Total productive maintenance (TPM)

A brief TPM overview, including OEE and key terminology

Summary
A brief overview of Total Productive Maintenance (TPM) is presented, which includes the concept of Overall Equipment Effectiveness (OEE). The commonly used terminology associated with the subject of TPM, such as the Six Losses, the Five S's, the Five Why's, and the Five Pillars, is also defined.

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1. Definition

Total Productive Maintenance (TPM) is a plant improvement methodology that enables continuous and rapid improvement of the manufacturing process through use of employee involvement, employee empowerment, and closed-loop results measurement. TPM has an operator-performed focus to involve all qualified employees in all maintenance activities [1].

The TPM philosophy is wholly built on the concept of ownership and a complete integration of production and maintenance functions. Some argue that TPM is manufacturing-led rather than maintenanceled, and therefore should be more correctly defined as Total Productive Manufacturing. This view is arguably supported by the modern definition of TPM, as given by the Japan Institute of Plant Maintenance, as follows:

- Aims at building up a corporate culture that thoroughly pursues production system efficiency improvement (Overall Equipment Efficiency)
- Constructs a system to prevent every kind of loss, for example, to achieve "zero accidents, zero defects and zero failures", based on Gemba (actual site) and Genbutsu (actual thing) over the entire life cycle of a production system
- Covers all departments including production, development, marketing and administration
- Requires all and full involvement from top management to frontline employees
- Achieves zero losses by overlapping small-group activities

2. Origins of TPM

The origins of TPM can be traced back to the work of an Englishman, Dr. W. Edwards Deeming, in Japan shortly after the Second World War. His application of statistical analysis techniques in manufacturing evolved into the concept of Total Quality Management (TQM) [2].

It was the consideration of maintenance activities within this context that resulted in the development of TPM. The man most widely credited with the formal definition of TPM is Seiichi Nakajima of the Japan Institute of Plant Maintenance (JIPM). Although TPM has evolved somewhat over the intervening years, his original publications, which date from the late 1980's, remain the cornerstone of the TPM philosophy. Moreover, much of the terminology that he employed remains in use today. The Japan Institute of Plant Management continues to be an enthusiastic advocate of the TPM approach, awarding annual prizes to deserving companies based largely on successful application of the TPM philosophy.

3. Classic versus modern TPM

TPM has undergone some changes since its inception. These are driven, in part, by competitive pressures brought about through globalization, which forces organizations to become more customer focused rather than concentrating on the internal organization. Another factor has undoubtedly been the influence of various commercial ventures that seek to establish themselves as competent purveyors of relevant expertise and appropriate resources.

Nakajima's original definition of TPM [3] was based on five pillars:

- Increase overall equipment effectiveness by attacking the six losses.
- Improve existing planned maintenance systems.
- Involve operators in the care of assets (Autonomous Maintenance).
- Develop skills to improve operator and engineer competence and motivation.
- Early equipment management.

These five pillars continue to provide the foundation for effective TPM. However, many organizations supplement this concept with additional pillars:

- Administration system improvement (TPM in the office) to improve plant utilization through better production planning.
- Safety and environment management

The following discussion simply concentrates on the five pillars of classic TPM.

4. Six Major Losses and Overall Equipment Effectiveness (OEE)

The prime driver of TPM is the concept of Overall Equipment Effectiveness (OEE). The philosophy hinges on making equipment effectiveness the concern of everyone in the organization, irrespective of his or her prime function, experience, or expertise. OEE requires strict attention to the measurement and quantification of losses.

TPM seeks to eliminate any waste of effort. The six classic losses arise from:

1 Breakdown
2 Setups and changeovers
3 Reduced operation speed
4 Minor stops and idling
5 Quality defects, scrap, and rework
6 Start-up losses

Losses one and two above relate to plant availability. Losses three and four are the effects of plant performance, and losses five and six concern themselves with quality issues.

OEE = Availability x Performance x Quality
Availability = Hours available to run
Hours required to run

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Performance = Actual Production
Achieved
Theoretical Capacity

Quality = Right First Time Output
Total Output

The availability component of the classic OEE calculation considers only the *loading time* (sometimes called *scheduled time*). This is found by subtracting excluded time (i.e. time during which the machine is planned to be unavailable) from the *total time* period of the study. OEE measurement therefore only concerns itself with the performance of a machine during the period when it is scheduled to run. It does not view machine effectiveness with respect to total calendar time. Therefore, some organizations also utilize calculations of Total Effective Equipment Performance (TEEP), this being the percent of total (calendar) time the equipment runs at ideal speed making good product [4].

5. Worked example

The following study is based on real data from a paper mill. This case illustrates the need for consistency in OEE / TEEP calculations.

Application details
Historical records relating to a particular paper machine over a one-year period were

studied. The machine operates seven days per week, twenty-four hours per day.

Therefore, Total Time is 365 days x 24 hours (i.e. 8760 hours).

During the year under study there was a fourteen day shutdown for a machine rebuild, and a four day shutdown over Christmas / New Year. A further 80 hours of stoppages were scheduled for planned maintenance activities. Therefore, total excluded time was 512 hours.

Thus, loading time (time available to run, sometimes called scheduled time) was 8760-512 = 8248 hours.

During the period of study the following time losses were recorded.

Cause	**Hours lost**	**Category**
Paper breaks	167	SO
Fabric changes	300	SO
Cleaning	200	SO
Unplanned maintenance	30	DT
No pulp / steam	40	DI
Total losses	**737**	

Table 1. Time losses

Operating time is loading time minus losses: 8248 - 737 = 7511hours.

Availability = operating time / loading time
= 7511.44 / 8248 = 91.06%

Nominal design performance rates for the machine are quoted as 1500 meters per minute, and 35 tons per hour. However, this machine produces three grades of paper, which affects operating speed. In consequence, the highest accredited operating speed is 1530 meters per minute. This higher
figure is taken as the ideal operating speed for the purpose of OEE calculations. Thus, the performance rate never exceeds 100%. [5]

Paper grade	Hours run	Run speed M/min	% ideal speed	Output (Tons)	Output rate (Tons / hr)	% design output
A	3826	1530	100.0%	126,250	33.0	94.3%
B	2211	1460	95.4%	76,500	34.6	98.9%
C	1474	1450	94.8%	51,500	34.9	99.7%
Totals	7511	-		254,250		

Table 2. Analysis of operating time.

Of the paper produced, approximately 14,250 tons were outside specification, leaving 240,000 tons available for customers. Therefore, the quality rate was 240,000 divided by 254,250, or 94.4%.

Output of Grade A paper accounted for 49.7% of the total at an output rate of 33 tons per hour. This is 94.3% of the ideal output rate for the machine (35 tons per hour).

Output of Grade B paper accounted for 30.1% of the total at an output rate of 34.6 tons per hour. This is 98.9% of the ideal output rate for the machine.

Output of Grade C paper accounted for 20.2% of the total at an output rate of 34.9 tons per hour. This is 99.7% of the ideal output rate for the machine.

Performance efficiency is calculated as follows:
(49.7% x 94.3%) + (30.1% x 98.9%) + (20.2% x 99.7%) = 96.7%

OEE = Availability x Quality x Performance
= 91.06% x 94.4% x 96.7% = 83.1%

5.1. World class OEE

Experience shows that an OEE of around 95% is achievable for plants engaged in continuous processing [5].

6. Improving Existing Planned Maintenance Systems

An effective asset care regime usually comprises elements of routine servicing (cleaning, lubrication, etc.), timely preventive maintenance, and application of modern monitoring and predictive technologies. Some argue that the best machine condition monitor is the operator, given the appropriate sense of ownership and involvement [6].

The TPM team should determine the regime applicable to individual plant items.

The resulting asset care regime is likely to vary from industry to industry, and plant to plant. Scope may exist for application of techniques (i.e. Reliability Centered Maintenance or Risk Based Maintenance) to play a part in this decision making process [7].

Another item of terminology often associated with TPM is the Five Why's. This alludes to the process of Root Cause Failure Analysis (RCFA), and suggests the question "why" should be asked at least five times to determine the real cause and solution of a problem.

7. Autonomous Maintenance

The resulting asset care regime is likely to vary from industry to industry, and plant to plant. Scope may exist for application of Total operator involvement in the maintenance process is key. Often referred to as autonomous maintenance, the approach is defined as "operators in independent groups undertaking routine and preventive maintenance" [8].

Autonomous maintenance requires operators to be motivated and empowered to undertake maintenance of their own machines by performing regular and frequent inspections, routine lubrication, and simple repairs and precision checks.

This usually requires a training and education program so operators can recognize abnormal operating conditions. Training programs also provide them with the skills and knowledge to preserve normal conditions so far as is possible. Operators must be taught the limitations of their maintenance skills to recognize when it is necessary to involve maintenance staff. TPM hinges on complete integration between production and maintenance functions, for which open and efficient lines of communication are a prerequisite.

The seven-step approach to TPM shown in table 3 helps develop the culture of ownership and empowerment necessary for a successful transition to autonomous maintenance [9].

The first step is sometimes summarized as the application of the Five S's. This term derives from the original Japanese publications on TPM as follows:

- Seiri (Organization)
- Seiton (Orderliness)
- Seiso (the act of cleaning)
- Seiketsu (the state of cleanliness)
- Shitsuke (discipline – the practice of cleanliness)

Given the current industry trend towards use of acronyms, the Japanese words that define the five S's have been translated into alternative English language expressions:

- Sort, Set, Shrine, Standardize, Sustain [10]

CAN DO (Cleanliness, Arrangement, Neatness, Discipline, Order) [6]

Step	Activity	Ownership and empowerment	
1	Initial cleaning.	Ability to determine machine abnormalities.	Development of the skill to spot abnormalities and opportunities to make improvements
2	Eliminate sources of contamination and inaccessible areas.	Ability to design and make improvements	
3	Creation of a checklist for cleaning and lubrication standards.		Operators determine by themselves what they have to do.
4	General inspection	Understanding operation principles of machine and its systems	More skilled operators and maintenance technicians teach the less experiences
5	Autonomous Inspection	Understanding the relationship between equipment conditions.	Data organization to describe optimal conditions and how to maintain them.
6	Organization and housekeeping		
7	Full implementation and continuity		

Table 3. Seven Steps of Autonomous Maintenance [9].

8. Skill development

Close integration of operations and maintenance functions inherently infers a significant training need, as operations personnel need to achieve a better understanding of relevant aspects of maintenance, and vice versa. The continuous improvement aspect of a TPM program further compounds the training issue. An effective training program is the key to program success and a detailed definition of training requirements for a particular organization will need to be based upon a detailed study. Training can be costly, but it is usually considerably less expensive or disruptive than the consequences of ignorance.

9. Early Equipment Management

The early equipment management aspect of a TPM program impacts directly upon organizational areas beyond Operations and Maintenance to include areas such as Design Engineering, Procurement, and outside suppliers.

The experience gained in operating and maintaining equipment is employed to influence the purchase (and perhaps even the design) of plant and equipment replacement.

Effective implementation of this program pillar eliminates at source many problems that result in poor maintainability, poor reliability, or poor operability, thereby having a significant impact on OEE.

10. Implementation

For many companies implementing full TPM philosophy is a long-term policy that usually takes several years to achieve. TPM frequently represents a fundamental cultural shift that requires restructuring the whole organization to align everyone with common goals.

The lines of demarcation that frequently exist between Maintenance and Operations are the most obvious barriers to TPM implementation. Recent years have seen many companies move towards "multi-skilling" in the workforce as a means of overcoming this Total Productive Maintenance (TPM) problem. TPM not only cuts across the boundaries of Operations and Maintenance, but also crosses other functional barriers such as those between mechanical, electrical, hydraulic, and lubrication trades.

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