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Analytical hierarchy process for justification of total productive maintenance

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Abstract. Total Productive Maintenance (TPM) has attracted the attention of industries all over the world. The perceptible impact of TPM lies in attaining the far-reaching productivity and quality standards. Attempts have been made to examine TPM for the feasibility in Indian industries. The present work describes a multiattribute decision model using analytical hierarchy process for the justification of TPM for Indian industries.

1. Introduction

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. The economic environment is becoming increasingly harsh. 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). On the other hand massive capital assets creation is taking place for meeting the ever increasing demand of various industrial goods. These capital assets in turn require substantial service support to achieve vitality and long life cycle. As automation and labour saving equipment take production task away from humans, the condition of production and office equipment increasingly affects output, quality, cost, delivery, health, safety and employee morale. The concept of TPM which aims at maximizing the equipment effectiveness originated from Japan. It made progressive strides in countries like USA, Europe and other South Asian countries after its successful implementation in Japan (Pardue *et al*. 1994). TPM is beginning to make the transition from a repair department to that of high

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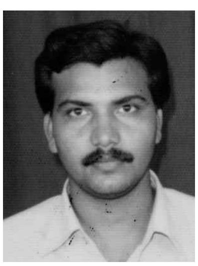

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level business function. TPM transcends this conventional approach in transforming the responsibility of a department into a company wide culture of autonomous maintenance by everyone, aimed at not just preventing the breakdowns, but also at making 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 TPM as a system of maintenance covering the entire life of the equipment in every division including planning, manufacturing, and maintenance. TPM was defined by the Japan Institute for Plant Maintenance (JIPM) in 1971 in terms of the goals:

- 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).

The objectives of TPM, according to Japan Institute of Plant Engineers (JIPE), the predecessor of JIPM (Nakajima 1982) are:

- Aims at maximizing equipment effectiveness.
- Elicits the participation of all staff members, from top-management to front-line operators.
- Promotes preventive maintenance through motivation management that is through small group autonomous activities.

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. Traditional attitudes across a range of companies are typified by statements like 'it is my job to operate the machine: it is someone else's job to fix it if it goes wrong'. Barriers between production and maintenance personnel shown up by this remark have been matched by barriers between trades themselves. 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. Poor maintenance practices have been quoted by multinationals as 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. Western experience in this key area has been somewhat chequered. In some industries such as aerospace and nuclear power, maintenance has always been high on the agenda and strongly managed. Many excellent concepts such as preventive maintenance and terotechnology have western origins. The coordination of several disciplines was urged in the report, and 'terotechnology' was born. The term was defined as '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 terotechnology 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.

2. Justification of TPM

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.

Preventive maintenance (PM: 1951–) This can be described as a kind of physical check-up of equipment before it can result into breakdown. The goal of interval based preventive maintenance is to provide control of planned maintenance activities rather than allow machine breakdowns (Pardue *et al.* 1994).

Corrective maintenance (CM: 1957–) This is a system in which the concept to prevent equipment failure has been further expanded to be applied to the improvement of equipment so that equipment failure can be eliminated (improving reliability) and equipment can be easily maintained (improving maintainability).

Maintenance prevention (MP: 1960–) This is an activity to design the equipment to be maintenance free. As the ultimate goal of the equipment and line is to keep them completely maintenance free, every effort should be made to try to achieve the ultimate ideal goal condition of 'What the equipment and the line must be.'

The role of operator and maintenance personnel must interface in a new and cooperative relationship which is aimed at the common enemy: unplanned disruptions due to equipment failures. If difficulties with operating machine are classified as 'maintenance problems,' and maintenance personnel regard such problems as caused by lack of care and attention by the operator, there will be little progress. An important management discipline is not to allow complaints either way. Operators are allowed to state problem points and to ask maintenance to improve those points. Progress by maintenance personnel on the other hand should include measuring the number of such problem points raised by operators, so that over time there are fewer points raised (Harrison 1992). In order to fulfill their part of the new, integrated relationship, new and enhanced skills are needed by both operators and maintenance personnel. This implies an important training need. Nakajima (1989) proposes five skills of particular value in the work place, to which a sixth (improvement) has been added here:

(i) *Attention*: The ability to concentrate and to discover deviations.
(ii) *Judgment*: The ability to think logically and to make sound decision.
(iii) *Corrective action/restoration*: The ability to restore normal conditions in the minimum time with minimum losses.
(iv) *Prevention*: The ability to prevent problems from arising through knowledge of correct operation.
(v) *Prediction*: The ability to predict that problems are about to happen by spotting deviation.
(vi) *Improvement*: The ability to propose ideas to eliminate the problem point so that problems do not recur.

However good the systems are, they will not work without the enthusiasm and drive of the people concerned – especially of maintenance and production personnel. The key point to recognize is that it is production personnel who must take responsibility for their equipment; without their cooperation, maintenance systems cannot work. It is production operators who are first confronted by machine problems, and who can help the maintenance effort in several vital ways as follows (Harrison 1992):

- Avoid mis-operation of the equipment.
- Detect machine problems before they become too serious by being alert to abnormal noise, smell, oil leaks, vibration, swarf build up behind guard plates, and so on. In this way, a number of impending breakdowns can be avoided. With further training, operators can carry out basic repairs (including minor controls on electrical equipment such as replacing solenoid valves).
- Carry out routine preventive maintenance tasks such as lubrication, cleaning (also a form of inspection), and adjustments.
- Carry out routine condition-monitoring tasks like data collection.

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 labour 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. Such changes do not take place at the expense of maintenance jobs. The challenge is to do things together at a higher standard than was previously possible. Schonberger (1986) recorded that, after they had taken over routine lubrication, operators at Harley Davidson found that some machine lubrication points had never been oiled or greased before. And that is not to say that maintenance personnel had previously been negligent. The role of maintenance is gradually upgraded too by the following:

- Higher level maintenance, such as long-term maintenance, strip-downs, and refurbishment.
- Training production operators to carry out more and more routine maintenance.
- Completing condition-monitoring analysis and acting on results.
- Closer involvement with purchasing new plant to improve the hand-over of information from vendors.
- Developing new machines and processes so that they operate better for the particular company products.
- Preparing for fast response to breakdowns and process problems.

Skill levels are improved by training and practice in the right way. Constant repetition leads to error-free and consistent performance. Auditing skills periodically helps to ensure that standards do not slip, so operator re-qualification is not demeaning but simply good practice. Murata and Harrison (1991) propose three levels of quality of work:

(i) *Repair level*: People carry out instructions, but cannot foresee the future, they simply react to problems.
(ii) *Prevention level*: People can foresee the future by predicting problems, and take corrective action.
(iii) *Improvement level*: People can foresee the future by predicting problems. They not only take corrective action but also propose improvements to prevent recurrences. So far, the focus has been limited to the systems and people involvement necessary to develop a reliability-centred maintenance programme with increasingly close integration of production and maintenance personnel. This is the essential foundation for TPM. Unless the basic PM disciplines and operator/maintenance cooperation are in place, it would be fruitless to attempt to introduce a full TPM programme. TPM is an evolutionary approach to excellence in maintenance, and feeds off many basic people preparation processes such as the housekeeping and safety disciplines. There is also a strong link, and many analogies, between TPM and TQM. As a result, TPM is incapable of independent existence.

It is evident that the roots of TPM lay in the good maintenance philosophies and proactive maintenance practices, discussed earlier. However, there can be two more propositions to the models discussed so far. Theses additional propositions are:

- Minimizing the total life-cycle cost of ownership, including purchase cost, maintenance cost, and the cost of deterioration. In this sense, TPM has some similarity to terotechnology, although the scope is narrower because TPM is practiced only by the equipment user. One report (Hays and Wheelwright 1990) indicated that Japanese companies spent more on improvement than Western counterparts, who allocated most of their capital to new capacity and replacement machines.
- As a result, TPM brings the maintenance issue on to the total company agenda, and demands the involvement of everyone in one role or another. This could, for example, make the reduction of overall maintenance costs over time.

Willmott (1993) refers to the fundamental changes in attitude that must take place:

- If a process is not working well, we will not only fix it, we will determine why it was not working well in the first place and correct those fundamental causes.
- If the process is working, can it be improved?

The starting point for changes in attitude must be within the top team. By recognizing the key role of total life cycle cost of ownership in the company, several important decisions flow (Turcotte and Stickler 1990). If everyone can be brought to recognize this key role, and their individual contribution to be well on the way to realizing the need to plan for achieving TPM and for the education which is needed to support it.

TPM provides a platform for such 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. No matter how advanced the technology is people play a key role in maintaining the optimum performance of the equipment. TPM calls for a dramatic change from the traditional 'I make–You fix' attitude that so often divide workers. Through TPM everyone co-operates to maintain equipment the company depends on for survival and ultimately for profitability. At the very heart is the motivation, participation and enhancement of shop floor personnel (Sharma 1995).

2.1. *TPM benefits*

The main benefits 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. The ratio between output and the input of these factors is known as 'productivity' of the factor concerned. Productivity in relation to machines is measured in terms of output per machine hour. In the case of materials, productivity is estimated in terms of the output per unit measure of a particular material. The productivity of workers is usually expressed in terms of output per man-hour, and output per kilowatt or megawatt of power in the case of energy or electric power productivity.

Quality: Quality is the measure of an organization to provide better acceptable products/services to the customer. Quality is never an accident; it is always the result of high intention, sincere effort, intelligent direction and skilful execution, it represent the wise choice of many alternatives. To prosper in today's economic climate, any organization and its suppliers must be dedicated to never-ending improvement, and more efficient ways to obtain products or services that consistently meet customer's needs. TPM system offers an organization the means to produce more usable products/services that meets customer approval.

Cost: A cost reduction programme means maximization of profits by reducing costs through economics and savings in the cost of manufacture, administration, selling, distribution and use. Cost reduction is neither technical nor commercial, but it is discipline which starts with the basic premise that 'there is always a better way of doing a things.' It calls for a continuous search for alternatives in every filed of activity to improve performance leading to higher productivity. Idling of men is visible waste. Improper supervision is also a visible waste. In a process if the workman is required to wait for the job to arrive or non-availability of tools or machines, it is a waste of production time. In any industrial activity, some waste is bound to occur. Waste of time is a hidden but most precious waste. Waste of time could be in the form of break down, rework etc. Spare parts and raw materials stocked in godowns are waiting to be used (Chandra 1991). Elucidated above are various forms of waste.

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). The following are some strategies that can facilitate small lot dependable deliveries:

- Improved logistics planning and scheduling by the buyer—including inbound shipment consolidation, identification and use of reliable carriers, development of long term relations with select carrier organizations in order to improve delivery performance (Bruun 1987).
- Improved planning and scheduling of production to attain stable production schedules—this helps minimize 'special' deliveries. Delivery seeks to fulfill customer requirements through the production of 100% quality goods, reducing lead times, elimination of waste, increasing productivity and continuous improvement (Andrew 1987, Ford 1987).

The following discussion of customer delivery addresses several approaches to meeting customer needs through improvement upon the above means.

- Increasing delivery frequency through production related elements. A method which is successful in reducing the time required of the manufacture to prepare and deliver the product to the customer is known as 'cycle time reduction' or 'increasing customer responsiveness'. Kidd and Reinbolt (1990) presented a case study of a cycle time reduction programme established in a firm which result in an increase of delivery frequency by 50%. Reducing cycle time, administrative and transit time were addressed through the use of a team approach.
- Improving customer delivery through problems identification—the application of brain storming techniques is effective in identifying the problems which may exist in a company's established course of delivery. Examples of common problems which pose barriers to the operation of an effective delivery system. The creation of excess forecasts on products which have a reputation for being difficult to deliver. Certain product lead times are longer than the forecast horizon. Ineffective supplier relations may cause a firm unnecessary delays in its production schedule.
- Improving customer delivery through forecasting and distribution requirements planning (DRP). One approach has been identified as customer networking and its meaning is aptly described as 'taking a proactive approach' to bring your customer into your plans and goals. It is establishing a partnership with these customers that offers: Trust, stability, inventory reduction and cost saving opportunities to both (Burns 1987).

The objectives of sales planning and forecasting are to establish a balance between supply and demand and to substantiate the level of future demand for the firm (Artes 1987). Distribution requirement planning plans the movement of material in a distribution system. DRP assist in determining the level of materials required for a fluctuating level of demand. Its functions include forecasting, monitoring, shipment and allocation planning, and interfacing to other established systems in an organization (Martin and Sandras 1990).

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. These factors may be physical, chemical or biological agents or ionizing radiation. The scientific approach adopted in applying industrial hygiene include, identifying the extent of toxicity (harmful) effects of chemical, physical and biological agents;

identifying the extent of employee exposure through inhalation, skin absorption or ingestion; recommending and implementing process controls that reduces exposure to harmful substances and following safe work practices including use of personal protective equipment to control exposures (Mehta 1998). A workplace where it is easy to work must first be one where people can work without worrying. To accomplish this, dangerous conditions and behaviour should be before they cause accidents.

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 1998). 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 programmes 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 firms 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).

3. Development of analytical hierarchy process

The AHP has been well received by all concerned as reported in the literature (Roger 1987). Application of this methodology has been found in numerous fields. The general approach of this AHP model is to decompose the problem and make pair-wise comparison of all the elements on a given level with the related elements in the level just above to which it belong. A highly user friendly computer model is developed which assists the user in evaluating his/her choices. The schematic of the model is shown in figure 1.

3.1. *Description of the model*

A thorough analysis of the problem is required along with the identification of the important attributes involved. The selection of attributes have been determined through literature survey and discussions held with experts during industrial visits. The attributes and the subattributes used in the AHP model for the justification of TPM are:

1. Productivity [PRO]
   - Equipment [EQP]
   - Energy [ENE]
   - Material [MAT]
   - Manpower [MAN]
2. Quality [QUL]
   - Defects in process [DIP]
   - Defective products [DEP]
   - Claims from clients [CFC]
   - Customer complaints [CCP]
3. Cost [CST]
   - Reduction in manpower [RIM]
   - Reduction in maintenance cost [RMC]
   - Reduction in power consumption [RPC]
   - Reduction in heat consumption [RHC]
   - Reduction in operating cost [ROC]
   - Reduction in breakdown [RIB]
   - Reduction in rework [RIR]
4. Delivery [DEL]
   - Stock reduced [STR]
   - Dependable delivery [DPD]
5. Safety [SAF]
   - Zero accidents [ZAC]
   - Zero pollution [ZPO]
6. Morale [MOR]
   - Increase in improvement ideas [IIM]
   - Small group meetings [SGM]
   - Group culture [GCL]
   - Motivation [MOT]
7. Work environment [WEN]
   - Free flow of information [FFI]
   - Owner-ship of equipment [OEQ]
   - Improved cooperation and coordination [ICC]
   - Self-confidence [SEC]
8. Competitive advantages [CMA]
   - Customized service and product support [CSP]
   - Customer delightment [CDT]
   - Value addition [VAD]

Alternatives: The alternative maintenance systems are: traditional maintenance system and TPM system. These alternatives are evaluated and compared in the light of above discussed set of attributes and subattributes.

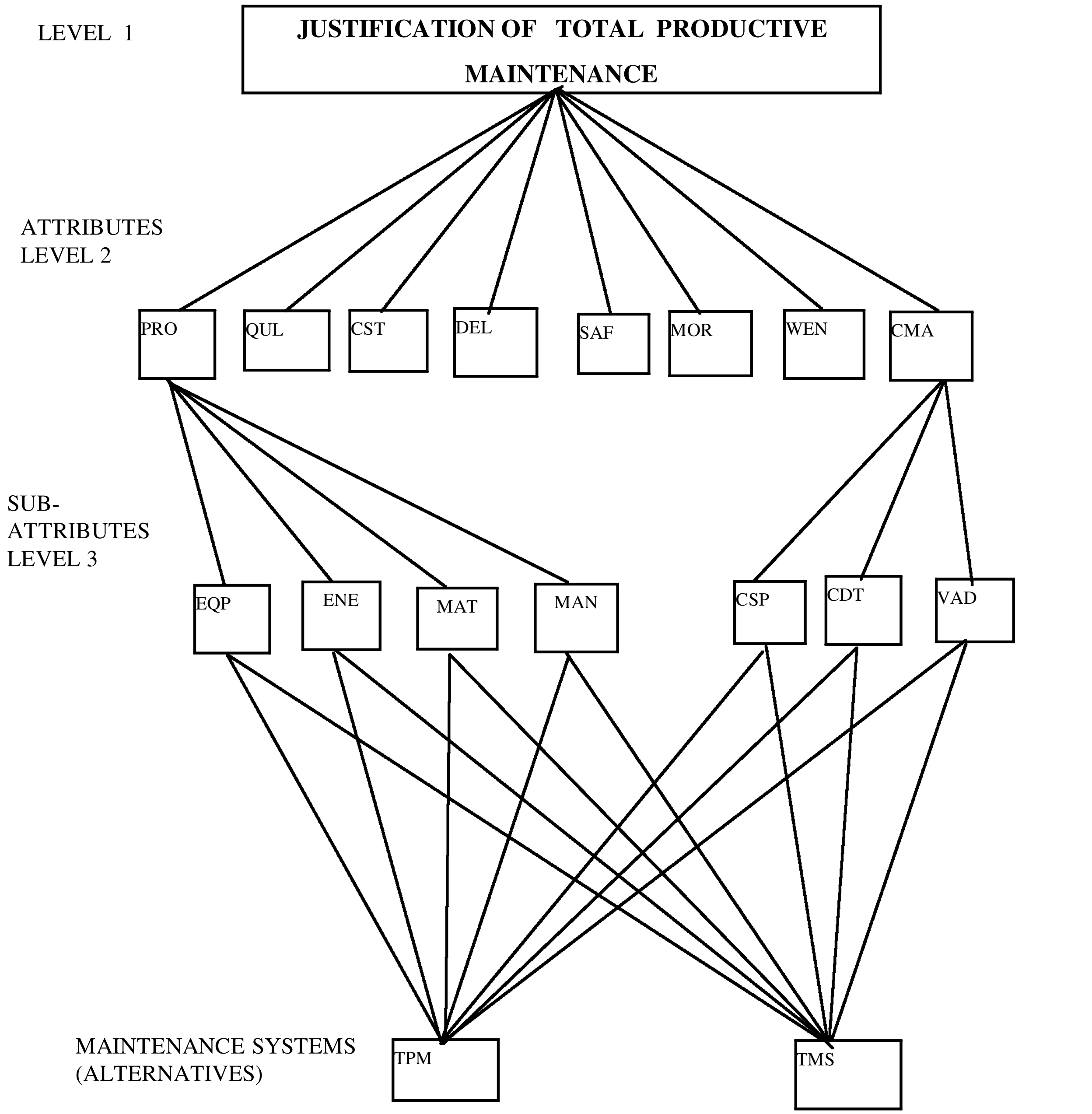

Figure 1. Schematic of the AHP model.

- TPM system [TPM]
- Traditional maintenance system [TMS]

3.2. *Analytical hierarchy process methodology*

AHP (Satty 1982) was developed in 1972 as a practical approach in solving relatively complex problems. AHP enables the decision maker to represent the simultaneous interaction of many factors in complex, unstructured situation. For the justification of Total Productive Maintenance (TPM) system, the judgement based on observation are fed into AHP for each criterion and sub-criterion of all level of hierarchy. Pair-wise comparisons of criterion at each level is done on a scale relative importance, 1 reflecting equal weightage and 9 reflecting absolute importance (see appendix for detailed information).

The steps to follow in using the AHP (Roger 1987):

(1) Define the problem and determine the objective.
(2) Structure the hierarchy from the top through the intermediate levels to the lowest level. See figure 1.

(3) Construct a set of pair-wise comparison matrices for each of the lower levels. An element in the higher level is said to be a governing element for those in the lower level, since it contributes to it or affects it. The elements in the lower level are then compared to each other based on their effect on the governing element above. This yields a square matrix of judgements. The pair-wise comparisons are done in terms of which an element dominates another. These judgements are then expressed as integers. If element A dominates over element B, then the whole number integer is entered in row A, column B and reciprocal is entered in row B, column A. If the elements being compared are equal, a one is assigned to both positions. Table 1 shows the pair-wise comparison matrix for level II criteria.
(4) There are $n(n-1)/2$ judgments required to develop the set of matrices in step 3 (reciprocals are automatically assigned in each pair-wise comparisons).
(5) Having done all the pair-wise comparisons and entered the data, the consistency is determined using the eigenvalue. To do so, normalize the column of numbers by dividing each entry by the sum of all entries. Then sum each row of the normalized values and take the average. This provides Principal Vector [PV]. Table 2 illustrates the normalized comparison matrix.

The check of the consistency of judgments is as follows:

Let the pair-wise comparison matrix be denoted M1 and principal vector be denoted M2.
Then define M3 = M1*M2; and M4 = M3/M2.
λ_{max} = average of the elements of M4.
Consistency Index (CI) = $(\lambda_{max} - \mathcal{N})/\mathcal{N} - 1$
Consistency Ratio (CR) = CI/RCI corresponding to $\mathcal{N}$
where RCI: Random Consistency Index and
$\mathcal{N}$: Number of elements

Random index table

$\mathcal{N}$	1	2	3	4	5	6
RCI	0	0	0.58	0.9	1.12	1.24

If CR is less than 10%, judgments are considered consistent. And if CR is greater than 10%, the quality of judgments should be improved to have CR less than or equal to 10%.
(6) Steps 3–5 are performed to have relative importance of each attribute for all levels and clusters in the hierarchy. Table 3 illustrates the subcriterion analysis of criteria, ‘Productivity’.

Table 1. Criteria pair-wise comparison matrix (level 2).

	⟨PRO⟩	⟨QUL⟩	⟨CST⟩	⟨DEL⟩	⟨SAF⟩	⟨MOR⟩	⟨WEN⟩	⟨CMA⟩
⟨PRO⟩	1	1/2	3	5	7	9	7	5
⟨QUL⟩	2	1	5	9	9	9	7	5
⟨CST⟩	1/3	1/5	1	2	3	3	2	1
⟨DEL⟩	1/5	1/9	1/2	1	2	2	3	1
⟨SAF⟩	1/7	1/9	1/3	1/2	1	2	1	1/2
⟨MOR⟩	1/9	1/9	1/3	1/2	1/2	1	1/2	1/3
⟨WEN⟩	1/7	1/7	1/2	1/3	1	2	1	1/2
⟨CMA⟩	1/5	1/5	1	1	2	3	2	1
⟨SUM⟩	4.13	2.376	1.667	19.333	25.5	31.00	23.5	14.333

Table 2. Criteria pair-wise comparison matrix (level 2) normalized.

	⟨PRO⟩	⟨QUL⟩	⟨CST⟩	⟨DEL⟩	⟨SAF⟩	⟨MOR⟩	⟨WEN⟩	⟨CMA⟩	⟨SUM⟩	⟨PV⟩
⟨PRO⟩	0.242	0.210	0.257	0.259	0.275	0.290	0.298	0.349	2.180	0.272
⟨QUL⟩	0.484	0.421	0.429	0.466	0.353	0.290	0.298	0.349	3.089	0.386
⟨CST⟩	0.081	0.084	0.086	0.103	0.118	0.097	0.085	0.070	0.723	0.090
⟨DEL⟩	0.048	0.047	0.043	0.052	0.078	0.065	0.128	0.070	0.530	0.066
⟨SAF⟩	0.035	0.047	0.029	0.026	0.039	0.065	0.043	0.035	0.317	0.040
⟨MOR⟩	0.027	0.047	0.029	0.026	0.020	0.032	0.021	0.023	0.224	0.028
⟨WEN⟩	0.035	0.060	0.043	0.017	0.039	0.065	0.043	0.035	0.336	0.042
⟨CMA⟩	0.048	0.084	0.086	0.052	0.078	0.097	0.085	0.070	0.600	0.075

Consistency Index (CI) = 0.0315 Consistency Ratio(CR) = 0.0224

Table 3. Productivity subcriteria analysis (level 3).

	⟨EQP⟩	⟨ENE⟩	⟨MAT⟩	⟨MAN⟩
⟨EQP⟩	1	5	7	5
⟨ENE⟩	1/5	1	2	1
⟨MAT⟩	1/7	1/2	1	1/3
⟨MAN⟩	1/5	1	3	1
⟨SUM⟩	1.543	7.500	13.000	7.333

Table 4. Alternatives analysis of equipment.

	⟨TPM⟩	⟨TMS⟩
⟨TPM⟩	1	9
⟨TMS⟩	1/9	1
⟨SUM⟩	1.111	10.000

Table 5. Case situation.

Industry type	Process
Production volume	High
Company vision	Star performer and market leader
Mission	Continuous improvement of products, processes and people.

Table 6. Weightages of attributes for alternatives.

Subcr	⟨L3 – Wt⟩	⟨L2 – Wt⟩	⟨TPM⟩	⟨TMS⟩
⟨EQP⟩	0.634	0.272	0.900	0.100
⟨ENE⟩	0.138	0.272	0.667	0.333
⟨MAT⟩	0.070	0.272	0.667	0.333
⟨MAN⟩	0.158	0.272	0.750	0.250
⟨DIP⟩	0.563	0.386	0.750	0.250
⟨DEP⟩	0.267	0.386	0.833	0.167
⟨CFC⟩	0.108	0.386	0.750	0.250
⟨CCP⟩	0.062	0.386	0.833	0.167
⟨RIM⟩	0.040	0.090	0.667	0.333
⟨RMC⟩	0.335	0.090	0.875	0.125
⟨RPC⟩	0.197	0.090	0.750	0.250
⟨RHC⟩	0.038	0.090	0.667	0.333
⟨ROC⟩	0.113	0.090	0.667	0.333
⟨RIB⟩	0.069	0.090	0.900	0.100
⟨RIR⟩	0.208	0.090	0.833	0.167
⟨STR⟩	0.667	0.066	0.750	0.250
⟨DPD⟩	0.333	0.066	0.875	0.125
⟨ZAC⟩	0.750	0.040	0.900	0.100
⟨ZPO⟩	0.250	0.040	0.875	0.125
⟨IIM⟩	0.162	0.028	0.833	0.167
⟨SGM⟩	0.060	0.028	0.875	0.125
⟨GCL⟩	0.288	0.028	0.833	0.167
⟨MOT⟩	0.489	0.028	0.875	0.125
⟨FFI⟩	0.144	0.042	0.833	0.167
⟨OEQ⟩	0.332	0.042	0.900	0.100
⟨ICC⟩	0.144	0.042	0.833	0.167
⟨SEC⟩	0.379	0.042	0.833	0.167
⟨CSP⟩	0.075	0.075	0.750	0.250
⟨CDT⟩	0.334	0.075	0.875	0.125
⟨VAD⟩	0.591	0.075	0.900	0.100

(7) The alternative analysis for the lowest level of subcriteria to be carried out in the similar manner as above. Table 4 illustrates the alternative analysis of 'Equipment'. The remaining alternative analysis to be carried out.

(8) The desirability index for each alternative is calculated by multiplying each value in 'weight of subcriteria' column by the respective value of 'criteria weight' column, then multiplying by the value for each respective alternative and summing the results.

For use in this problem, the focus is developed. In this case, it is to determine the justification of TPM. The attributes are compared with each other in a pair-wise comparison with respect to case situation discussed in table 5. From the analysis, it is clear that the TPM option

Table 7. Data summary

Subcr	⟨TPM⟩	⟨TMS⟩
⟨EQP⟩	0.155	0.017
⟨ENE⟩	0.025	0.013
⟨MAT⟩	0.013	0.006
⟨MAN⟩	0.032	0.011
⟨DIP⟩	0.163	0.054
⟨DEP⟩	0.086	0.017
⟨CFC⟩	0.031	0.010
⟨CCP⟩	0.020	0.004
⟨RIM⟩	0.002	0.001
⟨RMC⟩	0.027	0.004
⟨RPC⟩	0.013	0.004
⟨RHC⟩	0.002	0.001
⟨ROC⟩	0.007	0.003
⟨RIB⟩	0.006	0.001
⟨RIR⟩	0.016	0.003
⟨STR⟩	0.033	0.011
⟨DPD⟩	0.019	0.003
⟨ZAC⟩	0.027	0.003
⟨ZPO⟩	0.009	0.001
⟨IIM⟩	0.004	0.001
⟨SGM⟩	0.001	0.000
⟨GCL⟩	0.007	0.001
⟨MOT⟩	0.012	0.002
⟨FFI⟩	0.005	0.001
⟨OEQ⟩	0.013	0.001
⟨ICC⟩	0.005	0.001
⟨SEC⟩	0.013	0.003
⟨CSP⟩	0.004	0.001
⟨CDT⟩	0.022	0.003
⟨VAD⟩	0.040	0.004

Table 8. Decision index for the desirability of each alternative.

Decision Index of TPM	0.8123
Decision Index of TMS	0.1877

The most desirable alternative is TPM.

is the best under the circumstances of the developed case situation (see table 6, 7, 8).

A highly user-friendly software, the multiattribute decision model (AHP) is developed in Borland C^{++} to aid the user for pair-wise comparison of the attributes as well as for the alternatives and for analysing the user inputs. The reliability of the judgments supplied by the user can be estimated from the graphs (figures 2, 3) that are generated for each alternative and its corresponding deciding criteria.

3.3. *Usefulness of model*

The model developed is able to evaluate TPM for it's justification. The inputs to the model help to clarify the goals of the organization as it requires insights for constructive discussion. The salient features of AHP are:

- A user-friendly, interactive software which is menu driven.
- Options are offered to the user to define mode of input i.e. (a) from a file, and (b) by direct input on the screen.
- The screen input and editing are done on a clearly defined matrix. The editing can be carried out on the screen itself, thus on-line changes are possible.
- To see the results of the calculations and editing there are two options, i.e., (a) on the screen, and (b) on an output file, so as to get hard copy.
- The validity of the input data is checked through a consistency criteria. The consistency ratio is an approximate mathematical indicator of the consistency of pair-wise comparisons.
- Graphic display of the calculated weightages for each of the attribute and alternative allows a visual estimation of the data entered by the user. In case of a discrepancy, the user can immediately enter the edit mode, change the data and return to see the result of the changes.

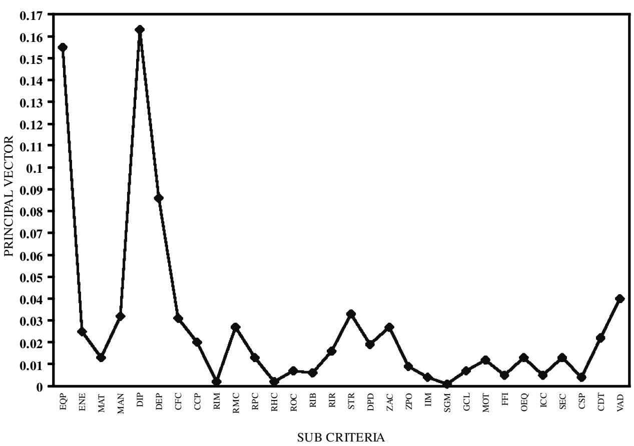

Figure 2. Data summary graph alternative: TPM.

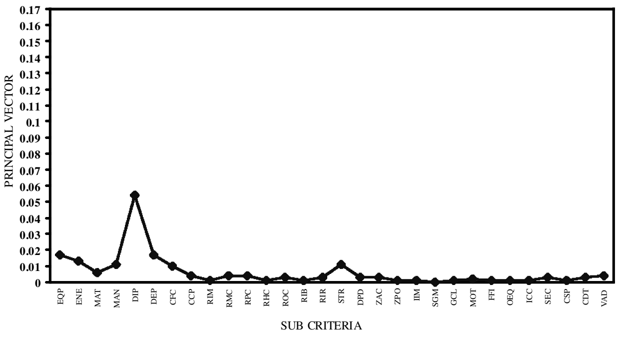

Figure 3. Data summary graph alternative: TMS.

4. Conclusions

From the result it is evident that TPM can bring in commendable reforms and improvement in terms of equipment effectiveness, better products quality, meeting promised delivery dates and conducive work place. The obtained results are quite significant and promising. Analytical hierarchy process is used to justify TPM and confer the adequacy of TPM implementation. The priorities can be very useful for strategic and operational decisions in reallocating resources. A self assessment procedure has been developed to aid managers in assessing the TPM *status quo* of TPM implementation for challenging the TPM Excellent Award. One case study is elucidated in order to reinforce the salient features of the concept.

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Appendix: Scale of relative importance

Intensity	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Weak importance of one over the other	Experience and judgement slightly favour one another
5	Essential or strong	Experience and judgement strongly favour one another
7	Very strong	An activity is strongly importance favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest degree
2, 4, 6, 8	Intermediate values	When compromise is needed