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Selection of Environmentally Conscious Manufacturing Programs Using the MADM Methods

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ABSTRACT

Nowadays, Environmentally Conscious Manufacturing (ECM) programs have been considered by many organizations from a strategic and competitive advantage point of view. Selection of ECM programs from the several proposed alternatives is a very important and difficult task. Decision makers are not limited to one Multi-attribute Decision Making method in critical conditions and several methods have been proposed for solving this problem. This study presents Polygons Area Method as a Multi-attribute Decision Making method for solving the ECM selection problem. The results of this method have been compared with other typical multiple attribute decision-making methods by giving an example. To find similarity in ranking given by different methods, Spearman's rank correlation coefficients are obtained for different pairs of these methods. It was observed that the introduced method is in good agreement with other well-known multi-attribute decision making methods in the Environmentally Conscious Manufacturing program selection problem.

KEYWORDS: Environmentally Conscious Manufacturing (ECM) Selection, Multi-attribute Decision Making (MADM), Polygons Area Method (PAM)

1. INTRODUCTION

Environmentally Conscious Manufacturing (ECM) is a methodical attitude toward process and product design, where environmental criteria are considered a primary objective or prospect, and not a constraint [1]. To this end, environmental problems are in high priority, and green products have become a significant concern for manufacturers and producers due to government and environmental regulations and market pressure toward environmentally friendly solutions to production and manufacturing [2].The issue with environmental destruction has been one of the main problems in recent times [3] and concerns about the sustainability and the protection of the natural environment have become increasingly significant issues among regulators, environmentalists and society in many countries [4].

ECM is a novel approach toward thinking about manufacturing that emphasizes on design for disassembly, product life-cycle analysis, ISO 14000 certification, green supply chains, environmental total quality management, remanufacturing, and minimizing adversarial effects on workers and the environment [5].Four main objectives exist for the enactment of ECM including material management, waste reduction, pollution prevention, and product enhancement [6]. In the other words, environmentally friendly product and manufacturing system helps organization to reduce use of material and enhance the business competitiveness [7].

Multiple Criteria Decision Making (MCDM) refers to making decisions in situations in which there are different and usually conflicting criteria. These methods are divided into two general Multiple Objective Decision Making (MODM) and Multiple Attribute Decision Making (MADM) categories. MODM has decision variables in the form of a continuous variable or an integer. MODM can have one or multiple alternatives, which the selected alternative is the one, which fulfills the constraints of the problem and satisfaction of the decision-maker [8].

Most MODM methods employ mathematical programming in some way. These methods are not easily compatible with problems of the manufacturing environment due to their specific mathematical difficulties. Although many applications and programs have been presented for these methods, lack of simplicity of understanding the theories placed behind them made them an unattractive option for users.

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MADM methods are widely used for real world problems [9]; [5]; [10]; [11]. Methods such as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW) or weighted sum model (WSM), Weighted Product Method (WPM) or Multiplicative Exponent Weighting (MEW), Analytic Hierarchy Process (AHP), ELimination Et Choix Traduisant la REalité (ELECTRE), Vise Kriterijumska Optimizacija Kompromisno Resenje (VIKOR), and Linear Assignment are widely used methods. However, these methods have their own advantages and disadvantages [9].

This study presents the polygons area method for the ECM selection problem. In this method, the maximum polygons area obtained from the attributes of an alternative ECM program on the radar chart is introduced as a decision-making criterion [12].

An advantage of the presented method is simplicity of the algorithm and primary calculations required for finding a decision criterion. The required calculations in this method are easily performed by four basic operations. In addition, the decision-making criterion is obtained based on a concrete and extremely precise method with proven experimental and mathematical formulas. Another advantage of this method is the sound agreement of the results from this method with other major MADM methods. The simplicity of learning and training is another advantage of this method[13].

To show the applicability of this method in ECM program selection, an example already studied by other researchers with other MADM methods have been proposed. To demonstrate the high correlation of the results from this method with main MADM methods, Spearman's correlation coefficient has been employed [5].

2. LITERATURE REVIEW

Studies which used MADM methods are presented for ECM program selection in the literature (Table 1). As seen in Table 1, MADM methods are the most common approach type applied for ranking ECM programs.

Table 1 literature review of ECM program selection

N0.	Name of the authors	Year	Method for ECM program selection
1	Sarkis [14]	1999	ANP & DEA
2	Sarkis & Weinrach [15]	2001	DEA
3	Khan et al.[16]	2002	Fuzzy composite programming & AHP
4	Madu et al. [17]	2002	AHP
5	Rao R.V. [18]	2004	Digraph and matrix method
6	Ravi et al. [19]	2005	ANP
7	Kuo et al. [20]	2006	Fuzzy MADM
8	Rao R.V. [21]	2008	AHP, TOPSIS, modified TOPSIS
9	Ravi et al.[22]	2008	ANP & goal programming
10	Rao R.V. [23]	2009	Improved VIKOR
11	Rao&Patal [24]	2010	PROMETHEE
12	Sutapa &Panjaitan [25]	2011	AHP, TOPSIS, modified TOPSIS
13	Rao [5]	2013	Improved PROMETHEE, Improved AHP
14	Dou et al.[26]	2014	Grey analytical network process-based (grey ANP-based)

Their major deficiency of MADM is that in a single problem, different methods present different results for selection or ranking. To solve this problem, some methods have been introduced [27]; [28]; [5] known as "aggregation methods". In this method, a problem with several MADM methods is ranked, and then, the final selection may be made on the basis of an aggregation of the results of those methods that have better Spearman's rank correlation coefficients. Another way of deciding is choosing an alternative that is suggested by the "majority" of the MADM methods applied [5].

Based on MADM literature, the reason that researchers seek new methods for decision-making is to enhance selection confidence or ranking, methods which perform the selection or ranking of alternatives easily and reliably, in addition to previous methods.

Considering availability of many MADM methods, we have utilized SAW, WPM, TOPSIS, and VIKOR methods for our study. The basis of our selection lies in the fact that these methods are the more common and widely used methods in this regard [9]; [29]. The chief assumptions in SAW and WPM are "additive and multiplicative weighted preferences in an interval scale" [8]. On the other hand, SAW was nominated as the foundation for comparing the other methods. The reason for this rests behind the fact that SAW's minimalism and simplicity makes it an attractive and sought after choice for experts, to an extent that some researchers maintain that SAW should be considered as the standard for such assessments [30].

The VIKOR and TOPSIS methods are based on an aggregating function representing "closeness to the ideal" choice [8]; [31]. VIKOR utilizes linear normalization, while TOPSIS employs vector normalization.

The primary principle behind TOPSIS is that the proposed solution to the problem should be in the shortest distance from the ideal solution on one hand, and furthermost distance from the negative-ideal (opposite) solution on the other hand. Conversely, it does not contemplate the relative importance of the aforementioned points [11].

3. MADM METHODS

In this study, we attempt to focus on deterministic MADM methods where there exists only a single decision maker. Nowadays, SAW, VIKOR, TOPSIS, WPM, and AHP methods are commonly employed in decision-making problems. These methods are considered sound rational decision-making methodologies, and have a higher prospective of solving decision-making problems in different conditions, especially in manufacturing environments [9].

3.1. The SAW Method

Also known as the Weighted Sum Method (WSM), SAW is the most commonly used approach among the other methods [32]. Using SAW, each attribute is assigned with a weight, and the sum of all weights must be one or 100%. After determining all the different alternatives to a problem, each option is assessed against every criterion. Thereafter, the assumption value or performance total of the alternative is attained using Equation (1):

$$S_i = \sum_{j=1}^{n} w_j x_{ij} \qquad for \quad i = 1,2,...,m \tag{1}$$

Where:
m: number of alternatives (i.e. choices, options);
n: number of decision criteria;
x_{ij} : actual value of the i^th^ alternative relative to the the j^th^ criterion, and
w_j: weight of importance of the j^th^ criterion.

It is noteworthy that this method should only be used in instances where all units possess equal units of measure. This method can also be employed for any type of attribute provided the units of the decision matrix are normalized.
Considering the i^{th} alternative, for the overall performance score (S_i), we have:

$$S_i = \sum_{j=1}^{n} w_j x'_{ij} \qquad for \quad i = 1,2,...,m \tag{2}$$

Where:
x'_{ij}: normalized value of x_{ij}.
The best choice here is the alternative with the highest S_i value [9].

3.2 The WPM Method

WPM is alike the SAW method. Although, the main modification is that in this method, we have multiplication in place of addition. For the i^{th} alternative, the overall performance score (P_i) is calculated as follows [9]:

$$p_i = \prod_{j=1}^{n} [\ x'_{ij}\ ]^{w_j} \quad for \quad i = 1,2,...,m \tag{3}$$

In the above relation, x'_{ij}, the normalized value of the i^{th} alternative on the j^{th} criterion is raised to the power of the relative weight of the corresponding criterion (w_j). The highest P_i value in this equation represents the best alternative solution at hand.

3.3 The TOPSIS Method

The TOPSIS method was designed and developed by Hwang and Yoon, and because of its simple and programmable nature, is widely used in many applications [11]. The basic concept behind this method is that a suitable alternative stands in the shortest Euclidean distance from the ideal solution, and in the longest Euclidean distance from the negative-ideal (opposite) solution. The method orders

the possible solutions based on the mentioned two distance measurements [33]. The core stages of the TOPSIS method are as follows [9]:
Step 1: Prepare the decision matrix ($D = [x_{ij}]_{m \times n}$)

Where m is the number of alternatives, n is the number of criteria, and x_{ij} is the actual value of the ith alternative in relation to the jth criteria.
Step 2: Convert the obtained **D** matrix in Step 1 to a normalized decision matrix ($\mathbf{D}' = [x_{ij}]_{m \times n}$) using the following equation:

$$x'_{ij} = \frac{x_{ij}}{\sqrt{{x_{i1}}^2 + \ldots + {x_{in}}^2}} \; for \quad i = 1,2,\ldots,m \quad j = 1,2,\ldots,n \tag{4}$$

Step 3: Process the weighted normalized matrix (**V**).

$$V_{ij} = w_j \times x'_{ij} \tag{5}$$

where x'_{ij} is the normalized value of x_{ij}, and w_j is the weight of importance of the jth criterion.
Step 4: Define the ideal (i.e. best) and the negative-ideal (i.e. worst) solutions as follows:

$$V^+ = \left\{[\max_i V_{ij} \mid j \in j], [\min_i V_{ij} \mid j \in j'] \mid i = 1,2,\ldots,m \right\} \tag{6}$$

$$= (V_1{}^+, V_2{}^+, V_3{}^+, \ldots, V_n{}^+)$$

$$V^- = \left\{[\min_i V_{ij} \mid j \in j], [\max_i V_{ij} \mid j \in j'] \mid i = 1,2,\ldots,m \right\}$$

$$= (V_1{}^-, V_2{}^-, V_3{}^-, \ldots, V_n{}^-)$$

Here, V_j^+ denotes the most preferable alternative, and V_j^- indicates the least preferable alternative. J=(j=1,2,...,n)/j is associated with favorable criteria (leading to the ideal (best) solution) and J′=(j=1,2,...,n) / j$'$ is associated with the non-favorable criteria (leading to the worst solution).

Step 5: Compute the separation measures of each alternative from the ideal and negative-ideal solutions via the equations below:

$$S_i{}^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j{}^+)^2}, i = 1,\ldots, m \tag{8}$$

$$S_i{}^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j{}^-)^2}, i = 1,\ldots, m$$

Where Si^+ is the separation of each alternative from the ideal solution, and S_i^- is the separation of each alternative from the negative-ideal solution.
Step 6: Determine relative closeness to the ideal solution.
The relative closeness of an alternative C_i to the ideal solution is defined as follows:

$$C_i = \frac{S_i{}^-}{(S_i{}^+ + S_i{}^-)} \tag{10}$$

Here, C_i is the priority criterion; other alternatives are in descending order.
Step 7: Rank the preference order

The alternatives can be organized in descending order based on the obtained relative closeness measures. The alternative with the shortest distance to the ideal solution and the outermost distance from the negative-ideal solution is considered the best alternative.

3.4 The VIKOR Method

Yu [34] and Zeleny [35] initially developed the VIKOR method, which is the acronym for 'Vlse Kriterijumska Optimizacija Kompromisno Resenje' meaning Multiple Criteria Optimization (MCO) and compromise solution method. This method was later presented as a relevant procedure for implementation within MADM [36].The VIKOR method was further developed by Opricovic and

Tzeng [31]; [37] as an MADM method. This technique emphases ranking and selecting within a set of alternative options manifested by conflicting criteria.

The VIKOR method begins with a form of L_P- metric [31]:

$$L_{p,i} = \left\{\sum_{j=1}^{n}[w_j\,(x_j^* - x_{ij})/(x_j^* - x_j^-)]^p\right\}^{\frac{1}{p}} \qquad (11)$$

$$1 \le p \le \infty \qquad i = 1, 2, \ldots, m$$

Assuming the j^{th} criteria representing a benefit

$$x_j^* = max_{\ i}\ x_{ij} \text{and} \qquad x_j^- = min_{\ i}\ x_{ij}$$

The alternative options are signified as a_1, a_2, a_3, …, a_m, and as before, w_j is the weight of the j^{th} criterion, where j=1, 2, …, n, and x_{ij} is the obtained performance score of the j^{th} criterion for a_i.

The routine steps for the VIKOR method are [31]:

Step 1: Formulate the decision matrix.

Step 2:

a) Define best, x_j^*, and worst, x_j^-, values of all criterion functions, j=1, 2,…, n

b) Compute S_i and R_i values.

$$S_i = L_{1,i} = \sum_{j=1}^{n}(w_j\,[(x_j^* - x_{ij})/(x_j^* - x_j^-)]) \qquad i = 1, \ldots, m \qquad (12)$$

$$R_i = L_{\infty,i} = max^m\ of\ \{w_j[(x_j^* - x_{ij})/(x_j^* - x_j^-)]\} j=1, \ldots, n \qquad (13)$$

For non-beneficial criteria , x_j^* and x_j^- can be amended as:

$$x_j^* = min_{\ i}\ x_{ij} \quad \text{and} \qquad x_j^- = max_{\ i}\ x_{ij}$$

c) Calculate the value of Q_i

$$Q_i = v[(S_i - S^*)/(S^- - S^*)] + (1 - v)[(R_i - R^*)\ \ /(R^- - R^*) \qquad (14)$$

where

$$S^* = min_{\ i}\ S_i S^- = max_{\ i}\ S_i R^* = min_{\ i}\ R_i R^- = max_{\ i}\ R_i$$

v is presented as weight of the strategy of ‘the majority of attributes’ (or ‘the maximum group utility’). The value of ***v*** is in the range of 0 to 1. Generally, the default value for this variable is taken as 0.5. Nonetheless, any value between 0 to 1 is allowable.

d) According to the values of Qi, Ri, and Si, organize the alternatives in ascending order. The alternative with minimum Q_i value is the best choice.

***Condition 1*:** Acceptable advantage:

$$Q(a'')-Q(a') \ge DQ \qquad (15)$$

Where a'' is the second-ranked alternative in the ranking list by Q; $DQ=1/(m-1)$, and m is the number of alternatives.

***Condition 2*:** Acceptable stability in decision-making: a' should also be the best-ranked alternative by *S* or/and *R*.

If one of the conditions is not fulfilled, then a set of settlement solutions are offered. These include:

- Alternatives a' and a'' only if C_2 is not satisfied, or
- Alternatives a', a'',…, a^m if C_1 is not satisfied; and a^m is determined by the below relation for maximum *m*.

$$Q(a^m)-Q(a') < DQ \qquad (16)$$

The alternative that has the minimum value of Q in this case is the best choice. According to Opricovic and Tzen"the core ranking result is the compromise-ranking list of alternatives and the compromise solution with the advantage rate" [31].

3.5 Aggregate Method

Considering that different possible MADM methods achieve diverse results, therefore, decision makers are not limited by one MADM method in critical conditions. Various methods known as "aggregate methods" have been introduced to remedy this situation. These methods comprise Rank Average, Borda, and Copeland methods [28].

The Average method ranks alternatives based on the average of their calculated ranks obtained via computation of different MADM methods.

Every MADM method is responsible for ranking all present alternatives. Assume there are *m* alternatives. In this case, each alternative obtains *(m-1)* points for the first choice, and (*m* –2) points for the second choice etc. In the Borda method, the alternative with the highest points is declared winner. On the other hand, the Copeland Method commences its operation at the end of the Borda method. Calculating the number of losses for all alternatives and subtracting them from the number of wins determines the reputation and ranking of each alternative [27].

We can reach consensus "by considering ranking strategies (i.e. Rank Average, Borda, and Copeland methods) and through creating one Partially Ordered Set (POSET)"[28].

3.6 The Proposed Method: Polygons Area Method (PAM)

The Radar (Spider) chart is one of the most commonly used charts in management problems and real-world situations. This chart as well as portraying general overall performance, shows areas of relative strengths and relative weaknesses in a graphical manner. In the case of MADM problems, performance of each alternative is shown by a polygon on the radar chart. In this study, we calculated the maximum number of polygon areas attained as a decision criterion on the radar chart.

Our systematic procedure of the proposed method is as follows [12]:

Step 1: Prepare decision matrix (**D**).

Assuming '*m*' alternatives and '*n*' attributes, the general form of the decision matrix ***(D)*** in an MADM problem is depicted as follows:

$$D = \begin{bmatrix} x_{11} & \dots & x_{1j} & \dots & x_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ x_{i1} & \dots & x_{ij} & \dots & x_{in} \\ \dots & \dots & \dots & \dots & \dots \\ x_{m1} & \dots & x_{mi} & \dots & x_{mn} \end{bmatrix}_{m\times n} \tag{17}$$

These attributes may be objective, subjective, or a combination of both.

Step 2: Normalization/Normalized decision matrix (**D'**)

Many normalization procedures exist in decision-making science. The linear normalization procedure is adopted in our proposed method [9]. Let x'_{ij} for attribute *j* compare with alternative *i* as follows:

$$x'_{ij} = \frac{x_{ij}}{\max(x_{ij})} \quad \text{; If attribute is beneficial} \tag{18}$$

$$x'_{ij} = \frac{\min(x_{ij})}{x_{ij}} \quad \text{; If attribute is non-beneficial} \tag{19}$$

For this method, the decision matrix will transform into the following using linear normalization (Rao, 2007; Singh & Rao, 2011).

$$D' = [x'_{ij}]_{m\times n} \tag{20}$$

Step 3: Relative importance of attributes (***W_j***)

In the case of MADM methods, defining the priority weight (w_j) of each criterion such that the sum of weights for all criteria equals one is essential. AHP or entropy methods are a good way of determining these priority weights [9].A pair wise comparison matrix is created using a scale of relative importance. Decisions are input using the fundamental scale of the AHP [38].

Step 4: Forming the weighted normalized decision matrix (**V**), we have:

$$V_{ij} = w_j \times x'_{ij} \tag{21}$$

Where w_j is the weight of the j^{th} criteria.

Step 5: Calculating maximum area of polygon on the radar chart

The attributes have been considered to form the radar (spider) chart. The attributes are plotted on the axes, and each alternative will form a polygon. From a different set of attributes, different polygons can be obtained, which seems to be unacceptable in reality. Hence, the polygon with maximum area is considered as a decision criterion. The polygon with maximum area is obtained using the following algorithm if $n \geq 4$:

a) In weighted decision matrix (V), for alternative *i*, attributes are ranked from the largest to the smallest in order.

b) An attribute with first raking is introduced over the base axis of the chart.

c) Attributes with even rankings, each having v_{ij} in length and $\theta = 2\pi / n$ angle of its previous attribute, are placed clockwise on the chart in a descending order.

d) Attributes with odd rankings are also placed counter clockwise similar to the previous step.

e) Connecting the points obtained from the two previous steps; draw the irregular polygon on the radar chart.

f) Represent the apexes of irregular polygon by beginning from the first ranking and moving counter clockwise by v'_{ij}.

g) The area of triangle (S_Δ) given SAS (Side, Angle, Side) for example (a, θ, b) is calculated as follows [39]:

$$S_\Delta = 1/2ab \sin\theta \tag{22}$$

Divide polygon into n triangle(s) and calculate the area of each one as follows:

$$S_{\Delta} = \frac{1}{2} v'_{ij} \times v'_{i(j+1)} Sin \frac{2\pi}{n} \qquad (23)$$

h) The area of an irregular polygon is obtained from the sum of the areas of these triangles, and is calculated as follows[39]:

$$S_{pi} = \frac{1}{2} Sin \frac{2\pi}{n} (V'_{i1}V'_{i2} + V'_{i2}V'_{i3} + \dots V'_{i(n-1)}V'_{in} + V'_{in} \times V'_{i1}) \qquad (24)$$

where S_{pi} is the area of polygon for the i^{th} alternative on the chart.

Step 6: Selecting the best alternative

the purpose of this step is selecting the best alternative, which is performed with the help of calculated areas of the irregular polygon of S_{pi} s. In this formula, all S_{pi}s is a common (1/2sin2π/n)value, which can be relinquished from all comparisons.

$$C_i = S_{pi} / \frac{1}{2} \sin \frac{2\pi}{n} \qquad (25)$$

Shifting the priority criterion from S_{pi} to C_i s, in which C_is are calculated as follows:

$$C_i = \sum_{j=1}^{n} (V'_{ij} \times V'_{i(j+1)}) + V'_{in} \times V'_{i1} \qquad i = 1, \dots, m \qquad (26)$$

a) If the number of attributes $n \geq 4$; the overall performance score (C_i) is calculated as Eq. (26).

b) If the number of attributes N=3, C_i is calculated from the V matrix as follows:

$$C_i = v_{i1} \times v_{i2} + v_{i2} \times v_{i3} + v_{i3} \times v_{i1} \quad i=1,\dots,m \qquad (27)$$

The best alternative is the one having the highest C_i value.

Figure 1shows the framework of decision making in this paper.

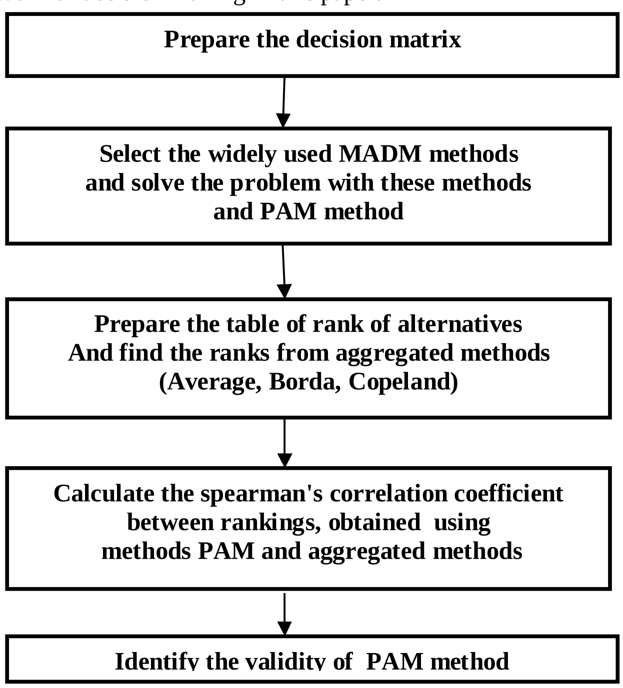

Fig. 1: Framework of decision making

4. EXAMPLES& FINDINGS

Sarkis [14] and Rao [9, 11] introduced a problem for assessing ECM programs in an industrial application. The addressed attributes were "**C**osts involved (C, USD), **Q**uality (Q, percent of defects), **R**ecyclability (R, percent of recyclable material), **P**rocess **W**aste **R**eduction (PWR, percent), **P**ackaging waste **R**eduction (PGR, percent), and **R**egulatory **C**ompliance (RC, percent of reduction in violations)".

They had gathered data from six attributes for some fifteen alternative ECM programs. The mentioned problem is demonstrated in Table 2.

Attributes C and Q are non-beneficial considering percentage of defects (lower values are better). Here, R, PWR, PGR, and RC are favorable attributes (higher values are preferred).

Table 2 Matrix (D)

	C	*Q*	*R*	*PWR*	*PGR*	*RC*
ECM P1	706967	2	29	17	0	51
ECM P2	181278	3	5	14	7	45
ECM P3	543399	4	5	3	7	71
ECM P4	932027	7	15	10	17	57
ECM P5	651411	4	19	7	0	21
ECM P6	714917	5	15	6	19	5
ECM P7	409744	1	8	17	1	35
ECM P8	310013	6	23	15	18	32
ECM P9	846595	2	28	16	19	24
ECM P10	625402	3	21	16	7	34
ECM P11	285869	2	1	13	12	54
ECM P12	730637	3	3	4	1	12
ECM P13	794656	5	27	14	14	65
ECM P14	528001	1	6	5	9	41
ECM P15	804090	2	26	6	5	70

The normalization of attribute data is carried out using Eq. (18), (19) and the normalized decision matrix (D') is given in Table 3.

Table 3

ECM P_i	*C*	*Q*	*R*	*PWR*	*PGR*	*RC*
ECM P1	0.2564	0.5	1	1	0	0.7183
ECM P2	1	0.3333	0.1724	0.8235	0.3684	0.6338
ECM P3	0.3336	0.25	0.1724	0.1765	0.3684	1
ECM P4	0.1945	0.1429	0.5172	0.5882	0.8947	0.8028
ECM P5	0.2783	0.25	0.6552	0.4118	0	0.2958
ECM P6	0.2536	0.2	0.5172	0.3529	1	0.0704
ECM P7	0.4424	1	0.2759	1	0.0526	0.493
ECM P8	0.5847	0.1667	0.7931	0.8823	0.9474	0.4507
ECM P9	0.2141	0.5	0.9655	0.9412	1	0.338
ECM P10	0.2899	0.3333	0.7241	0.9412	0.3684	0.4789
ECM P11	0.6344	0.5	0.0345	0.7647	0.6316	0.7606
ECM P12	0.2481	0.3333	0.1034	0.2353	0.0526	0.169
ECM P13	0.2281	0.2	0.931	0.8235	0.7368	0.9155
ECM P14	0.3433	1	0.2069	0.2941	0.4737	0.5775
ECM P15	0.2254	0.5	0.8965	0.353	0.2631	0.9859

The judgments made by decision makers or relative importance of attributes are given in Table 4.

Table 4

Attributes	**C**	**Q**	**R**	**PWR**	**PGR**	**RC**
C	1	3	2	1	2	3
Q	1/3	1	1/3	1/4	1/3	1
R	1/2	3	1	1/2	1/2	2
PWR	1	4	2	1	2	4
PGR	1/2	3	2	1/2	1	2
RC	1/3	1	1/2	1/4	1/2	1

The normalized weight of each attribute is obtained from Super Decision software, which are w_C=0.26, w_Q=0.066, w_R=0.014, w_{PWR}=0.29, w_{PGR}=0.17, w_{RC}=0.075 and consistency ratio (CR) is 0.018 which is much less than the allowed CR value of 0.1.
Multiplying the (D') by weight matrix, the weighted normalized matrix (V) is given in Table 5.

Table 5

ECM P_i	*C*	*Q*	*R*	*PWR*	*PGR*	*RC*
ECM P1	0.0667	0.0330	0.1400	0.2900	0.0000	0.0539
ECM P2	0.2600	0.0220	0.0241	0.2388	0.0626	0.0475
ECM P3	0.0867	0.0165	0.0241	0.0512	0.0626	0.0750
ECM P4	0.0506	0.0094	0.0724	0.1706	0.1521	0.0602
ECM P5	0.0724	0.0165	0.0917	0.1194	0.0000	0.0222

ECM P6	0.0659	0.0132	0.0724	0.1023	0.1700	0.0053
ECM P7	0.1150	0.0660	0.0386	0.2900	0.0089	0.0370
ECM P8	0.1520	0.0110	0.1110	0.2559	0.1611	0.0338
ECM P9	0.0557	0.0330	0.1352	0.2729	0.1700	0.0254
ECM P10	0.0754	0.0220	0.1014	0.2729	0.0626	0.0359
ECM P11	0.1649	0.0330	0.0048	0.2218	0.1074	0.0570
ECM P12	0.0645	0.0220	0.0145	0.0682	0.0089	0.0127
ECM P13	0.0593	0.0132	0.1303	0.2388	0.1253	0.0687
ECM P14	0.0893	0.0660	0.0290	0.0853	0.0805	0.0433
ECM P15	0.0586	0.0330	0.1255	0.1024	0.0447	0.0739

Now the proposed PAM method, SAW, WPM, TOPSIS and VIKOR methods are applied to this problem as explained before. Comparison of rankings obtained by these methods for ECM program selection example is given in Table 6.

Table 6

ECM	*SAW*	*WPM**	*TOPSIS*	*VIKOR*	*PAM*	*Average***	*Borda****	*Copeland*
ECM P1	6	13	8	6	6	8	8	8
ECM P2	3	2	4	2	3	2	2	3
ECM P3	14	12	13	14	14	14	14	14
ECM P4	9	7	9	12	9	9	8	9
ECM P5	13	14	14	11	13	13	13	13
ECM P6	11	11	10	10	10	11	10	10
ECM P7	8	8	7	5	7	7	7	7
ECM P8	1	1	1	1	1	1	1	1
ECM P9	2	5	2	7	2	3	2	2
ECM P10	7	4	6	4	8	5	6	6
ECM P11	5	6	3	3	5	4	4	4
ECM P12	15	15	15	15	15	15	15	15
ECM P13	4	3	5	8	4	6	4	4
ECM P14	12	10	11	13	12	12	12	12
ECM P15	10	9	12	9	11	9	10	11

* ECMP1=0 in WPM because $D'_{15}=0$; We replaced $D'_{15}=Min(D'_{i5})/10$; $Min(D'_{i5})= .05$ then $D'_{15}= 0.05$
**Average of SAW; WPM; TOPSIS and VIKOR methods ranks
*****Borda & Copeland methods for SAW; WPM; TOPSIS and VIKOR methods ranks
POSET:P8>(P2,P9)>(P11,P13)>P10>P7>(P1,P4)>(P6,P15)>P14>P5>P3>P12

From the ranking of ECM programs, it is clear that the ECM program 8 is the best choice among the alternative ECM programs considered. To find similarity in rankings given by different methods, Spearman's rank correlation coefficients [40]; [41]; [42]; [11] were obtained for different pairs of the five MADM methods and aggregate methods using SPSS software. Table 7 shows the Spearman's rank correlation coefficients.

Table 7

Method	*SAW*	*WPM*	*TOPSIS*	*VIKOR*	*PAM*
SAW	1	.850*	0.964*	0.857*	0.993*
WPM		1	0.871*	0.743**	0.829*
TOPSIS			1	0.854*	0.968*
VIKOR				1	0.850*
PAM					1
Average					.958*
Borda					.979*
Copeland					.985*

***sig.** = 0.000 Correlation is significant at the 0.01 level (2 tailed)
**sig. = 0.002 Correlation is significant at the 0.01 level (2 tailed)

5. DISCUSSION

The values of Spearman's rank correlation coefficients (Table 7) show that there is a perfect agreement between the introduced method (PAM) and other typical MADM methods. The rank order of ECM programs obtained using PAM (Table 6) is: 8- 9- 2- 13- 11- 1- 7- 10- 4- 6- 15- 14- 5- 3- 12. The rank order of ECM programs given by Rao [5] using improved AHP and improved PROMETHEE methods were: 8-9-2-13-11-1-10-7-4-15-6-14-5-3-12 and 8-7-1-9-2-10-11-13-14-6-15-4-3-5-12 respectively. The rank order given by Sarkis [14] using RCCR DEA and RCCR/AR DEA models were: 8-2-11-9-7-14-1-15-13-10-3-6-5-4-12 and 11-8-9-7-2-1-15-10-14-13-6-3-4-5-12 respectively. The best and worst alternative ECM programs obtained using PAM method are same as given by Rao using

(AHP and PROMETHEE) and Sarkis using RCCR DEA. This result confirms that the suggested ECM program selection method, is comparatively novel and applicable method, and hence, may be employed for any type of decision-making circumstances.

6. CONCLUSION

Recently, companies pay more attention to environment and environmental issues have become a key determinant of performance in the marketplace. Selecting the best ECM program is an important problem in the industrial environment considering various multiple performance attributes. This paper presents the PAM method using polygons area for solving the ECM program selection problem. A numerical ECM program selection example was presented to indicate the validity and advantages of the proposed method in comparison with the four well-known MADM methods. Spearman's rank correlation coefficient was obtained for different pairs of MADM methods. Observations showed that the proposed method is in good agreement with the other methods.

The ECM selection example shows that the PAM method can derive quite acceptable ranking results to assist decision makers in devising appropriate decisions. This confirms use of the suggested method for decision-making conditions in manufacturing environments, and can act as a comprehensive solution for other decision-making conditions. PAM can also be employed for other types of decision-making problems. It is a simple and logical instrument when compared with alternative MADM methods. We suggest that future studies contemplate and analytically compare other MADM methods.To rank fuzzy data, fuzzy model of the proposed method can be investigated by researchers in future studies.

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