Total Productive Maintenance/Manufacturing (TPM)

The Background to TPM

Unlike RCM that emerged from the American aircraft industry, TPM had its genesis in the Japanese car industry in the 1970s. It evolved at Nippon Denso, a major supplier of the Toyota Car Company, as a necessary element of the newly developed Toyota Production System which was originally thought to only incorporate Total Quality Control (TQC), Just in Time (JIT), and Total Employee Involvement (TEI). It was not until 1988, with the publication in English of the first of two authoritative texts on the subject by Seiichi Nakajima, that the western world recognised and started to understand the importance of TPM.

Suddenly it became obvious that TPM was a critical missing link in successfully achieving not only world class equipment performance to support TQC (variation reduction) and JIT (lead time reduction), but was a powerful new means to improving overall company performance. Hence it has only been since the early 90s that TPM has started to rapidly spread throughout the western world, significantly improving the performance of manufacturing, processing, and mining companies. TPM is now having a major impact on bottom-line results by revitalising and enhancing the quality management approach to substantially improve capacity while significantly reducing not only maintenance costs but overall operational costs. Its successful implementation has also resulted in the creation of much safer and more environmentally sound workplaces.

The Evolution of TPM

Traditionally high buffer stocks were allowed to develop between major pieces of the plant & equipment to ensure that if there was a problem with one piece of the plant or equipment then it would not affect production from the rest of the plant. Hence the role of maintenance was to cost effectively ensure major pieces of plant & equipment were available for an agreed period of scheduled time, for example 90%.

Because of the accepted practice of retaining high buffer stocks, most items of equipment could be considered independent. If the equipment in a process was maintained such that it achieved 90% availability, the availability of the process was 90%. If the equipment started to cause quality problems, these would probably be noticed in final quality inspection and the cause traced back to the offending piece of equipment and corrected by maintenance.

![Diagram: Equipment is 'independent' due to high buffer stocks. Equipment Availability = 90% Process Availability = 90%]
At Nippon Denso in 1970 with the introduction of the Toyota Production System, the buffer stocks were substantially reduced in their quest for shorter lead-times and improved quality. Statistical Process Control (SPC) supported by "Quality at Source" was introduced to ensure quality right first time so to provide maximum customer value through the highest quality at the lowest cost supported by quick responsiveness and superior customer service. Hence in this quest for maximum customer value, buffer stocks were reduced to both reduce lead-times and force the identification of cost consuming problems. This resulted in individual equipment problems affecting the whole process.

If one piece of equipment stopped then shortly afterwards the whole process stopped. This made the equipment interdependent. Under these circumstances, the availability of the process became the product of the individual availabilities of each piece of equipment. Thus, a process involving four pieces of equipment maintained at 90% no longer had an overall process availability of 90%, but an availability of 90% X 90% X 90% X 90%, or 66%!

Furthermore, as the quality approach changed to "Prevention at Source" by controlling process variables, equipment performance problems were identified much earlier. Conformance and reliability became much more important.

As buffer stocks reduced substantial pressure was placed on the maintenance department to improve process performance. From a maintenance perspective, the maintenance department's performance had not deteriorated, yet demand for the substantial improvement in equipment availability was overwhelming.

This caused friction between the production and maintenance departments. Production departments demanded former levels of process availability and quicker response times from maintenance, which were often unable to comply due to traditional organisation structures which keep maintenance as a separate function. After much conflict between maintenance and production, engineering were called in to find a solution. They soon realised that mathematically for the four pieces of equipment to achieve their original goal of 90% availability, their individual availabilities needed to increase from 90% to 97.5%.

The traditional view of maintenance was to balance maintenance cost with an acceptable level of availability and reliability often influenced by the level of buffer stocks which hid the immediate impact of equipment problems. In traditional companies, maintenance is seen as an expense that can easily be reduced in relation to the overall business, particularly in the short term. Conversely, maintenance managers have always argued that to increase the level of availability and reliability of the equipment, more expenditure needs to be committed to the maintenance budget. With the on set of substantial availability problems caused by the new way of running the plant, management soon realised that just giving more resources to the maintenance department was not going to produce a cost effective solution.
This conflict between maintenance cost and availability is similar to the old quality mind-set before the advent of Total Quality Control (TQC): that higher quality required more resources, and hence cost, for final inspection and rework. TQC emphasised "prevention at source" of the problem rather than by inspection at the end of the process. Instead of enlarging the inspection department, all employees were trained and motivated to be responsible for identifying problems at the earliest possible point in the process so as to minimise rectification costs. This did not mean disbanding the quality control department but having it now concentrate on more specialist quality activities such as variation reduction through process improvement. This new approach to quality demonstrated that getting quality right first time does not cost money but actually reduces the total cost of operating the business.

This new Quality approach of "prevention at source" was translated to the maintenance environment through the concept of TPM resulting in not only superior availability, reliability and maintainability of equipment but also significant improvements in capacity with a substantial reduction in both maintenance costs and total operational costs. TPM is based on "prevention at source" and is focused on identifying and eliminating the source of equipment deterioration rather than the more traditional approach of either letting equipment fail before repairing it, or applying preventive / predictive strategies to identify and repair equipment after the deterioration has taken hold and caused the need for expensive repairs.

TPM has developed over the years since its first introduction in 1970. Originally there were 5 Activities of TPM that is now referred to as 1st Generation TPM (Total Productive Maintenance). It focused on improving equipment performance or effectiveness only. Late in the 80's it was realised that even if the shopfloor were committed fully to TPM and the elimination or minimisation of the "six big losses" there were still opportunities being lost because of poor production scheduling practices resulting in line imbalances or schedule interruptions. Hence the development of 2nd Generation TPM (Total Process Management) which focused on the whole production process.

Finally, in more recent times it has been recognised that the whole company must be involved if the full potential of the capacity gains and cost reductions are to be realised. Hence 3rd Generation TPM (Total Productive Manufacturing / Mining) has evolved which now encompasses the 8 Pillars of TPM with the focus on the 16 Major Losses incorporating the 4Ms – Man, Machine, Methods and Materials. Some have expanded the Japanese 8 Pillars to 10 Pillars of 3rd Generation TPM based on extensive research of the past years:

1. Safety & Environmental Management
2. Focused Equipment & Process Improvement
3. Work Area Management
4. Operator Equipment Management
5. Maintenance Excellence for TPM
6. Education & Training
8. Administration & Support Systems Improvement
9. New Equipment Management

An important outcome of this new approach to equipment management which is now supported by many success stories throughout the world in a variety of operational industries, has been that senior management have realised that TPM is both strategically important for a world competitive business, and that TPM cannot be implemented by the maintenance department alone. TPM is a company wide improvement initiative involving all employees.
Although each enterprise may approach TPM in its own unique way, most approaches recognise the importance of measuring and improving overall equipment effectiveness along with the need to reduce both operational and maintenance costs in an environment that promotes continuous improvement.

**Understanding the Importance of Overall Equipment Effectiveness**

Many companies who recognise the important role equipment and process performance have on bottom-line results are turning to the measure which drives TPM called Overall Equipment Effectiveness (OEE) which incorporates not only Availability but also Performance Rate and Quality Rate. In other words, OEE addresses all losses caused by the equipment: not being available when needed due to breakdowns or set-up and adjustment losses; not running at the optimum rate due to reduced speed or idling and minor stoppage losses; and not producing first pass A1 quality output due to defects and rework or start-up losses. A key objective of TPM is to cost effectively maximise Overall Equipment Effectiveness through the elimination or minimisation of all losses. A simple model outlining these losses is shown in Figure 5.

![Overall Equipment Effectiveness Model](image)

When many organisations first measure Overall Equipment Effectiveness it is not uncommon to find they are only achieving around 40% - 60% (batch) or 50% - 75% (continuous process) whereas the international best practice figure is recognised to be +85% (batch) and +95% (continuous process) for Overall Equipment Effectiveness. In effect, this means there exists in most companies the opportunity to increase capacity / productivity by 25% - 100%.

**Understanding the Cost Impact of Failure**

TPM significantly reduces operational and maintenance costs by focusing on the Root Cause of Failure through the creation of a sense of ownership by the plant & equipment operators, maintainers and support staff to encourage "prevention at source". To help understand the thinking behind TPM we need to investigate what causes failure.
Most of us have heard of the concept of the ‘Root Cause of Failure’ and the tool most commonly used to assist in the search for the root cause – the 5-Whys. The 5-Whys is a simple technique of asking why 5 times recognising that statistically it has been shown that after 5 whys you are most likely to be at the root cause. In the workplace we rarely get to the root cause because we are too busy reacting to the symptoms of our problems. However, unless we get to the root cause we will always have problems reappearing.

What is the root cause of failure? Often, before failure we can have poor performance, prior to poor performance we may get moans and groans coming from our equipment, and before the moans and groans we will have accelerated deterioration (see Figure 6).

What do we mean by ‘Accelerated Deterioration’? This is where a piece of equipment or part of a piece of equipment wears out quicker than is expected. That is, its life is shortened because its natural deterioration is accelerated.

Let us look at the failure mechanisms of the parts that make up our plant & equipment. Most pieces of equipment in our plants can be broken up into 3 broad categories:

<table>
<thead>
<tr>
<th>Part</th>
<th>Structural Items</th>
<th>Wear Items</th>
<th>Working Items</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Frame Housing</td>
<td>Wear Plates</td>
<td>Transmission</td>
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<td></td>
<td>Casing</td>
<td>Pump Impellers</td>
<td>Hyd / Pneumatic</td>
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<td></td>
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<td>Table Rolls</td>
<td>Electrical</td>
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<tr>
<td>Failure Mechanisms</td>
<td>Corrosion</td>
<td>Dependent on throughput</td>
<td>Governed by the Laws of Physics</td>
</tr>
<tr>
<td></td>
<td>Erosion</td>
<td>Note: the higher the OEE - the shorter the life</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fatigue Damage</td>
<td></td>
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</tbody>
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Fig 6. The Root Cause of Failure and the Impact of Ownership

Lack of Care and Proper Operation

Accelerated Deterioration

Poor Performance

Failure
From the previous image we can see the different failure mechanisms for the three different categories of items. It is worth noting how TPM will actually reduce the life of your wear items due to the increase in throughput as your OEE increases some 50% or more.

Our main interest however, is with the Working Items. These by far make up the majority of items that need maintenance attention and contribute most to our overall maintenance spend. So let us understand the impact of the laws of physics on our working parts.

If, for example, I were to rub my hands together for the rest of the day what is going to happen? I will get very sore hands as they get several layers of skin rubbed off. To stop this from happening I would need to apply some form of lubrication to act as an interface between my hands.

Hence, proper lubrication provides an interface between moving surfaces, and a key role of lubrication is to be a sacrificial wear element. That is, the lubrication wears out as the moving surfaces interface with it. This is why it is recommended that we replace the oil in our cars at say every 10,000 km. This is not because the oil is dirty, even though it may look dirty it is continuously filtered and clean. The reason for replacement is that the oil has worn out.

Accelerated deterioration occurs when:

- lubrication is not present;
- lubrication is incorrect for the application;
- lubrication between surfaces is forced out due to overload;
- lubrication wears out; or
- lubrication becomes contaminated.

Who has ever seen an operator “blow down” his equipment with compressed air, or hose it down with water? What is this process doing to the equipment? More than likely the operator is forcing contamination into the equipment without even realising it or caring about it. This contamination is a primary source of accelerated deterioration.

Many studies have been conducted to determine the impact of accelerated deterioration. Let us consider the situation of the working parts of your equipment. If you were to plot say the 30-year history of the actual life of a part that normally fails after 12-months would you get a straight line? In most studies the result is a normal distribution where the part fails for the majority of the time at 12-months however on other occasions it may fail early or later often with a range of some 6-months either side of the 12-month majority. If we were to introduce a periodic or preventive maintenance plan for this part what would be our strategy. Obviously if we were to replace the part after 12-months we would still have a significant number of failures. If we were very conservative we could replace the part every 6-months. This would significantly reduce the failures however we would have very high maintenance cost. So what is the answer?

This is where TPM becomes so important. TPM is based on the precepts of:

- understand what causes the variation;
- reduce or minimise the variation; then
- look to improvement.

Under this approach the first task is to identify what is causing the variation. Studies conducted by the Japanese Institute of Plant Maintenance and companies like DuPont and Tennessee Eastman Chemical Company have shown that 3 major physical conditions make up some 80% of the variation.
These physical conditions are:

- Looseness
- Contamination
- Lubrication

The elimination of these three conditions is known as “establishing Basic Equipment Conditions”. Once “basic equipment conditions” have been established we find our normal distribution curve squash up some 80% and moves to the right thus significantly increasing the life of our parts.

In his book, TPM in Process Industries, Suzuki raises the important issue when he states:

> “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.

Rushing into predictive maintenance is equally risky. Many companies purchase diagnostic equipment and software that monitors conditions, while neglecting basic maintenance activities.

It is impossible, however, to predict optimal service intervals in an environment where accelerated deterioration and operating errors are unchecked.”