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The Lifetime Reliability Solutions
Certificate Course in Maintenance and Reliability
Module 1 – Introduction to Principles of Reliability and Precision Maintenance

Session 2
The Context of Maintenance Practices

1. An Historical Perspective of Maintenance

Much has happened in engineering since the industrial revolution a couple of hundred years ago, but perhaps the most dramatic changes have occurred in the last fifty years. These changes have of course affected how industry's plant has been maintained.

Prior to the Second World War machinery was generally quite rugged and relatively slow running; instrumentation and control systems were very basic. The demands of production were not overly severe so that downtime was not usually a critical issue and it was adequate to maintain on a **breakdown** basis. This machinery was inherently reliable. Even today we can see examples of machines made in that period which have worked very hard and are still essentially as good as the day they were made.

From the 1950's with the rebuilding of industry after the war, particularly those of Japan and Germany, there developed a much more competitive marketplace; there was increasing intolerance of downtime. The cost of labour became increasingly significant leading to more and more mechanisation and automation. Machinery was of lighter construction and ran at higher speeds - they wore out more rapidly and were seen as less reliable, perhaps it was too that they were utilised more fully. Production demanded better maintenance which lead to the development **of Planned Preventative Maintenance.**

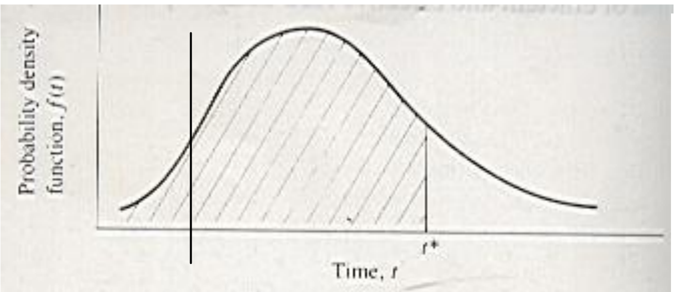
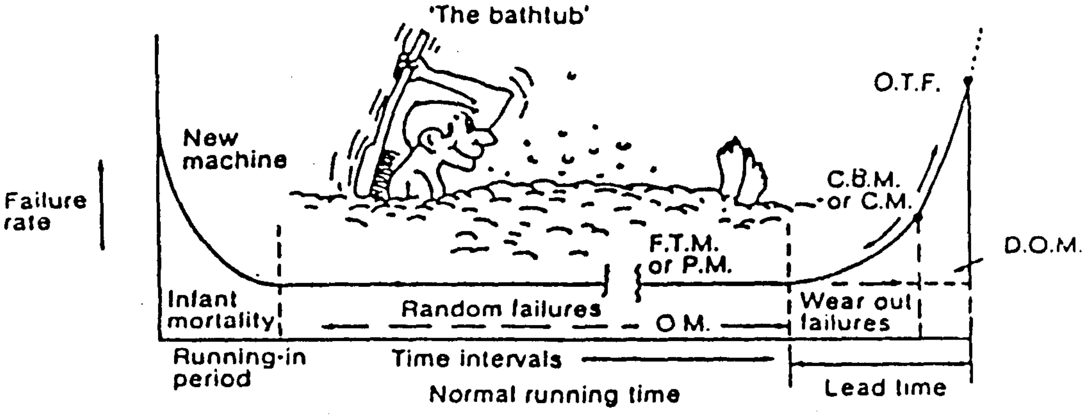


Fig. 6.1. Lifetime probability distribution

The value of time (or usage) at which failure occurs is, of course, unknown in advance, it is a random variable. Perhaps a more meaningful measure would be "relative frequency of failure" rather than "number of machine failures", i.e. the number of machines failing during a time interval divided by the total number of machines.

It was recognised that at a level of failure of, say, 10 machines in 100, the probability of failure had become unacceptably high and the full group of machines should be overhauled – this may be at the time indicated on the graph above. Obviously there is enormous potential life lost in the remaining group of machines, but in view of the risk this was considered justified.

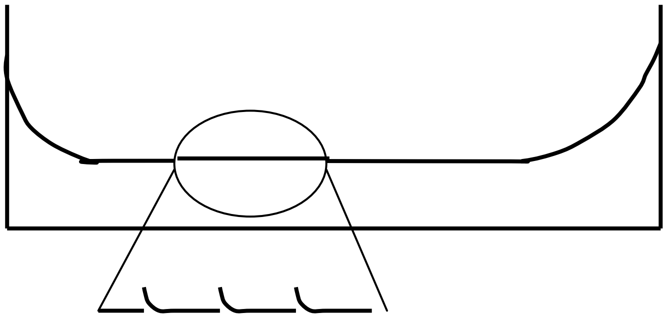
The planning involved plant overhauls based upon a time interval or usage at which the failure rate of a group of similar machines became unacceptable. This lead to the basic assumption that ***the older equipment gets the more likely it is to fail.*** This was the age of the "**Bathtub Curve**".



There are three identifiable phases within the Bathtub;

- **Running In**, also known as the **Infant Mortality,** phase. This recognises the premature failure of components and is often seen in plant for the first few hours, days or weeks in a plant that has been overhauled.
- **Normal Operating Life** phase. This shows a relatively constant probability of failure. Failures within this phase are usually referred to as **Random.**
- **Wear Out** phase. There is an increasing probability of component failure between equal and successive time intervals. Somewhere within this phase the failure rate would become unacceptable and widespread maintenance would be carried out, usually of an intrusive nature.

This intrusive scheduled maintenance would lead back to the beginning of a new bathtub curve – the phase of **Infant Mortality.**



Effectively, the process of Planned Preventative Maintenance gave rise to a series of mini-bathtub curves, each with their initial period of increased high risk

Within Planned Preventative Maintenance the name of the game became one of choosing best point in the Wear Out phase at which to perform maintenance, all other factors considered.

From the 1980's plant and systems became increasingly complex, the demands of the competitive marketplace and intolerance of downtime increased and maintenance costs continued to rise. Along with the demands for greater reliability at a lower cost came new understandings of failure processes, improved management techniques and new technologies to allow an understanding of machine and component health. Environmental and safety issues have become paramount. New concepts have emerged; condition monitoring, just in time manufacturing, quality standards, expert systems, reliability centred maintenance to name but a few.

Engineering, and maintenance with it, are subject to the whims of **fashion** – "value engineering, hazard and operations studies, project task force teams, World Class, CMMS, CAD, TPM, TQM etc".

We have seen the development of "**Centres of Excellence**" from such major players as Shell, ICI, Courtaulds, UKAEA etc, where reliability specialists were employed to advise, analyse, troubleshoot etc, and advocate on economic justification for increased expenditure to gain in reliability and availability against pressure of capital expenditure.

There is the thrust toward acceptance of **life cycle costs** which recognises that the design & build of a plant must be lumped in with the ongoing maintenance cost and the eventual cost of decommissioning and disposal. Manufacturing and production enterprises are under intense pressure to achieve maximum efficiency. The winners will be seen to be – so we are told, those that maximise their investment in people and equipment assets to achieve highest profitability.

In the United Kingdom the mid-90's saw the creation of The Institute of Asset Management. Interestingly, some of the top players in this concept have been companies traditionally associated with accountancy but now very involved as consultants in the new game of **asset management**.

Meantime, for the Maintenance Engineer in Western Australia there is no avenue in the universities for study in what is now recognised as a discipline in its own right – Maintenance Engineering. This is being offered by universities in Victoria, New South Wales and Queensland.

The search continues for ways to control maintenance costs, reduce downtime and ways to present information to managers so that effective maintenance decisions can be made. At the root of all this is the need for maintenance and production to work in partnership toward a common goal.

Maintenance can do no more than ensure that plant will perform to its built in (or inherent) reliability. If plant is not capable of delivering the desired performance to begin with, maintenance alone cannot enable it to do so. The plant (or components) must either be modified or production's expectations lowered.

2. The Optimised Utilisation of Assets

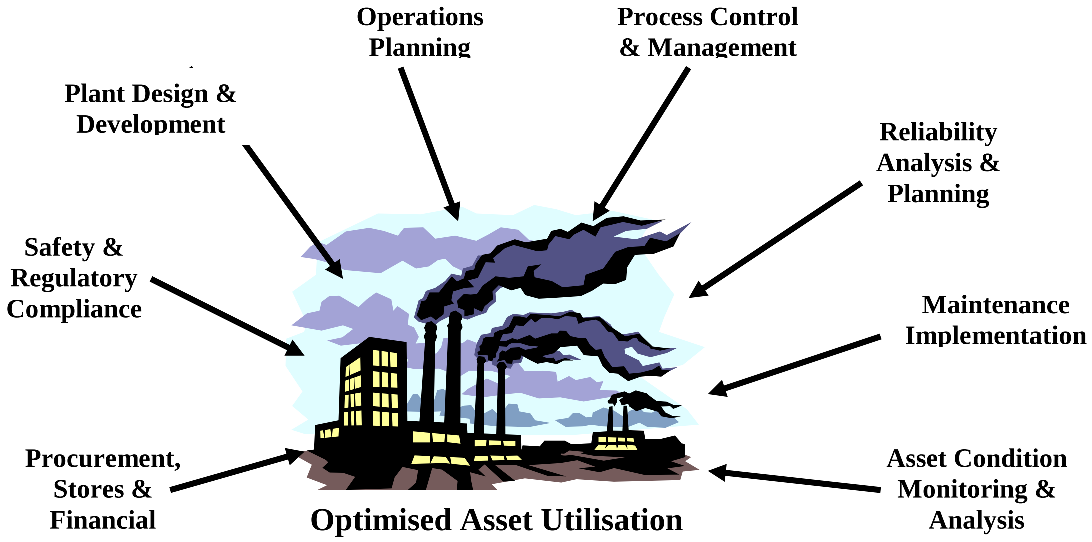
To go down the path of optimisation it is necessary to first identify what measures will be used to determine an "optimised asset utilisation" state. Input must be had from engineering, operations, reliability, maintenance, safety regulatory, procurement, risk**.**

Some organisations may justify the development of teams that take these inputs to develop criteria for performance and costs in conjunction with corporate business objectives. Inevitably these must be in the form of financial benchmarks for the use of senior executives. These criteria must take into account the life time financial impact that any asset installed has on installation, development, production, quality, safety, hazardous waste disposal, maintenance, purchasing, and final disposal.

However, it is equally important that the optimisation model identify in quite specific detail where losses are taking place and what it costs not to take action on these. Appropriate measures, or performance indicators, must be used that serve the practical purposes of production and maintenance.

Because business requirements may change daily in response to outside factors there needs to be a continuous refinement of the optimised asset profiles.

The figure below shows the information paths needed to establish optimised asset utilisation. By coordinating and merging this data into comprehensive asset information there can be **satisfaction of the goal to make timely and informed decisions to safely and profitably maximise the value of respective assets.**



Inputs for the Optimisation of Asset Utilisation

Reliability Analysis & Planning

Initially involves determining and communicating the performance indicators for tracking improvements, such as production downtime, reducing maintenance overtime costs, reducing costs of spares.

The next step involves a study of the criticality of all the production assets related to their impact on future production requirements, safety, regulatory compliance, spare parts costs, unplanned failure costs etc. A structured approach such as RCM can facilitate this study.

The output of this study must be a site appropriate maintenance plan specifying an optimised balance of CBM, PPM, and Breakdown Maintenance. This shapes reliability driven maintenance execution and reliability feedback activities.

Also involved is the regular review of failures and near-misses with RCFA to determine the causes. Modifications are then made to the reliability plan to prevent recurrences.

Condition Monitoring and Analysis

Most machine and process characteristics which affect quality, availability, capacity, safety, risk and cost can be continually evaluated throughout an asset’s lifetime. This is essential in identifying impending failure and will be applied to critical areas identified in the reliability plan.

The current "state of health" of process plant is important information related to current information, diagnosis and prognosis of various defects, and predicted useful life in the optimisation of safety, quality and high production rates.

Because of the sophisticated technology employed and its complex data, operators require clear and plain language information and forecasts.

Maintenance Implementation

The output from the Reliability plan is used (in conjunction with a CMMS) to create a system for its implementation. Inputs required for asset optimisation include maintenance resource availability, asset and problem histories, and work order planning, scheduling, tracking.

This will be significantly influenced by inputs from condition monitoring.

Process Control & Management

There are the obvious functions of monitoring and controlling the process for reasons of safety and product specification. Additionally, there is invaluable information to be gained from the process parameters that can give an understanding of the current health of the asset.

A further important output of this is the understanding of bottlenecks or backlogs within the current production stream which can assist in optimisation of the assets involved.

As process control systems become increasingly complex there comes an increased probability that they will cause production losses. Additional support resources may become necessary.

Operations Planning

Takes into account the whole process input supply chain – fuel, power, steam, water, raw materials, and requires to know the current, planned and historical production and efficiency levels in a process line, and be able to modify this level.

Safety & Regulatory Compliance

In more recent times the increasing demands of these compliances has had one of the more major impacts upon the utilisation of manufacturing assets, particularly with the movement toward self management of these roles.

Note that these changes can also introduce new freedoms in implementing improved technologies which not only satisfy compliance with the regulations but can contribute toward improved plant integrity and availability.

For example, the Australian/ New Zealand Standard for In-service Inspection of Pressure Equipment (i.e. AS/NZS 3788) is to some extent prescriptive in defining internal and external inspection intervals. However there is flexibility within the standard to extend these intervals and also use external non-destructive testing techniques to replace internal inspection, where it can be demonstrated that there is no increased safety risk.

Plant Design & Development

In the management of assets it is essential to understand the design specifications for the plant and the component parts. This enables proper process and component risk assessments so that the likely failure modes and their effects are understood. This will, in turn, provide a guide to the appropriate use of condition and performance based techniques and the application of non-destructive testing. In the event of equipment failure or failure to meet production specifications the design specifications must be reviewed to enable Root Cause Failure Analysis so that redesign or replacement will satisfy all operational requirements.

Again, if operational requirements are changed the plant and component specifications must be clearly understood to ensure compatibility of the changes.

MRO Procurement, Stores & Financial

The balance in holdings of spare parts and spare replacement assets is critical; too few may lead to increased production downtime, too many requires storage facilities and ties up capital.

The use of preferred vendors can lead to cost savings, reliable just-in-time deliveries, avoidance of panic buying. Interaction with other departments, particularly maintenance, is essential in finding this balance, or optimisation.

Of these inputs, this seminar is focussed on **Maintenance Implementation, Asset Condition Monitoring & Analysis,** and **Reliability Analysis & Planning.**

3. A Review of Concepts of Maintenance and Condition Monitoring

In the first session a formal definition was given of Maintenance within the context of the manufacturing and process industry environment.

"....Maintenance is the management, control, execution and quality of those activities which will ensure that optimum levels of availability and overall performance of plant are achieved, in order to meet business objectives...."

The key phrase here is "**..optimum levels of availability and overall performance of plant**..".

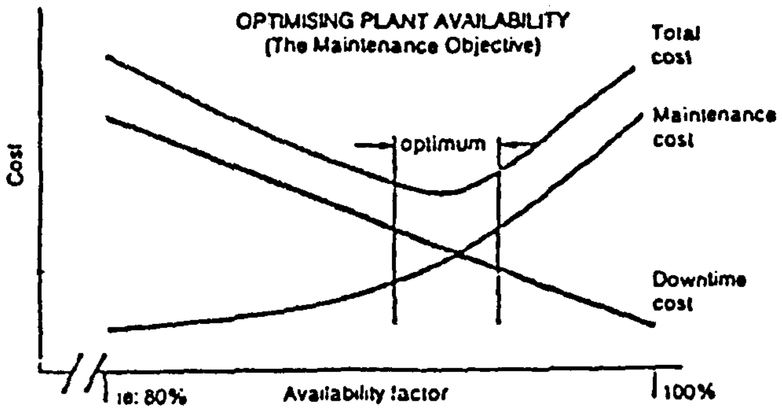
Note that there is little merit in increasing availability unless it can be gainfully utilised.

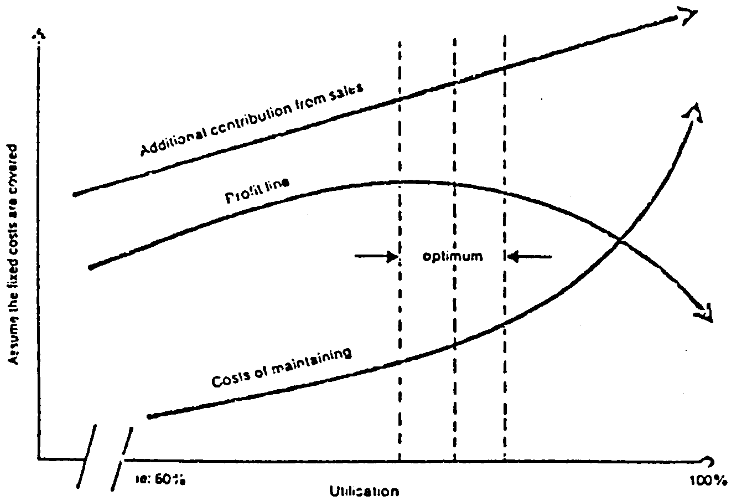
In Session 1 consideration was given to the impact of maintenance on profitability with an invitation to consider

- - what is the overall cost of plant failures - product, goodwill as well as material, and what benefit accrues from increased plant availability ?
- what do I know about my plant's present maintenance performance ?

3.1 What is the Cost of Plant Failure and the Benefit of Increased Uptime ?

Under the “traditional” maintenance concepts associated with the “Bathtub curve” generation there was a truth that maintenance costs increased with plant usage. These curves relating to cost-availability and utilisation were relevant then.





With greater understanding of the failure processes and changes in maintenance methods to condition monitoring and reliability concepts, coupled with the implementation of the Precision approach, there is no longer a validity in the old truth that the more a plant is used the more it costs to maintain. This goes against our general experience and ways of understanding, and will be explored further.

The challenge is to achieve the optimum cost benefit balance, while;

- minimising downtime costs through eliminating unplanned and emergency shutdowns, and reduced product quality losses,
- reducing turnaround times and thereby maximising availability.

3.2 What Do I Know About My Company's Current Maintenance Performance ?

Table 1 shows a selection of possible maintenance performance measures which help to build a picture of maintenance performance. The list is by no means exhaustive and there is a need to identify measures relevant to your operation.

Any figures produced are only of benefit in the long term if ;
- -there is a reference period for comparison,
- -regular actuals are measured against the reference and, most importantly, against realistic targets or standards of performance,
- -these figures, ratios and comparisons actually stimulate positive management action

As a minimum you should know the answers to at least six of the measures in the first two groups.

Table 1 Table of Maintenance Performance Measures

1.0 Overall Performance
- Maintenance Costs v % Sales Value of Production
- Maintenance Costs v % Value Added
- Maintenance Costs per Unit of Output
- Maintenance Manhours v % Total Labour Hours
- Maintenance Manhours per Unit of Output

2.0 Downtime (By Plant, Area, Machine etc)
- Downtime Due to all Causes v % of Total Time
- Downtime Due to Maintenance v % of Total Time
- Downtime Due to Maintenance v % of Planned Plant Downtime
- Analysis of Downtime by Cause

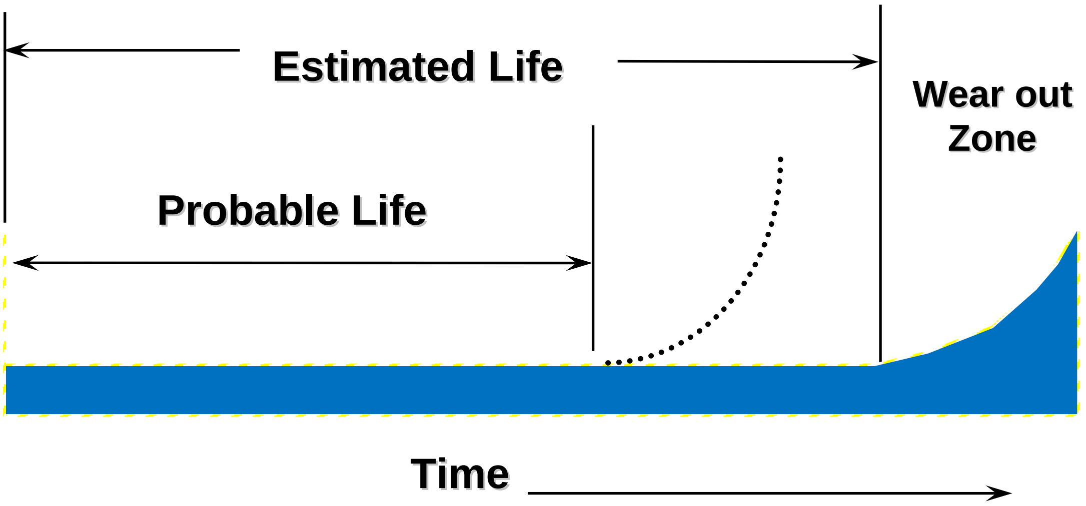
3.0 Analysis of Workload
- % of Maintenance Hours on Planned Maintenance v Corrective v Emergency v Capital and Installation v Tooling & Repairs

4.0 Analysis of Material
- Total Annual Maintenance Material Spend
- Spend on Materials as % Maintenance Labour Spend
- Maintenance Material per $1,000 SVOP

5.0 Miscellaneous
- Number of Failures per period by Category
- Mean Time between Failures by Category
- Mean Time to Repair by Category

3.3 Setting a Context for Condition Monitoring and Other Maintenance Methodologies

In the aviation industry, around the time of the introduction of the wide bodied civil aircraft, there was a search for improved reliability and questioning of the long established basic assumption that ***the older equipment gets the more likely it is to fail.***



Accident rates were in the order of 60 per million takeoffs. 20,000 hours flying time required some 2,000,000 man-hours of maintenance, performed on a time, or hours run, basis.

This basic assumption was questioned and the failure process researched. Six patterns of failure were identified, and of these three showed a relationship of increased probability of failure with age, but they totalled only 11% of failures.

The remaining 89% showed no age relationship, but an open ended period of constant probability of failure. In other words, failure is a random event. They do, however, have the potential to give warning of a developing failure through changing levels of a suitable measurement parameter, indicating a **change in condition** of the component, machine or system.

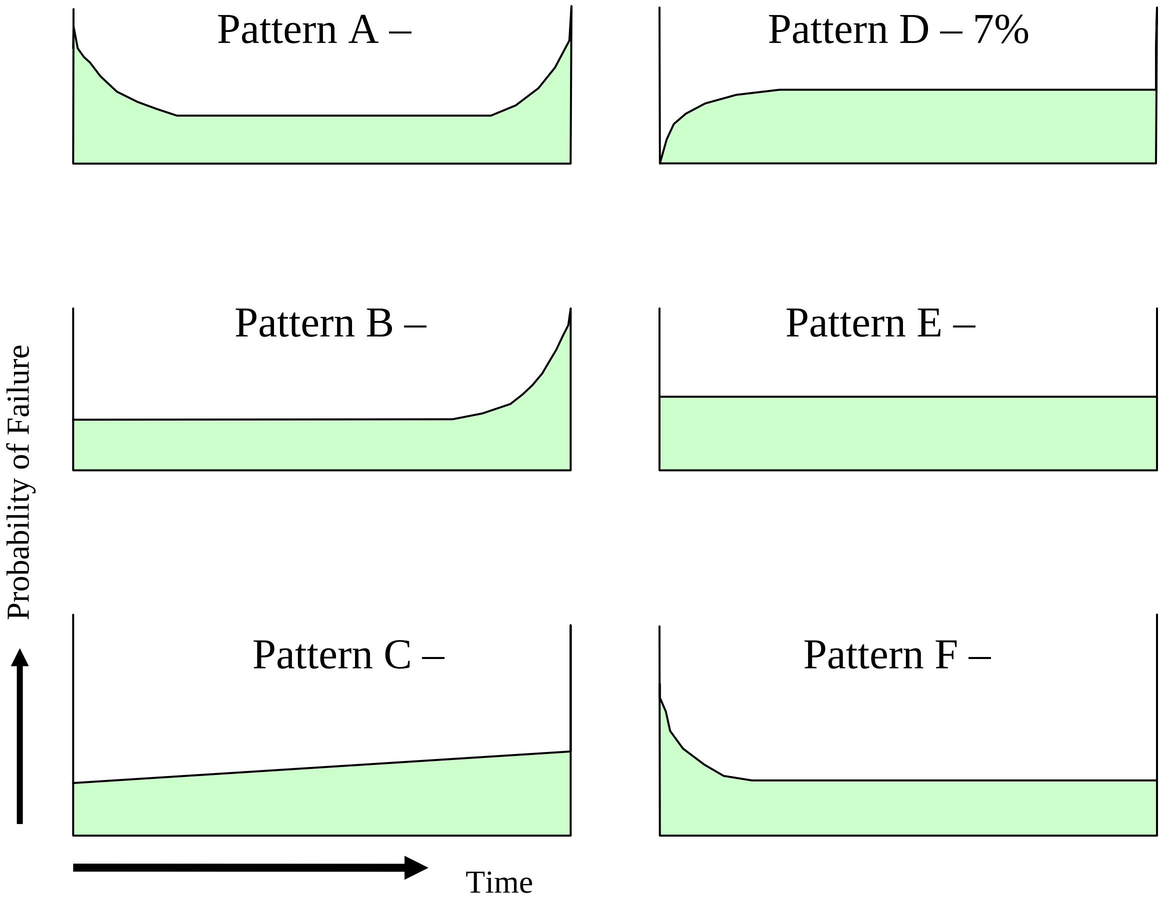
This is the only way to identify a need for maintenance under conditions of a constant probability of failure.

The aviation industry made major changes to its maintenance practices as a result of this study and the results were dramatic; maintenance man-hours for 20,000 hours flying time went from 2,000,000 down to 66,000 – a 30:1 reduction. If the flying public were aware of such reductions in maintenance there would probably be a similar drop in public confidence.

There was an equally dramatic improvement in safety – effectively reliability. Of course much of this improvement is due to design improvements and technology but condition based maintenance techniques are the provider of considerable information to assist in this development.

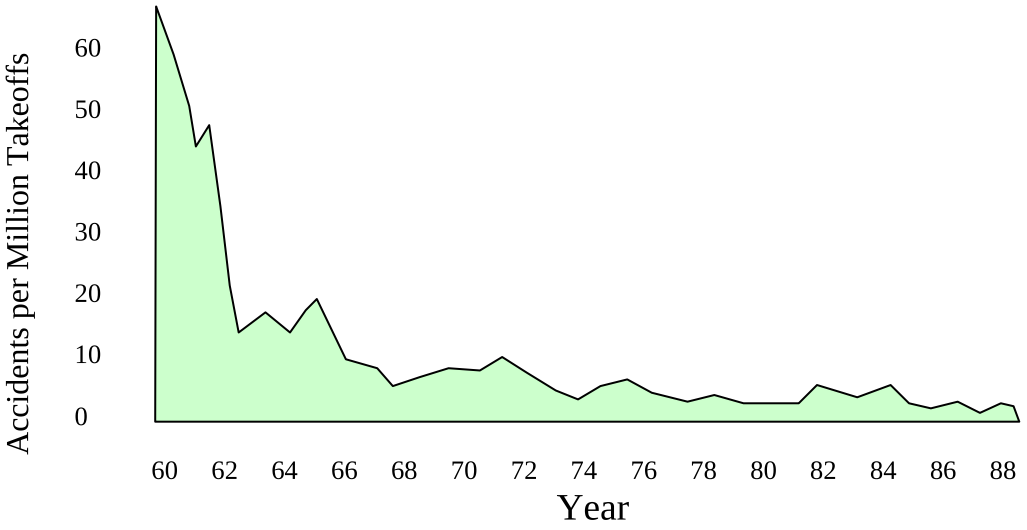
Industry is not an airline; over subsequent years industry has followed this study and found that there is a high degree of validity in it. This forms one of the principal foundations of **Reliability.**

Aircraft Modes of Failure



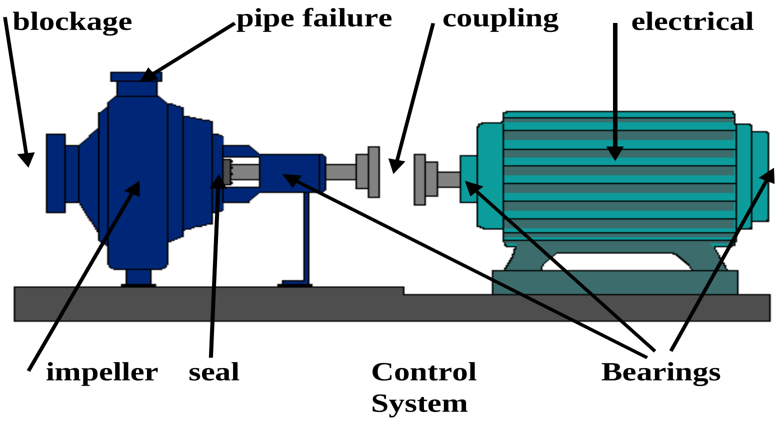
Age Related
11%

Random
89%



3.3.1 How Might My Machine Fail?

In choosing the parameters to be measured to identify this change in condition, it is necessary to consider how the machine or system might fail. Take as an example a simple pump set.

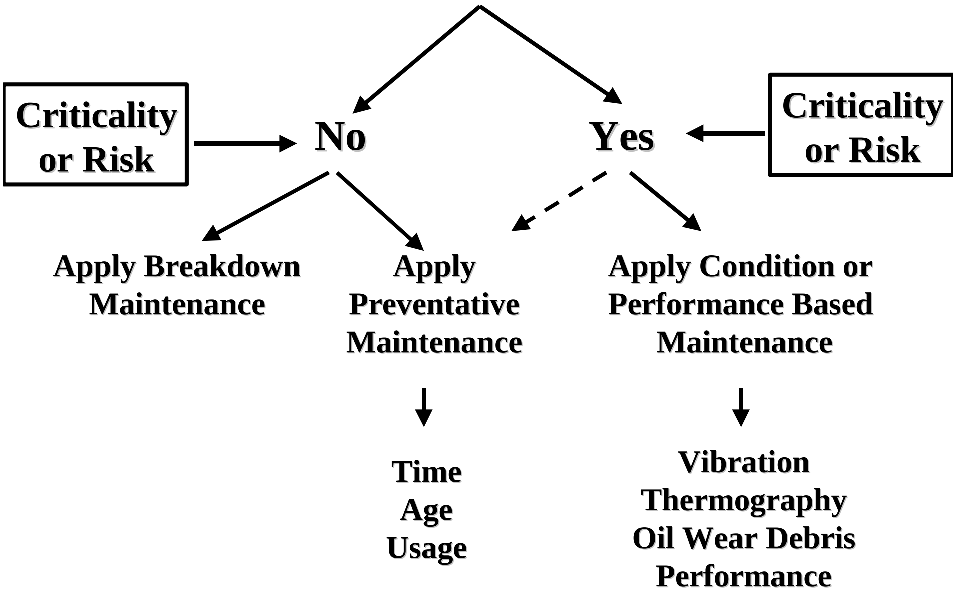


3.3.2 Can the Failure Process be Detected and Measured?

Having identified the possible ways in which it may fail, consider if it is possible to detect and measure the failure process. Consider the previous failure history, use “hindsight”.

If the answer is NO then either Planned Preventative or Breakdown Maintenance will be applied, depending upon the Criticality or Risk.

If the answer is YES and the Criticality justifies it then Condition Based Maintenance will be applied. If the answer is YES but Criticality does not justify it then Planned Preventative or Breakdown Maintenance will be applied.



4. Risk

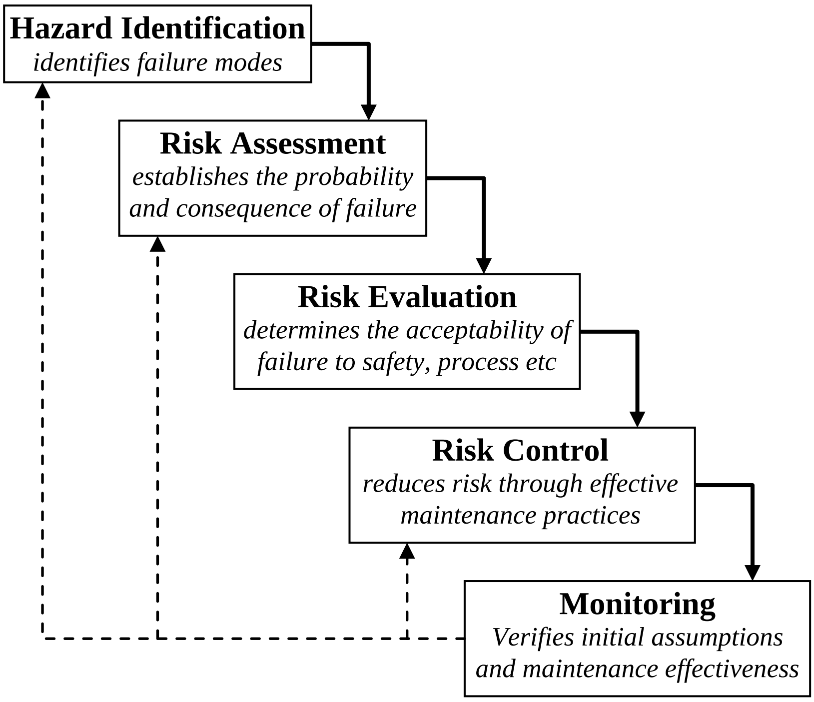
Risk Based Inspection is seen by some as a maintenance methodology in its own right. However, within any other methodology risk and criticality is an essential element and must be considered with regard to the management of safety and commercial risk .

- Maintenance is a Risk Control activity.
- Risk = Probability x Consequence

The requirement to consider risk/criticality was seen in the preceding section.

The expenditure of maintenance dollars on risk management (e.g. condition monitoring, process control, etc) should be directly related to the probability and consequences of failure. This is a very significant decision point in the management of condition monitoring expenditure!

Often reasonable judgements based on experience can be made without the rigour and expense of exhaustive failure modes analysis. Sometimes, however, a formal risk assessment must be made and decisions made based on those outcomes.



The Application of Risk Based Principles to Maintenance

There are standards which are relevant to Risk. These include

- ISO31000 Guide to Risk Management
- AS/NZ 4360 Risk Management
- AS/NZ 3931 Risk Analysis of Technological Systems – Application Guide

4.1 Non-Intrusive Inspection of Pressure Equipment

AS/NZS 3788 In-Service Inspection – Pressure Equipment is to some extent prescriptive in defining internal and external inspection intervals. However, there is flexibility within the standard to extend these intervals and also use external non-destructive techniques to replace internal inspection, where it can be demonstrated that there is no increased safety risk.

Risk Based Inspection (RBI) has lead to the development of rational and effective non-intrusive inspection (NII) programmes for pressure vessels that negate the requirements, or extend the intervals, for statutory internal examination. Advances in technology have also resulted in the availability of many new inspection techniques, which have been effectively validated in numerous NII programmes for a wide range of vessels, pipe work and other pressure equipment.

The process of Reliability Centred maintenance employs all these methodologies but in many instances a simpler and less resource hungry approach is quite appropriate. The model given above of the pump-set illustrates the approach that would be taken by someone such as an experienced and competent condition monitoring engineer.

5. ISO Working Draft Standard

This process is formalised in the ISO Standard ***Condition monitoring and diagnostics of machines – General guidelines***.

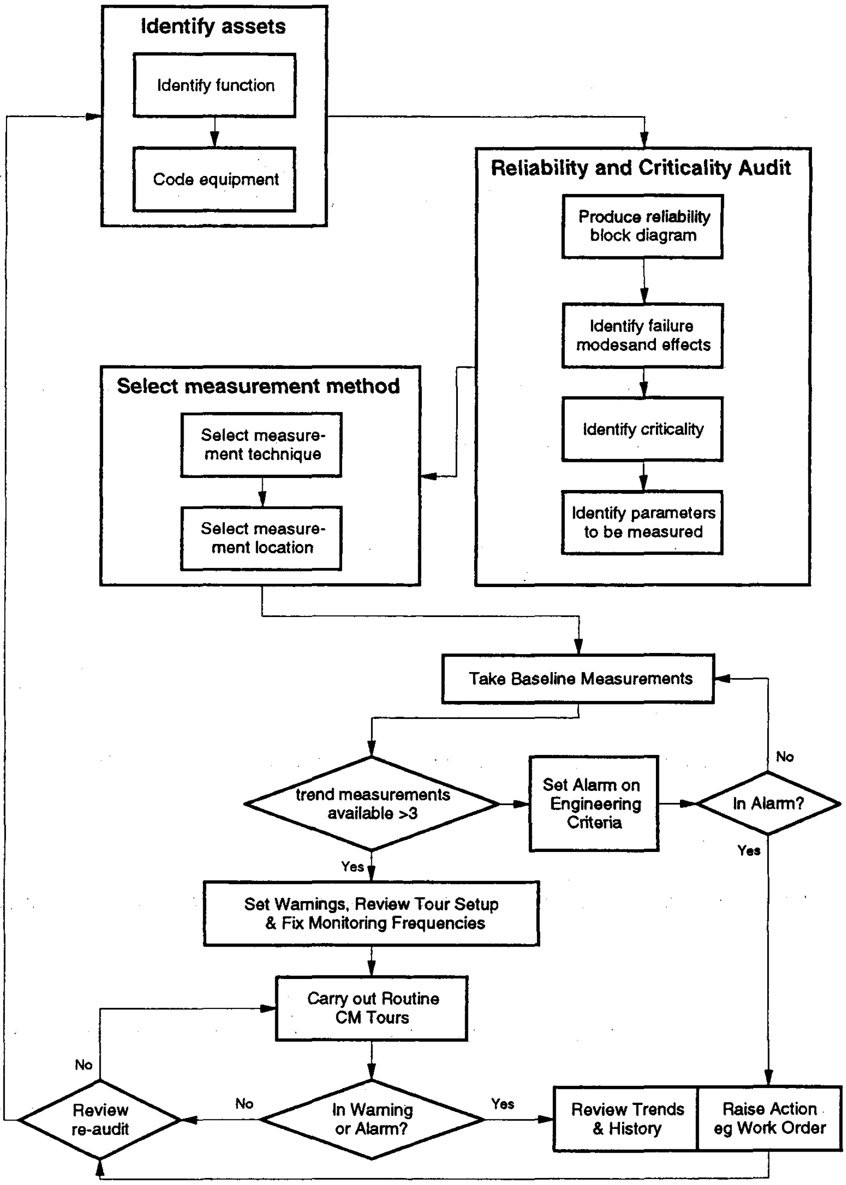
Related standards are;

- ISO/CD 13373: *Mechanical vibration and shock – Vibration condition monitoring of machines*
- ISO/CD 13380: *Condition monitoring and diagnostics of machines – Using performance parameters – General guidelines.*
- BS5760-5: *Reliability of systems, equipment and components – guide to failure modes, effect and criticality analysis (FMEA and FMECA)*
- BS EN 61078: *Reliability of systems, equipment and components – Guide to the block diagram technique.*

The following is extracted from the General Guidelines.

5.1 Overview of Procedure

The following is a typical condition monitoring flowchart.



5.2 Equipment Audit

- **Identify Assets** List and clearly identify all assets and associated power supplies, control and existing surveillance systems.
- **Identify Equipment Function** Identify the following information
  What is the equipment required to do?
  What are the operating conditions?
- **Code Equipment** Set out a clearly defined coding procedure for all assets.

5.3 Reliability Audit

- **Reliability Block Diagram** Produce a simple high level reliability block diagram including whether equipment has a series or parallel reliability effect. The use of reliability and availability factors is recommended to improve the targeting of the condition monitoring processes.

  Detailed information on producing reliability block diagrams is contained in BS EN 61078.

- **Failure Modes and Effects Analysis (FMEA)** Carry out FMEA to identify expected faults, symptoms and potential parameters to be measured which indicate the presence or occurrence of faults.

  Detailed information on carrying out a FMEA is contained in BS 5760-5.

  Fault diagnosis procedures shall be in accordance with ISO/CD 13379.

  Guidance on the selection of performance parameters useful to indicate faults for a range of machine types is contained in ISO/CD 13380.

- **Identify Criticality** Carry out a Failure Modes and Effects and Criticality Analysis (FMECA) to identify the relative criticality of the equipments being audited. This may be a simple rating system which includes a method of weighing factors including: failure rates, replacement cost, safety and environmental considerations and the results of failure occurring (secondary damage).

  More detailed methods of carrying out a FEMECA are contained in BS 5760-5.

5.4 Parameters to be Measured

The FMEA and FMECA audits will produce information on the range of parameters to be measured for particular failure modes. Parameters to be considered are generally those which will indicate a fault condition either by an increase or decrease in overall measured value, or by some other change to a characteristic value such as pump or compressor curves, reciprocating internal combustion engine pressure – volume curves and other efficiency curves.

Guidance on the selection of performance parameters useful to indicate faults for a range of machine types is contained in ISO/CD 13380.