The Reliability Theory behind TPM

Understanding the Nature of Failure

Total Productive Maintenance or TPM which in more recent times is often referred to as Total Productive Manufacturing or Mining, was developed in the late 1960's by applying Dr W. Edwards Deming's quality concept of Prevention at Source to equipment so as to significantly improve reliability to allow the success of the Toyota Production System, and in particular One-Piece Flow involving the linking of standalone equipment to create continuous production lines.

As such it is important to understand the reliability theory behind TPM which helps to explain why Autonomous Maintenance, or as we call it in Australasia, Operator Equipment Management (refer to back page of this article for an overview), is critical in obtaining zero breakdowns while significantly reducing maintenance costs.

The Role of Periodic Replacement

If we think about our motor vehicles, we realise that they are relatively reliable pieces of complex equipment, to the point that if we are about to embark on a long journey, we normally don't need to carry a massive tool box with us, or strap an electrician and fitter to the roof, in case we have a breakdown on our journey.

So what maintenance strategy do we apply to our motor vehicles to ensure their reliability? The strategy is called *Periodic Replacement*. This is where we have our vehicles serviced regularly, and at either a set time or usage interval, we replace specific components because we are told in our service manuals that specific components have certain lives eg oil filter at 15,000 kms, platinum sparkplugs at 40,000 kms, and timing belts for overhead cams at 110,000 kms etc.

With our equipment at work, we also use Periodic Replacement for many of the components, especially those that we cannot easily access for monitoring.

Let us use a control valve or relay as an example that has a life of 12 months. Over a period of say 50 years we would expect to replace this component 50 times.

If the impact of the failure of this component affected the overall performance of the equipment and the component couldn't be easily condition monitored, then a good maintenance strategy would be to set up a Periodic Replacement plan for this component so it wouldn't fail.

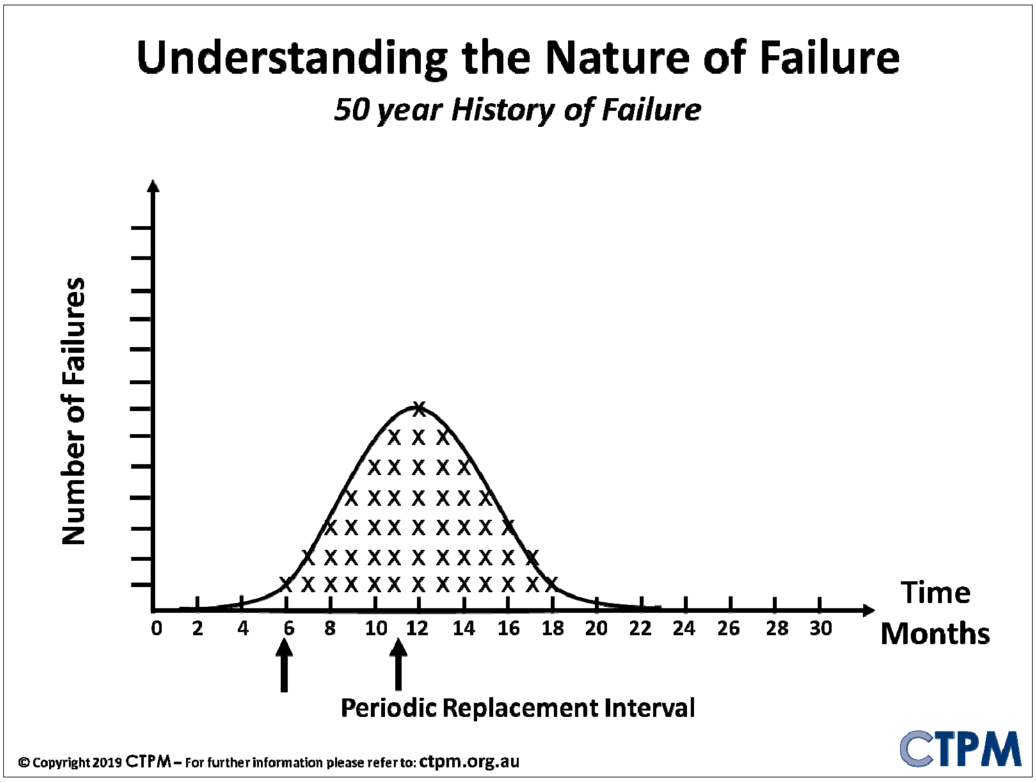
Under such a situation, a good time to replace it could be say 11 months. However, research by the Japan Institute of Plant Maintenance (JIPM) which has also been verified by companies in America such as DuPont and Alcoa, has shown if we were to allow the component to run to failure and plot the history of the component's life, we would often find that it doesn't always fail exactly at 12 months. We get failure sometimes less than 12 months and sometimes greater than 12 months. If we were to plot the failure pattern for the component we would typically find a distribution of failures as shown in Figure 1.

During our workshops or site visits we often find many people have experienced this with components in their workplace. During my early days in maintenance at the Port Kembla Steelworks we regularly came across this phenomenon when analysing failure records at the Hot Strip Mill after a breakdown that had occurred before the next replacement interval.

Hence, what does applying an 11 month periodic replacement strategy do for us?

We will stop more than half the breakdowns however we will still have some breakdowns as shown by the failures between 6 months and 11 months in Figure 1 below.

Figure 1 – Periodic Replacement Interval



So what happens when we have a breakdown? The maintenance manager normally gets dragged over the coals at the morning meeting, with the demand of doing something to stop the breakdown occurring again. This often results in reviewing the periodic replacement timeframe. If the replacement time was 11 months and the component failed at 10 months then the timeframe may be revised to 9 months.

This action will more than likely result in less breakdowns provided the law of probability is on the maintenance managers side however after several years of replacement at 9 months, it will probably breakdown again just before the 9 months. The same scenario will probably be repeated until such time as the replacement time is revised to below 6 months.

This will ultimately eliminate the breakdowns of the component however what has happened to the maintenance costs by replacing the component often at less than half its life?
The maintenance costs have more than likely doubled, however the good news is the breakdowns have stopped.

Real Life Example

This reminds me of a situation I came across several years ago when I visited a site in Tasmania. We were reviewing the site in preparation for kicking off Australasian TPM & Lean and we were discussing reliability of the plant with the maintenance planner. He was telling us what a great job the maintenance department had been doing over the years in reducing breakdowns and the results were impressive.

Basically it was a continuous processing food plant that would run 24 hours a day for some 21 days before stopping for 1 day to allow a 16 hour maintenance period and an 8 hour cleaning period. Their reliability record was very good with very little disruption to production during each 21 day run. This prompted me to ask the question about the cost to maintain the plant. Unfortunately the maintenance planner wasn't aware of the annual maintenance spend for the plant. As he put it, "we don't worry about how much we spend; it's all about ensuring the reliability of the plant".

Further investigations at the site revealed an annual maintenance spend of around $5m. We also determined with the site accountant that the replacement value of the plant was around $100m. This meant the 'Maintenance Spend to Equipment Replacement Value' ratio was running at 5% which is well over twice the industry best practice of 1.75% - 2.0%. This is a great example of where reducing the periodic replacement time to ensure reliability can have a significant impact on maintenance costs.

So back to our chart, what is the best strategy then?

One possibility would be to do a cost-benefit analysis to identify "the best or optimum time" to replace the component eg. 8, 9, or 10 months, and accept some breakdowns but at a lot lower overall maintenance cost, or we could follow what underpins the foundation which TPM came from – Dr W. Edwards Deming and his teachings about Quality.

One such teaching was about variation and improvement.

Many years ago I went to a Quality Training Course and the presenter spoke about shooting a rifle. I related to this because I was an air force cadet at High School and we would shoot these old 303 rifles on an open 200-yard firing range in Sydney, using old ammunition left over from the 1st World War.

I would lay on the dirt mound, aim for the bulls-eye and pull the trigger and I might hit a corner of the target. The target would be pulled down, the hole repaired and the target repositioned with the location of the shot signalled.

For the next shot, I would make an appropriate adjustment (diagonal distance from the bulls-eye compared to the results of the first shot) and aim so as to hopefully get a bulls-eye.

Unfortunately I would often end up hitting another corner of the target, well clear of the bulls-eye.

At the time I was not aware of any of Deming's teaching, however if I reflect on this experience now, it becomes clear why I didn't get a bulls-eye with my second shot.

The reason was simply the variation in my shotting process caused by:

- Dirty rifle;
- Loose sights;
- Wind;
- Very old ammunition;
- Jerked the trigger;
- Poor breathing; and/or
- Unsteady shot etc.

For example, if I wanted to become an Olympic shooter, what would I have to do? Obviously, follow Dr Deming's advice and understand and eliminate all the variables of the process ie learn how to shoot properly, get a decent rifle in excellent condition, get ammunition that was perfect. I won't be able to eliminate the wind, however I could learn how to monitor and adjust for it.

Hence, the learning is the need to understand what causes the variation then do something about it BEFORE adjusting for it.

Hence in Figure 1, we have all this variation in the life of our component. So if we follow Dr Deming's advice we need to ask the question: 'what is causing the variation in the life of our component'?

This question has been asked by many companies over the years and at CTPM we have certainly taken a great interest in the results from many sites. If we were to ask everyone at our workshops to list all the reasons for the variation I am sure we would be able to fill several sheets of butcher's paper.

The Causes of Variation in Component Life

The JIPM (Japan Institute of Plant Maintenance) has also conducted research on this matter over 30 years. Their conclusion was that the 80:20 Rule applied. That is, the majority of the variation was caused by only a few 'conditions' found at a typical manufacturing (or mining) site. They actually identified 3 major physical conditions that you can observe as you walk around a site and often see from looking at the equipment or would discover if you did a thorough inspection.

They are: ***Looseness***, ***Contamination***, and ***Lubrication***

Hence to reduce the variation of the life of your components by some 80%, you need to address and achieve 'Basic Equipment Conditions' which means you have:

- No looseness;
- No Contamination; and
- Perfect Lubrication.

Once this is achieved, the distribution curve will narrow by about 80% and move to the right as shown in Figure 2. This is what we aim for in Stage 1 of Operator Equipment Management which involves 3 steps:

Step 1: Identify and Rectify Equipment Defects including all looseness

Step 2: Address Sources of Contamination and Difficult to Access Areas

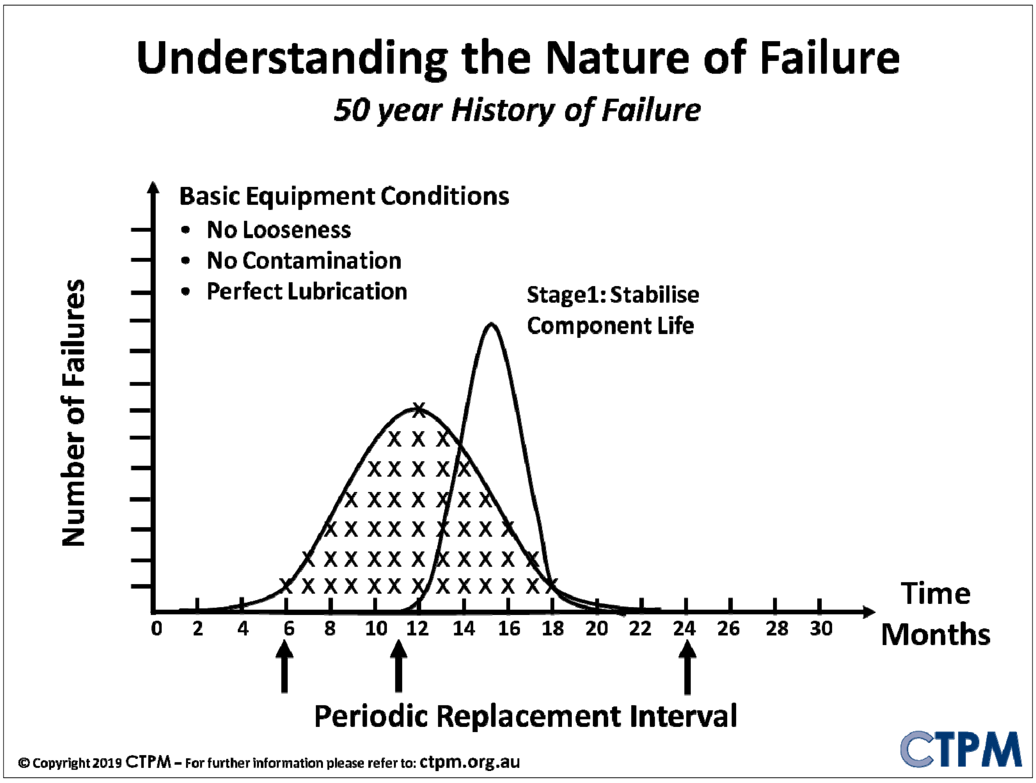
Step 3: Establish Perfect Lubrication and enhance Clean for Inspection Standards & Procedure to ensure Basic Equipment Conditions

This is also why periodic replacement works so well with our motor vehicles. Every service ensures all components are clean and properly lubricated. Any contamination on the engine is removed and the most critical nuts are colour marked to easily identify if they are coming loose.

Back to our plant, what is the benefit of achieving Basic Equipment Conditions through stage 1 of Operator Equipment Management?

After removing 80% of the variation, the average life of our component is now 15.6 months rather than 12 months and over 50 years, if we allowed it to fail we would expect to replace it 38 times rather than 50 times, or if we stuck to our 11 months periodic replacement plan we would eliminate breakdowns.

Figure 2 – Stage 1: Stabilise Component Life



This means we will reduce the workload on our maintenance resources so they can engage in reliability activities they often previously never had time for.

How often have our maintenance resources been to a job and carried out a repair and said “if we had time we could install newer technology or a stronger part so that failure won’t occur as often, but due to limited time we will just replace what was already there”.

Stage 2 of Operator Equipment Management

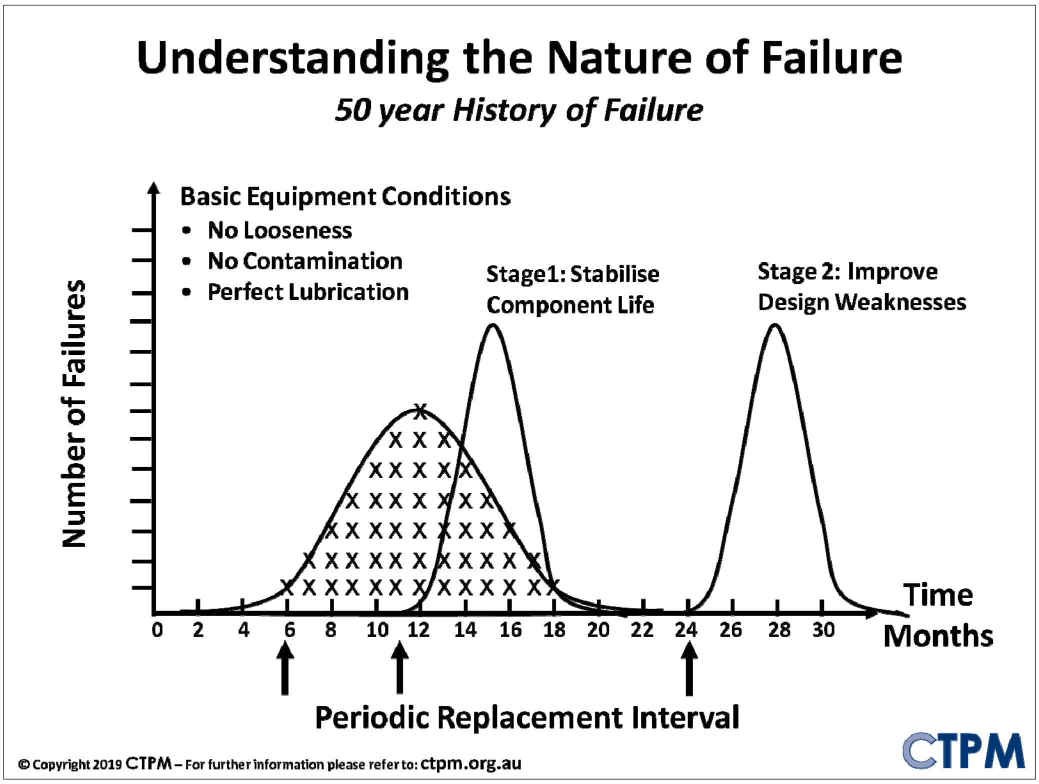
A key feature of TPM is to use this freed up time from 'achieving Basic Equipment Conditions' through Stage 1 of Operator Equipment Management activities to identify and rectify design weaknesses within the equipment. What we have found is that if this is successfully carried out then the failure curve moves further to the right with the average life now something like 24-26 months.

We can now carry out our periodic replacement at say 24 months (more than double the previous target) and not have any breakdowns.

This then leads to the question: 'Who are the best people to identify the design weaknesses in equipment?' Often it is our Operators who are with the equipment all the time, supported by our maintenance people.

Hence, Stage 2 of Operator Equipment Management is about having the maintenance personnel train the Operators in the 'functioning of their equipment' so that they can learn to identify problems at the earliest possible time along with any design weaknesses. It is through Operator designed inspection checklists that equipment problems or defects are identified at the earliest possible time so that maintenance can address them before they become expensive and time consuming problems.

Figure 3 – Stage 2: Improve Design Weaknesses



This issue of achieving 'Basic Equipment Conditions' also explains why a lot of Periodic and Preventive Maintenance strategies applied by maintenance departments often don't produce the desired results.

In the book “TPM in Process Industries” edited by Tokutaro Sukuzi and published in 1994 by Productivity Press, it identifies and explains this issue:

Limitations of Periodic / Preventive Maintenance
Implementing a periodic / preventive maintenance system before establishing basic conditions - when equipment is still dirty, nuts and bolts are loose or missing, and lubrication devices are not working properly - frequently leads to failures before the next major service is due.
To prevent these would require making the service interval unreasonably short, and the whole point of the preventive maintenance program would be lost.

Limitations of Predictive Maintenance
Rushing into predictive maintenance is equally risky. Many companies purchase diagnostic equipment and software that monitors conditions, while neglecting basic care activities.
It is impossible, however, to predict optimal service intervals in an environment where accelerated deterioration and operating errors are unchecked.

This also may explain why many RCM (Reliability Centred Maintenance) initiatives often don’t sustain or produce the desired results because Basic Equipment Conditions have not first been established.

We find that once Basic Equipment Conditions are established, RCM, if still required as it can be a very resource intensive activity, can be applied with much greater confidence of success.

Overview of Operator Equipment Management

There are 4 Stages and 7 Steps of Operator Equipment Management.

It is a 7 Step Operator and Maintainer development process typically spanning 3 years involving 9 cycles of formal structured Area Based Team improvement activity where each cycle spans up to 12-14 weeks.

Stage	Objective	Step	Description
1	**Cleaning for Inspection Activities** Learn how to recognise, rectify and prevent equipment defects so as to achieve and maintain Basic Equipment Conditions and thus reduce variation in Equipment Component Life (to allow Maint to enhance their PMs / PdMs) while improving Safety and Quality. ***Note***: PM = Preventive Maintenance PdM = Predictive Maintenance	1	**Identify & Rectify Equipment Defects**
		2	**Address Sources of Contamination and Difficult to Access Areas**
		3	**Establish Perfect Lubrication and Clean for Inspection Standards & Procedures**
2	**Training for Inspection Activities** Learn how equipment functions so as to diagnose equipment, quality and safety problems at the earliest possible time, be able to identify and contribute to improving Design Weaknesses and contribute to achieving a workplace that has Zero Breakdowns while improving Safety and Quality.	4	**Understand Equipment Functioning (by each inspection category or module)**
		5	**Finalise Inspection Standards & Procedures for Equipment Care**
3	**Consolidate Quality Assurance Activities** Develop a deeper understanding of the relationships between Quality and Equipment Conditions so as to create a workplace that has Zero Quality Problems while improving Safety.	6	**Understand Quality and Equipment Relationships**
4	**Consolidate On-going Continuous Improvement Activities** Manage own Workplace as a successful Mini Business (eg mature synergistic Area Based Team) so as to always achieve the Production Plan with Zero Breakdowns, Zero Quality Problems and Zero Accidents or Incidents.	7	**Manage own Workplace**

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