ANALYTICAL HIERARCHY PROCESS FOR IDENTIFICATION OF ATTRIBUTES FOR TPM IMPLEMENTATION

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Abstract

Total Productivity Maintenance is one of the effective strategy designed primarily to maximize the effectiveness of equipment throughout its entire life by the participation and motivation of the entire workforce. The paper presents the Analytic Hierarchy Process (AHP) methodology for the implementation of Total Productivity Maintenance (TPM) in an organization. A TPM implementation methodology has been developed for identification of weight and priorities of TPM attributes by using pare-wise comparison (PCM) method of AHP. The result of this paper is evident that TPM can bring in commendable reforms and improvement in terms of equipment effectiveness, better products quality, meeting promised delivery and conductive work place and may be very useful for strategic and operational decisions.

Key words : *AHP, TPM, PCM*

Efficiency and effectiveness of equipment plays a dominant role in service sector to determine the organizational performance and smooth functioning of all the equipment with the servant as. For more than two decades, the development of the service sector had registered an excellent performance and attracted a large number of capital investments. These excellent performances have enabled the service providers to enjoy an important competitive advantage in the global market, especially in terms of cost and quality. Many organizations began to realize that the continuity of this excellent performance must be supported by a strong backbone of efficient and effective equipment. Traditional maintenance technicians are regarded as passive and non-productive to the current requirement. Hence, implementing Total Productive Maintenance (TPM) in the service industry has emerged as an important operational strategy to overcome the losses due to equipment inefficiency. TPM is an innovative approach, which holds the potential for enhancing the efficiency and effectiveness of equipment by taking advantages of abilities and skills of all individuals in the organization. TPM and its implications received prestigious worldwide recognition in achieving the ultimate *Zero Defects* and *Zero Breakdown* targets. In modern day manufacturing and service industries, improved quality of products and services increasingly depend upon the features and conditions of the organization's equipment and facility. In order to survive every industry has to strive for improving productivity in all spheres of activities. Hence it is logical to utilize the resources like machinery, men, and material as optimally as possible (Krishnaiah, 1995). As automation and labor saving equipment take production task away from humans, the condition of production and once equipment increasingly affects output, quality, cost, delivery, health, and safety and employee morale. TPM is beginning to make the transition from a repair department to that of high level business function. TPM transcends this conventional approach in transforming the responsibility of a department into a companywide culture of autonomous maintenance by everyone, aimed at not just preventing the breakdowns, but also at making the machinery live up to its full potential (Majumdar 1998), however this would not be possible without TPM. In 1971, the Japanese Institute of Plant Maintenance (JIPM) defined the following goals covering the entire life of the equipment in every division including planning, manufacturing, and maintenance.

Maximize equipment effectiveness.

Develop a system of productive maintenance for the life of the equipment. Involve all departments that plan, design, use, or maintain equipment in implementing TPM. .

Actively involve all employees – from top management to shop floor workers.

Promote TPM through motivation management: autonomous small-group improvement activities (SGIA).

It would be very difficult to achieve the most cost effective objective if the business is continued to be operated in a very functional way, regarding the condition of machinery and equipment as the sole responsibility of maintenance department. Traditionally there are barriers between production and maintenance personnel related to machine operations and its maintenance. One of the bad results has been a traditional lack of further development training for skilled maintenance craftsmen once their apprenticeship has been completed (Spratling 1987). This often results in undue reliance on maintenance contracts with suppliers of original equipment and an erosion of in-house skills. Loss of in-house experience in maintenance, and of ownership of maintenance problems, has a devastating effect over time. It adds up to subcontracting a core part of the business.

Some multinational organization quoted that poor maintenance practices is a major reason for relatively poor manufacturing performance (HMSO 1970). It would be unfair to present TPM without referring to some of the ideas and practices which have developed in the past, and which form an essential part of an integrated maintenance strategy. Many excellent concepts such as preventive maintenance and tero-technology have originated. The tero-technology means the coordination of several disciplines means a combination of management, financial, engineering and other practices applied to physical assets in pursuit of economic life cycle costs' (HMSO 1975). It is a multidisciplinary approach to optimizing the life cycle costs of plant and buildings. Life cycle costs include the specification and design for reliability and maintainability, installation, commissioning, maintenance, and replacement. New ideas like condition-based maintenance (HMSO 1979) were swept up and included in the tero-technology philosophy. Although a broad-based concept, it did not become a 'total' company philosophy. The earlier maintenance techniques such as reactive maintenance, preventive maintenance, predictive maintenance, proactive maintenance, and reliability based maintenance do not sound most promising in improving the effectiveness of machine and manufacturing system.

Analytical Hierarchy Processes : AHP provides a proven, effective means to deal with complex decision making and can assist in identifying and weighing criteria, analyzing the data collected and expediting the decision-making process (Kalpande et al, 2013). It is used to calculate weight ages and confirm the consistency. An AHP can have as many levels as needed to fully characterize a particular decision situation. A number of functional characteristics make AHP a useful methodology. These include the ability to handle decision situations involving subjective judgments, multiple decision makers and the ability to provide measures of consistency of preference. Designed to reflect the way people think, AHP continues to be the most highly regarded and widely used decision-making method. The Analytic Hierarchy Process (AHP) is a theory of measurement through pair wise comparisons and relies on the judgments of experts to derive priority scales (Saaty, 2008). It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgments that represents how much more; one element dominates another with respect to a given attribute. The research (Kodali and Chandra, 2001, Kalpande et al, 2013) has used the AHP for identification of weithtages parameters used for TPM and TQM.

Identification of TPM Attributes : TPM is a unique Japanese system which has been evolved from the PM concept (preventive or productive maintenance) which was originated and developed in USA (Kodali and Chandra, 2001). The goal of interval based preventive maintenance (PM) is to provide control of planned maintenance activities rather than allow machine breakdowns (Pardue *et al*. 1994). The corrective maintenance (CM) means to improvement of equipment so that equipment failure can be eliminated. The maintenance prevention (MP) is an activity to design the equipment to be maintenance free. TPM is not a mere combination of MP-CM-PM but it emphasizes promoting maintenance through 'autonomous maintenance' by encouraging small group activities (Nakajima 1982). The concept of TPM lays much emphasis in maximizing the equipment effectiveness by eliminating all forms of inefficiencies, hindering capital, material and labor productivity. The mechanics of achieving such spectacular rise in equipment effectiveness is through the involvement of all employees in the organization belonging to various departments like production, maintenance, technical services and stores. This is possible when all employees channel their energies in a specific direction without adopting a compartmentalized segmented approach. According to Kodali and Chandra (2001) the role of maintenance is gradually upgraded by training, developing new machines and processes, preparing for fast response to breakdowns and higher level maintenance. TPM provides a platform for horizontal integration of employees to tackle any equipment related problem in a multidisciplinary fashion (Krishnaiah 1995). When employees accept this point of view, they will see the advantage of building quality into equipment and building an environment that prevents equipment and tools from generating production or quality problems. The starting point for such changes in attitude must be within the top team.

The main attributes derived from TPM are:

Productivity : Productivity implies development of an attitude of mind and a constant urge to find better, cheaper, easier and safer means of doing a job, manufacturing a product and providing a service. The output is obtained by the combined input of a number of factors such as men, material, machine and energy etc. Productivity in relation to machines, materials, workers is measured in terms of output per machine hour, per unit measure of a particular material and per man-hour respectively.

Quality : Quality is the measure of an organization to provide better acceptable products/services to the customer. TPM system offers an organization the means to produce more usable products/services that meets customer approval.

Cost : A cost reduction programmed means maximization of profits by reducing costs through economics and savings in the cost of manufacture, administration, selling, distribution and use. Idling of men and improper supervision is visible waste. Waste of time is a hidden but most precious waste (Chandra, 1991).

Delivery Performance : Delivery performance is the ability of the supplier to provide the required type and the number of items according to schedule (Korgaonkar 1992).

Safety : Safety and hygiene constitutes the foundation stone of the preventative approach in achieving the goals of industrial health, as it deals with identification, assessment and control of environmental factors harmful to the health of employees (Mehta 1998).

Morale : Morale is used to describe the overall group satisfaction (Newstorm and Devis 1998). Small group activities in the factory should be based on participative management. Small group goals should be the same as company goals to improve productivity and working conditions (Nakajima 1989). In order to produce extraordinary results organizations have to depend a great deal on the group culture, motivation programmes, suggestion schemes and team spirit.

Work Environment : Quality of work life programmers yields benefits such as improved inter/intra communication better employer–employee relationships, better career development, reduced stress, high confidence and self management (Gondhalekar 1996).

Competitive Advantage : A competitive advantage is defined not by cost alone but by the total time (gestation period) required to produce a product or service, dependable deliveries, rapid design changes, after sales services, rapid volume changes, consistent quality, loyalty and sustainable commitments towards customers promises. In any industry the firm with the fastest response to customer demands has the potential to achieve an overwhelming market advantage (Chandra and Kodali 1998, Everett and Ronald, 1998).

With the help of extensive literature review (Kodali and Chandra, 2001; Everett and Ronald, 1998, Korgaonkar 1992) and discussions held with experts the selection of attributes has been determined which is used in AHP model for the justification of TPM are given below and the schematic of the model is shown in figure 1 where Improve Productivity [IP], Improve Quality [IQ], Reduction in Cost [RC], Delivery Performance [DP], Safety and Hygiene [SH], Morale [Mo], Work Environment [WE] and Competitive Advantages [CA]

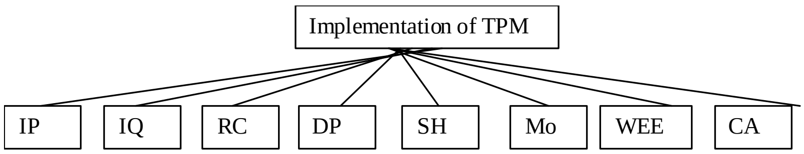

Figure 1
The schematic Diagram of AHP Model for TPM

Implementation of AHP Technique

After identification of various attributes of TPM, the decision for prioritizing attributes is carried out by AHP. Comparing these attributes and defining their importance over each other are done using the PCM. Giving importance ratios for each pair of alternatives, a matrix of pair-wise comparison ratios is obtained. For reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made among the selected CSF is checked by calculating the consistency ratios (CR).

However in practice it has unrealistic to expect the decision-makers provide pairwise comparison matrices which are exactly consistent especially in the cases with a large number of alternatives. The consistency of expert opinion can be monitored by using CR. Therefore, AHP is a reliable way to synthesize expert opinion for this analytical context. Saaty suggested that a CR less than 0.10 or 10% is considered adequate. If CR more than 0.1 or 10% the inconsistency of judgments within that matrix has occurred and the evaluation process should therefore be reviewed, reconsidered and improved (Crowe et al., 1998; Saaty, 2008). The CR is used as the main indicator of ranking consistency, is then calculated by dividing the consistency index (CI) µ value by the random consistency index (RCI) value. The RCI is obtained from a large number of simulation runs and varies depending upon the order of matrix (Kannan, 2008). Table 1shows the value of RCI for matrices of order 1-15 obtained by approximating random.

Table 1
Fundamental Scale of Absolute Numbers for RCI

Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.58	1.59
Source: Saaty, 2008															

Source: Saaty, 2008

The criteria might also have different importance compared to each other. Therefore a pair-wise comparison matrix is considered for the criteria. Elements of this matrix are pair-wise or mutual importance ratios between the criteria which are decided on the basis that how well every criterion serves and how important it is in reaching the final goal.

For creating the pair-wise comparison matrix in the PCM, Saaty has employed a system of numbers to indicate how much one criterion is more important than the other. These numerical scale values and their corresponding intensities are shown in Table 2 and called as Saaty's Fundamental Scale.

Table 2
Fundamental Scale of Absolute Numbers

Intensity	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate value	When compromise is needed
Reciprocals Of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	A logical assumption
Source: Saaty, 2008		

In order to compare homogeneous elements whose comparison falls within one unit, decimals are used. If the elements of the pair-wise comparison matrix are shown with *Cij*, which indicates the importance of i^{th} criterion over j^{th}, then *Cji* could be calculated as 1/ *Cij* (Boroushaki and Malczewski, 2008).

The AHP method employs different techniques to determine the final weights; one of the methods is geometric mean. According to Buckley (1985) the weights in pair-wise comparison matrix of attributes and sub-attributes are calculated by following formula.

$$r_i = \prod_{j=1}^{n} \left(a_{ij}\right)^{1/n}$$

Where, r_i represents the geometric mean of i^{th} criterion at which a_{ij} (*i, j*= 1…………..n) are the comparison ratios in the pair-wise comparison matrix and *n* is number of alternatives.The relative priority of each criterion or weightage is then calculated by normalizing this column by dividing each value by the total of the column (or the sum of the geometric mean values)

$$W_i = \frac{r_i}{\sum_j r_j}$$

Where, w_i represents the relative priority of i^{th} criterion.

Consistency ratio in the AHP: However in practice it is unrealistic to expect the decision-makers provide pair-wise comparison matrices which are exactly consistent especially in the cases with a large number of alternatives. Expressing the real feelings of the decision makers generally lead to matrices that are not quite consistent. However some matrices might violate consistency very slightly by only two or three elements while others may have values that cannot even be called close to consistency.

A measure of how far a matrix is from consistency is performed by CR. Han and Tsay (1998) explained that having the value of $ë_{max}$ required in calculating the CR. This is obtained by calculating matrix product of the pair-wise comparison matrix and the weight vectors and then adding all elements of the resulting vector. After that a CI (µ) is introduced as-

$$\mu = \frac{\lambda max - n}{n-1}$$

Where, $ë_{max}$ is the biggest eigenvalue at which *n* is the number of criteria.

RCI is the consistency index of a pair-wise comparison matrix which is generated randomly. Random index depends on the number of elements which are compared and as it is shown in Table 1. The final CR is calculated by comparing the CI (µ) with the RCI.

$$CR = \frac{\mu}{RCI}$$

The CR is designed such a way that shows a reasonable level of consistency in the pair-wise comparisons if CR< 0.10 and C.R. ? 0.10 indicate inconsistent judgments.

Result Analysis and Testing

In this study, identified attributes of TPM is compared with each other on the scale of attribute by various experts in the field of TPM. The experts were selected randomly without affecting their uniformity. The consistencies of the responses were determined by calculating a consistency ratio (CR) for each response. The final weight-ages or priorities of attributes were calculated by taking mean of the eight responses, which shown in Table 3. To test the accuracy of the responses, student's t-distribution were used, as the sample size is less than thirty. The Saaty's Fundamental scale of absolute numbers is used for pair-wise comparison matrix.

For the 99 % confidence level and sample size, n = 8 the distribution of t statistic from 7 (n-1) degree of freedom (Dof) is 2.998. As all t- calculated values of mean of attribute shown in Table 3 are less than 2.998 (Walpole et al, 2007, (Table of Critical Values of the t-Distribution)). i.e. t_{cal} = Around 0.5 < 2.998 = $t_á$ with $_á$ = 0.005 and *v* = 7 Dof, the process is under control.

Table 3 shows the final weightage of each attribute and its T-distribution value. The top level priorities are improving quality; improve productivity and reduction in cost respectively. The second and middle level priorities are competitive advantages and delivery performance and bottom level priorities are work environment, safety and hygiene and morale respectively.

Table 3
Summary of Weightage of TPM Attributes

	IP	IQ	RC	DP	SH	Mo	WE	CA	Avg of Crite.Priority	T-dist
IP	0.342	0.110	0.157	0.490	0.318	0.389	0.318	0.449	0.322	0.379
IQ	0.584	0.321	0.529	0.466	0.453	0.329	0.398	0.590	0.459	0.330
RC	0.098	0.074	0.096	0.203	0.218	0.087	0.075	0.087	0.117	0.455
DP	0.058	0.057	0.053	0.062	0.068	0.075	0.128	0.077	0.072	0.472
SH	0.045	0.057	0.039	0.026	0.024	0.085	0.053	0.045	0.047	0.482
Mo	0.057	0.037	0.029	0.026	0.032	0.022	0.031	0.012	0.031	0.488
WE	0.055	0.070	0.053	0.027	0.049	0.055	0.063	0.024	0.049	0.481
CA	0.068	0.084	0.099	0.052	0.078	0.087	0.085	0.067	0.077	0.470

Conclusion : It was observed that the developed AHP model works adequately and yields acceptable results in attributes selection for TPM implementation. AHP is used to justify TPM and confer the adequacy of TPM implementation. The identified weight and priorities can be very useful for strategic and operational decisions. From the result it is apparent that TPM can bring in remarkable improvements in term of equipment effectiveness, better products quality with promised delivery. In future, the identification of sub-attributes of these attributes may provide the in-depth study of TPM and will help for identification of key parameters which helps to improve the business performance.

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