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Maintenance Maturity Level Identification using MABAC Method: An Adaptation of TPM Pillars in a Public Service Sector

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Having systematic maintenance practices does sustain the lifecycle of the facilities. Hence, engineers have always been seeking for practical approaches toward providing better maintenance scheme. Such attempts have resulted in the appearance of numerous maintenance management models including the most commonly accepted one, that is, the total productive maintenance (TPM). Although the concept of TPM and its corresponding pillars have extensively been investigated in the recent literature of Maintenance Engineering and Management, the majority of the previous research attempts, including the multi-criteria decision making (MCDM) applications, have handled them within the context of the manufacturing sector; and almost none of them have been applied in the services sector. This paper proposes the multi-attributive border approximation area comparison (MABAC) method, a newly developed MCDM technique, as a tool upon which eight TPM pillars are evaluated in order to identify the maintenance maturity level in a public service sector. The investigations indicate that the proposed model equips maintenance engineers with an insight into the mechanism upon which TPM pillars can operate effectively. The results of the proposed model indicate that the investigated institution is generally not matured enough to be up to the desired level of TPM performance.

Keywords: MABAC, Maintenance, MCDM, TPM

Introduction

Total productive maintenance (TPM) pillars have extensively been investigated in the recent literature of maintenance engineering and management (MEM). However, the majority of the previous research attempts have handled them only within the context of the manufacturing sector and almost none of these attempts have employed TPMs in the services sector.[1] Moreover, none of the previous studies have utilized such a newly multi-criteria decision making (MCDM) technique as the multi-attributive border approximation area comparison (MABAC) method. This paper aims to propose the MABAC method as a tool upon which eight TPM pillars are evaluated in order to identify the maintenance maturity level in the service sector.

TPM Evaluation using MABAC

In life, “there’s birth, there’s death, and in between there’s maintenance”.[2] Indeed, having systematic maintenance practices do sustain the lifecycle of the facilities. Hence, engineers have always been seeking for practical approaches toward providing better maintenance scheme. Such attempts have resulted in the appearance of numerous maintenance notions and/or maintenance management models such as preventive maintenance (PM), predictive maintenance (PdM), corrective maintenance (CM), maintenance prevention (MP), and finally TPM.[3] The roots of TPM belong to 1964 in which the Plant Maintenance award (PM Award) was launched by the Japan Institute of Plant Maintenance (JIPM) and has been given to such respected companies as Toyota, Nissan, and Mitsubishi.[4] In 1971, the award has been given to Nippondenso Company, a Japan's leading producer of automobile components and one of the leading international producers (currently known as DENSO Corporation), and since then the award is known as a TPM Award.[3,4] The notion of TPM can be defined as an innovative practical approach for improving maintenance efficiency and effectiveness throughout better utilization of resources such as time, materials, equipment, and workers.[5–7] TPM has eight pillars, namely, autonomous maintenance (TPM1), focused improvement (TPM2), planned maintenance (TPM3), quality maintenance (TPM4), education and training (TPM5), safety, health and environment (TPM6), office TPM (TPM7), and development management (TPM8).[3,8,9] These pillars have always been under investigation in the TPM literature.[10,11]

In order to examine the adaptation of TPM pillars in a relatively different workplace environment

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compared to the manufacturing sector, a MABAC model is developed for a case chosen from the public service sector. In order to implement MABAC, six steps should be followed:[12–15]

Step 1: Let ($\tilde{F}$), *m, n refer* to the initial decision matrix, number of criteria, and number of alternatives, respectively. Accordingly, $\tilde{F}$ can be expressed as follows:

$$\tilde{F} = \begin{matrix} & D_1 & D_j & D_m \\ B_1 \\ B_i \\ B_n \end{matrix} \begin{bmatrix} \tilde{f}_{11} & \tilde{f}_{1j} & \tilde{f}_{1m} \\ \vdots & \vdots & \vdots \\ \tilde{f}_{n1} & \tilde{f}_{nj} & \tilde{f}_{nm} \end{bmatrix} \quad \dots (1)$$

Where D_j refers to the criterion j, ($j = 1, \dots, m$); B_i refers to the alternative i, ($i = 1, \dots, n$); and $\tilde{f}_{ij}$ refers to the value of alternative B_i with respect to the criterion D_j.

Step 2: Finding the normalized version of the initial decision matrix, $\widetilde{H}$, as follows:

$$\widetilde{H} = \begin{matrix} & D_1 & D_j & D_m \\ B_1 \\ B_i \\ B_n \end{matrix} \begin{bmatrix} \tilde{h}_{11} & \tilde{h}_{1j} & \tilde{h}_{1m} \\ \vdots & \vdots & \vdots \\ \tilde{h}_{n1} & h_{nj} & \tilde{h}_{nm} \end{bmatrix} \quad \dots (2)$$

Where $\tilde{h}_{ij}$ equals to:

a. In the case of benefit criterion (i.e. higher value is preferable):

$$\tilde{h}_{ij} = (\tilde{f}_{ij} - \tilde{f}_i^-) / (\tilde{f}_i^+ - \tilde{f}_i^-) \quad \dots (3)$$

b. In the case of cost criterion (i.e. lower value is preferable):

$$\tilde{h}_{ij} = (\tilde{f}_{ij} - \tilde{f}_i^+) / (\tilde{f}_i^- - \tilde{f}_i^+) \quad \dots (4)$$

Where $\tilde{f}_i^+$and $\tilde{f}_i^-$ are elements located in $\tilde{F}$ and defined as:

$$\tilde{f}_i^+ = \max(\tilde{f}_1, \tilde{f}_2, \dots, \tilde{f}_n); \quad \dots (5)$$

$(i.e. the\ maximum\ value\ among\ alternatives\ with\ respect\ to\ the\ criterion\ .)$

$$\tilde{f}_i^- = \min(\tilde{f}_1, \tilde{f}_2, \dots, \tilde{f}_n); \quad \dots (6)$$

$(i.e. them\ inimumv\ alue\ among\ alternatives\ with\ respecttothecriterionj.)$

Step 3: Calculating the weighted matrix, $\tilde{R}$, as follows:

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{1j} & \tilde{r}_{1m} \\ \vdots & \vdots & \vdots \\ \tilde{r}_{n1} & r_{nj} & \tilde{r}_{nm} \end{bmatrix} = \begin{bmatrix} \tilde{k}_1(\tilde{h}_{11} + 1) & \tilde{k}_j(\tilde{h}_{1j} + 1) & \tilde{k}_m(\tilde{h}_{1m} + 1) \\ \vdots & \vdots & \vdots \\ \tilde{k}_1(\tilde{h}_{n1} + 1) & \tilde{k}_j(\tilde{h}_{nj} + 1) & \tilde{k}_m(\tilde{h}_{nm} + 1) \end{bmatrix} \quad \dots (7)$$

Where $\tilde{r}_{ij}$ is calculated as:

$$\tilde{r}_{ij} = \tilde{k}_j \,.\, (\tilde{h}_{ij} + 1) \quad \dots (8)$$

Where $\tilde{k}_j$ is the weight of each criterion D_j; ($j = 1, \dots, m$).

Step 4: Determining the Border Approximation Area (BAA) and BAA matrix. For each criterion, BAA is calculated as follows:

$$g_j = (\prod_{i=1}^{n} \widetilde{h_{ij}})^{1/n} \quad ... (9)$$

After determining the value of g_j for each criterion, the BAA matrix ($\tilde{G}$) can be constructed in a form of *m x 1* (m represents the total number of criteria) as follows:

$$\tilde{G} = \begin{matrix} D_1 & D_j & & D_m \\ [g_1 & g_j & \dots & g_m] \end{matrix} \quad \dots (10)$$

Step 5: Determining the distance of the alternatives from BAA, ($\tilde{t}_{ij}$), as follows:

$$\tilde{T} = \tilde{R} - \tilde{G} = \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{1j} & \tilde{r}_{1m} \\ \vdots & \vdots & \vdots \\ \tilde{r}_{n1} & \tilde{r}_{ij} & \tilde{r}_{nm} \end{bmatrix} - \begin{bmatrix} g_1 & g_j & g_m \\ \vdots & \vdots & \vdots \\ g_1 & g_j & g_m \end{bmatrix} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{1j} & t\tilde{r}_{1m} \\ \vdots & \vdots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{ij} & \tilde{r}_{nm} \end{bmatrix} \quad \dots (11)$$

Alternative B_i eht no detacol eb dluoc BAA (i.e. $\tilde{G}$), Upper Approximation Area ($\widetilde{G}^+$), or Lower Approximation Area ($\widetilde{G}^-$); So $B_i \in \{\tilde{G} \cup \tilde{G}^+ \cup \tilde{G}^-\}$. $\tilde{G}^+$ is the area in which the ideal alternative (B^+) is located while $\tilde{G}^-$ is the area in which the anti-ideal alternative (B^-) is located. The location of Alternative B_i is determined as follows:

$$B_i \in \begin{cases} \tilde{G}^+ \ \ if \ \ \tilde{t}_{ij} > 0 \\ \tilde{G} \ if \ \ \tilde{t}_{ij} = 0 \\ \tilde{G}^- \ \ if \ \ \tilde{t}_{ij} < 0 \end{cases} \quad \dots (12)$$

The best alternative is selected based on the number of criteria that belong to the $\tilde{G}^{+}$, that is, it is Imperative for the winner alternative to have as many criteria located within $\tilde{G}^{+}$ as possible. Figure 1 illustrates the upper ($\tilde{G}^{+}$), lower ($\tilde{G}^{-}$), and border ($\tilde{G}$) approximation area.

Step 6: Ranking the alternatives as follows:

$$Z_i = \sum_{j=1}^{m} \tilde{t}_{ij}, \ i = 1, 2, \dots, n; \ j = 1, 2, \dots, m. \quad \dots (13)$$

Where Z_i represents the value through which the ranking of alternative *i* is identified.

Results and Discussion

The eight pillars of TPM were employed in order to formulate the proposed MABAC model. Additionally, according to the corresponding literature of TPM, six criteria were identified in the proposed model: productivity, quality, costs, delivery, safety, morale[3]. These criteria represent the base upon which TPM pillars have been evaluated. Although these criteria have always been involved with respect to manufacturing sectors[1], the attempt herein was to adapt these criteria for the purpose of measuring and evaluating maintenance maturity level in one of the biggest public service institutions in the Middle East, North Africa, and Turkey (MENAT) region. A group of experts was carefully selected from different divisions that represent the maintenance and operational affairs within the vice presidency for projects in the investigated institution. Experts' opinions were collected in order to feed the initial decision matrix using linguistic terms. The linguistic termsof Very High (VH), High (H), Fair (F), Weak (W), and Very Weak (VW) were translated into five triangular fuzzy numbers:(4.5, 5, 5), (3.5, 4, 4.5), (2.5, 3, 3.5), (1.5, 2, 2.5), and (1, 1, 1), respectively. The results of all mathematical computations of the MABAC's steps are shown in Fig. 1. As TPM3 (Planned Maintenance) represents relatively the best practice and attains the highest score among all TPMs (B_3 = 0.312), it can be utilized as a benchmark. Utilizing TPM3 as a benchmark implies considering it as a reference point with which all other TPMs can be evaluated. By normalizing the final score (Z_i) of each TPM, benchmarking scores can be extracted as shown in Table 1.

Conclusions

Maintenance issues in the public services sector are in need to be investigated using MCDM-based research works and studies, which have not been attempted previously in the literature of MEM. This paper has introduced a MABAC method as a tool for screening, measuring, and evaluating TPM performance in such a sector. The results of the proposed model indicate that the investigated institution is generally not matured enough to be up to the desired level of TPM performance. It is suggested for future MCDM studies to investigate the TPM pillars implementation process in terms of identifying which TPM pillars are to be implemented in initial phases (Drivers), which TPM pillars that are dependents, and which TPM pillars are in between (Linkages). The technique of Interpretive Structural Modelling (ISM) is the most suitable

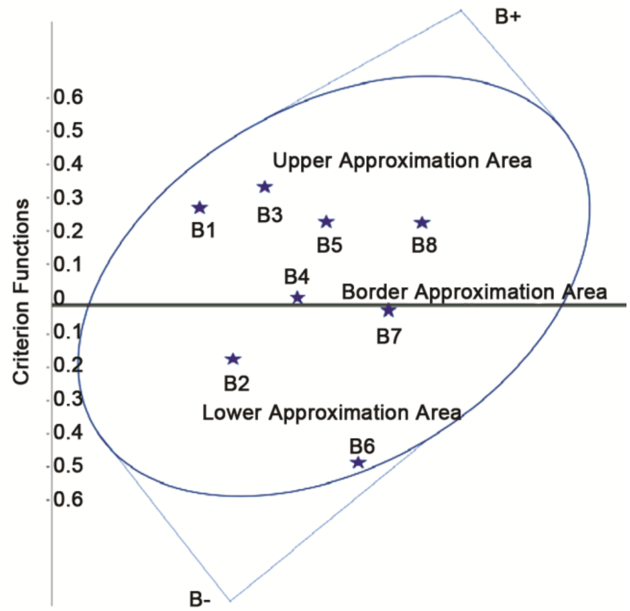

Fig. 1 — TPM Pillars and the corresponding upper ($\tilde{G}^{+}$), lower ($\tilde{G}^{-}$), and border ($\tilde{G}$) approximation area

Table 1 — Benchmarking scores

TMP Pillars	Final Score (Zi)	Benchmarking Scores*
TPM 1 (Autonomous maintenance)	0.260	83%
TPM 2 (Focused improvement)	−0.188	−60%
TMP 3 (Planned Maintenance)	0.312	100%
TPM4 (Quality Maintenance)	0.061	19%
TPM5 (Education and Training)	0.227	73%
TPM6 (Safety, health and environment)	−0.517	−166%
TPM7 (Office TPM)	−0.025	−8%
TPM8 (Development management)	0.227	73%
Maximum Zi	0.312	—

Benchmarking Score (or the Normalized final score) of TPM1, for example, = (Final Score (Zi) for TPM1 / Maximum Zi)*100= (0.260/0.312)*100 = 83

MCDM tools in order to conduct such an investigation. Another suggestion for future attempts is to measure the efficiency scores for each TPM pillar using the technique of Data Envelopment Analysis (DEA). Input and output measures for such a DEA model can be extracted from the literature, or even from the commonly practiced criteria for TPM as discussed in this research.

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