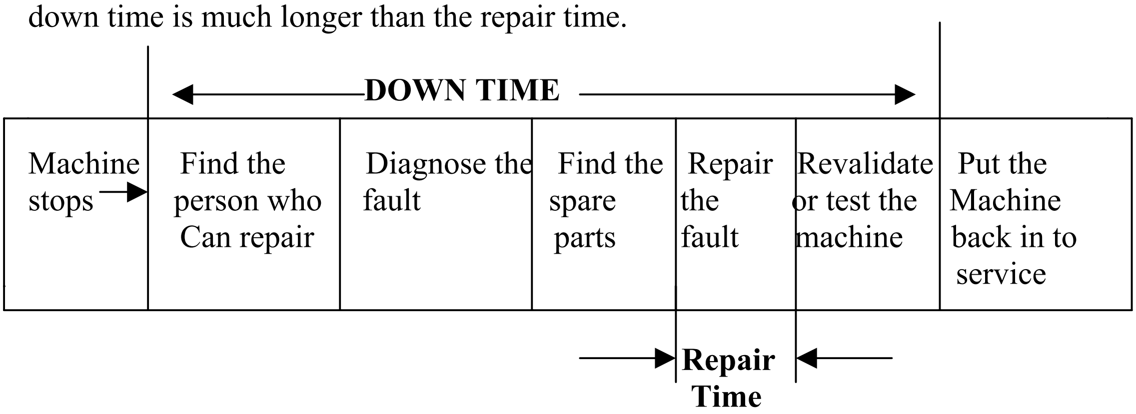


Fig: DOWN TIME VS REPAIR TIME

Sources of information about Modes and effects

One needs to be proactive, while drawing up the FMEA, as such, much emphasis should be placed on what could happen than what has happened. The common sources of information with a brief review of their main advantages and disadvantages are:

- The manufacturer or vendor of the equipment
- Other users of the same equipment
- Technical history records
- The people who operate and maintain the equipment

Levels of analysis and the information worksheet

Failure modes can be described at almost any level of detail, only the degree (level) of information will vary. The detail used to describe failure modes on information worksheets is also influenced by the level at which the FMEA as a whole is carried out.

For example, if we apply RCM to a truck, is the entire truck the asset? Or do we subdivide the truck analyse the drive train separately from the braking system, the steering, the chassis and so on? Or should we further subdivide the drive train analyse (say) the engine separately from the gearbox, propeller shaft, differentials, axles and wheels? Or should the engine not be divided into engine block, engine management system, cooling system, fuel system so on before starting the analysis? What about subdividing the fuel system into tank, pump. Pipes and filters?

Starting at a low level

RCM INFORMATION WORKSHEET	SYSTEM: ENGINE **SUB-SYSTEM** ***FUEL SYSTEM***	
FUNCTION	FUNCTIONAL FAILURE (Loss of function)	FAILURE MODE (Cause of failure)
1.To transfer fuel from fuel tank to the engine at a rate rate of up to 1 litre per min.	A. Unable to transfer any fuel at all	1. No fuel in tank 3. Fuel filter blocked 7. Fuel line blocked by foreign object 12.Fuel line severed …Etc

Fig. Failure modes of a fuel system

FMEA's are often carried out at too low a level in the equipment hierarchy, because of the belief that there is a correlation between the level at which, we identify the failure modes and the level at which the FMEA (or the RCM analysis as a whole) should be performed.

Staring at the top

RCM INFORMATION WORKSHEET	**System:** 40 ton truck **Sub-system**:	
FUNCTION	FUNCTIONAL FAILURE (Loss of function)	FAILURE MODE (Cause of failure)
1. To transfer up to 40 tons of material from Startsville to Endburg speeds of up to 75 kph (average 60 kph) on one tank of fuel	A. Unable to move at all	10. No fuel in the tank 37. Fuel filter blocked 73. Fuel line blocked by foreign particles 112.Fuel line severed --------------etc.

Fig: Failure modes of a truck

Intermediate levels

After seeing top and the low level of analysis, it may be sensible to carryout an analysis at intermediate level. At top level, too many failure modes per function exists to permit any sensible analysis.
With a bit of practice, the most suitable level at which to carry out any analysis eventually becomes intuitively obvious. It should also be noted that, it is not necessary to analyse every system at the same level throughout the asset hierarchy.

HOW FAILURE MODES AND EFFECTS SHOULD BE RECORDED

Once the level of the entire RCM analysis has been established, we then have to decide what degree of details is necessary to define each failure mode within the framework of that analysis. There is no technical reason why all the failure modes cannot be listed (together with their effects) at a level which enables a suitable failure management policy to be selected. Depending on the context and consequences, these sub-assemblies can be handled in four different ways.
The failure of services (power, water, steam, air, gases, vacuum, etc) are treated as a single failure mode from the point of view of the asset which is supplied by that service, because detailed analysis of these failures is usually beyond the scope of the asset in question.

A completed Information Worksheet

Failure effects are listed in the last column of the Information Worksheet alongside the relevant failure mode.

RCM II INFORMATION WORKSHEET	SYSTEM:5 MW Gas Turbine	System no **216-05**	Facilitator **N Smith**	Date **7/2/01**	sheet no **1**
	Sub-System Exhaust system.	S-Sys. No 216-05-11	Auditor P Jones	Date 7/3/01	of 5

FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE EFFECTS

REFERENCE:

1.Moubray, J.(1999), Reliability Centered Maintenance (2nd Edition) , Butterworth Heinmann

2.Coetzee, J.L,(1998),Maintenance, Maintenance Publishers (pty), South Africa

3.Wilson,A,(1999), Asset Maintenance Management, Conference Communication,UK