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Article

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A novel multi-attribute decision making approach for selection of appropriate product conforming ergonomic considerations

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ABSTRACT

Ergonomic design of a product considers design, cognitive and behavioral information during the design stage with a view to improve the comfort level of the user and aesthetic look of the product. However, a large number of products are available in the market place possessing a wide range of features to address the ergonomic considerations. Many times, the features may be redundant and hardly enhance interaction between the user and the product leading to user dissatisfaction. But few important features focusing its functionality and physical comfort can possibly address the usability of product and improve satisfaction level of the user. This paper proposes a fuzzy multi-attribute decision making (MADM) approach integrating both subjective and objective weights for each criterion so that superior ergonomically designed product can be evaluated. The methodology is explained with the help of an example of selection of an office chair. Three popular approaches have been considered to compare the ranking of alternatives.

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1. Introduction

Competition in the market place demands high workload in an office environment resulting in prolonged sitting. Prolonged sitting may cause health risk like muscular disorders [7]. Therefore, ergonomically designed office chair possessing capability of maintaining compatibility between the user and product may lead to reduce fatigue. While designing or procuring an office chair, the psychological needs must be fulfilled in addition to physical needs to improve user satisfaction. Selection of an office chair with salient features satisfying ergonomic needs (both physical and psychological needs) becomes a complex decision making process. Keeping in view of complexity of the problem, multi-attribute decision making (MADM) approach can be considered during product design focusing on the requirements of user in terms of conflicting criteria in order to solve the task of selection of an ergonomically designed product. In a decision making process, it is unlikely that decision makers can express their preferences using crisp rating for attributes [13,14]. As experts are not able to exactly specify their preferences, linguistic variables using a fuzzy scale is used to con-

veniently deal with impreciseness and ambiguity in judgement [4–6]. Still the decision making becomes inconsistent because most of the approaches consider either objective or subjective attributes [21,33]. The attributes need to be properly evaluated for estimating attribute weights integrating both objective and subjective criteria [32]. The subjective attributes can be dealt using eigen method [34] or Delphi method [11] whereas the objective attributes can be effectively managed by entropy method [10] for weight estimation. To address this issue, a novel decision making technique is proposed in this work considering both subjective and objective weights for attributes in order to facilitate the decision maker to deal with objective information regarding the product as well as the uncertainty of human judgement. The attribute ratings obtained from multiple experts are aggregated for effective decision making.

Three different popular MADM methods such as TOPSIS (Techniques for Order Preference by Similarity to Identical Solution), VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenjeja) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) are used to solve the selection problem of choosing the best ergonomically designed office chair. All the methods are considered under same managerial decision. TOPSIS, a linear weighting technique developed by Hwang and Yoon [10] in its crisp form and then in expanded form by Chen and Hwang, is

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based on the concept that the chosen alternative should have the shortest Euclidean distance from positive ideal solution and farthest from negative ideal solution VIKOR, on the other hand, determines a compromise solution which is feasible and closest to the ideal solution but makes an agreement by mutual concession which the help of the decision maker to take a decision with conflicting criteria [27]. It introduces the multi-criteria ranking index based on the particular measure of “closeness” to the “ideal” solution [26]. PROMETHEE proceeds to a pair-wise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of an alternative ‘a’ over alternative ‘b’ [31]. In order to check the stability of ranking with respect to different weighted attributes, a sensitivity analysis has been performed considering different proportion of attribute weight (subjective and objective) and the evaluation carried under three different MADM methods.

2. Literature review

In order to compete in the market-place, functions are being added to the product based on assumption that more functions would enhance the product performance. However, addition of more functions to a product usually results in complex user-product interface making it difficult to use. Therefore, In a product design environment, conceptual as well as physical design approach is used to prioritize the important features possessing the ability to fulfill customer requirements taking into account customer preference, experience in handling the product and designer’s technical skill [1]. Jindo et al. [15] have conducted a subjective evaluation using semantic differential method in order to find out a relation between design elements and user perception. Nagamachi [25] in Kansei engineering approach has proposed an elegant methodology for translating customer requirements expressed in subjective manner into objective design attributes using statistical method. Park and Han [29] have attempted linear regression and quantification theory to develop a relation between design variables of a product and affective user satisfaction.

Isiklar and Buyukozkan [12] have applied analytical hierarchy process (AHP) for product selection considering both user and product related attribute. Lin et al. [20] have used AHP and TOPSIS in order to identify customer requirements and design characteristics for the evaluation of best design of personal digital assistant (PDA). Recently, Hua et al. [9] have proposed a hybrid multi-criteria decision making model using DEMATEL-based analytic network process (ANP) and VIKOR to select the smart phone. Quang et al. [30] have proposed a fuzzy multi-criteria decision making approach to select parting curve in mold design. Kumar et al. [17] have applied four multi-criteria decision making methods such as Fuzzy AHP-TOPSIS, Fuzzy AHP-VIKOR, Fuzzy AHP-ELECTRE, and Fuzzy AHP-PROMETHEE for selecting pipe material in sugar industry. Kabak [16] have proposed a fuzzy hybrid multi-criteria decision making approach using Fuzzy ANP, Fuzzy TOPSIS, and Fuzzy ELECTRE techniques for sniper selection. Kou et al. [18] proposed an approach to resolve disagreements among MCDM methods based on Spearman’s rank correlation coefficient to examine five MCDM methods using 17 classification algorithms and 10 performance criteria over 11 public-domain binary classification datasets through experimental study for ranking. Kou and Lin [19] proposed a cosine maximization method (CM) based on similarity measure that maximizes the sum of the cosine of the angle between the priority vector and each column vector of a PCM. Hsu et al. [8] have implemented DEMATEL-based ANP with VIKOR to solve the recycled material selection problem in order to increase the utilization of scarce resources. Mardani et al [22] presented a systematic review of the VlseKriterijuska Optimizacija I Komoromisno Resenje

Table 1
Decision matrix.

Alternatives	Attributes				
	C ₁ (w ₁)	C ₂ (w ₂)	-	-	C _m (w _m)
A ₁	x ₁₁ ^e	x ₁₂ ^e	-	-	x _{1m} ^e
A ₂	x ₂₁ ^e	x ₂₂ ^e	-	-	x _{2m} ^e
-	-	-	-	-	-
-	-	-	-	-	-
A _n	x _{n1} ^e	x _{n2} ^e	-	-	x _{nm} ^e

(VIKOR) method in several application areas such as sustainability and renewable energy.

Existing Literature on selection of products for particular application rests on exploring various methodologies in original or and integrated form under deterministic and uncertain environment to improve the decision making process. However, decision making processes hardly explore selection of alternatives with specific relevance to ergonomic considerations. Further, most of the methods consider either objective or subjective criteria only. In real life situations, most of the decision making processes deal with both objective and subjective criteria. The attribute weights must also be based on subjective and objective evaluation to consider both uncertainty in decision making and variance of the ratings of the criteria. To deal with such situation, an integrated weight calculation approach is adopted in this work.

3. Proposed methodology

MADM has established as an effective methodology for solving a large variety of multi-criteria decision making and ranking problems [10]. In this study, a novel approach of MADM has been proposed to find a suitable ergonomically designed product with respect to design characteristics (attributes). The best alternative is chosen from a set of n alternatives {A₁,A₂, ..., A_n} whereas the performance of the alternatives are decided on the basis of m attributes {C₁, C₂, ..., C_m} by a group of k decision maker (DMs) {DM₁, DM₂, ..., DM_k}as given in Table 1. The weight for the attributes are considered as {w₁, w₂, ..., w_m}.

Different steps of the proposed work are described in Fig. 1. The methodology consists of six major computational steps as discussed below.

Step 1: Identify the problem

To illustrate the approach, an ergonomically designed office chair selection problem is considered as a case study. As the selection of an ergonomically designed office chair includes technical specification as well as user preference, it becomes a difficult task to choose an office chair with specific features that satisfy a range of customers. In addition to design characteristics in terms of technical specifications provided by manufacturers, expert opinion is also considered to take into account the customer preferences. A group of DMs analysed the possible attributes and alternatives from a set of available office chairs in the market place and important attributes and alternatives are considered. Since impreciseness and ambiguity exist to assign rating for each attribute and alternative, a linguistic scale is used to express decision makers’ opinion on each alternative with respect to attribute.

Step 2: Preparation of decision table

To model decision makers’ judgement, fuzzy scales are employed which translate the linguistic terms into triangular fuzzy numbers as linguistic variables deal with ambiguity and subjectivity. To convert the qualitative terms into quantitative values, a five point fuzzy scale with triangular fuzzy numbers based on the works of Chen (1985) is chosen. As shown in Fig. 2, linguistic terms “very low” (VL), “low” (L), “medium” (M), “high” (H), “very high” (VH) are included to measure the performance of each alternative



Fig. 1. Graphical representation of generic MADM model.

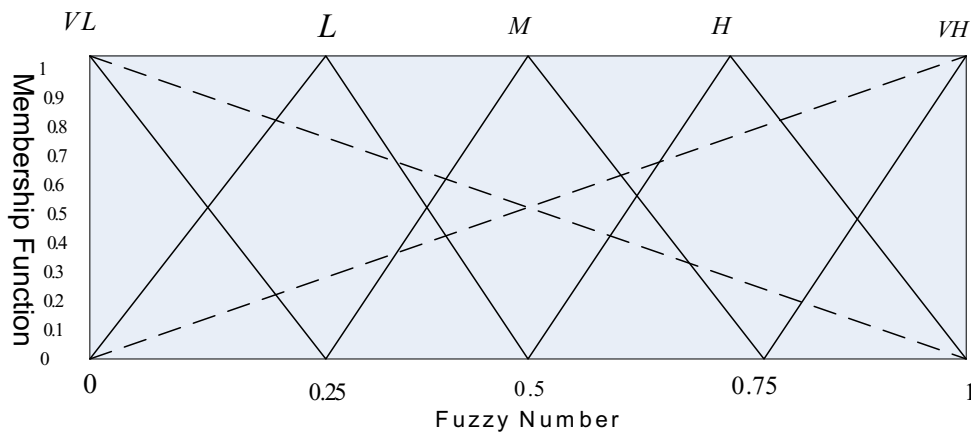


Fig. 2. Linguistic terms to fuzzy numbers conversion (5-point scale).

C ₁	A ₁	A ₂	A ₃				
	C ₂	A ₁	A ₂	A ₃			
A ₁		C ₃	A ₁	A ₂	A ₃		
A ₂	A ₁		C ₄	A ₁	A ₂	A ₃	
A ₃	A ₂	A ₁		A ₁	—	P _{4,12}}	P ₄
	A ₃	A ₂	A ₃	A ₂	P _{4,21}}	—	P _{4,23}}
				A ₃	P _{4,31}}	P _{4,32}}	—

Π	A ₁	A ₂	A ₃
A ₁	—	Π _{12}}	Π _{13}}
A ₂	Π _{21}}	—	Π _{23}}
A ₃	Π _{31}}	Π _{32}}	—

Fig. 3. Preference indices for a problem consisting of three alternatives and four attributes.

with respect to each attribute. The crisp score of fuzzy number ‘M’ is obtained as follows (Chen, 1985):

$$\mu_{\max}(x) = \begin{cases} x, & 0 \leq x \leq 1 \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

$$\mu_{\min}(x) = \begin{cases} 1 - x, & 0 \leq x \leq 1 \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

The fuzzy max and fuzzy min of fuzzy numbers are defined in a manner such that absolute location of fuzzy numbers can be automatically incorporated in the comparison case. The left score of each fuzzy number ‘M_i’ is defined as

$$\mu_L(M_i) = \sup [\mu_{\min}(x) \Delta \mu_{Mi}(x)] \tag{3}$$

The $\mu_L(M_i)$ score is a unique, crisp, real number in (0, 1). It is the maximum membership value of the intersection of fuzzy number M_i and the fuzzy min. The right score is obtained as:

$$\mu_R(M_i) = \sup [\mu_{\max}(x) \Delta \mu_{Mi}(x)] \tag{4}$$

Again $\mu_R(M_i)$ is a crisp number (0, 1). Given the left and right scores, the total crisp score of a fuzzy number M_i is defined as:

$$\mu_T(M_i) = [\mu_R(M_i) + 1 - \mu_L(M_i)]/2 \tag{5}$$

These ratings may be given by a single or a group of decision maker. Yue [37] states that MADM problems can provide reliable results if analysis of multiple experts is taken into account instead of the analysis of a single expert.

After evaluation of aggregate crisp score value (x_{ij}), the rating value for alternative i with respect to each attribute j, the aggregate crisp values are normalized so that rating values given by the decision makers can be converted into a common scale. Considering the normalized value (x_{ij}^{*}), a decision table is prepared. Normalization is carried out using following relationship.

$$x_{ij}^* = x_{ij} / (x_{ij})_{\max} \tag{6}$$

where, x_{ij} is the aggregate crisp score of alternative ‘i’ under attribute ‘j’.

Step 3: Allocate the weights of importance of the identified attributes

The proposed methodology uses integrated weights of objective and subjective preference for assigning attribute weights. By varying proportion of objective and subjective weights, a large number

of decision making scenarios can be generated to provide the decision makers a wide range of solutions to choose the best one.

Step 3.1. Computation of objective weights of importance of the attributes

The objective weights can be computed by using the normalized data given in decision matrix developed in previous step. As the statistical variance gives a measure of dispersion of data points around their mean value [32], the proposed method determines the objective weight of attributes in terms of statistical variance method. The statistical variance for determining the objective weights of importance of the attributes is given by the following equation.

$$v_j = (1/n) \sum_{i=1}^n (x_{ij}^* - (x_{ij}^*)_{mean})^2 \tag{7}$$

where v_j is the variance of the data corresponding to the j th attribute and $(x_{ij}^*)_{mean}$ is the average value of x_{ij}^* .

The objective weight of the j th attribute, w_j^0 can be computed by dividing the statistical variance of the j th attribute with the total value of the statistical variances for m number of attributes. Thus, w_j^0 can be computed by the following equation.

$$w_j^0 = v_j / \sum_{j=1}^m v_j \tag{8}$$

Step 3.2. Computation of subjective weights of importance of the attributes

The subjective preferences can be evaluated through pair-wise comparison of the attributes. A pair-wise comparison matrix ($m \times m$) for all attributes can be constructed with respect to objective by using Saaty’s 1–9 scale of pair-wise comparisons so that each attribute can be compared with each other attribute. For each comparison, the decision maker decides which of the attribute is most important among two and then assigns a score to show how much more important it is than the other. After making the pair-wise comparisons, the consistency is checked by using the following computations.

$$\text{Consistency Index, CI} = \frac{\lambda_{max} - m}{m - 1} \tag{9}$$

where, λ_{max} is the maximum Eigen value of the matrix and m is matrix size

$$\text{Consistency Ratio, CR} = \frac{CI}{RI} \tag{10}$$

Consistency ratio (C.R.) can be defined as the ratio of consistency index (C.I.) and randomly generated consistency index (R.I.) values. The judgement matrix is consistent if a CR value is less than 0.10.

Step 4: Computation of integrated weights of importance of the attributes

For utilizing both objective and subjective weights of the attributes, an integrated weight of importance is to be calculated. The integrated weight can be described by using the following equation.

$$w_j^i = w^o \times w_j^o + w^s \times w_j^s \tag{11}$$

where, w_j^i , w_j^o and w_j^s denote the integrated, objective and subjective weight of the j th attribute respectively. The weightings are taken in between 0 and 1. w^o and w^s represent the weightings proportion considered for objective and subjective weights respectively. The weightings are taken between 0 and 1.

Step 5: Determination of ranking of the alternatives

Each decision matrix has three main components viz., (a) alternatives, (b) attribute, (c) weight or relative importance of each attribute. Three different MADM methods such as Techniques for Or-

der Preference by Similarity to Identical Solution (TOPSIS), a compromise ranking method known as ViseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) are considered to measure the performance of alternative. These three MADM methods are based on three different solutions for ranking the alternatives. TOPSIS method choose the alternative based on shortest distance from the positive ideal solution and the farthest distance from the negative-ideal solution whereas VIKOR method provides a compromising solution in which an agreement is established between two mutual concessions. PROMETHEE method introduces “net preference flow” value function to rank the alternatives [2]. Both VIKOR and PROMETHEE methods use linear normalization as given in Eq. (6). TOPSIS method uses vector normalization, and the normalized value can be obtained by following equation.

Step 5.1. Techniques for Order Preference by Similarity to Identical Solution (TOPSIS)

TOPSIS method is based on calculation of preference index in order to evaluate the ranking of alternatives by computing the shortest Euclidean distances to both positive ideal solution and negative ideal solution simultaneously. It is based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution and on the other hand, the farthest distance from the negative ideal solution. Here, the normalized decision matrix can be obtained by Eq. (13).

$$x_{ij}^* = x_{ij} / \left[\sum_{j=1}^m x_{ij}^2 \right]^{1/2} \tag{12}$$

The weighted normalized decision matrix considering integrated weights can be expressed as $Y_{ij} = W_j^i \times X_{ij}^*$. The positive ideal solution and negative ideal solution can be calculated using following formulae.

The positive ideal (best) solutions can be expressed as:

$$A^+ = \{y_1^+, \dots, y_m^+\} = \left\{ \left(\max_i y_{ij} / j \in J^I \right), \left(\min_i y_{ij} / j \in J^{II} \right) \right\} \tag{13}$$

The negative ideal (worst) solutions can be expressed as:

$$A^- = \{y_1^-, \dots, y_m^-\} = \left\{ \left(\min_i y_{ij} / j \in J^I \right), \left(\max_i y_{ij} / j \in J^{II} \right) \right\} \tag{14}$$

where J^I is associated with beneficial attribute and J^{II} is associated with non-beneficial attribute.

The separation of each alternative from the ideal one is given by the Euclidean distance. The separation of each alternative from the positive ideal solution is given as

$$D_i^+ = \sqrt{\sum_{j=1}^m (y_{ij} - y_j^+)^2}, i = 1, 2, \dots, I \tag{15}$$

Similarly, the separation of each alternative from the negative ideal solution is expressed as

$$D_i^- = \sqrt{\sum_{j=1}^m (y_{ij} - y_j^-)^2}, i = 1, 2, \dots, I \tag{16}$$

After calculating the separation the relative closeness to the ideal solution is carried out. The relative closeness (preference index) of the alternatives to the ideal solution is defined as

$$C_i^+ = \frac{D_i^-}{D_i^* + D_i^-}, i = 1, 2, \dots, I \tag{17}$$

C_i^+ is also called as the overall performance score of alternative. A set of alternatives is generated according to the value of C_i^+ indicating the most preferred and least preferred feasible solutions. The alternative which has highest value of performance score will be given top ranking in the order. Ranking will be done for different proportion of subjective and objective weights. The final selection of the best alternative will be assessed through the analysis of final ranking matrix.

Step 5.2. ViseKriterijumska Optimizacija I Kompromisno Rešenje (VIKOR)

The foundation for compromise solution was established by Yu and Zeleny and later advocated by Oprovcovic and Tzeng [28,35] and Tzeng et al. [35,36]. The compromise solution is closest to the ideal solution which is a feasible solution. The compromise ranking algorithm of the VIKOR method has the following steps:

For alternative A_i the rating of j th attribute is expressed as f_{ij}

Step 5.2.1. The first step is to determine the objective, also determine the best, i.e., f_j^+ and the worst, i.e. f_j^- , values of all attributes.

$$f_j^+ = \max_i f_{ij}, \quad j = 1, 2, 3, \dots, m \tag{18a}$$

$$f_j^- = \min_i f_{ij}, \quad j = 1, 2, 3, \dots, m \tag{18b}$$

Step 5.2.2: Compute the values S_j and R_j , $i = 1, 2, \dots, n$.

$$S_i = \sum_{j=1}^n w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-) \tag{19}$$

$$R_i = \max_j w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-) \tag{20}$$

where w_j are the weights of the attribute expressing the relative importance.

Step 5.2.3: Compute the values Q_i , $i = 1, 2, \dots, n$ by the following relation

$$Q_i = \nu(S_i - S^*) / (S^- - S^*) + (1 - \nu)(R_i - R^*) / (R^- - R^*) \tag{21}$$

where S^* is the minimum value of S_i i.e. $S^* = \min_i S_i$ and S^- is the maximum value of S_i i.e. $S^- = \max_i S_i$

Similarly, R^+ is the minimum value of the R_i i.e. $R^+ = \min_i R_i$ and R^- is the maximum value of R_i i.e. $R^- = \max_i R_i$

ν is introduced as the weight of strategy of “the majority of attribute” (or the maximum group utility”), usually $\nu = 0.5$.

Step 5.2.4: By arranging the alternatives in the ascending order of S , R and Q values, the three ranking lists can be obtained. The compromise ranking list for a given ν is obtained by ranking with Q_i measures. The best alternative, ranked by Q_i , is the one with the minimum value of Q_i .

Step 5.2.5: Propose a compromise solution for alternative A_k

Under a given weight of attribute, alternative A_k is the best ranked by Q value (Minimum) if the following two conditions are satisfied [36]:

Condition 1: ‘Acceptable advantage’:

$$Q(A_k) - Q(A_1) \geq DQ \tag{22}$$

$$DQ = \frac{1}{(N - 1)} \tag{23}$$

where, A_1 the second best alternative in the ranking list by Q . N is the number of alternatives.

Condition 2: ‘Acceptable stability in decision making’: Alternative A_k must also be the best ranked by S or/and R . This compromise solution is stable within a decision making process, which

could be “voting by majority rule” (when $\nu > 0.5$ is needed), or “by consensus” ($\nu \approx 0.5$), or “with veto” ($\nu < 0.5$). Here, ν is the weight of the decision making strategy “the majority of attribute” (or “the maximum group utility”).

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- 1- Alternatives A_k and A_1 if only condition 2 is not satisfied
- 2- Alternatives A_k, A_1, \dots, A_p if condition 1 is not satisfied; A_p is determined by the relation

$$Q(A_p) - Q(A_1) < DQ$$

Step 5.3: Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

PROMETHEE method was introduced by Brans et al. [2]. Like all other ranking methods, PROMETHEE deals with a pair wise comparison of alternatives for each single attribute in order to determine partial binary relations denoting the strength of preference of an alternative A_1 over alternative A_2 . The alternatives are evaluated on different attribute. The implementation of PROMETHEE also requires relative importance or the weights of the attribute considered and information on the decision maker preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate attribute. The preference function (P_i) translates the difference between the evaluations obtained by two alternatives (A_1 and A_2) in terms of a particular attribute, into a preference degree ranging from 0 to 1. The method covers the following steps given below

Here the decision maker gives his/her preference function by comparing the contribution of one alternative with respect to another in terms of each separate attribute. The preference function (P_i) finds a difference between two alternatives (A_1 and A_2) for a particular attribute in terms of a preference degree 0 or 1. Let $P_{j, A_1 A_2}$ be the preference function associated to the attribute C_j .

$$P_{j, A_1 A_2} = G_j [C_j(A_1) - C_j(A_2)] \tag{24}$$

$$0 \leq P_{i, A_1 A_2} \leq 1$$

where, G_j is a non-decreasing function of the observed deviation (d) between two alternatives A_1 and A_2 over the attribute C_j . Let the decision maker have specified a preference function P_j and weight w_j for each attribute C_j ($j = 1, 2, \dots, m$). The multiple attribute preference index $\Pi_{A_1 A_2}$ is then defined as the weighted average of the preference functions P_j

$$\Pi_{A_1 A_2} = \sum_{j=1}^m w_j P_{j, A_1 A_2} \tag{25}$$

$\Pi_{A_1 A_2}$, represents the intensity of preference of the decision maker of alternative A_1 over alternative A_2 when considering simultaneously all the attribute and the value ranges from 0 to 1. This preference index determines a valued outranking relation on the set of actions. As an example, the schematic calculation of the preference indices for a problem consisting of three alternatives and four attribute is given in [3,23].

For PROMETHEE outranking relations, the leaving flow, entering flow and the net flow for a particular alternative (A) belonging to a set of alternatives ‘ A ’ are defined by the following equations:

$$\varphi^+(A) = \sum_{x \in A} \prod_{xa} \tag{26}$$

$$\varphi^-(A) = \sum_{x \in A} \prod_{xa} \tag{27}$$

$$\varphi(A) = \varphi^+(A) - \varphi^-(A) \tag{28}$$

Table 2
Linguistic rating for alternatives selection.

Decision Maker	Alternative	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
D ₁	A1	L	L	VL	M	L	H	M	M	VL	L
	A2	M	M	H	H	H	M	M	M	H	L
	A3	L	H	M	M	L	L	H	VL	VL	M
	A4	L	VL	L	H	M	M	H	VL	M	M
	A5	M	H	M	M	M	M	M	L	VH	L
	A6	L	L	VL	M	L	H	M	L	M	L
D ₂	A1	M	M	L	H	M	VH	H	H	L	M
	A2	H	M	H	H	VH	H	H	H	M	L
	A3	M	H	H	H	M	M	VH	L	L	H
	A4	M	M	M	VH	M	H	H	L	M	H
	A5	VH	H	H	M	H	H	H	M	H	L
	A6	M	M	L	M	M	VH	M	M	M	M
D ₃	A1	H	M	M	M	M	VH	H	VH	L	L
	A2	VH	H	VH	VH	VH	VH	VH	VH	H	M
	A3	H	VH	H	M	M	H	VH	L	VL	H
	A4	H	M	M	VH	H	VH	VH	L	M	H
	A5	VH	VH	H	M	H	VH	H	H	VH	M
	A6	H	M	M	L	M	VH	H	M	H	L
D ₄	A1	VL	L	VL	H	L	M	M	M	M	L
	A2	M	L	M	VH	M	M	M	L	VH	L
	A3	L	M	M	M	L	L	H	VL	L	M
	A4	L	VL	L	H	L	M	H	VL	M	M
	A5	M	M	M	M	M	M	M	L	H	L
	A6	VL	L	VL	L	L	M	L	VL	M	L

Table 3
Fuzzy numbers associated with alternatives.

Alternatives (Decision maker)	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	
D ₁	A ₁	L(0,0,3,0,5)	L(0,0,3,0,5)	VL(0,0,0,3)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	VL(0,0,0,3)	L(0,0,3,0,5)
	A ₂	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	H(0,5,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	L(0,0,3,0,5)
	A ₃	L(0,0,3,0,5)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	L(0,0,3,0,5)	H(0,5,0,7,1)	VL(0,0,0,3)	VL(0,0,0,3)	M(0,3,0,5,0,7)
	A ₄	L(0,0,3,0,5)	VL(0,0,0,3)	L(0,0,3,0,5)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	VL(0,0,0,3)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)
	A ₅	M(0,3,0,5,0,7)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	VH(0,7,0,7,1)	L(0,0,3,0,5)
	A ₆	L(0,0,3,0,5)	L(0,0,3,0,5)	VL(0,0,0,3)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	L(0,0,3,0,5)
D ₂	A ₁	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	VH(0,7,0,7,1)	H(0,5,0,7,1)	H(0,5,0,7,1)	L(0,0,3,0,5)	M(0,3,0,5,0,7)
	A ₂	H(0,5,0,7,1)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	H(0,5,0,7,1)	VH(0,7,0,7,1)	H(0,5,0,7,1)	H(0,5,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	L(0,0,3,0,5)
	A ₃	M(0,3,0,5,0,7)	H(0,5,0,7,1)	H(0,5,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	VH(0,7,0,7,1)	L(0,0,3,0,5)	L(0,0,3,0,5)	H(0,5,0,7,1)
	A ₄	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	VH(0,7,0,7,1)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	H(0,5,0,7,1)
	A ₅	VH(0,7,0,7,1)	H(0,5,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	H(0,5,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	L(0,0,3,0,5)
	A ₆	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	VH(0,7,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)
D ₃	A ₁	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	VH(0,7,0,7,1)	H(0,5,0,7,1)	VH(0,7,0,7,1)	L(0,0,3,0,5)	L(0,0,3,0,5)
	A ₂	VH(0,7,0,7,1)	H(0,5,0,7,1)	VH(0,7,0,7,1)	VH(0,7,0,7,1)	VH(0,7,0,7,1)	VH(0,7,0,7,1)	VH(0,7,0,7,1)	VH(0,7,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)
	A ₃	H(0,5,0,7,1)	VH(0,7,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	VH(0,7,0,7,1)	L(0,0,3,0,5)	VL(0,0,0,3)	H(0,5,0,7,1)
	A ₄	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	VH(0,7,0,7,1)	H(0,5,0,7,1)	VH(0,7,0,7,1)	VH(0,7,0,7,1)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	H(0,5,0,7,1)
	A ₅	VH(0,7,0,7,1)	VH(0,7,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	VH(0,7,0,7,1)	H(0,5,0,7,1)	H(0,5,0,7,1)	VH(0,7,0,7,1)	M(0,3,0,5,0,7)
	A ₆	H(0,5,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	VH(0,7,0,7,1)	H(0,5,0,7,1)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	L(0,0,3,0,5)
D ₄	A ₁	VL(0,0,0,3)	L(0,0,3,0,5)	VL(0,0,0,3)	H(0,5,0,7,1)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)
	A ₂	M(0,3,0,5,0,7)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	VH(0,7,0,7,1)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	VH(0,7,0,7,1)	L(0,0,3,0,5)
	A ₃	L(0,0,3,0,5)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	L(0,0,3,0,5)	H(0,5,0,7,1)	VL(0,0,0,3)	L(0,0,3,0,5)	M(0,3,0,5,0,7)
	A ₄	L(0,0,3,0,5)	VL(0,0,0,3)	L(0,0,3,0,5)	H(0,5,0,7,1)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	H(0,5,0,7,1)	VL(0,0,0,3)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)
	A ₅	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	H(0,5,0,7,1)	L(0,0,3,0,5)
	A ₆	VL(0,0,0,3)	L(0,0,3,0,5)	VL(0,0,0,3)	L(0,0,3,0,5)	L(0,0,3,0,5)	M(0,3,0,5,0,7)	L(0,0,3,0,5)	VL(0,0,0,3)	M(0,3,0,5,0,7)	L(0,0,3,0,5)

$\varphi^+(A)$ is called the leaving flow, $\varphi^-(A)$ is called the entering flow and $\varphi(A)$ is called the net flow. $\varphi^+(A)$ is the measure of the outranking character of A (i.e. dominance of alternative 'A' over all other alternatives) and $\varphi^-(A)$ gives the outranked character of A (i.e. degree to which alternative A is dominated by all other alternatives). The net flow, $\varphi(A)$ 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. For example, for each alternative A, belonging to the set of alternatives (A_1, A_2, \dots, A_n) , \prod_{A_1, A_2} is an overall preference index of A_1 over A_2 , taking into account all the attribute. Alternative A_1 outranks A_2 if $\varphi(A_1) > \varphi(A_2)$ and A_1 is said to be indifferent to A_2 if $\varphi(A_1) = \varphi(A_2)$.

4. Results and discussion

Keeping view with the increasing demand for a suitable ergonomically designed office chair, six different alternatives with respect to ten design characteristics (attribute) are considered. The attribute are considered with an extensive literature review of previous report for ergonomically designed office chair [24]. A survey among manufacturers of chairs and opinion of experts specialized in ergonomically designed chair revealed that the evaluation of office chair should carry ten important design characteristics. Based on the evaluation of four decision makers, a decision matrix is made considering six alternatives $\{A_1, A_2, A_3, A_4, A_5, A_6\}$ and ten attributes $\{C_1, C_2, \dots, C_{10}\}$. Relative weights $\{w_1, w_2, \dots, w_{10}\}$ are assigned to each design characteristic (attribute) to represent the DM's preference information. Ten important attributes considered

are Depth of seat (C_1), Overall depth (C_2), Width of seat (C_3), Size of base (C_4), Width height ratio (C_5), Seat adjustment (C_6), Backrest height (C_7), Swivel angle (C_8), Decoration (C_9), and Density of cushion (C_{10}). Based on the dimensions considered and comparison with Bureau of Indian standard data, the attributes are classified into beneficial and non-beneficial category. Out of ten attribute, $C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8$ and C_9 are beneficial (higher the value is desired) and C_{10} is non-beneficial attribute (lower the value is desired). As the alternatives (Office chair) based on attributes are of conflicting in nature, a five point fuzzy scale with triangular fuzzy numbers is chosen to rate the alternatives. A team of four decision makers, DM_1, DM_2, DM_3 and DM_4 has been formed to evaluate the alternatives. An individual decision maker's judgment is evaluated by using fuzzy rating scale with triangular membership functions in order to extract the rating values of alternatives where individual attribute is given linguistic terms as is given in Table 2. Linguistic terms are further converted to their corresponding fuzzy numbers as shown in Table 3. In order to assess with each attribute weight, individual fuzzy numbers are aggregated as is highlighted in Table 4. Aggregate fuzzy numbers are then transformed into crisp values and the corresponding values are given in Table 5.

The aggregate crisp values of attribute are now normalized using Eq. (6) so that the attribute ratings given by the decision makers can be converted into a common scale. The normalized decision matrix for attribute is shown in Table 6. On the basis of statistical variance method, the variance and the objective weights of the attributes are computed by using Eqs. (7) and (8). The variance and the objective weight value for ten attribute are given in Table 7.

Analytic Hierarchy Process (AHP) is used to calculate subjective weights of attribute. A pair-wise comparison matrix (10×10) as shown in Table 8 can be constructed for attribute based upon the intensity of importance. The value of CR is calculated by using Eqs. (9) and (10). The value of CR obtained is 0.0654 which is less than 0.1 and hence the result is acceptable. The subjective weights are calculated using geometric means and the result is shown in Table 9.

To check the consistency of matrix eigen value λ_{max} is to be calculated

Consistency index (CI):

$$\frac{\lambda_{max} - n}{n - 1} = \frac{10.86 - 10}{10 - 1} = 0.0956$$

$$\text{Consistency ratio (CR)} := \frac{CI}{RI} = \frac{0.0956}{1.45} = 0.0654 < 1$$

The integrated weights of attributes are obtained using Eq. (11). Table 10 gives the integrated weights of attributes considering the different weightings proportion of the objective and subjective weights within the range 0 to 1.

The normalized decision matrix for TOPSIS is obtained by using Eq. (12) and the decision matrix is shown in Table 11. Here the ranking of the alternatives is illustrated by considering purely subjective weight ($w^0 = 1$ and $w^s = 0$). By multiplying normalized decision matrix with corresponding integrated attribute weights, the weighted normalized decision matrix can be obtained as is given in Table 12.

The positive ideal solution and the negative ideal solution for the alternatives are calculated using Eqs. (13) and (14) respectively. The positive ideal solution is given as {0.0288, 0.058, 0.099, 0.033, 0.035, 0.014, 0.013, 0.103, 0.097, 0.032}. Similarly, the negative ideal solution is given by {0.019, 0.028, 0.041, 0.019, 0.022, 0.009, 0.009, 0.038, 0.031, 0.051}. The positive and negative separation (D_i^* and D_i^-) of each alternative from ideal solutions is calculated using Eqs. (15) and 16 respectively. The Preference index (C_i^*) showing

Table 4
Aggregate fuzzy number of alternatives.

Alternatives	Attribute									
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	(0.2,0.375,0.625)	(0.15,0.4,0.6)	(0.075,0.2,0.45)	(0.4,0.6,0.85)	(0.15,0.4,0.6)	(0.55,0.65,0.925)	(0.4,0.6,0.85)	(0.4,0.6,0.85)	(0.075,0.275,0.5)	(0.075,0.35,0.55)
A_2	(0.45,0.6,0.85)	(0.27,0.5,0.725)	(0.5,0.65,0.92)	(0.6,0.71)	(0.5,0.65,0.92)	(0.45,0.6,0.85)	(0.45,0.6,0.85)	(0.375,0.55,0.8)	(0.5,0.65,0.925)	(0.075,0.35,0.55)
A_3	(0.2,0.45,0.675)	(0.5,0.65,0.925)	(0.4,0.6,0.85)	(0.35,0.55,0.775)	(0.15,0.4,0.6)	(0.2,0.45,0.675)	(0.6,0.71)	(0.0,0.15,0.4)	(0.0,0.15,0.4)	(0.4,0.6,0.85)
A_4	(0.2,0.45,0.675)	(0.15,0.25,0.5)	(0.15,0.325,0.55)	(0.6,0.71)	(0.27,0.5,0.725)	(0.45,0.6,0.85)	(0.55,0.7,0.1)	(0.0,0.15,0.4)	(0.3,0.5,0.7)	(0.075,0.35,0.5)
A_5	(0.5,0.6,0.85)	(0.5,0.65,0.925)	(0.4,0.6,0.85)	(0.3,0.5,0.7)	(0.4,0.6,0.85)	(0.45,0.6,0.85)	(0.45,0.6,0.85)	(0.2,0.45,0.675)	(0.6,0.71)	(0.075,0.35,0.55)
A_6	(0.2,0.375,0.675)	(0.15,0.4,0.6)	(0.075,0.2,0.45)	0.15,0.4,0.6	(0.15,0.4,0.6)	(0.55,0.65,0.925)	(0.27,0.5,0.725)	(0.15,0.325,0.5)	(0.35,0.55,0.77)	0(0.075,0.35,0.55)

Table 5
Crisp ratings of alternatives.

Alternatives	Attribute									
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀
A ₁	0.409574	0.41	0.268889	0.59	0.41	0.6582	0.59	0.600867	0.318665	0.36642
A ₂	0.60087	0.5	0.645354	0.702797	0.6582	0.60087	0.60087	0.554043	0.645354	0.36642
A ₃	0.45551	0.645354	0.59	0.545493	0.41	0.45551	0.702797	0.225217	0.225217	0.59
A ₄	0.45551	0.313636	0.362788	0.702797	0.5	0.60087	0.688963	0.225217	0.5	0.59
A ₅	0.612727	0.645354	0.59	0.5	0.59	0.60087	0.59	0.45551	0.702797	0.36642
A ₆	0.409574	0.41	0.268889	0.41	0.41	0.6582	0.5	0.362788	0.545493	0.36642

Table 6
Normalized crisp ratings.

Alternatives	Attribute									
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀
A ₁	0.668445	0.63531	0.416652	0.839503	0.622911	1	0.839503	1	0.453424	0.62105
A ₂	0.980648	0.774769	1	1	1	0.912898	0.854969	0.922072	0.918265	0.62105
A ₃	0.743415	1	0.914227	0.776175	0.622911	0.692054	1	0.374821	0.320459	1
A ₄	0.743415	0.485991	0.562153	1	0.759648	0.912898	0.980316	0.374821	0.711443	1
A ₅	1	1	0.914227	0.711443	0.896384	0.912898	0.839503	0.758088	1	0.62105
A ₆	0.668445	0.63531	0.416653	0.583383	0.622911	1	0.711443	0.603774	0.776175	0.62105

Table 7
Objective weights of attribute.

Attribute	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Variance	0.0189	0.0369	0.0602	0.0224	0.0220	0.0105	0.0093	0.0598	0.0580	0.0320
Objective weights	0.057	0.112	0.182	0.068	0.0668	0.032	0.028	0.181	0.176	0.096

Table 8
Pair wise comparison matrix.

	Depth	Overall depth	Width of seat	Size of base	Width height ratio	Seat adjustment	Back rest height	Swivel angle	Decoration	Density
Depth	1	3	2	3	1	2	4	3	6	1/4
Overall depth	1/3	1	1/3	1/4	1/6	1/5	1/2	1/5	2	1/5
Width of seat	1/2	3	1	3	1/3	2	4	3	5	1/4
Size of base	1/3	4	1/3	1	1/3	1	4	1/3	4	1/2
Width height ratio	1	6	3	3	1	4	5	3	6	1/4
Seat adjustment	1/2	5	1/2	1	1/4	1	2	1/3	3	1/5
Backrest height	1/4	2	1/4	1/4	1/5	1/2	1	1/4	1/2	1/6
Swivel angle	1/3	5	1/3	3	1/3	3	4	1	3	1/3
Decoration	1/6	1/2	1/5	1/4	1/6	1/3	2	1/3	1	1/6
Density	4	5	4	2	4	5	6	3	6	1

Table 9
Subjective weight design characteristics (attributes).

Criterion	Weight	
1	Depth seat pan	0.143
2	Overall depth	0.027
3	Width of seat	0.110
4	Size of base	0.065
5	Width height ratio	0.188
6	Seat adjustment	0.0611
7	Backrest height	0.0268
8	Swivel angle	0.0881
9	Decoration	0.0259
10	Density	0.261

the ranking of alternatives can be obtained by using Eq. (17). and the final ranking of six alternatives are depicted in Table 13. In the similar manner, the ranking preference order of all those six alternatives considering integrated weights of different proportions is given in Table 14.

The normalized decision matrix for VIKOR method can be obtained in a linear method as shown in Table 6. Keeping in view with the normalized decision matrix, the best value

(f_j^+) and the worst value (f_j^-) for the attributes are obtained using Eqs. 19(a) and 19(b) respectively. The best values and worst values are: $f_j^+ = (1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0.621051)$, $f_j^- = (0.668445, 0.485991, 0.416653, 0.583383, 0.622911, 0.692054, 0.711443, 0.374821, 0.320459, 1)$. For ranking the alternatives, the methodology needs to calculate S_i, R_i along with the final values of Q_i as given in Table 15 based on Eqs. (19)–(21) where $i = 1, 2, \dots, n$. It has been seen alternative A_2 is best ranked by ‘minimum Q value’ and the stability in decision making is completely satisfied (condition 2) for all weighing proportion “ $w^o = 0 \ w^s = 1$ ”, “ $w^o = 0.2 \ w^s = 0.8$ ”, “ $w^o = 0.4 \ w^s = 0.6$ ”, “ $w^o = 0.6 \ w^s = 0.4$ ”, “ $w^o = 0.8 \ w^s = 0.2$ ”, “ $w^o = 1 \ w^s = 0$ ”, but the acceptance advantage (condition 1) is not satisfied as we have $Q(A_2) - Q(A_5) = 0.15 < 0.2$. Therefore, a final ranking of alternatives as shown in Table 15 is obtained through a compromise solution satisfying Eqs. (22) and (23) i.e. the alternative in the second position (A_5) forms a compromise solution together with the alternative (A_2) in the first position satisfying the conditions provided in VIKOR method. Considering integrated weight with different proportion of objective and subjective weights, the ranking of the alternatives is illustrated.

Table 10
Integrated weight calculation.

Importance of objective weight (w^o)	Importance of subjective weight (w^s)	Integrated weights of attribute									
		Attributes									
		C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀
1.0	0	$w_{C_1}^i$ 0.057	$w_{C_2}^i$ 0.111	$w_{C_3}^i$ 0.182	$w_{C_4}^i$ 0.068	$w_{C_5}^i$ 0.066	$w_{C_6}^i$ 0.032	$w_{C_7}^i$ 0.028	$w_{C_8}^i$ 0.181	$w_{C_9}^i$ 0.175	$w_{C_{10}}^i$ 0.096
0.8	0.2	0.074	0.094	0.167	0.067	0.091	0.037	0.028	0.162	0.145	0.129
0.6	0.4	0.091	0.077	0.153	0.066	0.115	0.043	0.027	0.143	0.115	0.162
0.5	0.5	0.100	0.069	0.146	0.066	0.127	0.046	0.027	0.134	0.100	0.178
0.4	0.6	0.108	0.060	0.138	0.066	0.139	0.049	0.027	0.125	0.085	0.195
0.2	0.8	0.125	0.043	0.124	0.065	0.163	0.055	0.027	0.106	0.055	0.228
0	1.0	0.143	0.027	0.110	0.065	0.188	0.061	0.026	0.088	0.025	0.261

Table 11
Normalized decision matrix.

Alternatives	Attribute									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A ₁	0.336	0.333	0.228	0.411	0.330	0.448	0.391	0.570	0.251	0.330
A ₂	0.493	0.406	0.548	0.490	0.531	0.410	0.398	0.526	0.508	0.330
A ₃	0.373	0.524	0.501	0.381	0.330	0.310	0.466	0.214	0.177	0.531
A ₄	0.373	0.255	0.308	0.490	0.403	0.410	0.456	0.214	0.394	0.531
A ₅	0.502	0.524	0.501	0.350	0.476	0.410	0.391	0.432	0.553	0.330
A ₆	0.335	0.333	0.228	0.286	0.330	0.449	0.331	0.344	0.430	0.330

Table 12
Weighted normalized matrix for alternatives.

Alternative	Attributes									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A ₁	0.019	0.037	0.042	0.028	0.022	0.014	0.011	0.103	0.044	0.032
A ₂	0.028	0.045	0.099	0.033	0.035	0.013	0.011	0.095	0.090	0.032
A ₃	0.021	0.058	0.091	0.026	0.022	0.009	0.013	0.038	0.031	0.051
A ₄	0.021	0.028	0.056	0.033	0.027	0.013	0.013	0.038	0.070	0.051
A ₅	0.029	0.058	0.091	0.240	0.031	0.013	0.011	0.078	0.097	0.032
A ₆	0.020	0.037	0.041	0.020	0.022	0.014	0.009	0.062	0.075	0.032

Table 13
Ranking index (C_i^*) of alternatives.

Alternatives	Positive separation measure D_i^+	Negative separation measure D_i^-	Preference index C_i^*	Ranking of the alternatives
A ₁	0.0057	0.0043	0.4389	3
A ₂	0.0002	0.0093	0.9762	1
A ₃	0.0076	0.0028	0.2692	5
A ₄	0.0070	0.0014	0.1692	6
A ₅	0.0006	0.0080	0.9213	2
A ₆	0.0055	0.0025	0.3153	4

Table 14
Ranking of alternatives considering integrated weight.

Alternatives	$w^o = 1$ $w^s = 0$	$w^o = 0.8$ $w^s = 0.2$	$w^o = 0.6$ $w^s = 0.4$	$w^o = 0.4$ $w^s = 0.6$	$w^o = 0.2$ $w^s = 0.8$	$w^o = 0$ $w^s = 1$
A ₁	3	3	3	3	3	3
A ₂	1	1	1	1	1	1
A ₃	5	5	5	5	5	5
A ₄	6	6	6	6	6	6
A ₅	2	2	2	2	2	2
A ₆	4	4	4	4	4	4

In PROMETHEE method, the decision maker gives his/her preference in order to compare the alternatives for each separate attribute. A preference value ranging between 0 and 1 will be assigned to the 'better' alternative whereas the 'worst' alternative receives a value 0. Based on this theory a pair wise comparison of attribute 'depth of seat' is prepared as shown in Table 16. As 'depth of seat' is a beneficial attribute higher values are desired, of-

fice chair having a comparatively high value of depth of cut is said to be 'better' than the other. Considering $w^o = 1$ and $w^s = 0$, the leaving (The measure of the outranking character, $\varphi^+(A)$ (i.e. dominance of alternative a overall other alternatives)), entering ($\varphi^-(A)$ (i.e. degree to which alternative A is dominated by all other alternatives)) and net flows ($\varphi(A)$) as well as the ranking of the alterna-

Table 15
The ranking and the compromise solutions.

Weight		A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	Ranking	Compromise solution
w ^o = 0 w ^s = 1	S	0.522	0.066	0.786	0.720	0.180	0.618	A ₂ > A ₅ > A ₁ > A ₆ > A ₄ > A ₃	A ₂
	R	0.188	0.0176	0.261	0.261	0.051	0.188	A ₂ > A ₅ > A ₆ = A ₁ > A ₄ = A ₃	A ₂
	Q	0.667	0	1	0.953	0.150	0.733	A ₂ > A ₅ > A ₁ > A ₆ > A ₄ > A ₃	A ₂ , A ₅
w ^o = 0.2 w ^s = 0.8	S	0.569	0.120	0.660	0.699	0.187	0.654	A ₂ > A ₅ > A ₁ > A ₆ > A ₄ > A ₃	A ₂
	R	0.182	0.049	0.181	0.181	0.047	0.182	A ₂ > A ₅ > A ₁ = A ₆ > A ₄ = A ₃	A ₂
	Q	0.888	0.006	0.961	0.995	0.058	0.962	A ₂ > A ₅ > A ₁ > A ₆ > A ₄ > A ₃	A ₂ , A ₅
w ^o = 0.4 w ^s = 0.6	S	0.560	0.108	0.685	0.702	0.185	0.647	A ₂ > A ₅ > A ₁ > A ₆ > A ₄ > A ₃	A ₂
	R	0.168	0.041	0.162	0.162	0.063	0.168	A ₂ > A ₅ > A ₁ = A ₆ > A ₄ = A ₃	A ₂
	Q	0.880	0	0.963	0.978	0.150	0.953	A ₂ > A ₅ > A ₁ > A ₆ > A ₄ > A ₃	A ₂ , A ₅
w ^o = 0.6 w ^s = 0.4	S	0.550	0.097	0.710	0.7077	0.183	0.640	A ₂ > A ₅ > A ₁ > A ₆ > A ₄ > A ₃	A ₂
	R	0.153	0.034	0.162	0.162	0.055	0.153	A ₂ > A ₅ > A ₁ = A ₆ > A ₄ = A ₃	A ₂
	Q	0.834	0	1	0.997	0.154	0.906	A ₂ > A ₅ > A ₁ > A ₆ > A ₄ > A ₃	A ₂ , A ₅
w ^o = 0.8 w ^s = 0.2	S	0.540	0.086	0.735	0.711	0.182	0.631	A ₂ > A ₅ > A ₁ > A ₆ > A ₃ > A ₄	A ₂
	R	0.140	0.026	0.195	0.195	0.048	0.140	A ₂ > A ₅ > A ₁ = A ₆ > A ₃ = A ₄	A ₂
	Q	0.684	0	1	0.981	0.138	0.754	A ₂ > A ₅ > A ₁ > A ₆ > A ₃ > A ₄	A ₂
w ^o = 1 w ^s = 0	S	0.530	0.076	0.760	0.715	0.180	0.624	A ₂ > A ₅ > A ₁ > A ₆ > A ₃ > A ₄	A ₂
	R	0.163	0.020	0.228	0.228	0.045	0.163	A ₅ > A ₁ > A ₄ = A ₃ > A ₁ = A ₆	A ₅
	Q	0.678	0	1	0.966	0.140	0.746	A ₂ > A ₅ > A ₁ > A ₆ > A ₃ > A ₄	A ₂ , A ₅

Table 16
Preference function(P_i) resulting from the pair wise comparisons of the six alternative office chair with respect to criterion depth of cut.

	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆
A ₁	–	0	0	0	0	0
A ₂	1	–	1	1	1	1
A ₃	1	0	–	1	0	1
A ₄	1	0	0	–	0	1
A ₅	1	0	1	1	–	1
A ₆	0	0	0	0	0	–

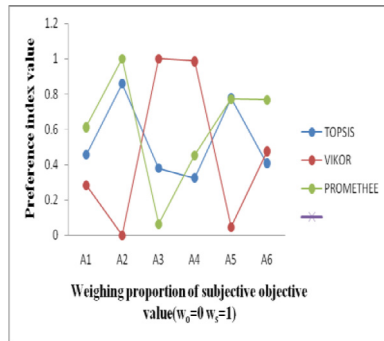


Fig. 4. Integrated subjective objective weight with w^o = 0 and w^s = 1.

tives are evaluated by, (27) and (28).The final ranking is illustrated in Table 17.

Similarly, other value functions (net flows) for different proportion of objective and subjective weight for all the attributes can be tried. The ranking thus obtained based on φ(A) value and is given in Table 18.

As it is apparent from Figs. 4–6, the preference index values for different alternatives with three MADM methodologies specify alternate A₂ as the best among all when attribute weight be-

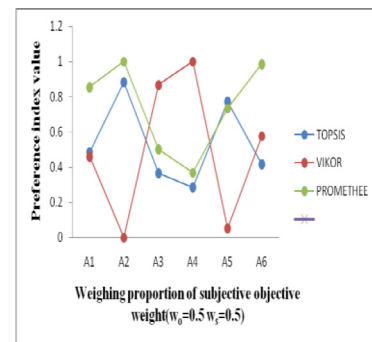


Fig. 5. Integrated subjective objective weight with w^o = 0.5 and w^s = 0.5.

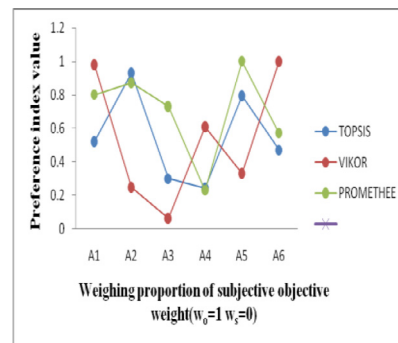


Fig. 6. Integrated subjective objective weight with w^o = 1 and w^s = 0.

came more subjective The ranking order for alternatives changes according to the change in proportion of attribute weight (subjective and objective). It has been found that ranking order for the alternatives change with increase of the proportion of objec-

Table 17
Positive(φ⁺(A)), negative(φ⁻(A)) and net flows(φ(A)) for the scenario.

	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	φ ⁺ (A)	φ ⁻ (A)	φ(A)	Rank
A ₁	–	0.213	0.213	0.391	0.213	0.210	1.24	2.967	-1.727	5
A ₂	0.787	–	0.696	0.843	0.517	0.968	3.811	0.995	2.816	1
A ₃	0.543	0.303	–	0.543	0.303	0.543	2.235	2.056	0.179	3
A ₄	0.608	0.125	0.276	–	0.193	0.432	1.634	2.912	-1.278	4
A ₅	0.787	0.354	0.514	0.775	–	0.968	3.398	1.226	2.172	2
A ₆	0.242	0	0.357	0.360	0	–	0.959	3.121	-2.162	6

Table 18
Ranking of alternatives considering integrated weight.

Alternatives	$w^0 = 1$ $w^s = 0$	$w^0 = 0.8$ $w^s = 0.2$	$w^0 = 0.6$ $w^s = 0.4$	$w^0 = 0.4$ $w^s = 0.6$	$w^0 = 0.2$ $w^s = 0.8$	$w^0 = 0$ $w^s = 1$
A ₁	5	5	5	5	5	5
A ₂	1	1	1	1	1	1
A ₃	3	3	3	3	3	2
A ₄	4	4	4	4	4	4
A ₅	2	2	2	2	2	3
A ₆	6	6	6	6	6	6

Table 19a
Ranking order comparison.

Alternative	$W^0 = 1$ $W^s = 0$			$W^0 = 0.8$ $W^s = 0.2$			$W^0 = 0.6$ $W^s = 0.4$		
	TOPSIS	VIKOR	PROMETHEE	TOPSIS	VIKOR	PROMETHEE	TOPSIS	VIKOR	PROMETHEE
A ₁	3	3	5	3	3	5	3	3	5
A ₂	1	1	1	1	1	1	1	1	1
A ₃	5	5	3	5	5	3	5	6	3
A ₄	6	6	4	6	6	4	6	5	4
A ₅	2	2	2	2	2	2	2	2	2
A ₆	4	4	6	4	4	6	4	4	6

Table 19b
Ranking order comparison.

Alternative	$W^0 = 0.4$ $W^s = 0.6$			$W^0 = 0.2$ $W^s = 0.8$			$W^0 = 0$ $W^s = 1$		
	TOPSIS	VIKOR	PROMETHEE	TOPSIS	VIKOR	PROMETHEE	TOPSIS	VIKOR	PROMETHEE
A ₁	3	3	5	3	3	5	3	3	5
A ₂	1	1	1	1	1	1	1	1	1
A ₃	5	5	3	5	5	3	5	6	2
A ₄	6	6	4	6	6	4	6	5	4
A ₅	2	2	2	2	2	2	2	2	3
A ₆	4	4	6	4	4	6	4	4	6

tive weight for all the methods. However, change of ranking order with increase of objective weight is more pronounced in the VIKOR method. When only objective weight for attributes is considered, A₃ becomes best alternative instead of A₂ in case of VIKOR. In case of TOPSIS method, the ranking of alternative remains same whatever may be the weighing proportion. The final ranking of alternatives considering different weighting proportion of objective and subjective weights is summarized in Table 19.

In the similar way, the final ranking is obtained considering different weightings proportion of objective and subjective weights is given in Tables 19a and 19b.

5. Conclusion

In this work, an attempt has been made to select best office chair with ergonomic considerations using three important MADM methodologies. In the selected MADM approaches, attribute weights are determined using combination of objective and subjective weights to emulate real life decision making process. It is observed that the best alternative chosen remains same for different weighing proportions although the selected MADM methods use different types of normalization to eliminate the units of criterion functions and different ranking index measurement method. The proposed method attempts to consider both subjective and objective weights of qualitative and quantitative attributes and integrates them to decide the importance of weights of the alternatives. The result indicates that all MADM methods considered in this work behave in a similar manner resulting same best alternative irrespective of proportion of weightings for objective and subjective weights. Therefore, the decision makers have the liberty of choosing the best method depending on ease of computational procedure. The method uses only ten features of the product.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.orp.2018.01.004](https://doi.org/10.1016/j.orp.2018.01.004).

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