TOTAL PRODUCTIVE MAINTENANCE USING COSINE MAXIMIZATION MULTI ATTRIBUTE METHOD

[a]SUNIL KUMAR SHARMA1, [b]SUBHASH CHANDRA,
[c]KUMAR ARPIT SINGH

[a]College of Computer and Information Sciences, Majmaah University,Arabia Alsawany St, King Fahd, Al Majma'ah 15362, Saudi Arabia.
[b]Mechanical Engineering department, Federal Technical vocational and educational training institute, Addis Ababa, 190310 Ethiopia.
[c]Mechanical Engineering department, G.L. Bajaj Institute of Technology & Management, Plot No.2, Knowledge Park III, Greater Noida, Uttar Pradesh 201306, India.
email: [a]s.sharma@mu.edu.sa, [b]suchandra404@gmail.com, [c]kumararpitchndra@gmail.com.

Abstract: Leading manufactures off late pay sincere attention towards maintenance management to improve equipment productivity, capital productivity, material productivity, as well the labor. Total productive maintenance (TPM) has emerged in recent times a promising and participatory equipment maintenance system. TPM implementation is not a cut and paste solution but a careful thought must be given prior to its implementation about its evolution, beliefs and ethos. A number of practices are collectively responsible to yield expectable outcomes. These practices are referred as attributes. The attributes weight is computed with the aid of cosine maximization multi attribute decision model (CMMADM). The attributes having high scores do impart greater impact vis a vis attributes having low score in the pursuit of achieving objectives. Three continuing strategies viz. corrective maintenance (CM), reliability centered maintenance (RCM), and TPM are evaluated using CMMADM. Relative importance on the basis of relative weights is used to set priority areas. In order to make implementation effective, each attribute must be vigorously explored about its completeness, cultural aspects, stringent requirement, and inter alia commitments needed from one and all concerned.

Keywords: Cosine Maximization Multi Attribute Decision Model (Cmmadm), Total Productive Maintenance (Tpm), Analytic Hierarchy Process, Priority Vector, Consistency Index

1. Introduction

It is considered that performing preventive maintenance is an unnecessary action which causes extra cost to the organization (Mohamad & Tabikh, 2011). But companies have realized that the unplanned functional failure of equipment brings emergency, failure to meet delivery schedules, production loss, secondary damages, and prolonged down time (Shamsuddin, 2005). Maintenance is now a strategic tool to provide competitive edge. An appropriate system of maintenance amongst the existing's like reliability centered maintenance (RCM), corrective maintenance (CM), condition based maintenance (CBM), or total productive maintenance (TPM) may be selected that suits the company. A cursory review of TPM implementation shows that TPM is integration of various manufacturing functions in a coherent manner. TPM is primarily based upon total employee participation, continuous improvement, and complete state of production with zero defects, zero accidents. The practices sprawling across value added activities have to be perceived differently in prioritizing (Kodali et al, 2009). The value-added activities that are involved towards the end of production processes must be paid more emphasis compared to the processes at the beginning of conversion. All the value-added efforts will go in vain if processes at the end of conversion are defective (Tlusty et al, 1990; Deighton-Smith & Jacobs, 1997; Aven & Dekker, 1997; Sharma & Shudhanshu, 2012).

The implementation of TPM has not always succeeded. Some of the reasons of failure are as follows. Lack of commitment and sincere efforts of top management is one of the reasons of failure. The training that fails to provide knowledge of TPM in breadth and depth is another major cause of failure. Collective decision making through persistent and bottom up flow of information provides opportunity to know the level of skills acquired by team players. A well thought planning that takes care of all possible loop holes and lacunae is quintessential to ensure preemptive measures to proceed. Having right strategy and right execution are sine qua known for successful implementation of TPM. The relative rankings of all the attributes is done scrupulously based on opinion of experts and field data. The weightage of each attributes can be obtained with suitable mathematical model like AHP model (Saaty, 1980), priority vector from a pair-wise comparison matrix PCM (Wu & Xu, 2012), rank ordering (Kadzin´ ski, et al., 2012; Siraj, et al., 2012, B. Srdjevic & Srdjevic, 2013). The attributes which will obtain high rank will ranked high towards their contribution for the probable outcomes. The validity of the derived priority vectors mainly relies on the design of prioritization methods and PCM of experts' judgments. This paper emphasizes on prioritization the attributes using improved cosine maximization. The approach is scientific in solving the problems of diversified nature of criteria and alternatives in obtaining pragmatic priorities. The industries may embrace the best methods to keep themselves upgraded to face fierce completion emanating from global and local competitors (Poduval & Pramod, 2015). Skilled maintenance workmanship is invariably missing in most traditional industries. This causes dependence on external maintenance agencies and thus attrition of in-house skills.

Every industry must harness its intellectual potential to achieve the unparalleled productivity of all its resources. TPM has proved time and again that successful implementation of TPM has impact on wide spectrum of productivity, quality and safety standards (Shamsuddin, 2005; Tabikh et al., 2011; Kodali et al., 2009).

World class maintenance is attempting to break down all barriers that hampers the performance of any individual. It seeks to get best from human capital. It seeks the mind set of fixing the problem, rather blame fixing. All the departments must provide synergic support and input to others to minimize the efforts in utilizing the existing information (Ahmed & Mohiuddin, 2005). The organizational system is designed in such a way that the organizational data is available to make use of it. Waste of any type, idle time of machines, speed loss, work in process(WIP), long lead times, long make span time etc. are aimed to be measured at first stance to embark upon improvement drive. TPM aims at raising the plant productivity by upholding the availability, performance rate and quality rate of each machine (Ahuja & Khamba, 2008).

Parochial thinking in the past has widened the gap between production and maintenance departments. The compartment thinking between production staff and maintenance staff has to be relooked with broader perspectives towards achieving the common goal jointly. It demands better cooperation and coordination between two departments rather having individualistic approach. A comprehensive system of maintenance has to be developed (Ahmed et al, 2004). It needs irrevocable and impeccable understanding of subject, roles, objectives and measureable outcomes. The standards will keep rising to new levels every time. Thus deficit capability will pose intimidations and aggravate to gap between the required and what is delivered. Thus, tutelage the work force on continuous basis is inevitable for sustainability and meeting organization goals effectively (Zavadskas et al, 2016; Hashim et al, 2012; Ravishankar et al., 1992).

2. Development of the Model

Industries must prepare themselves to face formidable competition in the age of globalization for sustainable presence. Careful thoughts have to be given before accepting views of others as different strategies may suit to different conditions. A wide ranging, all-inclusive analysis of the problem is required that includes vital key maintenance practices to start with. A Delphi study is conducted to provide the initial relative importance of each attributes. The most consistent data are considered for pairwise comparison and consistency for the case situation given in Table 1. The schematic diagram of the model is shown in Figure 1.

Table 1. Information of industry type, sale, vision and mission

Industry type	Mass production
Sales volume	Average
Vision	To be a company of International standard
Mission	Meeting the ever changing customer needs through upgradation of products, processes and people

As it can be seen in Table 1, the case situation (such as vision and mission) must be duly taken care of to become world class performer. Performance of production system also rely heavily on the skills of work force (Sugimori et al, 1977; Schonberger, 1982; Sakuri, 1986)

The vital 30 elements that a promising maintenance system must support are given below:
Equipment and machines efficiency [EQM], Cellular manufacturing and focused factory [CMF], Reduced inventories [REI], Improved worker productivity and skills [IWP], Statistical process control [SPC], Total quality control [TQC], Total quality people [TQP], Quality circle [QCL], Reduced labour cost [RLC], Maintenance system cost [MSC], Over all equipment effectiveness [OEE], Energy consumption [ECN], Operating cost [OPC], Breakdown cost [BDC], Reduction in rejects [RIR], Flow manufacturing [FLM], Buyer supplier linkage [BSL], Improved employee health and safety [IEH], Eco-efficient manufacturing [EEM], Suggestions schemes [SGS], Small group activities[SGA], Organizational culture[ORG], Improved worker motivation [IWM], Over all employee participation [OEP], Autonomous maintenance [AUM], Cooperation and coordination [ICC], Self-realization [SRL], Customization [CSP], Customer satisfaction [CSA], and Value addition [VAD]

The vital potential attributes for the development of CMMADM model to evaluate the priority weights are grouped and stated below:

EQM, CMF, REI, And IWP are considered part of Production System Performance [PSP]. The sub attributes SPC, TQC, TQP, and QCL are grouped to form attribute Quality [QLT]. Cost [CST] attribute is comprised of sub-attributes RLC, MSC, OEE, ECN, OPC, BDC, and RIR.

FLM and BSL are clubbed with criterion Supply [SPL]. IEH, and EEM are considered part of attribute Work Place Safety [WPS]. SGS, SGA, ORG, and IWM are considered sub attribute of Collective Working [COW].

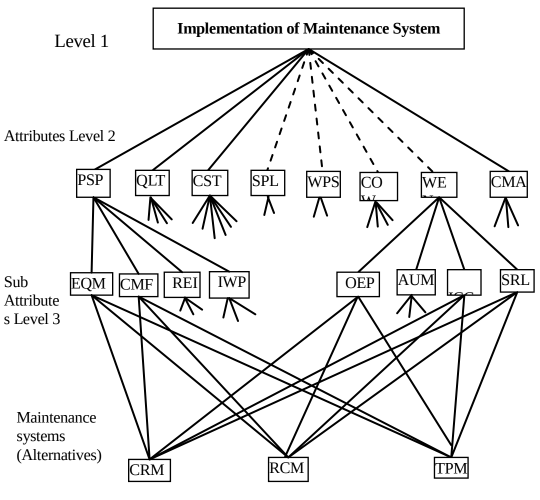

Figure 1. schematic of multi criteria model

OEP, AUM, ICC, and SRL are elements of Working Environment [WEN]. CSP, CSA, and VAD are sub attributes of Competitive Advantages [CMA].

3. Description of Attributes

Each attribute is explained in brief in the following paragraphs.

Production system performance [PSP]: Performance of manufacturing system depends upon how well the combined efforts of all functions are directed towards the upkeep of machines (Prabhuswamy et al, 2013, Rousseeuw & Leroy, 2005). Single minute exchange of dies (SMED) (Hong, 1992), lean manufacturing (Ericsson, 1997) and JIT system (Hall, 1983) must be embraced to raise plant performance. Autonomation, equipment efficiency (Bartezzaghi et al., 1992, Guinipero, 1990), cellular manufacturing (Vrat et al, 1993, Saxena & Sohay, 1999), and focused factory.

Quality [QLT]: The main aim of maintenance system is prevention and early detection of defects. All those who are affecting the quality of parts like manufacturing processes, machines, and workers are built with total quality and process control to deliver least possible rejects. Continuously upgrading the manpower should be companywide culture (Golhar & Stamm, 1991). There are deterrence's available in the company, due to workers of diversified background, ethnicity, and ranks must not have shadow on quality. Quality is viewed as a step forward in producing future products for today's market. It needs visionary foresightedness to predict what future beholds (Crosby, 1992: Crosby, 2017).

Cost [CST]: It aims at maximization of profits by reducing costs of process operations, supervision, labor, storage, handling and distribution (Guinipero & Law, 1990). Reduction drive starts with the conjecture that existing processes can always be improved upon leading to narrow way to material conversion (Kodali & Chandra, 2001; Hall, 1983; Shaomin & Clements, 2005). Thus, alternatives in every field must be explored that will eventually lead to higher performance (Chandra, 2017).

Supply [SPL]: Material in the supply chain must flow in compliance with demand per unit time without intermittent storage. The strategies that can facilitate small lot dependable deliveries without adding cost. JIT delivery system of proven quality products without further intermittent quality checks on supply chain (Korgaonkar, 2017; Martin & Sandras, 1990).

Work place safety [WPS]: Work place must be the safe place to work, free from occupational hazards, illness, injuries, accidents and near misses. Industrial health deals with identification, assessment and control of environmental factors harmful to the health of employees and society at large.

Collective working [COW]: The Japanese work culture like dedication, commitment, perseverance has great bearing in successful implementation of world class maintenance [Shamsuddin Ahmed, 2005]. Team work always outperforms the sum of individual output. Work force is motivated to have sense of belongingness, purpose, and spirit the corps (Bowels, 2009).

Work Environment [WEN]: First and foremost, thing for an organization that wants to be successful must believe in developing human resource through investment on Manpower (Coetzee,1999; Park & Han, 2001). Organizations led by supportive, encouraging, and committed top management are more likely to perform well (Patterson et al., 1995; Gondhalekar, 1996).
Competitive Advantages [CMA]: Searching better methods to raise productivity and quickly respond to the market changes is the need of the global competition (Ahuja, 2008). The value of goods or services provided sounds better than the worth of pay (Jonsson & Lesshammar, 1999).

4. Alternatives

Corrective Maintenance (COM), reliability centered maintenance (RCM), and total productive maintenance (TPM) are considered for quantifying the relative score of each for each sub-attribute.

[COM]: The corrective maintenance begins with detection of problem initiation due to parts deterioration. COM identifies, and rectify the fault. Corrective tasks can aid to spot and fix the existing problems (Wang et al., 2014; Ding et al., 2009). The purpose of corrective maintenance is improving equipment instant readiness, reduced breakdown, maintainability, and safety. Maintenance information, obtained from CRM, is useful for maintenance prevention, fault finding and fault fixing. CRM aims to improves equipment and its components design so that equipment life can be prolonged.

Reliability Centered Maintenance [RCM]: A product may fail due to poor design, defective manufacturing, improper processes or services. A reliability-centered maintenance (RCM) process identifies the ways in which product fails. It also identifies causes of these failures. The assessment of degradation phenomena and preemptive measures towards the prevention of failures must be accorded right place in realizing the failure free performance (ETI et al, 2006).

Total Productive Maintenance [TPM]: TPM is about developing maintenance skills in an operator, top management participation, clean up practices, planned maintenance and continuous maintenance skill upgrade. TPM strives a balance between the expected level of skills for maintaining the machine along with normal skills needed for operating the machine operator (Borris, 2015; Graisa & Habaibeh, 2011; Suzaituladwini, 2012; Swanson, 2001). Organizational goals are not compromised at the cost of an individual's goals. TPM is not a radically new idea; it is simply to make gradual advancement and to do the right things every time (Yasin et al, 2001).

5 Cosine Maximization Method

Priority weights derivation using cosine maximization is discussed below (Kou & Lin, 2013).: Condition 1: Matrix A $=(a_{ij})_{n\times n}$ is said to be positive reciprocal if $a_{ij} > 0$ and $a_{ij} = 1/a_{ji}\ \ \forall\ \ i, j \in \{1, 2, 3, \dots\dots, n\}$.

Condition 2: A non-negative reciprocal matrix A $=(a_{ij})_{n\times n}$ is said to be perfectly consistent if $a_{ij} = a_{ik}a_{kj}\forall\ i, j\ , k\ \in \{1, 2, 3, \dots\dots, n\}$.

Condition 3: A Similarity measure between two vectors t_i and t_j, $SM\ (t_i, t_j)$ in a 'n' dimensional vector space V is a mapping from $V \times V$ to range $[0, 1]$. Thus SM $(t_i, t_j) \in [0, 1]$.

Property 1: The similarity measure in condition 3 has the following features:

a. $\forall\ t_i \in V,\ SM(t_i, t_j) = 1$;
b. $\forall\ t_i, t_j \in V, SM(t_i, t_j) = 0$ if t_i *and* t_j are not similar to all;
c. $\forall t_i, t_j, t_k \in V, SM(t_i, t_j) < SM(t_i, t_k)$ If t_i is more like to t_k then it is like t_j.

The objective is to define a similarity mapping such that more similar vectors have a higher similarity values.

Theorem 1: Let two vectors be $t_i = (t_{i1}, t_{i2}, t_{i3}, \dots\dots, t_{in})^T$ and $t_j = (t_{j1}, t_{j2}, t_{j3}, \dots\dots, t_{jn})^T$, then the cosine similarity measure between two vectors t_i and t_j is defined as

$$\mathrm{CSM}(\mathrm{t_i}, \mathrm{t_j}) = \left(\sum_{k=1}^{n} \mathrm{t_{ik}t_{jk}}\right) \Big/ \left(\sqrt{\sum_{k=1}^{n} \mathrm{t_{ik}^2}}\sqrt{\sum_{k=1}^{n} \mathrm{t_{jk}^2}}\right) \quad (1)$$

The reliable priority vector from a PCM based cosine similarity measure is derived here.

Let A $= (a_{ij})_{n\times n}$ be a positive reciprocal PCM and $w = (\omega_1, \omega_2, \omega_3, \dots\dots \omega_n)^T$ with $\sum_{i=1}^{n} \omega_i = 1$ and $\omega_i \geq 0 (i = 1, 2, \dots\dots, n)$ be a priority vector from A using some prioritization method.

If A is consistent, it follows that (Satty, 1980)

$a_{ij} = \omega_i/\omega_j i, j\ \in \{1, 2, \dots\dots, n\}$.

From (1), A can be precisely characterized by

$$A = \begin{bmatrix} \frac{\omega_1}{\omega_1} & \frac{\omega_1}{\omega_2} & \cdots & \frac{\omega_1}{\omega_n} \\ \frac{\omega_2}{\omega_1} & \frac{\omega_2}{\omega_2} & & \frac{\omega_2}{\omega_n} \\ \vdots & & \cdots & \vdots \\ \frac{\omega_n}{\omega_1} & \frac{\omega_n}{\omega_2} & \cdots & \frac{\omega_n}{\omega_n} \end{bmatrix} \quad (2)$$

Let A $= (a_{ij})_{n\times n}$ be a positive reciprocal PCM and $w = (\omega_1, \omega_2, \omega_3, \dots\dots \omega_n)^T$ with $\sum_{i=1}^{n} \omega_i = 1$ and $\omega_i \geq 0 (i = 1, 2, \dots\dots, n)$ be a priority vector from A using some prioritization method.

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According to Eq. 2, A can be viewed as consisting of the following n column vectors:

$(\omega_1, \omega_2, \omega_3, \dots\dots \omega_n)^T/\omega_i, i = 1, 2, \dots\dots, n$.

Let C_j be the cosine similarity measure between the priority vector w and the jth column vector a_j of A, where $w = (\omega_1, \omega_2, \omega_3, \dots\dots, \omega_n)^T$ and $a_j = (a_{1j}, a_{2j}, a_{3j}, \dots\dots, a_{nj})^T$

$$C_j = CSM(w, a_j) = \left(\sum_{k=1}^{n} \omega_k a_{kj}\right) \Big/ \left(\sqrt{\sum_{k=1}^{n} \omega_k^2}\sqrt{\sum_{k=1}^{n} a_{kj}^2}\right), \quad j = 1, 2, \dots, n \quad (4)$$

Since $a_{ij} = \frac{\omega_i}{\omega_j}, i, j\ \in \{1, 2, \dots\dots, n\}$, we have

$$C_j = CSM(w, a_j) = \left(\sum_{k=1}^{n} \omega_k \frac{\omega_i}{\omega_j}\right) \Big/ \left[\sqrt{\sum_{k=1}^{n} \omega_k^2}\sqrt{\sum_{k=1}^{n}\left(\frac{\omega_i}{\omega_j}\right)^2}\right] = 1 \quad (5)$$

$$j = 1, 2, \dots\dots, n$$

The measure of cosine similarity between the derived priority vector and each column vector of A is equal to 1. Provided that A is perfectly consistent.

If A is not perfectly consistent, from Definition 3 it follows that $0 \leq C_j < 1$

The cosine similarity measure between the derived priority vector and each column vector of a PCM should be equal to 1 to derive a reliable priority vector. An optimization model thus is as follows:

$$Maximize\ C = \sum_{j=1}^{n} C_j = \sum_{j=1}^{n}\sum_{i=1}^{n} \omega_i a_{ij} \Big/ \left(\sqrt{\sum_{k=1}^{n} \omega_i^2}\sqrt{\sum_{k=1}^{n} a_{ij}^2}\right)$$

$$\text{Subject to} \begin{cases} \sum_{i=1}^{n} \omega_i = 1, \\ \omega_i \geq 0,\ \ i = 1, 2, \dots\dots, n \end{cases} \quad (6)$$

We set $\widehat{\omega_i} = \frac{\omega_i}{\sqrt{\sum_{k=1}^{n} \omega_k^2}} \geq 0, \quad i = 1, 2, 3 \dots\dots, n.$

And $b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{n} a_{kj}^2}} > 0, \quad i, j = 1, 2, 3 \dots\dots, n \quad (7)$

Then we have

$\sum_{i=1}^{n} \widehat{\omega_i^2} = 1.$ (8)

and

$\sum_{i=1}^{n} b_{ij}^2 = 1.$

Optimization model (Eq. 7) can be transformed into the following optimization model:

$$Maximize\ C = \sum_{j=1}^{n} C_j = \sum_{j=1}^{n}\sum_{i=1}^{n} b_{ij}\widehat{\omega_i} = \sum_{j=1}^{n}\left(\sum_{i=1}^{n} b_{ij}\right)\widehat{\omega_i}$$

(9)

Subject to $\begin{cases}\sum_{i=1}^{n} \widehat{\omega_i^2} = 1, \\ \widehat{\omega_i} \geq 0,\ \ i = 1, 2, \dots \dots \dots, n\end{cases}$ (10)

With regard to the optimization model (Eq. 10), the following conditions hold true.

Theorem 2. If $\widehat{w^*} = (\widehat{\omega_1^*}, \widehat{\omega_2^*}, \widehat{\omega_3^*}, \dots \dots \dots, \widehat{\omega_n^*})$ is the optimal solution for the optimization model (12) and C^* is the optimal objective function value of it. Then

$\widehat{\omega_i^*} = b_{ij} = \frac{\sum_j^n b_{ij}}{\sqrt{\sum_{k=1}^{n}\left(\sum_j^n b_{kj}^2\right)^2}},\quad i = 1, 2, 3 \dots \dots, n$ (11)

$C^* = \sqrt{\sum_{i=1}^{n}\left(\sum_j^n b_{ij}^2\right)^2}$
(12)

Proof. Maximum point exits for optimization model (12) for abounded vector $\hat{w} = (\widehat{\omega_1}, \widehat{\omega_2}, \dots \dots \dots \dots \widehat{\omega_n})^T$ and C is a continuous function of $\hat{w}$. To find the maximum point, the following Lagrangian function is formed.

$L(c, \lambda) = C + \lambda\left(\sum_{i=1}^{n} \widehat{\omega_i^2} - 1\right)$
(13)

$= \sum_{j=1}^{n}\left(\sum_{i=1}^{n} b_{ij}\right)\widehat{\omega_i} + \lambda\left(\sum_{i=1}^{n} \widehat{\omega_i^2} - 1\right)$ (14)

Taking the partial derivatives of the Lagrangian function with respect to $\widehat{\omega_i}$ and letting them be zero.

$\frac{\partial L(c,\lambda)}{\partial \widehat{\omega_i}} = \sum_{i=1}^{n} b_{ij} + 2\lambda\widehat{\omega_i} = 0, i = 1, 2, 3 \dots \dots, n$

(15)

This yields

$$\widehat{\omega_i} = -\sum_{j=1}^{n} b_{ij}/2\lambda$$

Since

$$\sum_{i=1}^{n} \widehat{\omega_i^2} = 1, \qquad \widehat{\omega_i} \geq 0\ and \quad b_{ij} \geq 0$$

Then,

$$\sum_{i=1}^{n}\left(\sum_{j=1}^{n} b_{ij}/2\lambda\right)^2 = 1, \qquad \sum_{i=1}^{n} \widehat{\omega_i^2} = 1\ , \lambda < 0.$$

It follows that

$\lambda = -\sqrt{\sum_{k=1}^{n}\left(\sum_{j=1}^{n} b_{kj}\right)}$ (16)

The results obtained are as follows:

$$\widehat{\omega_i^*} = -\sum_{j}^{n} b_{ij}\ /2\lambda = \frac{\sum_j^n b_{ij}}{\sqrt{\sum_{k=1}^{n}\left(\sum_j^n b_{kj}^2\right)^2}},\qquad i = 1, 2, 3 \dots \dots, n$$

and $C^* = \sum_{j=1}^{n}\left(\sum_{i=1}^{n} b_{ij}\right)\widehat{\omega_i^*}$

$=\sum_{j=1}^{n}\left(\sum_{i=1}^{n} b_{ij}\right)\sum_j^n b_{ij}\ /\sqrt{\sum_{k=1}^{n}\left(\sum_j^n b_{kj}^2\right)^2}$

$= \sqrt{\sum_{k=1}^{n}\left(\sum_j^n b_{kj}^2\right)^2}$ (17)

Furthermore, we write

$\Omega = \{w = (\omega_1, \omega_2, \omega_3, \dots \dots, \omega_n)^T | \sum_{i=1}^{n} \omega_i = 1,\quad \omega_i > 0 (i = 1, 2, \dots \dots, n)\}$ (18)

Then the objective function C of optimization model (7) has a unique maximum point

$w^* = (\omega_1^*, \omega_2^*, \omega_3^*, \dots \dots \dots, \omega_n^*)^T \in \Omega.$
(19)

This is to say, the optimization model can produce a unique solution, avoiding the inconvenience of how to chose one solution from a set of solutions. The unique solution can be indirectly determined by the optimization model. We have

$\omega_i^* = \widehat{\omega_i^*}\sqrt{\sum_{k=1}^{n} \omega_k^2},\quad i = 1, 2, 3 \dots \dots, n$

(20)

Let

$\beta = \sqrt{\sum_{k=1}^{n} \omega_k^2}\ \geq 0$

(21)

Then (15) can be equivalently written as

$\omega_i^* = \widehat{\omega_i^*}\ \beta \quad i = 1, 2, 3 \dots \dots, n$
(22)

Where β is called the weight assignment coefficient?

Solving the following system of the equation

$\begin{cases}\sum_{i=1}^{n} \omega_i^* = \sum_{i=1}^{n} \widehat{\omega_i^*}\ \beta \\ \sum_{i=1}^{n} \omega_i^* = 1\end{cases}$

Hence

$$\beta^* = 1/\sum_{j=1}^{n} \widehat{\omega_j^*}$$

From (21), we have

$$\omega_i^* = \widehat{\omega_i^*}\,\beta = \widehat{\omega_i^*}/\sum_{j=1}^{n}\widehat{\omega_j^*} \quad i = 1,2,3 \dots\dots,n \qquad (23)$$

Theorem 3. Let PCM A $=(a_{ij})_{n\times n}$ be perfectly consistent, the CM method can precisely derive the optimal objective function value $C^* = n$ and the priorities $\omega_j^* = 1/\sum_{i=1}^{n} a_{ij}$ $(j = 1,2,3 \dots\dots,n)$.

Proof. Let $w = (\omega_1, \omega_2, \omega_3, \dots\dots, \omega_n)^T$ be a priority vector derived from A. Since A is perfectly consistent, it follows that

$a_{ij} = \frac{\omega_i}{\omega_j} a_{ij} = a_{ik}a_{kj}$ for all $i,j,k \in \{1,2,3,\dots\dots,n\}$.

$$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{n} a_{kj}^2}} = b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{n}\left(\frac{a_{ij}}{a_{ik}}\right)^2}} = \frac{1}{\sqrt{\sum_{k=1}^{n}\left(\frac{1}{a_{ik}}\right)^2}} = \frac{1}{\sqrt{\sum_{k=1}^{n}(a_{ki})^2}} \qquad (24)$$

Thus,

$$\sum_{j=1}^{n} b_{ij} = \sum_{j=1}^{n}\left(\frac{1}{\sqrt{\sum_{k=1}^{n}(a_{ki})^2}}\right) = \frac{n}{\sqrt{\sum_{k=1}^{n}(a_{ki})^2}} = \frac{n}{\sqrt{\sum_{k=1}^{n}\left(\frac{\omega_k}{\omega_i}\right)^2}} = n\omega_i \qquad (25)$$

The pairwise matrix for the sub criterion of cost criterion is given below.

Table 2. Pair-wise matrix of cost criterion

	RLC	MSC	OEE	ECN	OPC	BDC	RIR
RLC	1	1/3	1	3	1/3	1/7	1/3
MSC	3	1	1	3	1/3	1/5	1/7
OEE	1	1	1	2	1/5	1/3	1/3
ECN	1/3	1/3	1/2	1	1/5	1/9	1/5
OPC	3	3	5	5	1	3	5
BDC	7	5	3	9	1/3	1	2
RIR	3	7	3	5	1/5	1/2	1

The values of relative weights W_1(RLC), W_2(MSC), W_3(OEE), W_4(ECN), W_5(OPC), W_6(BDC), W_7(RIR) obtained upon the application of CMM are 0.0666, 0.087, 0.0622, 0.0336, 0.3237, 0.2498, and 0.177 respectively.

6 Multi-Attribute Decision Model (Madm)

MADM allows decision makers to concoct the enigmatic and interacting factors of complex, unstructured problem into a clustered hierarchy. Pair-wise square comparison matrices are developed for each level. An attribute in the higher level is said to be a governing attribute for those in the lower level, since it contributes to it or affects it. The alternative analysis for the lowest level of sub attributes is carried out in the similar manner as above keeping sub attribute in mind for which the alternatives are being compared. Table 2. illustrates the pairwise comparison of cost criterion.

6.1 Weightages of Attributes

The weightings of attributes i.e. Production system performance [PSP], Quality [QLT], Cost [CST], Supply [SPL], Work place safety [WPS], Collective working [COW], Work environment [WEN], and Competitive advantages [CMA] are obtained first. The same are summarized below (also see Figure 2).

Table3. Weightages of attributes level 2

Attribute	PSP	QLT	CST	SPL	WPS	COW	WEN	CMA
weightage	0.0278	0.0556	0.0833	0.1111	0.2222	0.1667	0.1944	0.2222

The weightages of sub attributes level 3 of production system performance are given in table 3. If 80-20 rule is applied, then the work place safety and competitive advantages must be focused first followed by working environment and collective working.

Table 4. Weightages of sub attributes level 3 of production system performance

Sub attribute	EQM	CMF	REI	IWP
weightage	0.6438	0.1425	0.0942	0.1196

7. Relative weights through CMMADM

The relative weights of attributes of level 1 are obtained in table 2. The work place safety and competitive advantages are valued highest. This is followed by working environment and collective working. There is growing need to have emphasis on safety and gaining competitive advantage on top priority in the industry under consideration. The weightages of sub-attributes for each level and alternatives are given in Table 4. The data summary table is created in table 5 for the justification of alternatives.

7.1 Interpretation of weightage of sub attributes

The weightages of grouped sub attributes belonging to preceding attribute at each level are calculated based on expert inputs. The weightage of sub attributes improved employee health and safety [IEH] under the attribute Work place safety [WPS] measures 0.833. Value addition [VAD] under competitive advantage [CMA] is rated 0.6477. The overall weights of [IEH], and [VAD] are 0.18516, and 0.14392 respectively. Similarly the relative ranking of sub attributes viz. Over all employee participation [OEP], Autonomous maintenance [AUM]], Improved cooperation and coordination [ICC], Self-realization [SER] for the attribute working environment [WEN] are weighted 0.0685, 0.3353, 0.1764, and, 0.4199 respectively. Self-realization [SRL] will make great contribution for the attribute [WEN] to which it is affiliated. Thus strategies must be oriented in a manner to give due emphasis.

The second priority under the same attribute is accorded to autonomous maintenance [AUM]. The absolute weightages of sub attributes at level 3 viz. EQM, CMF, REI, IWP, SPC, TQC, TQP, QCL, RLC, MSC, OEE, ECN, OPC, BDC, RIR, FLM, BSL, IEH, EEM , SGS , SGA, ORG, IWM, OEP, AUM, ICC, SRL , CSP, CSA, VAD are given in table 4.

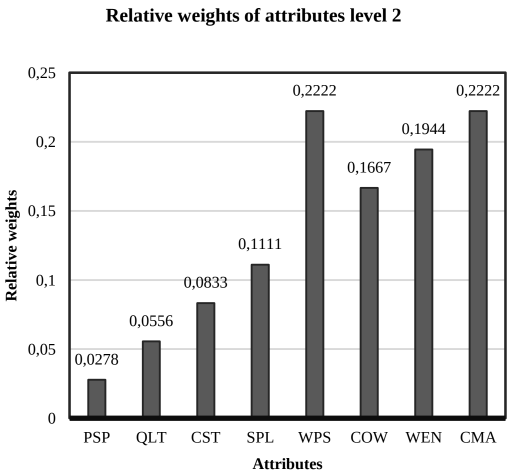

Figure 2. Histogram of weights of attributes of level 1

The improved employee health and safety [IEH] is ranked highest priority, followed by value addition [VAD], then Flow manufacturing [FLM], and self-realization [SRL] and so on. The same is presented in figure 3.

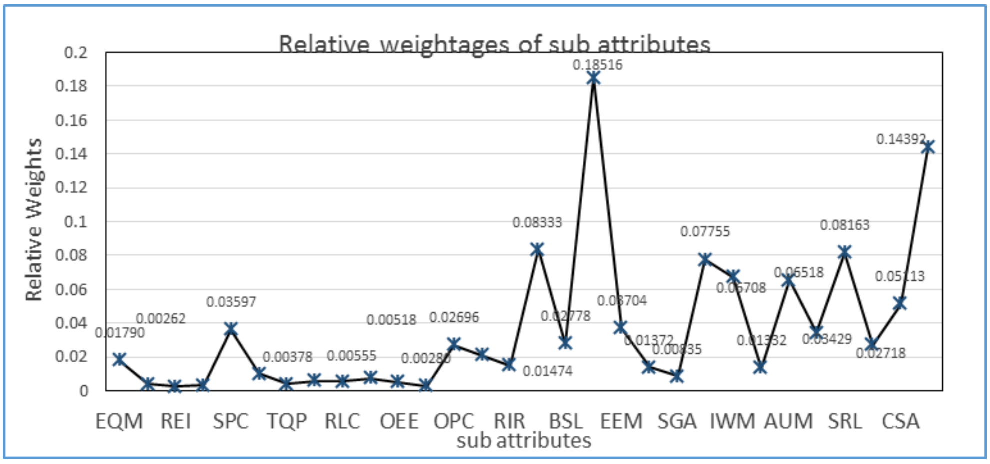

Figure 3. Absolute weights of sub attribute level 3

The alternatives RCM, CRM, and TPM are evaluated across all the level3 sub-attributes as shown in table 4. The total sum of alternative TPM is highest i.e. 0.625298. Thus TPM in total sounds better compared to RCM and CRM. The alternative RCM is ranked second with overall score 0.251463 and lowest sum is for alternative CRM. The graphs for all the three alternatives are plotted in figure 4.0 for analysis purpose and identifying the best performing sub attributes among the three alternatives.

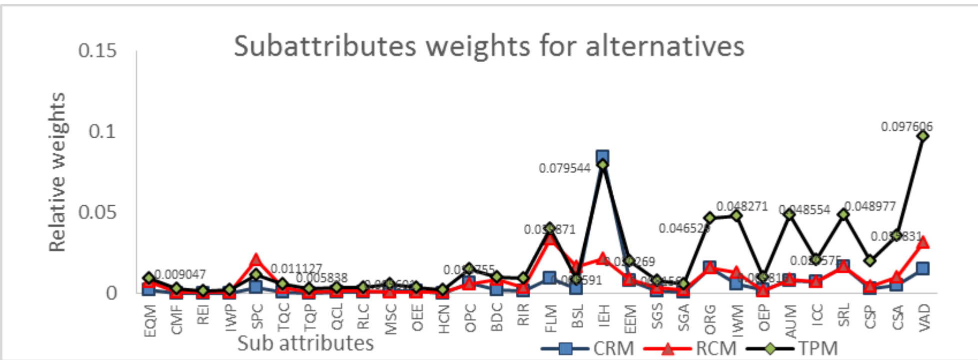

Figure 4. Priority weight of sub attributes for altern

8 Conclusions

The sub attributes of level 3 as stated in table 4 and described in the development of model gets their overall standing and relative rankings in the hierarchical cluster.

The alternative strategies corrective maintenance [CRM], reliability centered maintenance [RCM], and total productive maintenance [TPM] are evaluated on eight criteria production system performance [PSP], quality [QLT], cost [CST], Supply [SPL], Work Place Safety [WPS], Collective Working [COW], and competitive Advantages [CMA]. The evaluation of the model can be viewed from Figures 3 and 4. The total sum of alternative TPM is highest as given in Table 5. i.e. data summary. Thus total productive maintenance is most promising for the case situation given. However, changing the corporate culture to rightly implement TPM is easier said than achieved.

Table 5. The weightages of sub-attributes for each level and alternatives

Attrib.	Level2-Wt	Sub-attribute Level 3	Level 3-Wt	Absolute wt. of sub attrib.	Weightages of Alternatives		
					CRM	RCM	TPM
PSP	0.0278	EQM	0.643	0.0178	0.111	0.383	0.505
		CMF	0.142	0.0039	0.084	0.196	0.719
		REI	0.094	0.0026	0.057	0.347	0.594
		IWP	0.119	0.0033	0.074	0.286	0.639
QLT	0.0556	SPC	0.647	0.0359	0.109	0.581	0.309
		TQC	0.178	0.0099	0.075	0.334	0.589
		TQP	0.068	0.0037	0.061	0.221	0.716
		QCL	0.106	0.0059	0.074	0.286	0.639
CST	0.0833	RLC	0.066	0.0055	0.074	0.286	0.639
		MSC	0.087	0.0072	0.158	0.069	0.772
		OEE	0.062	0.0051	0.230	0.122	0.647
		ECN	0.033	0.0028	0.088	0.243	0.668
		OPC	0.323	0.0269	0.241	0.211	0.547
		BDC	0.249	0.0208	0.115	0.406	0.478
		RIR	0.177	0.0147	0.106	0.262	0.630
SPL	0.111	FLM	0.75	0.0833	0.115	0.406	0.478
		BSL	0.25	0.0277	0.109	0.581	0.309
WPS	0.2222	IEH	0.833	0.185	0.455	0.115	0.4296
		EEM	0.166	0.0370	0.211	0.241	0.547
COW	0.1667	SGS	0.082	0.0137	0.128	0.276	0.594
		SGA	0.050	0.0083	0.088	0.243	0.668
		ORG	0.465	0.0775	0.2	0.2	0.6
		IWM	0.402	0.0670	0.084	0.196	0.719
WEN	0.1944	OEP	0.068	0.0133	0.168	0.094	0.737
		AUM	0.335	0.0651	0.120	0.134	0.744
		ICC	0.176	0.0342	0.2	0.2	0.6
		SRL	0.419	0.0816	0.2	0.2	0.6
CMA	0.2222	CSP	0.12	0.0271	0.112	0.162	0.724
		CSA	0.23	0.0511	0.102	0.196	0.700
		VAD	0.64	0.143	0.103	0.217	0.6782

Table 6. Data summary

Sub-attri. Level 3	Weightages of Alternatives		
	CRM	RCM	TPM
EQM	0.001987	0.006864	0.009047
CMF	0.000333	0.000778	0.002851
REI	0.000151	0.000911	0.001557
IWP	0.000247	0.000952	0.002126
SPC	0.003943	0.020900	0.011127
TQC	0.000748	0.003310	0.005838
TQP	0.000234	0.000838	0.002709
QCL	0.000441	0.001701	0.003801
RLC	0.000412	0.001588	0.003548
MSC	0.001145	0.000501	0.005601
OEE	0.001192	0.000634	0.003356
ECN	0.000247	0.000682	0.001870
OPC	0.006515	0.005698	0.014755

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