

Multi criteria Decision model (MCDM) for the evaluation of maintenance practices and Implementation of Total Productive Maintenance(TPM) in Indian Industries

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ABSTRACT

The perceptible impact of Total Productive Maintenance (TPM) lies in raising productivity standards, gaining profitability, and improving the quality besides cutting down the non value added costs greatly. This paper is an attempt to provide a frame work and pragmatic approach in implementation of TPM. A number of novel success factors or practices that are responsible for the decisive role to overture the process are identified. These practices are interchangeably called as sub-attributes. These practices must have evolved from different strategies. The sub-attributes are quantified using least square multi attribute decision model (LSMADM) for three alternative strategies viz. corrective maintenance, reliability centered maintenance(RCM), and TPM. Any sub-attribute irrespective of its own high or low relative score among the number of sub attributes is evaluated over three alternative strategies. To implement any sub-attribute, an investigation of its highest relative score for given alternatives will guide the managers to opt the best alternative. The best practices must come from different strategies to get most optimal results. The priorities established using LSMADM will act as base line to implement the industrial activities in a more systematic and balanced way to gain far-reaching optimized productivity and quality standards. The higher priority task will be given higher consideration in terms of committing the resources vis a vis less priority task. This will aid in orienting the collective efforts for optimal outcomes.

Keywords: Attribute, Least Square Multicriteria Decision Model (LSMADM), Optimized Productivity, Total Productive Maintenance (TPM). World-class maintenance system [WCMS]

I. INTRODUCTION

Industries all over the world are concerned to implement novel practices to reduce cost of operations to stay ahead and competitive. Each and every activity has role to play but the magnitude must differ. The excess efforts than needed on any activity may go waste or may be counterproductive. The relative rankings among all attributes must be established to put efforts in the restrained ratio. The weightage of each attributes must be known to establish the relative ranking among the attributes. The attributes which have high rank will contribute most towards raising the profitability, brand image etc. of the firm.

Industries must gear up to set in place the priorities to guide their roles in a new era of competitiveness for sustainable, advanced and surging manufacturing systems. The industries, which will remain traditional and ignore the advancements, will soon find it difficult to stay operational. Different researchers have expressed their experiences in their own way, but careful thought has to be given before accepting their views

as different strategies suits to different conditions. The same may not work for all industrial set ups.

Every industry has to thrive to excel across all the business functions to gain the unparalleled productivity of all its resources. It is exhibited that the distinctive impact of TPM lies in raising the wide spectrum of productivity, quality and safety standards [1]. Hence, it is coherent to utilize the resources like machines, men, and material as optimally as conceivable. The liberalization of global economy has caused unprecedented business challenges making the maintenance function under the spotlight as never before. The maintenance activities have to deal with reduction in set-up time, cycle time, buffer inventory, enhancing productivity of resources, facilitating quality improvements; capacity expansions, and making improvements in organizational work culture [2]. An effective maintenance program is vital towards making valuable contributions for enhancing production efficiency, plant availability, machines reliability and organizational productivity [3]. World-class maintenance system [WCMS] has evolved through

numerous tried and tested noble practices. These practices includes the following [4]:

1. Leadership and policy deployment
2. Organizational structure
3. Inventory control
4. Computerized maintenance management systems
5. Preventive maintenance
6. Predictive maintenance
7. Planning & scheduling
8. Work flow
9. Financial control
10. Operational involvement
11. Staffing and development
12. Continuous improvement

A definition of best practices adapted to the maintenance strategies would read: The maintenance practices or success key factors (SKF) that enable a company to achieve competitive advantage over its competitors.

II. DEFINITION OF TOTAL PRODUCTIVE MAINTENANCE

TPM differs from the traditional practices in reinvigorating the compartment approach into a companywide culture of autonomous maintenance by everyone irrespective of department barriers. TPM aims at improving the overall effectiveness, availability and restoration of plant performance to the maximum extent [5]. The Japanese Institute of Plant Maintenance (JIPM) defined TPM as a system that encompasses the life cycle of the equipment in all levels of product development viz. planning, designing, manufacturing, installing, and maintenance. The goals of TPM are:

- a) Optimize equipment effectiveness.
- b) Design the maintenance system for the entire life span of the equipment.
- c) Impart Training to all employees for deficiencies starting from top management to shop floor workers.
- d) Promote TPM through motivation management, all inclusive and small-group improvement activities.

The objectives of TPM, as per Japan Institute of Plant Engineers (JIPE), the predecessor of JIPM [6] are:

- a) Aims to make best use of equipment effectiveness.
- b) Total employee involvement, from top-management to front-line operators.
- c) Continues improvement as all time event.
- d) Promotes preventive maintenance.
- e) Developing belongingness to the extent of turning workforce into highly committed and dedicated human resource.

It is a matter of serious concern that the third world countries do not have the required level of technical skills, advanced techniques and tools to

overcome the organizational flaws. The objective of cost effectiveness can be achieved through embracing the latest and proven techniques judiciously and conspicuously.

Traditional thinking has created attitudinal barrier between production and maintenance departments. This creates the blame fixing and face saving environment across the various functions of industry. The reporting of machine faults by operate does not mean always the same to the maintenance crew. Hence the diagnosis becomes stray. I operate you fix mentality has to be relooked and needs to be renounced. Skilled maintenance craftsman ship is also a missing link in most traditional industries [7]. This results in growing 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. Training must be tailored to suit the needs of maintenance at company level. A comprehensive system of maintenance has to be developed. There must be thorough and impeccable understanding the subject, roles, objectives and outcomes. The standards will keep rising to new levels every time. Thus deficit capability will prove fatal and aggravate the gap between the required and what is delivered. Thus grooming the work force regularly is inevitable for sustainability and meeting organization goals effectively.

III. DEVELOPMENT OF THE MODEL:

A methodical and comprehensive analysis of the problem is required along with the identification of the key maintenance practices. A Delphi study is conducted to provide the initial relative importance of each attributes. There are variations in opinions. Only the most consistent data are averaged. The effect of variance is not considered. The relative importance provided here is solely based upon the data provided by experts for the case situation given in table 1.

Table 1. Case situation

Industry type	Process
Production volume	High
Company vision	World class company of national repute
Mission	Continuous improvement of products, processes and people

The attributes and the subattributes used in the LSMADAM model for the evaluation of relative weights are [1]:

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]

IV. DESCRIPTION OF ATTRIBUTES

The broad description of each attribute is provided here in the following paragraphs.

Productivity [PRO]:The TPM aims at increasing the productivity of plant and equipment with an improvable approach towards maintenance [8] to ameliorative waiting time, speed loss and production of defectives. The desired production output is achieved through highly planned and well executed workflow analysis, which is influenced by the upkeep of the equipment reliability and maintainability. A well thought maintenance plan is responsive to improve the equipment availability and reliability. Overall equipment effectiveness (OEE) goes hand in hand to achieve the plant effectiveness [9] and gain the control over the objective of high profitability. There are six preventable losses. The downtime loss is responsible to demean the plant availability. The minor stoppage, set up and adjustment loss, reduced speed loss do adversely affect the performance of the

plant. The amount of rework or reject will cause the quality loss [10]. The break down brings down the availability of machine. The set up, minor stoppage, and reduced speed mounts to poor performance of the equipment.

Energy saving methods, wastages of energies, under capacity utilization of machines need to be analyzed and promising solutions must be sought. The better methods of doing the job, use of single minute exchange of dies (SMED), reduction of external set ups, motion study, and many industrial techniques are practiced to raise machines and labor productivity. The timely identification of deficiencies of worker's skills and providing prompt training to bridge the gap is all time event. Saving energy must be company wide drive. Poor performing equipment's are easily identified based on output, variability of final dimensions and hourly operating cost. All ways and means are explored to reduce hourly cost of operating plant [11].

Quality [QUL]:It is essential to make sure the correctness of the process. The processes can be forging, rolling, polishing, grinding and so on. The processes must be made fool proof from all perspectives on a continuous basis to reduce defects due to ill processes. If the process has high process capability index it is likely to make less rejects. Precision and accuracy are measured for each process to take corrective action for deviations and improvement. Latest techniques like six sigma and jidoka will ingrain quality into processes and prevention of problems.

If any activity involved from customer needs, product development, and product design is defective, the product cannot be good to use no matter how carefully it is manufactured and vice versa. Quality of late means to produce future products in present time.

TPM system provides new promising vistas that uses the untapped potential of all the individuals to harness their strength to the fullest capacity and capability [12]. TPM provides an organization the adherence to stringent quality standards to not only meet their requirements, but also seek the delight of customer approval.

Cost [CST]:The maximization of profits can be obtained by improvised methods of processing the task. All the non-value adding activities such as administration, selling, logistics and distribution must be curtailed if not eliminated. The axioms of industrial premise are technology driven. The ineffective or obsolete methods are replaced with innovative to provide the cutting edge solutions. There will always be a better way of doing a thing if the alternatives are sought after. It is about continuous search for a promising change to exploit

to their advantage. New alternatives in every field of activity to improve performance leading to higher productivity are perennially sought after. Any activity that does add value during any stage of value chain must be removed if possible. The supervisory role must be subjected to scrutiny. In any industrial activity some waste is bound to occur. Waste of time could be in the form of breakdown, rework etc. spare parts and raw materials stocked in godowns that are waiting to be used [13]. Outbound logistics to make the shipment of items from a company location to customers or other company locations is synchronized with input material flowing from external suppliers through controlled inbound logistics.

Delivery [DEL]: It is all about to provide the right product at the right time, in the right quantity at the right place. It may devise its method to enable collaborative planning, forecasting and replenishment to meet stated objectives [14]. The frequent and small lot inventory replenishment can be facilitated through the followings:

- Synchronizing the logistics planning and scheduling by the buyer – including inbound shipment consolidation, multiple product replenishment, use of ICT tools, identification and use of reliable carriers, development of collaborative relations with dedicated and committed carrier organizations in order to improve delivery performance [15].
- Production smoothing and leveling to attain stable production schedules to minimize crises and scope of special deliveries [16, 17]. The following points are essential in addressing the issues concerning customer needs:
- Locating and promoting the supplier plants in the geographical proximity and sharing the design and development activities. Increasing delivery frequency through production related elements. The product make span time covering the time from manufacturing to delivery can be drastically reduced. The third party shipment to the customer may be very swift with little additional cost of shipments if customer agrees for it. Kidd [18] have found that the small lot production can reduce the inventory drastically. The responsiveness to meet the dependable deliveries can be improved if these approaches are followed:
- Streamlining the flow of material from source to manufacturing processes till the last mile delivery can improve the product availability, reduced time to market and response time.
- The point of sale (POS) data at different stages of the supply chain must forecast and plan jointly to improve customer delivery. It is establishing a conglomerate with these customers that offers:

Confidence, stability, inventory reduction, cost saving opportunities leading to win win situation to both.

The continuous replenishment program and vendor managed inventory (VMI) through advanced methods, as electronic data interchange will provide the added advantage to establish a balance between supply and demand and to substantiate the level of future demand for the firm. The third party logistic provider can aggregate inbound and outbound transportation to gain economies of scale. Its functions include forecasting, monitoring, shipment and allocation planning, and interfacing with other established systems in an organization [19].

Morale [MOR]: Morale is the state of individual psychological well-being based upon a sense of confidence, satisfaction and overall outlook to take pride in work [20]. Employees well being, engagement to work, passion, enthusiasm, and commitment are different facets of Morale. Almost everything which happens to a human being at work such as delay in pay, the amount of information they receive, facilities at working area, the lighting in their work area can affect his or her experience of “well-being” or “morale”, positively, or negatively.

TPM enables the need for the employee involvement in the improvement efforts, collaborative practices, delegation of decision making, and extending self directed roles. The engagement to the work results in an elevated level of morale, in which employees feel a strong bond with their organization and will strive to go the extra mile for it. It is sine qua non that employee morale is all time high to get their best.

An organizations must look forward to create conducive work environment based on value system comprising of job enrichment, multi skills training, motivational programmes, suggestion schemes and team spirit [21]. The factors stated below, when taken care of the employee morale is sustained high even in hard time [6].

- All time respect, recognition, and duly appreciation to employees,
- Empowering and engaging employees in decision making
- Offering open door communication to nip the problems at the beginning
- Providing feedback and coaching,
- Timely investment on training to produce high morale is long term investment.
- Offering profit sharing benefits and compensation
- Engaging employees with well defines roles and job expectations.

Working Environment [WEN]: The very purpose of TPM is to elevate the level of belongingness among employees across all the departments of the

organization. Human resource need to be continuously upgraded about latest tools, techniques, knowledge and skills in order to achieve greater success. All employee must take pride in the quality of their workmanship. Everyone observes and practices honesty, respect, and ethics into their daily business practices. All must assume the responsibility of their work. Team work culture is highly prevalent. The knowledge transfer is facilitated to see the team outperforms and objectives are met [22]. There is no space for derogatory remarks, demean and causing human resource demoralize at work place. Organization has to ensure that upgrading skills of employees, filling the gaps to bridge the causes of underperformance. Any Problem related to the processes, machines, organization is identified at the embryonic stage per se and fixed thereof. TPM is beyond simply a maintenance policy, it encompasses all the elements that affects the equipment utilization, performance and quality rate. It is a culture of serving the company whole heartedly, a philosophy and a new attitude towards maintenance [23]. Quality of work life (QWL) programmes are sine qua non that yields benefits such as improved inter/intra communication better employer-employee relationships, better career development, reduced stress, high confidence and self management.

Competitive advantages [CMA]:TPM has been envisioned as a comprehensive manufacturing strategy to improve company performance of the organization and competitive position. The efforts of small groups and individuals in their capacity are all well synced to exploit the synergy of human resource. Each member, machine and entity is part of oneobject. Any flaws with anyone can make the failure to purpose and hence TPM attempts collectively to remedy The quality of the process, the product is subjected to periodic scrutiny and continuous improvement to enhance reliability,maintainability and restore deterioration to gain competitive advantage[10]. The benchmarking is key to know competitors position. It gives space to know how the new levels of performances can be gained. The value addition to the product or services must be done conspicuously so that it sound like better products at lower prices. The worth that a product or service bears in the mind of the consumer is worth paying the price [24].

V. ALTERNATIVES:

Three alternatives, corrective maintenance, reliability centered maintenance(RCM), and total productive maintenance (TPM) are considered for quantifying the relative score of each with respect to each sub-attribute. Some sub-attribute may perform well in some alternatives, and some in other. It can be seen in the weights obtained for alternatives.

Corrective Maintenance [CM]:The corrective maintenancebegins with detection of problem initiation due to parts deterioration. Corrective maintenance identifies the specific maintenance task required for each failure source. Corrective tasks canaid to spot and fix the existing problems. Corrective maintenance, is focused on planned actions that will keep all critical plant machinery and systems in optimum operating conditions. The purpose of corrective maintenance is improving equipment instant readiness, reduced breakdown, maintainability, and safety; design weaknesses (material, shapes). Maintenance information, obtained from CM, is useful for maintenance prevention (MP) for the next equipment and improvement of existing manufacturing facilities.

The following four maintenance activities are essential:

- Fault finding.
- Fault segregation.
- Fault abolition.
- Corroboration of fault elimination.

It improves equipment and its components design so that equipment life can be prolonged. The robust design is used to safeguard the failures to improve reliability and maintainability. Maintenance effectiveness is judged on the life-cycle costs of critical plant machinery, equipment, and systems, not on how fast a broken machine can be returned to service.

Reliability Centered Maintenance [RCM]: A reliability-centered maintenance (RCM) process systematically identifies the failure modes and criticality of failures. It also identifies all likely causes of these failures. It then proceeds to identify the effects of these likely failure modes and to identify in what way those effects matter. Can the preventive action be deferred or it needs immediate prevention of failure mode. In case of gradual progression of failure is the function degradation evident to the operator? Are there arrangements made to perform service on planned time. Is there need of condition monitoring? The assessment of condition of function degradation and preemptive measures of prevention of functional failures is performed and necessity of repair is scheduled and justified. These questions must be answered timely. The RCM is a comprehensive procedure for developing or optimizing the maintenance requirements of a physical resource for desired capability to achieve the level of reliability which can be achieved with an effective maintenance program[25]. RCM methodically carryout reconnaissance to determine the maintenance requirements of any physical asset in its operating context by identifying the functions of the asset, the causes of failures and the criticality effects of the

failures leading to secondary damage, injuries, or increase in life cycle cost.

Total Productive Maintenance[TPM]: The starting point of TPM is changing the attitude of the operator to maintain the equipment they use. It is believed that the person who handle the machine, knows machine the best. This is followed by training vigorously the worker in maintenance skills and knowledge. Total productive maintenance (TPM) is a strategy which utilizes the scientific techniques to manage equipment resources, that minimizes equipment failure, production defects, and accidents. TPM calls for the new order of utilizing the resources in value addition activities. It involves everyone in the value chain, from top level management to production staff, and manufacturing support groups to outside suppliers. The objective is to continuously improve the availability and prevent the degradation of equipment to achieve maximum effectiveness. The boundaries between production and maintenance department have to be synced in order to gain better control in solving organizational problems. These objectives require strong management support as well as continuous use of work teams and small group activities (SGA) to achieve incremental improvements. TPM is not a radically new idea; it is simply to make gradual advancement in doing the things every time. It is not a one time event but always striving to improve upon the existing standards[26].

VI. NEW LEAST SQUARES METHOD:

In least square method, the error is $x_{ij} - w_i/w_j$. The parameter x_{ij} is the element of judgement matrix. It is the relative importance of attribute I vis a vis attribute j. The expression $x_{ij} - w_i/w_j$ is nonlinear which leads in the form a nonlinear programming problem. If the error is $x_{ij}w_j - w_i$, the expression is linear. Using sum of squares of error as objective function, the model is

$$\min \sum_{i=1}^n \sum_{j=1}^n (x_{ij}w_j - w_i)^2$$

On applying the new least square method, the normalized matrix is:

-162.22	6.6667	4.0000	6.6667	6.6667	14.285	6.6667	-1.0000	W_1	=	0
6.6667	-176.44	4.0000	6.6667	6.6667	10.400	14.2857	-1.0000	W_2		0
4.0000	4.0000	-98.500	5.0000	10.400	6.6667	6.6667	-1.0000	W_3		0
6.6667	6.6667	5.0000	-314.00	10.400	18.222	10.400	-1.0000	W_4		0
6.6667	6.6667	10.4000	10.400	-8.9067	6.6667	10.400	-1.0000	W_5		0
14.2857	10.4000	6.6667	0.4444	6.6667	-26.867	5.0000	-1.0000	W_6		0
6.6667	14.2857	6.6667	0.8000	10.400	5.0000	-66.565	-1.0000	W_7		0
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	λ		1

The values of weights $W_1, W_2, W_3, W_4, W_5, W_6, W_7$ are 0.0473, 0.0441, 0.0776, 0.0346, 0.4815, 0.2022, and 0.1127 respectively. The weights of attribute level 2, attribute level 3 and overall weights are given in the table

Subject to the condition $\sum_{i=1}^n w_i = 1, w_i \geq 0, i = 1, 2, \dots, n$

The Lagrange's function is given below

$$Z = \min \sum_{i=1}^n \sum_{j=1}^n (x_{ij}w_j - w_i)^2 + \lambda \sum_{i=1}^n (w_i - 1)$$

where, λ is known as Lagrange's multiplier.

The weights can be calculated by equating $\frac{\partial Z}{\partial w_i} = 0$ to minimize the error.

$$\frac{\partial Z}{\partial w_i} = -2(x_{ij}w_1 - w_i) - 2(x_{ij}w_1 - w_i) - \dots - 2(x_{ij}w_n - w_i) + 2x_{i1}(x_{i1}w_1 - w_1) + 2x_{i2}(x_{i2}w_2 - w_2) + \dots + 2x_{in}(x_{in}w_n - w_n) + \lambda = -2(x_{i1} + x_{i1})w_1 - 2(x_{i2} + x_{i2})w_2 - \dots - [2(n-1) + \sum_{j \neq i}^n x_{ij}^2]w_i - \dots -$$

$$2(x_{in} + x_{ni})w_n + \lambda$$

Let $\frac{\partial Z}{\partial w_i} = 0 (i = 1, 2, 3, \dots, n)$, the result are

$$-2(x_{i1} + x_{i1})w_1 \text{ for } i \neq 1 - 2(x_{i2} + x_{i2})w_2 \text{ for } i \neq 2 - \dots + [2(n-1)$$

$$+ 2 \sum_{\substack{j=1 \\ j \neq i}}^n x_{ij}^2]w_i$$

- ... for above diagonal elements eg.

for 3rd row $i = 3$, and $n > 3$, $-2(x_{i1} + x_{ni})w_n + \lambda = 0 \quad i = 1, 2, 3, \dots, n$,

Add $\sum_{i=1}^n w_i = 1$, We have linear system about $n + 1$ equations. Solve the linear system, We obtain w_1, w_2, \dots, w_n and λ .

The a_{ij} values for Attribute Cost [CST] is given in table 2

Table 2: Relative importance of attributes of Cost criterion

$$A = \begin{bmatrix} 1 & 1/3 & 1 & 3 & 1/3 & 1/7 & 1/3 \\ 3 & 1 & 1 & 3 & 1/3 & 1/5 & 1/7 \\ 1 & 1 & 1 & 2 & 1/5 & 1/3 & 1/3 \\ 1/3 & 1/3 & 1/2 & 1 & 1/5 & 1/9 & 1/5 \\ 3 & 3 & 5 & 5 & 1 & 3 & 5 \\ 7 & 5 & 3 & 9 & 1/3 & 1 & 2 \\ 3 & 7 & 3 & 5 & 1/5 & 1/2 & 1 \end{bmatrix}$$

Table 3: Data Summary

Attribute	Weights Attribute Level 2	Sub-Attribute Level 3	Weights Sub-Attribute Level 3	Overall criteria weight
Productivity [PRO]	0.6053	Equipment [EQP]	0.6966	0.42
		Energy [[ENE]	0.1128	0.07
		Material [MAT]	0.0819	0.05
		Manpower[MAN]	0.1086	0.07
Quality [QUL]	0.1323	Defects in Process [DIP]	0.7182	0.10
		Defective Products [DEP]	0.1213	0.02
		Claims from clients [CFC]	0.0753	0.01
		Customer Complaints [CCP]	0.0852	0.01
Cost [CST]	0.0805	Reduction in Manpower [RIM]	0.047	0.00
		Reduction in maintenance cost [RMC]	0.044	0.00
		Reduction in Power consumption [RPC]	0.078	0.01
		Reduction in heat consumption[RHC]	0.035	0.00
		Reduction in operating cost [ROC]	0.482	0.04
		Reduction in break down [RIB]	0.202	0.02
		Reduction in rework[RIR]	0.113	0.01
Delivery [DEL]	0.0557	Stock reduced [STR]	0.7817	0.04
		Dependable delivery [DPD]	0.2183	0.01
Safety [SAF]	0.0419	Zero accident [ZAC]	0.8521	0.04
		Zero Pollution [ZPO]	0.1479	0.01
Moral [MOR]	0.0333	Increase in improvement ideas [IIM]	0.0704	0.00
		Small group activities [SGM]	0.0504	0.00
		Group Culture [GCL]	0.511	0.02
		Motivation [MOT]	0.3682	0.01
Work Environment [WEN]	0.0275	Free flow of information [FFI]	0.0668	0.00
		ownership of Equipment [OEQ]	0.2863	0.01
		Improve cooperation and coordination [ICC]	0.1321	0.00
		Self-confidence [SEC]	0.5149	0.01
Competitive Advantage [CMA]	0.0234	Customize service and product support [CSP]	0.1079	0.00
		Customer delightment [CDT]	0.1753	0.00
		Value addition [VAD]	0.7168	0.02

VII. RESULTS AND DISCUSSIONS:

The relative weights of all the attributes of level 1 are shown in figure 1.0. The priority values of attributes in ascending order are 1. Productivity, 2. Quality , 3. Cost, Safety and so on.

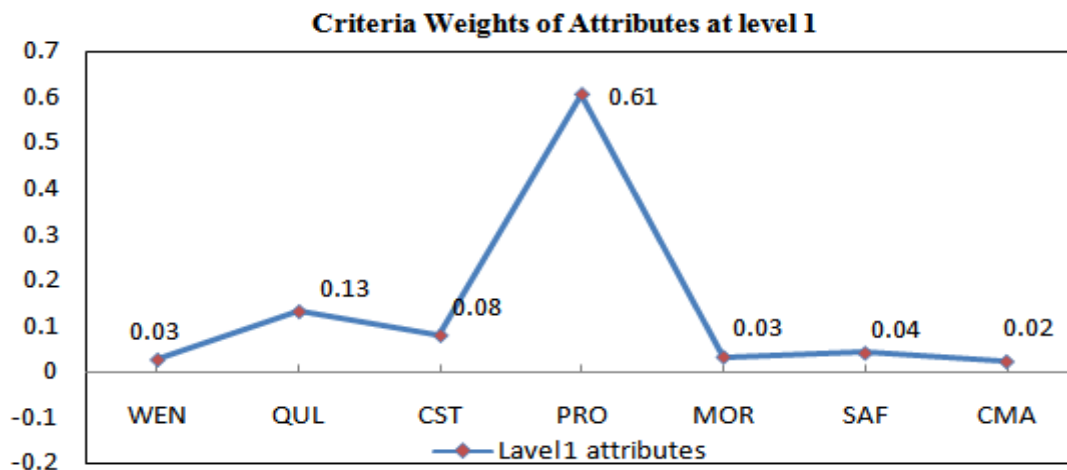


Figure 1.0 Weights of attributes of level1

The work environment [WEN] is though non dominating attribute. It is at fourth in priority sequence after productivity, quality, and cost. The priority areas of WEN are building self confidence [SEC] in employees. It can yield to boost up the organizational performance and decision making process. Ownership of equipment [OEQ] will be subsequent priority. The relative scores of subattributes of work environment are shown in figure 2.0

Criteria weights of Work Environment [WEN] attribute

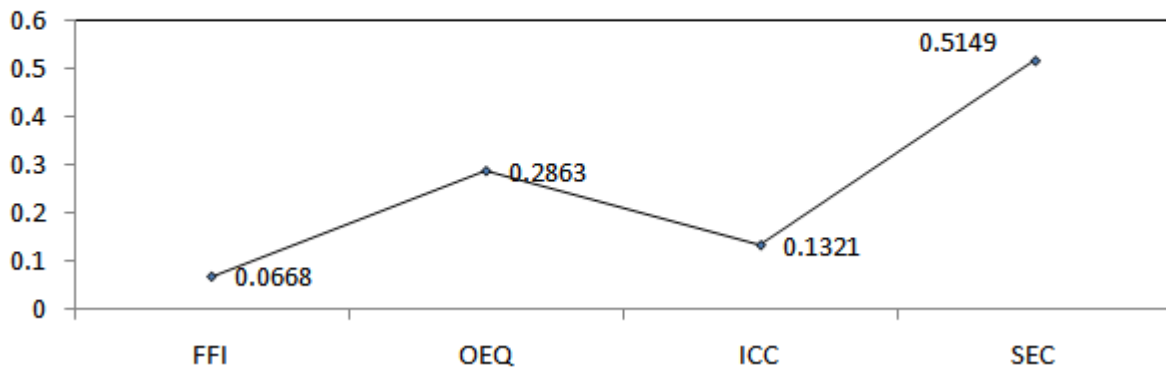


Figure 2.0 Weights of sub-attributes of Work Environment[WEN] attribute

The weights of subattributes of attribute Cost. Reduction in operation cost [ROC] is having highest score 0.482 followed by reduction in breakdown [RIB] scoring 0.22, then reduction in power consumption. It will be easy for an industry to set their goals and priorities once it is known what contributes heavily for the cause.

Criteria Weights of Cost [CST] Attribute

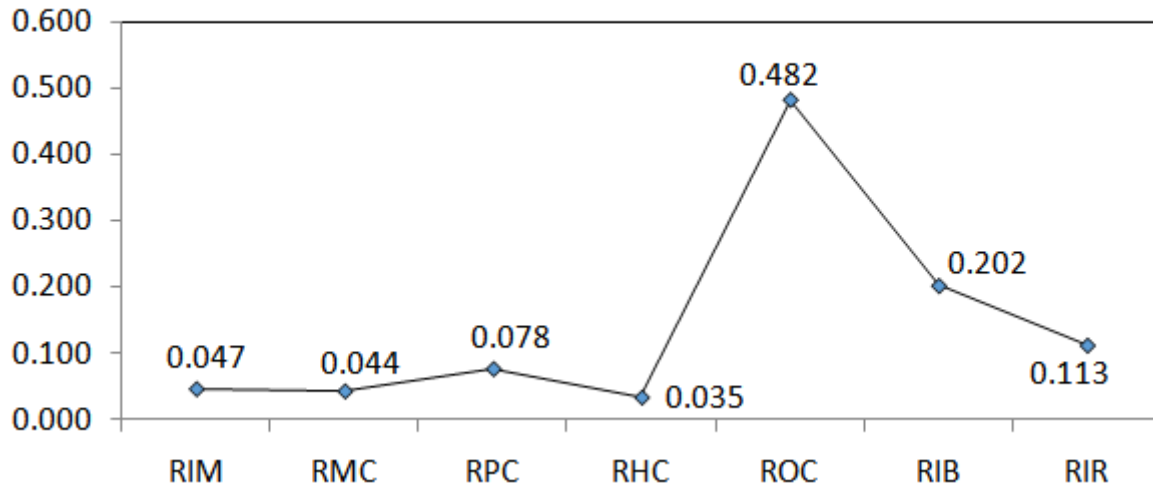


Figure 3.0 Weights of sub-attributes of Cost [CST] attribute

The most important attribute productivity is the leading attribute of all. Whose sub attributes equipment productivity [EQP] with highest score followed by energy productivity [ENE] and manpower productivity [MAN] (refer table 3.0 for numerical values).

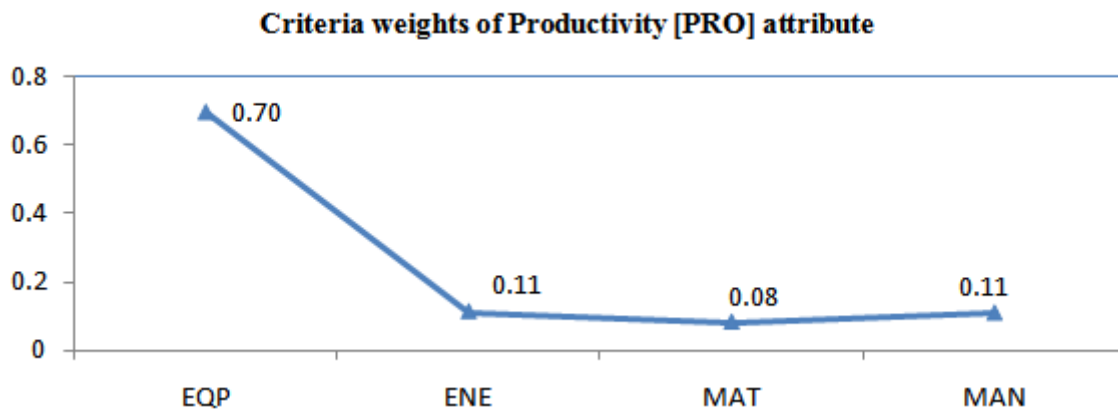


Figure 4.0 Weights of sub-attributes of Productivity attributes.

Figure 5.0 provides the relative priority of all the sub-attributes in a single combined data form. This helps in knowing the comparative weights of each and every sub-attributes. Among all the sub-attributes, equipment productivity [EQP] is weighted highest. Hence organization must extend efforts to raise the equipment productivity as top priority. Defects in Process [DIP] is next in the row, organization wide campaign to eliminate defects in the process must be accorded in the right place. The manpower productivity [MAN] and energy productivity [ENE] must be given due consideration to reap the benefits of successful implementation of TPM. The other sub-attributes will follow the suit in accordance of their relative rank.

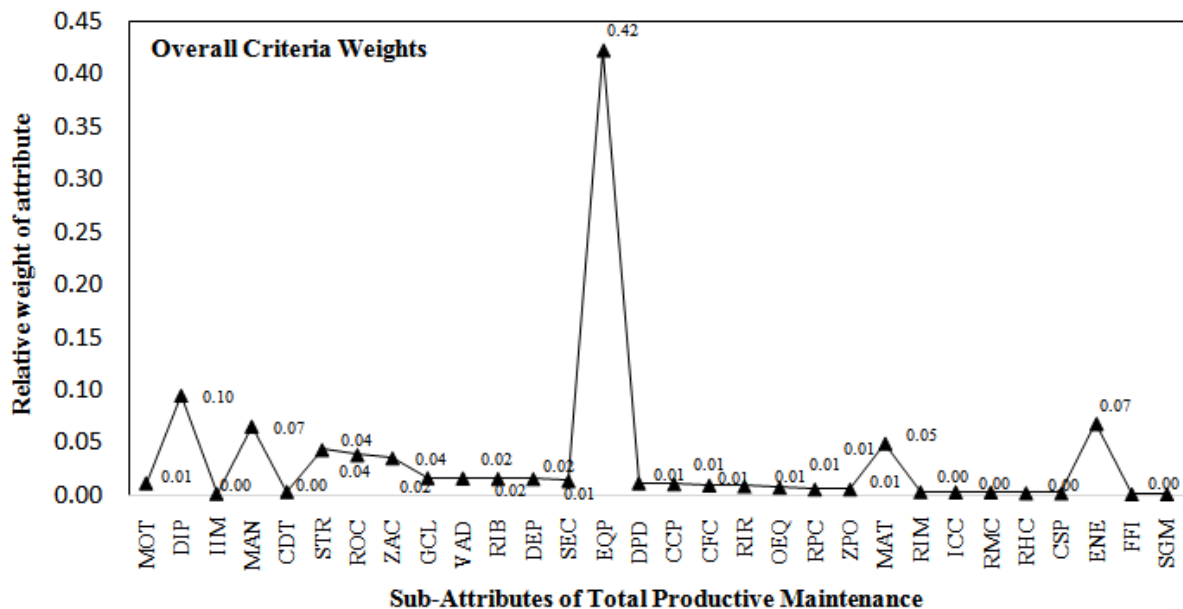


Figure 5.0 Combined relative weights of all the sub attributes

Table 4.0 The scores of sub attributes of each alternative

Sub Attributes	Corrective Maintenance	Reliability Centered Maintenance	Total Productive Maintenance
EQP	0.1063	0.2312	0.6624
ENE	0.0837	0.1265	0.7898
MAT	0.0545	0.2698	0.6757
MAN	0.0704	0.1947	0.7349
DIP	0.1079	0.1753	0.7168
DEP	0.0698	0.2622	0.6680

CFC	0.064	0.1315	0.8045
CCM	0.0704	0.1947	0.7349
RIM	0.0704	0.1947	0.7349
RMC	0.0983	0.0727	0.8290
RPC	0.1753	0.1079	0.7168
RHC	0.0824	0.1801	0.7375
ROC	0.2092	0.1654	0.6254
RIB	0.0919	0.4209	0.4872
RIR	0.0978	0.1859	0.7163
STR	0.0919	0.4209	0.4872
DPD	0.1654	0.2092	0.6254
ZAC	0.6735	0.1633	0.1633
ZPO	0.1654	0.2092	0.6254
IIM	0.1063	0.2313	0.6624
SGM	0.0824	0.1801	0.7375
GCL	0.1633	0.1633	0.6735
MOT	0.0837	0.1265	0.7898
FFI	0.1226	0.0889	0.7884
OEQ	0.0929	0.1178	0.7893
ICC	0.1633	0.1633	0.6735
SEC	0.1633	0.1633	0.6735
CSP	0.1091	0.0963	0.7946
CDT	0.098	0.0995	0.8025
VAD	0.098	0.1287	0.7733

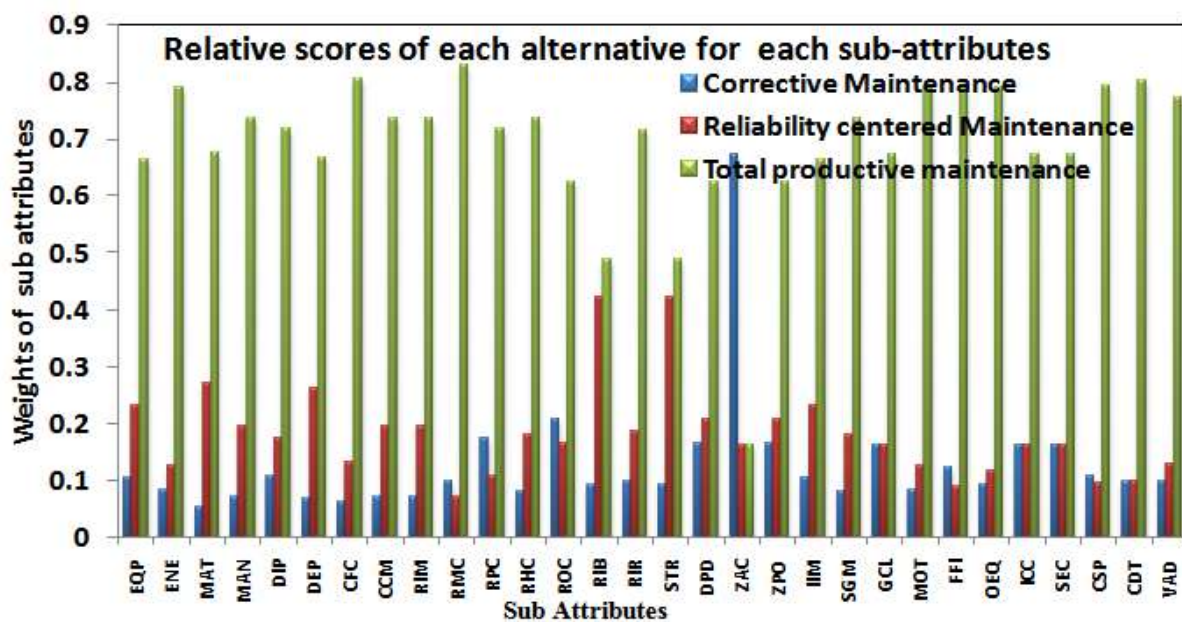


Figure 6.0 Relative scores of each alternatives

The graphs of each sub attribute for all alternatives are shown below for ready reference. Zero accidents [ZAC] is scoring higher under corrective maintenance. Rest of all the sub-attributes are excelling under the TPM strategy. Hence TPM can be embraced for all the sub attributes where TPM is exhibiting promising score.

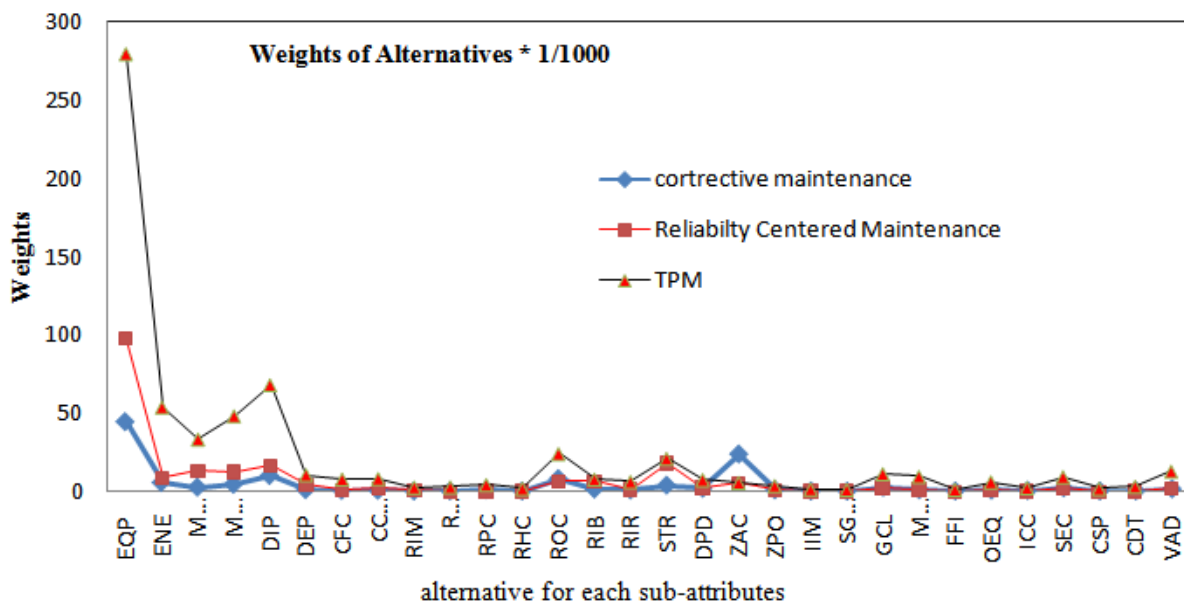


Figure 7.0 The final scores of each alternative

VIII. CONCLUSIONS

How each alternative is performing with regard to each subattribute can be seen from figure 7.0 and table 4.0. The data also show that which subattributes contribute more among the alternatives by comparing the weights across the alternatives. The relative weight in overall hierarchy are obtained from overall criteria weight in Table 3.0. and refer figure 5.0. TPM alternative for most subattributes is scoring maximum except one attribute ZAC of corrective maintenance (refer figure 6.0 or 7.0). TPM has scored highest among other two maintenance strategies corrective and reliability centered maintenance. Thus TPM can be chosen as strategy. The sub attributes scoring highest under any alternative should refer the strategy to which it outperforms. The ZAC should be considered to yield best performance when its association with corrective maintenance is secured for implementation. Any subattribute belonging to any alternative and scoring highest must follow the practices of alternative under consideration. The alternatives with highest scores over all the subattributes will be accepted as best strategy for adoption and implementation.

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