Ranking of Product Alternatives Based on Customer-designer Preferences

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***Abstract* - In this research paper the alternatives of vacuum cleaners are ranked using MADM methods such as Simple Additive Weighing (SAW) Method, Weighted Product Method (WPM), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method, Modified TOPSIS, Grey Relational Analysis (GRA) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). The results of various methods are then compared and a new quantitative approach has been suggested in case of tie. It is observed that the proposed quantitative approach provides better guidelines to the decision maker, than that provided by qualitative approach applied by earlier researchers.**

***Keywords*-Multi-attribute decision making (MADM) methods; analytical hierarchy process; vacuum cleaner alternatives; quantitative approach.**

I. INTRODUCTION

Different customer may have different choices for the particular product based on multi attribute. Similarly, they may have different preferences within the brand also. Depending on the nature of the demand, it is necessary to make product differentiation based on multiple attributes. To compete in the market, manufacturers have to expand their product lines and differentiate their product offerings with the belief that large product variety may stimulate sales and generate more revenue [1]. The final decision to select a particular design for a given product is perhaps the most critical stage in product design development. Several market-based decision support methodologies have been reported in the literature to aid product selection. Isiklar G. and Buyukozkan G. [2] applied TOPSIS method to rank the mobile phone alternatives. Hsiao [3] proposed a fuzzy decision-making method for selecting an optimum design from various design alternatives. The development of a juicer was taken as an example in the study. Besharati et al. [4] generated a number of product alternatives within the design and proposed a generalized purchase modeling approach for a decision support system for supporting the selection in product design.

The vacuum cleaner selection can be considered as a complex multi-attribute decision problem since the expectations differ from customer's point of view as well as designer's point of view. In this paper, existing four branded product alternatives of vacuum cleaners are considered for evaluation. Customer preferences and designer preferences are considered for ranking the alternatives .The weight for each attribute is determined using analytical hierarchy process (AHP), as calculated by Kreng and Lee [5] and the same weights are then used in MADM methods presented in this paper. A more reasonable and reliable way to prioritize alternatives is to apply several MADM approaches to the same problem, compare their results, and then make the final decision [6].The alternatives of vacuum cleaners are ranked on the basis of attribute using Simple Additive Weighing (SAW) Method, Weighted Product Method (WPM), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method, Modified TOPSIS, Grey Relational Analysis (GRA) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). To validate the ranking provided by these various methods, a quantitative approach is also proposed.

II. METHODOLOGY

A. Multiple Criterion Decision Making

MADM methods have four main parts, namely: (a) alternatives (b) attributes (c) weight or relative importance of each attribute, and (d) measures of performance of alternatives with respect to the attributes. The decision matrix is shown in Table I. It shows alternatives, A_i (for i = 1, 2,….., n), attributes, B_j (for j = 1, 2,….., m), weights of attributes, w_j (for j=1, 2,….., m) and the measures of performance of alternatives, y_{ij} (for i= 1, 2,….., n; j=1, 2,….., m).

TABLE I
DECISION MATRIX IN MADM METHODS [7]

Alternatives	Attributes				
	B_1 (w_1)	B_2 (w_2)	B_3 (w_3)	------- -------	B_m (w_m)
A_1	y_{11}	y_{12}	y_{13}	-------	y_{1m}
A_2	y_{21}	y_{22}	y_{23}	-------	y_{2m}
A_3	y_{31}	y_{32}	y_{33}	-------	y_{3m}
-	-	-	-	-------	-
-	-	-	-	-------	-
A_n	y_{n1}	y_{n2}	y_{n3}	-------	y_{nm}

Following MADM methods are considered in this work.

A.1.Simple Additive Weighing (SAW) Method:

This method is also called Weighted Sum Method developed by Fishburn in 1967. The overall or composite score P_i of the alternative A_i is determined by (1).

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$$P_i = \sum_{j=1}^{m} w_j \left(y_{ij}\right)_{normal} \quad (1)$$

Where $(y_{ij})_{normal}$ represents the normalized value of y_{ij}. The ranking of the alternative is termed as the 'Product Selection Index (PSI)' in the present example. The alternative with the highest composite score (PSI), P_i is considered as the best alternative.

A.2. Weighted Product Method (WPM):

This method is developed by Miller and Starr in1969 is similar to SAW. The overall or composite performance score (PSI), P_i of an alternative A_i is determined by (2).

$$P_i = \prod_{j=1}^{m} \left[\left(y_{ij}\right)_{normal}\right]^{w_j} \quad (2)$$

A.3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method:

TOPSIS method, which is based on choosing the best alternative having the shortest distance to the ideal solution and the farthest distance from the negative-ideal solution, was first proposed in by Hwang and Yoon [8]. Firstly, the decision matrix, representing the performance values of each alternative with respect to each criterion is prepared. Next, these performance values are normalized and then these values are multiplied with the criteria weights to obtain weighted normalized. The ideal solution consists of the best values of alternatives and the negative-ideal solution consists of the worst values of alternatives. Subsequently, the alternatives are ranked with respect to their relative closeness to the ideal solution. The normalized value (R_{ij}) is calculated using (3).

$$R_{ij} = \frac{y_{ij}}{\sqrt{\sum_{j=1}^{m} y_{ij}^2}} \quad (3)$$

The weighted normalized value (V_{ij}) is calculated using (4).

$$V_{ij} = w_j \times R_{ij} \quad (4)$$

The ideal and negative-ideal solutions are determined using (5) and (6) respectively.

$$V^+ = \left\{\left(\max_i V_{ij} \mid j \in J\right), \left(\min_i V_{ij} \mid j \in J'\right)\right\} \quad (5)$$

$$V^- = \left\{\left(\min_i V_{ij} \mid j \in J\right), \left(\max_i V_{ij} \mid j \in J'\right)\right\} \quad (6)$$

Where J is associated with beneficial attributes, and J' is associated with non beneficial attributes. The separation measures are calculated using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given by (7) and (8)

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2} \quad (7)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2} \quad (8)$$

The relative closeness (PSI) of a particular alternative to the ideal solution, P_i can be expressed using (9).

$$P_i = \frac{S_i^-}{(S_i^+ + S_i^-)} \quad (9)$$

A.4. Modified TOPSIS Method:

Deng et al. [9] presented the weighted Euclidean distances rather than creating a weighted decision matrix as in case of TOPSIS method. In this method, the positive ideal solution(R^+) and the negative ideal solution (R^-) are not dependent on the weighted decision matrix and can be represented by (10) and (11) respectively.

$$R^+ = \left\{\left(\max_i R_{ij} \mid j \in J\right), \left(\min_i R_{ij} \mid j \in J'\right)\right\} \quad (10)$$

$$R^- = \left\{\left(\min_i R_{ij} \mid j \in J\right), \left(\max_i R_{ij} \mid j \in J'\right)\right\} \quad (11)$$

The weighted Euclidean distances are calculated using (12) and (13)

$$D_i^+ = \sqrt{\sum_{j=1}^{m} w_j \left(R_{ij} - R_j^+\right)^2} \quad (12)$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} w_j \left(R_{ij} - R_j^-\right)^2} \quad (13)$$

The relative closeness (PSI) of particular alternative to the ideal solution P_i can be determined by (14).

$$P_i = \frac{D_i^-}{\left(D_i^+ + D_i^-\right)} \quad (14)$$

A.5. Grey Relational Analysis (GRA)

The grey system theory is proposed by Deng [10]. The procedure of grey relational analysis is given below;

Step 1: Grey Relational Generating

When the units in which performance is measured are different for different attributes, the influence of some attributes may be neglected. Therefore, processing all performance values for every alternative into comparability sequence, in a process analogous to normalization, is necessary. This processing is called grey relational generating in GRA.

For MADM problem, the i^{th} alternative can be expressed as $A_i = (y_{i1}, y_{i2}, y_{i3,\ldots}, y_{ij,\ldots} y_{im})$ where y_{ij} is the performance value of attribute j of alternative i. The term

y_i can be translated into the comparability sequence X_i = ($x_{i1}, x_{i2}, x_{i3},..., x_{ij},...., x_{im}$) by (15) and (16).

$$x_{ij} = \frac{y_{ij} - Min\{y_{ij}, i=1,2,...,n\}}{Max\{y_{ij}, i=1,2,...,n\} - Min\{y_{ij}, i=1,2,...,n\}} \quad (15)$$

$$x_{ij} = \frac{Max\{y_{ij}, i=1,2,....,n\} - y_{ij}}{Max\{y_{ij}, i=1,2,...,n\} - Min\{y_{ij}, i=1,2,...,n\}} \quad (16)$$

Equation (15) is used for larger-the-better attributes and Equation (16) for the smaller- the better attributes.

Step 2: Reference sequence definition

After the grey relational generating procedure, all the performance values are scaled into [0,1] An alternative will be the best choice if all of its performance values are closest to or equal to 1,however, such type of alternative may not exist. The reference sequence X_o is to be defined as ($x_{o1}, x_{o2}, x_{o3},..., x_{oj},...., x_{om}$) = (1, 1,…,1,…,1), and then aims to find the alternative whose comparability sequence is the closest to reference sequence.

Step3: Grey relational coefficient calculation

Grey relational coefficient is used for determining how close x_{ij} and x_{oj}. The larger the grey relational coefficient, the closer x_{ij} and x_{oj} are. The grey relational coefficients can be calculated by (17).

$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{ij} + \zeta \Delta_{\max}} \quad (17)$$

Where $\gamma(x_{oj}, x_{ij})$ *is the* grey relational coefficient between x_{oj} *and* x_{ij}, *and*

$$\Delta_{ij} = |x_{oj} - x_{ij}|$$

$\Delta_{min} = Min\{\Delta_{ij}, i = 1, 2,..., n; j = 1,2,...,m\}$,

$\Delta_{max} = Max\{\Delta_{ij}, i = 1, 2,..., n; j = 1,2,...,m\}$,

ζ is the distinguishing coefficient, $\zeta \in [0,1]$.

The distinguishing coefficient can be taken by the decision maker exercising judgment. The rank order of alternative remains always same though the different coefficient is adopted [11]. After grey relational generating, Δ_{max} will be equal to 1 and Δ_{min} will be equal to 0. In this paper, the distinguishing coefficient is set as 0.5.

Step 4: Grey relational grade calculation

After calculating the entire grey relational coefficient $\gamma(x_{oj}, x_{ij})$, grey relational grade can be calculated using (18).

$$\Gamma(X_O, X_i) = \sum_{j=1}^{m} w_j \gamma(x_{oj}, x_{ij}) \quad for\, i = 1,2,...,n \quad (18)$$

$\Gamma(X_o, X_i)$ is the grey relational grade (PSI) between X_o and X_i. The highest grey relational grade with the reference sequence, it means that the comparability sequence is most similar to the reference sequence, and that alternative would be the best choice.

A.6 Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

The PROMETHEE method was developed by Brans et al. [12]. It proceeds to pairwise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of an alternative A_1 over alternative A_2. The steps in PROMETHEE method are described below:

Step 1: Identify the selection attribute and short-list the alternatives on the basis of the identified attribute satisfying the requirements.

Step 2: Prepare a decision table including the measures or values of all attribute for the short-listed alternatives and the relative importance of the attribute is assigned.

Step 3: The next step is to have information on the decision maker preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion. The preference function (F_j) translates the difference between the evaluations obtained by two alternatives (A_1 and A_2) in terms of particular criterion, into preference degree ranging from 0 to 1. Let $F_{j,A1A2}$ preference function associated to the criterion B_j.

$$F_{j,A_1A_2} = G_j\lfloor B_j(A_1) - B_j(A_2)\rfloor, \text{ for } \quad 0 \le F_{j,A_1A_2} \le 1$$

Where, G_j is a non decreasing function of the observed deviation between two alternatives A_1 and A_2 over the criterion B_j. In this paper the preference 'usual function' for all attribute is used. The 'usual function' is an easy to use preference function and is generally used with quantitative criteria [13]. If two alternatives have a difference $d \neq 0$ in criterion B_j, then a preference value ranging between 0 and 1 is assigned to the 'better' alternative whereas the 'worse' alternative receives a value 0. If d=0, then they are indifferent which results in an assignment of 0 to both alternatives. The pairwise comparison of all the alternatives of each criterion is to be carried out.

Let the decision maker have specified a preference function F_j and weight w_j for each criterion B_j (j=1, 2, . . . , m) of the problem. The multiple attribute preference index Π_{A1A2} is then defined as the weighted average of the preference functions F_j:

$$\Pi_{A_1A_2} = \sum_{j=1}^{m} w_j F_{j,A_1A_2}$$

Π_{A1A2} represents the intensity of preference of the decision maker of alternative a_1 over alternative a_2, when considering simultaneously all the attribute. Its value ranges from 0 to 1. This preference index determines a valued outranking relation on the set of actions.

For PROMETHEE outranking relations, the leaving flow, entering flow and the net flow for an alternative a belonging to a set of alternatives A are defined by the following equations.

$$\varphi^+(a) = \sum_{x \in A} \Pi_{xa} \quad (19)$$

$$\varphi^-(a) = \sum_{x \in A} \Pi_{xa} \quad (20)$$

$$\varphi(a) = \varphi^+(a) - \varphi^-(a) \quad (21)$$

φ^+ (a) is called the leaving flow, φ^- (a) is called the entering flow and φ (a) is called the net flow. φ^+ (a) is the measure of the outranking character of a (i.e. dominance of alternative a over all other alternatives) and φ^- (a) gives the outranked character of a (i.e. degree to which alternative a is dominated by all other alternatives). The net flow, φ (a), represents a value function, whereby a higher value reflects a higher attractiveness of alternative a. The net flow values are used to indicate the outranking relationship between the alternatives.

B. An example

Now to demonstrate the above mentioned decision-making approaches an example considered in this work is same as considered by Kreng and Lee [5]. According to brand and market share, four vacuum cleaners were selected from Japanese markets, which are TK-V9299 (A_1), CVW86(A_2), MC-S83XD(A_3), and VPF-21(A_4).The weightage for various attributes are decided in this work using analytical hierarchy process used by Kreng and Lee.The weightages of each attribute between the criteria and within the sub-criteria for customer preferences and for designer preferences are shown in Table II. The values of the decision matrix [5] are shown in Table III. The values represent the importance of each attribute on the scale 1 to 5 with increasing order of importance.

TABLE II
PRIORITY WEIGHTS IN AHP DECISION TREE

Criteria	Weight between the criteria (%)	Weight within the criteria(%)	Weight among the sub-criteria(%)
Customer's Preferences	**0.500**		
ER		0.216	0.108
DA		0.197	0.098
WL		0.156	0.078
ES		0.144	0.072
MU		0.120	0.060
DC		0.096	0.048
MP		0.072	0.036
Designer's Preferences	**0.500**		
LA		0.186	0.093
FS		0.279	0.139
HV		0.217	0.108
SC		0.155	0.077
DQ		0.162	0.081

Exhaust Reclamation (ER), Disinfectant Ability (DA), Weight Lightness (WL), Easy Storage (ES), Multi-Usage (MU) Dust Container Volume (DC), Motor Power (MP), Least Assembly Component Design (LA), Fashion Shape (FS) Low Cost High Variety Design (HV) Sharing Component Design in a product family (SC) and Design Quality Control (DQ).

TABLE III.
DECISION MATRIX FOR CUSTOMER'S AND DESIGNER'S PREFERENCE

	ER	DA	WL	ES	MU	DC	MP	LA	FS	HV	SC	DQ
A_1	1	1	3	2	2	5	3	5	2	5	2	1
A_2	2	5	4	4	4	4	4	4	3	3	4	4
A_3	4	3	5	3	5	2	5	3	4	4	5	3
A_4	5	4	2	5	3	3	2	2	5	2	3	5

B.1. SAW and WPM method: The normalized matrix for SAW and WPM methods as discussed in section II is shown in Table IV. The overall or composite scores (PSI) of SAW and WPM method; P_i of the alternative A_i are shown in Table VIII.

TABLE IV
NORMALIZED MATRIX FOR SAW AND WPM METHODS.

	ER	DA	WL	ES	MU	DC	MP	LA	FS	HV	SC	DQ
A_1	0.2	0.2	0.6	0.4	0.4	1	0.6	1	0.4	1	0.4	0.2
A_2	0.4	1	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.6	0.8	0.8
A_3	0.8	0.6	1	0.6	1	0.4	1	0.6	0.8	0.8	1	0.6
A_4	1	0.8	0.4	1	0.6	0.6	0.4	0.4	1	0.4	0.6	1

B.2. TOPSIS and Modified TOPSIS: The normalized matrix (R_{ij}) for TOPSIS and Modified TOPSIS as discussed in section II is shown in Table V.

TABLE V
NORMALIZED MATRIX (R_{ij}) FOR TOPSIS AND MODIFIED TOPSIS

	ER	DA	WL	ES	MU	DC	MP	LA	FS	HV	SC	DQ
A_1	0.15	0.14	0.41	0.27	0.27	0.68	0.41	0.68	0.27	0.68	0.27	0.14
A_2	0.29	0.70	0.54	0.54	0.54	0.54	0.54	0.54	0.41	0.41	0.54	0.54
A_3	0.59	0.42	0.68	0.41	0.68	0.27	0.68	0.41	0.54	0.54	0.68	0.41
A_4	0.74	0.56	0.27	0.68	0.41	0.41	0.27	0.27	0.68	0.27	0.41	0.68

The relative closeness of particular alternative (PSI) to the ideal solution, P_i of TOPSIS and Modified TOPSIS is shown in Table VIII.

B.3. GRA: The grey relational coefficients are shown in Table VI. The grey relational grade Γ (PSI) between X_o and X_i, (X_o, X_i) is shown in Table VIII.

TABLE VI
GREY RELATIONAL COEFFICIENT

	ER	DA	WL	ES	MU	DC	MP	LA	FS	HV	SC	DQ
A_1	0.33	0.33	0.43	0.33	0.33	1	0.43	1	0.33	1	0.33	0.33
A_2	0.40	1	0.60	0.60	0.60	0.60	0.60	0.60	0.43	0.43	0.6	0.67
A_3	0.67	0.50	1	0.43	1	0.33	1	0.43	0.60	0.60	1	0.50
A_4	1	0.67	0.33	1	0.43	0.43	0.33	0.33	1	0.33	0.43	1

B.4. PROMETHEE: The leaving flow, entering flow and the net flow values for different alternatives are shown in Table VII. Based on the net flow values φ (a); the resulting preference indices (PSI) are given in Table VIII.

TABLE VII
LEAVING FLOW, ENTERING FLOW AND THE NET FLOW VALUES

	A_1	A_2	A_3	A_4	φ^+(a)	φ^-(a)	φ (a)
A_1	-	0.25	0.25	0.36	0.86	2.14	-1.27
A_2	0.75	-	0.39	0.60	1.74	1.26	0.48
A_3	0.75	0.61	-	0.45	1.81	1.19	0.62
A_4	0.64	0.40	0.55	-	1.58	1.42	0.17

III. RESULTS

The result of MADM approaches as discussed in section II applied to the ranking of vacuum cleaner is shown in Table VIII. From the Table VIII, it is understood that product design alternative 3 is the most preferred choice and 1 is worst among the four alternatives when both the customers and designers preferences are considered. The ranking will be 3-2-4-1; which is the same for SAW, WPM, Modified TOPSIS and PROMETHEE, However, TOPSIS Method suggests the ranking 3-4-2-1 and GRA approach gives the ranking 4-3-2-1. Table VIII clearly indicates that the alternative 3 is superior to 4 as five out of six methods are in favor of alternative 3. It is also reported in the literature [6] that in case of conflict between the alternatives, the ranking suggested by more number of methods is an appropriate choice.

TABLE VIII
RESULTS OF VARIOUS MADM APPROACHES

	Product Selection Index (PSI)					
A_i	SAW	WPM	TOPSIS	MOD. TOPSIS	GRA	PROMETHEE
A_1	0.515	0.431	0.336	0.343	0.510	-1.274
A_2	0.727	0.706	0.542	0.568	0.581	0.483
A_3	0.762	0.741	0.616	0.608	0.649	0.623
A_4	0.717	0.666	0.593	0.568	0.651	0.167
Rank:	3-2-4-1	3-2-4-1	3-4-2-1	3-2-4-1	4-3-2-1	3-2-4-1

IV. DISCUSSION AND CONCLUSION

A close look at the values of the attributes shown in Table III for the alternatives 3 and 4, reveals that alternative 3 is much better than alternative 4 in the case of six attribute: WL, MU, MP, LA, HV and SC, and alternative 4 is better than alternative 3 in the case of other six attribute namely: ER, DA, ES, DC, FS and DQ. This indicates that alternatives 3 and 4 are equally important. However, the above comparison is qualitative only and hence may not necessarily provide the correct choice. Hence in this work quantitative approach for comparison of the alternatives is developed. In this approach the two alternatives to be compared are given a superiority value based on the performance value of one alternative over the other. The positive value indicates the superiority of an alternative over other whereas negative value indicates inferiority. The overall superiority index is then calculated by considering algebraic sum of all the superiority values. If the overall superiority index is positive then the alternative is said to be superior over other. This procedure of comparing the alternatives quantitatively will certainly help decision maker to choose correct alternative, than comparing the alternatives qualitatively. The superiority of alternative 3 over 4 is shown in Table IX. The overall superiority index (*OSI*) of alternative 3 is positive (i.e. +5) therefore the alternative 3 is said to be superior over alternative 4. From this point of view it is clear that the ranking suggested by GRA method is not appropriate even though qualitative approach indicates that GRA ranking is equally competent as that provided by other methods. This clearly shows the usefulness of the quantitative approach over the qualitative approach.

TABLE IX
SUPERIORITY OF ALTERNATIVE 3 OVER ALTERNATIVE 4

ER	DA	WL	ES	MU	DC	MP	LA	FS	LC	SC	DQC	*OSI*
-1	-1	+3	-2	+2	-1	+3	+1	-1	+2	+2	-2	**+5**

(+) sign indicates superiority; (-) sign indicates inferiority.

Using this approach the ranking 3-2-4-1 is more logical. Thus from the customer's and designer's preferences point of view, vacuum cleaner MC-S83XD (A_3) is most preferred choice whereas TK-V9299 (A_1) is least preferred. It is thus observed that for this particular case, vacuum cleaner MC-S83XD is the most appropriate choice for customer as well as for designer

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