A hybrid fuzzy multiple criteria group decision making approach for sustainable project selection

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\textbf{A R T I C L E   I N F O}

\textbf{Article history:}
Received 30 August 2011
Received in revised form 11 February 2012
Accepted 19 July 2012
Available online 21 August 2012

\textbf{Keywords:}
Fuzzy preference relations
Goal programming
Fuzzy TOPSIS
Fuzzy distance measurement
Modified preference ratio
Sustainable project selection

\textbf{A B S T R A C T}

In this paper, a new hybrid fuzzy multiple criteria group decision making (FMCGDM) approach has been proposed for sustainable project selection. First, a comprehensive framework, including economic, social, and environmental effects of an investment, strategic alliance, organizational readiness, and risk of investment has been proposed for sustainable project selection. As the relative importance of the criteria of the proposed framework are hard to find through several conflictive preferences of a group of Decision Makers (DMs) so, a goal programming (GP) has been supplied to this aim considering multiplicative and fuzzy preference relation. Then, a fuzzy TOPSIS method has been developed to assess the fitness of investment chances. It is based on Preference Ratio (PR), which is known as an efficient ranking method for fuzzy numbers, and a fuzzy distance measurement. The properties of proposed hybrid approach make it robust for modeling real case of uncertain group decision making problems. The FMCGDM has been developed through a linkage between Lingo 11.0, MS-Excel 12.0, and Visual Basic 6.0. The proposed hybrid approach has been applied in a real case study called Iranian financial and credit institute for sustainable project selection.

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\textbf{1. Introduction}

There exist lots of project and portfolio selection, capital investment procedures and methodologies in literature [1–4]. Classic project selection procedures usually used to pay lots to the all of attentions to financial criteria. Second generation of project selection procedures applied total frameworks to plot a strategic map for financial outcomes of a project [5]. Among them Balanced Score Card (BSC) is a well-known procedure which can assess a project using different perspectives called, financial, customer, internal process, and learning and growth aspects [6]. Outcomes and results of a project are assumed to have short term and long term effects on social and economic, and environmental conditions. So, in the third generation, new criteria, called sustainable development has received more attentions. Other criteria, which have impressive effects on project selection, including alliance of a project with business main strategies [7,8], risk of investment in project [9,10], organizational readiness for implementation of project [11,12], micro and macro-economic effects of the project, were also received scattered attentions in recent decades.

Although it seems that practical project selection procedures should include all of aforementioned criteria, but a comprehensive framework, in which all aforementioned criteria considered, has rarely been reported in literature of project selection. Moreover, in group decision making environment, several DMs may represent conflictive preferences on priority of the criteria of a comprehensive framework. This can make the decision making process more inexplicable in real cases.

More formally, although different approaches have been proposed for project selection and capital investment problems but, the following main issues have rarely been considered simultaneously.

First, a comprehensive framework which considered risk, sustainability, organizational, and strategic aspects of a project selection has not been considered in literature of project selection.

Second, the group decision making orientation of the project selection and capital investment problems has received a very low attention in literature. In group decision making procedures several issues should be considered. One of the main cases is treating with the conflictive opinion of DMs on preferences of relative importance of involved criteria in real problem. This may harden the process of determination of relative importance of criteria in presence of several conflictive ideas.

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http://dx.doi.org/10.1016/j.asoc.2012.07.030
Third, the uncertainty of considered criteria in proposed framework should be interpreted using linguistic terms parameterized through fuzzy sets. Although this can help the procedure of the modeling of the uncertainty of real life problems but the associated methodologies should properly be developed in fuzzy environment.

Overcoming the aforementioned issues persuaded us to propose a hybrid approach based on GP and fuzzy TOPSIS to select projects in this paper. Initially, a comprehensive framework, which contains all aforementioned criteria for project selection, has been proposed. Then, in the first stage of proposed approach, a GP based on different type of DMs’ preferences (multiplicative preference relation and fuzzy preference relation) on priority of the criteria has been proposed to achieve the relative importance of criteria of associated group multiple criteria decision making (MCDM) problem.

In the second stage of proposed MCDM approach, a modified fuzzy TOPSIS has been developed based on modified Preference Ratio (PR) and an efficient fuzzy distance measurement. PR method has been used to rank fuzzy closeness coefficients to find a proper relative order of alternatives. PR determines the preference of fuzzy numbers in an interval through a relative manner rather than absolute way. This type of ranking of fuzzy numbers can properly considers the uncertainty nature of the real life project selection problem. Moreover, as human reasoning says, it is more realistic that distances between fuzzy numbers be a fuzzy measure. So, an efficient fuzzy distance measurement has been supplied in proposed fuzzy TOPSIS procedure. This measurement has been applied to calculate distances between each alternatives and ideals. The hybrid approach has been applied to rank a set of projects in form of investment chances considering sustainability and supportive criteria in a case called Iranian financial and credit institute.

The following sections of the paper are arranged as follows. A brief literature of MCDM approaches, including TOPSIS method, different forms of representation of DMs’ preference, and GP, is represented in Section 2. Section 3 is allocated to extend sustainability criteria and supportive criteria as well as linguistic terms, fuzzy numbers, and framework for sustainable investment selection. The hybrid MCDM approach, including GP modeling and fuzzy TOPSIS algorithm, is represented in Section 4. Section 5 talks about application of proposed hybrid MCDM approach in a real case study of Iranian financial and credit institute. Finally in Section 6, the paper will be ended with conclusion remarks.

2. Literature of past research works

Multiple criteria decision making (MCDM) approaches, including multiple attribute decision making (MADM) and multiple objective decision making (MODM), have attracted lots of research efforts due to adaptability for real conditions decision making problems. Hwang and Yoon [13] developed Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

2.1. Fuzzy TOPSIS

Ambiguity made researchers to develop MCDM approaches, including TOPSIS, through fuzzy sets. Sadi-Nezhad and Khalili-Damghani [14] presented a TOPSIS approach based on preference ratio and an efficient fuzzy distance measurement for a fuzzy multiple criteria group decision-making problem (FMCGDMP). Preference ratio with a moderate modification for negative fuzzy numbers was used as an efficient ranking method for fuzzy numbers in a relative manner. All distances between fuzzy numbers had been calculated as fuzzy numbers using an efficient fuzzy distance measurement. The proposed algorithm applied in assessment of traffic police centers. Chamodrakas et al. [15] proposed an innovative fuzzy approach for ranking alternatives in multiple attribute decision making problems based on TOPSIS. They compared their method with the original method through simulation. Their model enabled a parameterization of the method according to the risk attitude of the decision maker.

Chamodrakas and Martakos [16] presented a method that took into account user preferences, network conditions, QoS and energy consumption requirements in order to select the optimal network which achieved the best balance between performance and energy consumption. The aggregation of multiple criteria for the calculation of the overall rating of the networks was performed through the use of the Fuzzy Set Representation TOPSIS method. Torfi et al. [17] proposed a Fuzzy multi-criteria decision-making approach based on Fuzzy AHP and Fuzzy TOPSIS to evaluate the alternative options in respect to the user’s preference orders. Ashitani et al. [18] proposed interval-valued fuzzy TOPSIS method aiming at solving MCDM problems in which the weights of criteria are unequal, using interval-valued fuzzy sets concepts. Wang et al. [19] proposed fuzzy hierarchical TOPSIS, which could provide more objective and accurate criterion weights, while simultaneously avoiding the problem of previous method by Chen [20].

2.2. Formulation of DMs’ preferences

According to preference information may be required from DM, the MCDM procedures have been systematically classified into classes as no articulation of preference information, priori articulation of preference information, progressive articulation of preference information, and posterior articulation of preference information by Hwang and Masud [21].

Chiclana et al. [22,23] introduced different forms of representation of DMs’ preference over a set of alternatives/criteria. Based on this idea, DMs’ preferences over the set of alternatives/criteria can be represented one of the forms such as preference ordering, fuzzy preference relation, utility function, and multiplicative preference relation.

2.3. Application of goal programming for calculating preference of DMs

Fan et al. [24] proposed a method to solve the MCDM problems based on a linear goal programming model, where the preference of DM on alternatives were represented through a fuzzy relation. Fan et al. [25] also proposed a goal programming approach to solve group decision-making problems where the preference information on alternatives provided by decision makers was represented through multiplicative preference relations and fuzzy preference relations. Wang et al. [26] also proposed a chi-square method for obtaining a priority vector from an arbitrary mixture of multiplicative and fuzzy preference relations of DMs on alternatives. Wang and Fan [27] presented optimization aggregation approaches to determine the relative weights of individual fuzzy preference relations. Gong et al. [28] proposed goal programming models for deriving the priority vector of intuitionistic fuzzy preference relation.

3. Proposed framework for project selection

Although the economic analysis is the most common used criteria of investment assessment in the classic decision making procedures, sustainability which considers the balance of economic, social, and environmental effects of an investment, concurrently, is a modern paradigm. The economic, social, and environmental effects are interpreted as sustainability in literature of
project life cycle management [29]. The most well-adopted and most often quoted definition of sustainability is that of the Brundtland Commission “development that meets the needs of the present without compromising the ability of future generations to meet their needs” [30]. There are currently over 100 definitions of sustainability and sustainable development, but most agree that the concept aims to satisfy social, environmental and economic goals. These goals are also referred to as the three pillars or objectives of sustainable development [29].

Moreover, a set of supportive criteria such as strategic alliance, organizational readiness, and risk of investment should be considered for a comprehensive sustainable investment selection. Risk of investment is a critical factor considered in different methodologies and applications of Project Selection Problem (PSP). Many approaches have been reported to measure and assess the risk of investment in literature of PSP [31,9,10]. The strategic considerations are mainly treated as an upstream theme in PSP [7,8]. The hide and apparent perspectives of an organization such as cultural and structural form of an organization as well as different active/potential capabilities of an organization facing an investment is a key factor in PSP [11,12].

### 3.1. Proposed comprehensive criteria

Although different criteria have been proposed for project selection in the literature, but there exists no obvious framework which considers all of the effective financial and non-financial criteria, sustainability paradigm, risk of investment, organizational readiness, and strategic theme in a unique framework, simultaneously.

Due to exhaustive literature review, a comprehensive evaluation of an investment opportunity is proposed to include both financial and non-financial factors which mainly talks about economic, environmental, and social effects of an investment plus risk of investment, strategic alliance of investment, and organizational readiness for investment. Table 1 represents the brief definition of the considered criteria in our proposed framework. Radar diagram of Fig. 1 represents rough position of evaluation aspects and criteria considered in our proposed framework for sustainability.

#### Table 1

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_1$: Economic Effect (EF)</td>
<td>Positive economic effect of selection of the project $j$</td>
</tr>
<tr>
<td>$c_2$: Social Effect (SE)</td>
<td>Direct positive social effect of implementation of the project $j$</td>
</tr>
<tr>
<td>$c_3$: Environmental Effect (EnE)</td>
<td>Direct positive environmental effect of implementation of the project $j$</td>
</tr>
<tr>
<td>$c_4$: Risk of Investment (R)</td>
<td>The risk of implementation of project $j$</td>
</tr>
<tr>
<td>$c_5$: Strategic Alliance (SA)</td>
<td>The alignment of implementation of project $j$ with organizational strategies</td>
</tr>
<tr>
<td>$c_6$: Organizational Readiness (OR)</td>
<td>Previous and common experiences of the organization in implementation of project $j$</td>
</tr>
</tbody>
</table>

![Fig. 1. Radar diagram of main evaluation aspects and criteria in the proposed D. (a) Economic effect, social effect, and strategic alliance and (b) organizational readiness, risk of investment, and environmental effects.](image-url)
Let us plan the MADM problem more formally. Suppose there are \( n \) alternative and \( m \) attribute. We ask \( k \) different experts about rating each alternative with respect to each criterion of Table 1 using linguistic terms of Section (a) of Table 2. Let \( \tilde{x}_{ij}^k \) be the associated TrFNs of rating of \( k \)th expert to \( i \)th alternative with respect to \( j \)th criterion. By these definitions the problem can be represented more formally as (1).

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\[
\tilde{D}^k = \begin{bmatrix}
\tilde{x}_{11}^k & \tilde{x}_{12}^k & \ldots & \tilde{x}_{1j}^k \\
\tilde{x}_{21}^k & \tilde{x}_{22}^k & \ldots & \tilde{x}_{2j}^k \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{x}_{n1}^k & \tilde{x}_{n2}^k & \ldots & \tilde{x}_{nj}^k
\end{bmatrix}
\]

where \( \tilde{D}^k \) is the fuzzy decision matrix of \( k \)th expert. It has \( i \) row and \( j \) column which are related to alternatives and criteria, respectively. The experts’ ideas aggregate using (1).

\[
\tilde{D} = \begin{bmatrix}
\tilde{n}_{11} & \tilde{n}_{12} & \ldots & \tilde{n}_{1j} \\
\tilde{n}_{21} & \tilde{n}_{22} & \ldots & \tilde{n}_{2j} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{n}_{i1} & \tilde{n}_{i2} & \ldots & \tilde{n}_{ij}
\end{bmatrix}, \quad \text{where} \, \tilde{n}_{ij} = \frac{\tilde{n}_{1j} + \tilde{n}_{2j} + \ldots + \tilde{n}_{kj}}{k}
\]

(a)

Fig. 2. Membership functions of linguistic terms. (a) Rating of alternatives with respect to criteria and (b) comparison of relative importance of criteria (multiplicative/fuzzy preference ratio).
By these assumptions the first stage of proposed hybrid MCDM approach is as below.

4.1. First Stage: proposed GP to achieve weights of criteria in a group decision making problem

In this section, based on method by Fan et al. [25], a goal programming (GP) model is supplied to achieve the relative importance of criteria based on multiplicative preference relations and fuzzy preference relations in presence of achieved priority of a group of DMs. It is notable that the DMs were requested to make pair-wise comparison about criteria of a sustainable investment in two forms of multiplicative preference relations and fuzzy preference relations. Inconsistent comparisons were requested to modify by DM or ignored if inconsistency lasted. The result of multiplicative preference relation of jth expert and result of fuzzy preference relation of jth expert are represented in (3) and (4), respectively.

$$A_j = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix}$$ \tag{3}

where \((a_{ij}) = 1, \ (a_{ik}) = 1/(a_{ik}), \ (a_{ik}) \neq 0, \ i, \ k = 1, \ldots, m, \ i \neq k, \ j = 1, \ldots, n_i,\)

$$P_j = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{bmatrix}$$ \tag{4}

where \(p_{ij} = 1, \ p_{ij} = [0,1], \ p_{ij} = 1 - p_{ik}, \ i, \ k = 1, \ldots, m, \ j = n_1 + 1, \ldots, n.\)

Suppose that the relative importance of criteria \(c_i, i = 1, \ldots, m\) be \(w_i,\) and \(w_j\) is to be calculated where \(\sum_{i=1}^{m} w_i = 1, \ w_i \geq 0, i = 1, \ldots, n.\) The problem is how to determine the relative importance of each criterion based on two forms of preference relations provided by DMs. The full alignment of final relative importance of each criterion with DMs’ ideas is a goal. On the other hand, the resultant weights of criteria must have a high degree of conformity to multiplicative preference relations and fuzzy preference relations of DMs. Let \(A^* = (a^*_{ij})_{m \times m}\) and \(P^* = (p^*_{ij})_{m \times m}\) be the optimum matrixes of multiplicative preference relation and fuzzy preference relation, respectively. Where,

$$a^*_{ij} = \frac{w_i}{w_j}, \ \forall i, j \in \{1, \ldots, m\}, \ l = 1, \ldots, n.$$ \tag{5}

$$p^*_{ij} = \frac{w_i}{w_j + w_l}, \ \forall i, j \in \{1, \ldots, m\}, \ l = n_1 + 1, \ldots, n.$$ \tag{6}

As mentioned, considering DMs opinion, it is desirable to determine the relative importance of each criterion, \(w_j\) such that:

$$d_{ij}^+ = \frac{w_i}{w_j}, \ i, j = 1, \ldots, m, \ l = 1, \ldots, n_i.$$ \tag{7}

$$p_{ij}^+ = \frac{w_i}{w_j + w_l}, \ i, j = 1, \ldots, m, \ l = n_1 + 1, \ldots, n.$$ \tag{8}

The deviation value between \(d_{ij}^+\) and \(w_i/w_j,\) and deviation value between \(p_{ij}^+\) and \(w_i/(w_i + w_j)\) are represented as (9) and (10). It is clear that \(q_{ij}^+(w)\) and \(r_{ij}^+(w)\) are function of \(w_i, \ i, j = 1, \ldots, n_i.\)

$$q_{ij}^+(w) = w_i - d_{ij}^+ \times w_j, \ i, j = 1, \ldots, m, \ l = 1, \ldots, n_i.$$ \tag{9}

$$r_{ij}^+(w) = w_i - p_{ij}^+ \times (w_i + w_j), \ i, j = 1, \ldots, m, \ l = n_1 + 1, \ldots, n.$$ \tag{10}

Considering the important degree of each DM, the aforementioned deviation values, and \(q_{ij}^+(w)\) and \(r_{ij}^+(w)\) a new collective deviation value is calculated as (11).

$$\Phi_{ij}(w) = \sum_{l=1}^{n_1} \lambda_l \times |w_i - d_{ij}^+ w_j|$$

$$+ \sum_{l=n_1+1}^{n} \lambda_l \times |w_i - p_{ij}^+ (w_i + w_j)|, \ \ i, j = 1, \ldots, m; i \neq j.$$ \tag{11}

Total deviation value of group consensus is represented by (12).

$$D(w) = \sum_{i=1}^{m} \sum_{j=1}^{m} \Phi_{ij}(w) = \sum_{i=1}^{m} \sum_{j=1}^{m} \left[ \sum_{l=1}^{n_1} \lambda_l \times |w_i - d_{ij}^+ w_j| \right.$$ \n
$$+ \sum_{l=n_1+1}^{n} \lambda_l \times |w_i - p_{ij}^+ (w_i + w_j)| \left.] \right], \ \ i, j = 1, \ldots, m; i \neq j.$$ \tag{12}

The smaller value of total deviation value \(D(w)\) is the higher the group consistencies are. To make the group consensus higher, \(\Phi_{ij}(w)\) can be minimized through assessing the relative importance of each criterion, \(w_i.\) The following multiple objective constraint optimization model is the direct result of aforementioned requests.

$$\min \Phi_{ij}(w) = \sum_{l=1}^{n_1} \lambda_l \times |w_i - d_{ij}^+ w_j|$$

$$+ \sum_{l=n_1+1}^{n} \lambda_l \times |w_i - p_{ij}^+ (w_i + w_j)|, \ \ i, j = 1, \ldots, m; i \neq j.$$ \tag{13}

$$\text{s.t.} \sum_{i=1}^{m} w_i = 1$$ \tag{14}

$$w_i \geq 0, \ \ i = 1, \ldots, m.$$ \tag{15}

The model (13)–(15) can easily be transformed into linear goal programming model (16)–(20), where \(d_{ij}^+\) and \(d_{ij}^-\) represent the overachievement and underachievement variables, respectively. The values of \(\alpha_{ij}\) and \(\beta_{ij}\) are associated to weights of overachievement and underachievement variables in objective function (14). The DM may consider a preference relation between segments of objective function (14). For simplicity, let \(\alpha_{ij} = 1, \ i, j = 1, \ldots, m; i \neq j.\)

$$\min \theta = \sum_{i=1}^{m} \sum_{j=1}^{m} \left( \alpha_{ij} d_{ij}^+ + \beta_{ij} d_{ij}^- \right)$$ \tag{16}

$$\text{s.t.} \sum_{i=1}^{n_1} \lambda_l (w_i - d_{ij}^+ w_j) + \sum_{l=n_1+1}^{n} \lambda_l (w_i - p_{ij}^+ (w_i + w_j))$$

$$- d_{ij}^+ + d_{ij}^- = 0, \ \ i, j = 1, \ldots, m; i \neq j$$ \tag{17}

$$\sum_{i=1}^{m} w_i = 1$$ \tag{18}

$$w_i \geq 0, \ \ i = 1, \ldots, m.$$ \tag{19}
4.2. Second stage: fuzzy TOPSIS

Main differences between fuzzy TOPSIS approaches can be summarized in choosing the normalization method of decision matrix, determining Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS), and distance calculation between fuzzy numbers.

Using the result of first module, we have revisited a modified fuzzy TOPSIS approach based on Preference Ratio (PR) and fuzzy distance measurement which was first introduced by Sadi-Nezhad and Khalili-Damghani [14]. It is notable that PR was first introduced by Modares and Sadi-Nezhad [32]. PR determines the preference of fuzzy numbers in an interval through a relative manner rather than absolute way. Moreover, it is more realistic that distances between fuzzy numbers be a fuzzy measure. Sadi-Nezhad and Khalili-Damghani [14] used an efficient fuzzy distance measurement proposed by Chakraborty and Chakraborty [33]; Guha and Chakraborty [34] in their TOPSIS procedure. As the details of presented fuzzy TOPSIS method can be found in Sadi-Nezhad and Khalili-Damghani [14] a brief introductory is supplied here.

4.2.1. Preference ratio

Preference ratio is a ranking method introduced by Modares and Sadi-Nezhad [32]. They evaluate fuzzy numbers point by point and rank them at each point in PR method. Then, the overall preference over all points is calculated. So the preference in this way is relative rather than absolute. Suppose the objective is to rank fuzzy numbers. Let \( N \) be the ith one defined over a real domain \( S_i \subset \mathbb{R} \) and it is identified by a membership function \( \mu_N(x), x \in S_i \), with \( \mu_N(x) \in [0, 1] \). Let \( S_1 \) be the support of \( N_1 \), one more precisely \( S_1 = \{ x, \mu_N(x) > 0 \} \), and \( \Omega = \bigcup_{i=1}^{m} S_i \) then \( \Omega \) is the union of the support of all fuzzy numbers. In other word, fuzzy numbers are ranked over \( \Omega \). To rank fuzzy numbers, we assume their spans are not disjoint, because in that case the ranking is clear.

A fuzzy number is evaluated by a function called Preference Function. At each point \( \alpha \in \Omega \), this function is defined as follows:

\[
G(\alpha) = \frac{\int_{L}^{U} \mu(x) \, dx}{\int_{L}^{U} \mu(x) \, dx}
\]

where \( \mu(x) \) is the membership function of the fuzzy number, \( L = \min\{x : x \in \Omega\} \) and \( U = \max\{x : x \in \Omega\} \). This function has the same definition as \( 1 - F(\alpha) \) in probability theory, where \( F(\alpha) = \mathbb{P}(X \leq \alpha) \) is the distribution function. At \( \alpha \in \Omega \), let \( p(\alpha) = i \) denote the ith fuzzy number, which is the most preferred one. Therefore \( p(\alpha) = i \), if \( G_i(\alpha) = \max\{G_j(\alpha), j \in I\} \), where \( G_i(\alpha) \) is the preference function of the jth fuzzy number. Let \( \Omega_l \) be the set of point at which the ith number is ranked number one. Then \( \Omega_l = \{ \alpha \in \Omega, p(\alpha) = i \} \).

**Definition 3.1.** For the ith fuzzy number, \( R(i) \), the preference ratio, is by definition, the percentage of \( \Omega \) that the ith fuzzy number is the most preferred one. Then

\[
R(i) = \frac{|\Omega_l|}{|\Omega|} \tag{22}
\]

where \( |\Omega_l| \) and \( |\Omega| \) are the lengths of the real set \( \Omega_l \) and \( \Omega \), respectively.

**Definition 3.2.** (a) We define that two fuzzy numbers A and B are preference ratio equivalent if \( R(A) = R(B) = 0.5 \), where \( R(A) \) and \( R(B) \) are preference ratio of A and B, respectively. Preference ratio equivalence is shown as follows:

\[
A^\text{PR} = B
\]

(b) If \( k \times A^\text{PR} = B \), then we say k is the “Equivalence multiplier” of A with respect to B.

4.2.2. Fuzzy distance measure

The fuzzy distance measure has been presented briefly to make a comfort sense. Let us consider two GFNs as \( \tilde{A}_1 = (\alpha_1, \alpha_2; \tilde{p}_1, \gamma_1) \) and \( \tilde{A}_2 = (\alpha_3, \alpha_4; \tilde{p}_2, \gamma_2) \). Therefore \( \alpha \)-cut of \( \tilde{A}_1 \) and \( \tilde{A}_2 \) represents two intervals, respectively \( [\tilde{A}_1]^\alpha = [\tilde{A}_1^L(\alpha), \tilde{A}_1^R(\alpha)] \) and \( [\tilde{A}_2]^\alpha = [\tilde{A}_2^L(\alpha), \tilde{A}_2^R(\alpha)] \), for all \( \alpha \in [0, 1] \). Since it may be possible to obtain the distance between two interval numbers by means of their difference, they employ the interval-distance operation for interval \( [\tilde{A}_1^L(\alpha), \tilde{A}_1^R(\alpha)] \) and \( [\tilde{A}_2^L(\alpha), \tilde{A}_2^R(\alpha)] \) to formulate the fuzzy distance between \( \tilde{A}_1 \) and \( \tilde{A}_2 \). So the distance between \( [\tilde{A}_1]^\alpha \) and \( [\tilde{A}_2]^\alpha \) for every \( \alpha \in [0, 1] \) can be one of the following:

\[
d_G(\tilde{A}_1, \tilde{A}_2) = \begin{cases} 
\frac{1}{2} \left( \tilde{A}_1^L(1) + \tilde{A}_1^R(1) \right) \quad & \text{if } \tilde{A}_1^L(1) + \tilde{A}_1^R(1) > \tilde{A}_2^L(1) + \tilde{A}_2^R(1) \\
\frac{1}{2} \left( \tilde{A}_2^L(1) + \tilde{A}_2^R(1) \right) \quad & \text{if } \tilde{A}_1^L(1) + \tilde{A}_1^R(1) \leq \tilde{A}_2^L(1) + \tilde{A}_2^R(1) 
\end{cases} \tag{24}
\]

As mentioned, fuzzy number is assumed to be TrFNs throughout the paper. The extension and proof of the proposed fuzzy distance measurement for TrFNs has been accomplished in Sadi-Nezhad and Khalili-Damghani [14]. Generally, two main categories may be occurred for distance calculation. In first category the compared TrFNs have some overlap while in second category TrFNs are assumed to be exactly distinct. The fuzzy distance measurement can be calculated for two ordered arbitrary TrFNs (i.e. \( a_i \leq b_i \leq c_i \leq d_i \)) such as \( \tilde{m}_1 = (a_1, b_1, c_1, d_1) \) and \( \tilde{m}_2 = (a_2, b_2, c_2, d_2) \) as follows.

(a) For an arbitrary \( \alpha \)-cut level such as \( \alpha_0 \) in some cases of the first and second categories, we have:

\[
\tilde{d}(\tilde{A}_1, \tilde{A}_2) = (d^L_{\alpha=\alpha_0}, d^R_{\alpha=\alpha_0}; \theta, \sigma) = (b_2 - c_1, c_2 - b_1; \theta, \sigma). \tag{25}
\]

(b) For an arbitrary \( \alpha \)-cut level such as \( \alpha_0 \) in some cases of the first and second categories, we have:

\[
\tilde{d}(\tilde{A}_1, \tilde{A}_2) = (d^L_{\alpha=\alpha_0}, d^R_{\alpha=\alpha_0}; \theta, \sigma) = (b_1 - c_2, c_1 - b_2; \theta, \sigma) \tag{26}
\]

where left and right spread of the fuzzy distance between \( \tilde{A}_1 \) and \( \tilde{A}_2 \) are represented by \( \theta, \sigma \), respectively. The proofs of (25) and (26) can be found in Sadi-Nezhad and Khalili-Damghani [14].

4.2.3. Proposed fuzzy TOPSIS algorithm

**Step 1.** In order to achieve a more smooth decision matrix, we apply a columnar normalization at first step. We name the normalized decision matrix \( \hat{N} \) as (27).
\[ \bar{N} = \begin{bmatrix} \bar{r}_{11} & \bar{r}_{12} & \ldots & \bar{r}_{1j} \\ \bar{r}_{21} & \bar{r}_{22} & \ldots & \bar{r}_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ \bar{r}_{11} & \bar{r}_{12} & \ldots & \bar{r}_{1j} \end{bmatrix} \quad \text{where} \quad \bar{r}_j = \begin{cases} \begin{bmatrix} \frac{a_{ij}}{d^+_{ij}} & \frac{b_{ij}}{d^+_{ij}} & \frac{c_{ij}}{d^+_{ij}} & \frac{d_{ij}}{d^+_{ij}} \end{bmatrix} & \text{if} \ j \text{is a benefit attribute} \\ \begin{bmatrix} \frac{a_{ij}}{d^-_{ij}} & \frac{a_{ij}}{d^-_{ij}} & \frac{a_{ij}}{d^-_{ij}} & \frac{a_{ij}}{d^-_{ij}} \end{bmatrix} & \text{if} \ j \text{is a cost attribute and} \ d_j^+ \text{ is not zero} \\ \begin{bmatrix} 1 - \frac{a_{ij}}{d_j^+} & 1 - \frac{b_{ij}}{d_j^+} & 1 - \frac{c_{ij}}{d_j^+} & 1 - \frac{d_{ij}}{d_j^+} \end{bmatrix} & \text{if} \ j \text{is a cost attribute and} \ d_j^+ \text{ is zero} \end{cases} \]

and
\[ d^+_j = \max(d_{ij}), \quad a_{ij}^- = \min(a_{ij}), \quad i = 1, 2, \ldots, m. \]  

**Step 2.** According to different relative importance of the criteria, which have been calculated using proposed GP model in (14)–(18), construct the weighted normalized decision matrix as (29).

\[ \tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \ldots & \tilde{v}_{1j} \\ \tilde{v}_{21} & \tilde{v}_{22} & \ldots & \tilde{v}_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{v}_{11} & \tilde{v}_{12} & \ldots & \tilde{v}_{1j} \end{bmatrix}, \]

\[ \tilde{v}_{ij} = \tilde{r}_j(x)w_j, \quad i = 1, 2, \ldots, n, \quad j = 1, 2, \ldots, m. \]  

where \( \tilde{v}_{ij} \) is a normalized TrFN and varies in closed interval [0,1].

**Step 3.** Define a FPIS and a FNIS as follows. Name them \( S^+ \), and \( S^- \), respectively.

\[ S^+ = (\tilde{v}^+_1, \tilde{v}^+_2, \ldots, \tilde{v}^+_n) \]

where
\[ \tilde{v}^+_i = \max v_{ij} = (\max a_{ij}, \max b_{ij}, \max c_{ij}, \max d_{ij}), \quad i = 1, 2, \ldots, n \]

\[ S^- = (\tilde{v}^-_1, \tilde{v}^-_2, \ldots, \tilde{v}^-_n) \]

where
\[ \tilde{v}^-_i = \min v_{ij} = (\min a_{ij}, \min b_{ij}, \min c_{ij}, \min d_{ij}), \quad i = 1, 2, \ldots, n \]

**Step 4.** Calculate fuzzy distance of each alternative from \( S^+ \) and \( S^- \). Call these distances positive fuzzy distance (PFD) and negative fuzzy distance (NFD), respectively.

\[ PFD_i = \tilde{d}(A_i, S^+), \quad i = 1, 2, \ldots, n \]
\[ NFD_i = \tilde{d}(A_i, S^-), \quad i = 1, 2, \ldots, n \]

**Step 5.** Define a fuzzy closeness coefficient (FCC) as follows:

\[ FCC_i = \frac{\tilde{d}(A_i, S^+)}{\tilde{d}(A_i, S^-)}, \quad i = 1, 2, \ldots, n \]

\[ FCC_i = \frac{NFD_i}{PFD_i + NFD_i}. \]

Obviously whatever the \( FCC_i \), \( i = 1, 2, \ldots, n \) value is close to unit, the utility of the associated alternative is higher for decision group makers. But it is clear that \( FCC_i \), \( i = 1, 2, \ldots, m \) are TrFNs and generally a TrFN is not bigger than the other in an absolute manner but they are compared relatively in a proposed interval using PR.

**Step 6.** Apply Steps 1 and 2 of algorithm III from Sadi-Nezhad and Ghaleh Assadi [35] for achieving \( CC_i \), \( i = 1, 2, \ldots, n \) crisp value which are associated to each \( FCC_i \), \( i = 1, 2, \ldots, n \).

**Step 7.** Order the \( CC_i \), \( i = 1, 2, \ldots, n \) in non-increasing mode. Choose the alternative with biggest \( CC_i \) index.

The schematic structure of proposed approach is shown in Fig. 3 where the relations between to main stages can be graphically recognized.

### 4.3. Main findings of proposed approach

The properties of proposed hybrid MCDM approach is mainly different from reported methodologies in literature and make it unique and well posed for real-life problem modeling. The main specifications of proposed hybrid approach, which distinguish it from other existing approaches in literature, are briefly reviewed as follows:

- It uses a comprehensive framework including financial, non-financial, and sustainability criteria, as well as risk, organizational readiness, and strategic alliance to select the proper set of projects.
- The conflictive groups of DM’s preferences on priority of criteria of the problem have been considered in calculating the proper relative importance of the criteria of proposed framework through a GP.

The ranking of investment chances which were in form of projects has been accomplished using an efficient TOPSIS method. The proposed TOPSIS method utilizes modified PR as an efficient ranking method for fuzzy numbers as well as an efficient distance calculating method for fuzzy numbers. This type of TOPSIS can model the uncertainty of real cases in an effective manner.

### 5. Application of proposed hybrid approach in sustainable project selection

The proposed hybrid MCDM approach has been applied for sustainable project selection of an Iranian financial and credit institute. The projects are treated as investment chances. We used the experimental experiences of experts to determine the relative importance of proposed criteria of sustainable project selection. The data collected from experts of an Iranian financial and credit institute through questionnaires. The experts who filled the questionnaires were experienced financial project managers working for the financial institutes. These managers had 10 years of rating experience on average.

A set of 6 managers was selected and each manager was requested to evaluate his/her preference on priority of affecting
criteria. This type of mixed data gathering, supplied more flexibility in analyzing the required information of real problem cases, which rarely reported in previous research works in the field of project selection. This issue is occurred frequently in real cases and the proposed approach suggests a practical methodology to overcome the aforementioned problem. Moreover, as a GP has been proposed to achieve the relative importance of criteria from among a set of conflictive opinion of a group of different DMs so, conflictive preferences of DMs on priority of different criteria of proposed framework causes no disturbance in determination of final relative importance of criteria. This type of group decision making has also rarely been reported in literature of project selection problems.

Table 3
Managers preferences on evaluation criteria.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Multiplicative preference relations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manager #1: Matrix A1</td>
</tr>
<tr>
<td></td>
<td>$c_1$ $c_2$ $c_3$ $c_4$ $c_5$ $c_6$</td>
</tr>
<tr>
<td>$c_1$</td>
<td>1/3 5 1/7 9 1/9</td>
</tr>
<tr>
<td>$c_2$</td>
<td>3 1 1/6 1/4 1/8 1/5</td>
</tr>
<tr>
<td>$c_3$</td>
<td>1/5 6 1 6 1/2 9</td>
</tr>
<tr>
<td>$c_4$</td>
<td>7 4 1/6 1 1/9 1</td>
</tr>
<tr>
<td>$c_5$</td>
<td>1/9 8 2 9 1 1</td>
</tr>
<tr>
<td>$c_6$</td>
<td>9 5 1/9 1 1/9 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Fuzzy preference relation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manager #4: Matrix P1</td>
</tr>
<tr>
<td></td>
<td>$c_1$ $c_2$ $c_3$ $c_4$ $c_5$ $c_6$</td>
</tr>
<tr>
<td>$c_1$</td>
<td>0.5 0.3 0.8 0.2 0.9 0.1</td>
</tr>
<tr>
<td>$c_2$</td>
<td>0.7 0.5 0.7 0.6 0.1 0.3</td>
</tr>
<tr>
<td>$c_3$</td>
<td>0.2 0.3 0.5 0.8 0.6 0.2</td>
</tr>
<tr>
<td>$c_4$</td>
<td>0.8 0.4 0.2 0.5 0.8 0.2</td>
</tr>
<tr>
<td>$c_5$</td>
<td>0.1 0.9 0.4 0.2 0.5 0.1</td>
</tr>
<tr>
<td>$c_6$</td>
<td>0.9 0.7 0.8 0.8 0.9 0.5</td>
</tr>
</tbody>
</table>

Table 4
Aggregation of rating of alternatives (investment projects) with respect to sustainability criteria.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>$c_1$</th>
<th>$c_2$</th>
<th>$c_3$</th>
<th>$c_4$</th>
<th>$c_5$</th>
<th>$c_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
<td>(0.7, 0.8, 0.9, 1)</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
</tr>
<tr>
<td>$A_2$</td>
<td>(0.7, 0.8, 0.9, 1)</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
<td>(0.1, 0.2, 0.3, 0.4)</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
</tr>
<tr>
<td>$A_3$</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.7, 0.8, 0.9, 1)</td>
<td>(0.7, 0.8, 0.9, 1)</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
</tr>
<tr>
<td>$A_4$</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
<td>(0.7, 0.8, 0.9, 1)</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
</tr>
<tr>
<td>$A_5$</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
<td>(0.1, 0.2, 0.3, 0.4)</td>
</tr>
</tbody>
</table>
Table 5
The relative importance of criteria

<table>
<thead>
<tr>
<th>w1</th>
<th>w2</th>
<th>w3</th>
<th>w4</th>
<th>w5</th>
<th>w6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0206795</td>
<td>0.0672084</td>
<td>0.2227102</td>
<td>0.1067428</td>
<td>0.4665054</td>
<td>0.1161537</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>c1</th>
<th>c2</th>
<th>c3</th>
<th>c4</th>
<th>c5</th>
<th>c6</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_{0}^{+})</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(d_{0}^{-})</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DN</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Objective function value: \(\theta = 4.296518\).

Table 6
Normalized decision matrix.

<table>
<thead>
<tr>
<th>c1</th>
<th>c2</th>
<th>c3</th>
<th>c4</th>
<th>c5</th>
<th>c6</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_1</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
<td>(0.67, 0.78, 0.89, 1)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.4, 0.6, 0.8, 1)</td>
<td>(0.7, 0.8, 0.9, 1)</td>
</tr>
<tr>
<td>A_2</td>
<td>(0.7, 0.8, 0.9, 1)</td>
<td>(0.22, 0.33, 0.44, 0.56)</td>
<td>(0.1, 0.2, 0.3, 0.4)</td>
<td>(0.4, 0.6, 0.8, 1)</td>
<td>(0.7, 0.8, 0.9, 1)</td>
</tr>
<tr>
<td>A_3</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
<td>(0.67, 0.78, 0.89, 1)</td>
<td>(0.7, 0.8, 0.9, 1)</td>
<td>(1.4, 1.5, 1.6, 1.7)</td>
<td>(0.4, 0.5, 0.6, 0.7)</td>
</tr>
<tr>
<td>A_4</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.44, 0.56, 0.67, 0.78)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.8, 1.2, 1.4)</td>
<td>(0.7, 0.8, 0.9, 1)</td>
</tr>
<tr>
<td>A_5</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(0.44, 0.56, 0.67, 0.78)</td>
<td>(0.6, 0.7, 0.8, 0.9)</td>
<td>(1.2, 1.4, 1.6, 1.8)</td>
<td>(0.2, 0.3, 0.4, 0.5)</td>
</tr>
</tbody>
</table>

Fig. 4. Interface of developed application software for PR methodology.
Table 7
Weighted normalized decision matrix.

<table>
<thead>
<tr>
<th></th>
<th>c₁</th>
<th>c₂</th>
<th>c₃</th>
<th>c₄</th>
<th>c₅</th>
<th>c₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁</td>
<td>(0, 0.01, 0.012, 0.014)</td>
<td>(0.045, 0.052, 0.06, 0.067)</td>
<td>(0.134, 0.156, 0.178, 0.2)</td>
<td>(0, 0.064, 0.085, 0.107)</td>
<td>(0.327, 0.373, 0.42, 0.467)</td>
<td>(0.066, 0.083, 0.1, 0.116)</td>
</tr>
<tr>
<td>A₂</td>
<td>(0, 0.017, 0.019, 0.021)</td>
<td>(0.015, 0.022, 0.03, 0.037)</td>
<td>(0.022, 0.045, 0.067, 0.089)</td>
<td>(0, 0.064, 0.085, 0.107)</td>
<td>(0.28, 0.327, 0.373, 0.42)</td>
<td>(0.066, 0.083, 0.1, 0.116)</td>
</tr>
<tr>
<td>A₃</td>
<td>(0, 0.006, 0.008, 0.01)</td>
<td>(0.045, 0.052, 0.06, 0.067)</td>
<td>(0.156, 0.178, 0.2, 0.223)</td>
<td>(0, 0.171, 0.192, 0.213)</td>
<td>(0.187, 0.233, 0.28, 0.327)</td>
<td>(0.033, 0.05, 0.066, 0.083)</td>
</tr>
<tr>
<td>A₄</td>
<td>(0, 0.014, 0.017, 0.019)</td>
<td>(0.03, 0.037, 0.045, 0.052)</td>
<td>(0.134, 0.156, 0.178, 0.2)</td>
<td>(0, 0.107, 0.128, 0.149)</td>
<td>(0.327, 0.373, 0.42, 0.467)</td>
<td>(0.033, 0.05, 0.066, 0.083)</td>
</tr>
<tr>
<td>A₅</td>
<td>(0, 0.014, 0.017, 0.019)</td>
<td>(0.03, 0.037, 0.045, 0.052)</td>
<td>(0.134, 0.156, 0.178, 0.2)</td>
<td>(0, 0.149, 0.171, 0.192)</td>
<td>(0.093, 0.14, 0.187, 0.233)</td>
<td>(0.017, 0.033, 0.05, 0.066)</td>
</tr>
</tbody>
</table>

Table 8
Fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).

<table>
<thead>
<tr>
<th></th>
<th>c₁</th>
<th>c₂</th>
<th>c₃</th>
<th>c₄</th>
<th>c₅</th>
<th>c₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPIS</td>
<td>(0.014, 0.016, 0.018, 0.021)</td>
<td>(0.04, 0.052, 0.059, 0.067)</td>
<td>(0.156, 0.178, 0.2, 0.223)</td>
<td>(0.042, 0.064, 0.085, 0.106)</td>
<td>(0.326, 0.373, 0.419, 0.466)</td>
<td>(0.066, 0.082, 0.099, 0.116)</td>
</tr>
<tr>
<td>FNIS</td>
<td>(0.004, 0.006, 0.008, 0.01)</td>
<td>(0.015, 0.022, 0.03, 0.037)</td>
<td>(0.0223, 0.044, 0.066, 0.089)</td>
<td>(0.149, 0.17, 0.192, 0.213)</td>
<td>(0.093, 0.139, 0.186, 0.233)</td>
<td>(0.016, 0.033, 0.049, 0.066)</td>
</tr>
</tbody>
</table>
Table 9  
FPD and FND for each alternative.

<table>
<thead>
<tr>
<th>Fuzzy positive distance</th>
<th>Fuzzy negative distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁ (0.004, 0.053, 0.077)</td>
<td>A₁ (0.547, 0.844, 0.992)</td>
</tr>
<tr>
<td>A₂ (0.134, 0.287, 0.385)</td>
<td>A₂ (0.395, 0.632, 0.751)</td>
</tr>
<tr>
<td>A₃ (0.332, 0.569, 0.725)</td>
<td>A₃ (0.18, 0.366, 0.459)</td>
</tr>
<tr>
<td>A₄ (0.077, 0.281, 0.383)</td>
<td>A₄ (0.396, 0.693, 0.841)</td>
</tr>
<tr>
<td>A₅ (0.387, 0.684, 0.885)</td>
<td>A₅ (0.103, 0.273, 0.358)</td>
</tr>
</tbody>
</table>

Table 10  
Fuzzy closeness coefficients.

| A₁ | (0.0001, 0.61, 1.531, 4724.738) |
| A₂ | (0.0001, 0.43, 1.196, 3576.408) |
| A₃ | (0.0001, 0.193, 0.715, 2187.886) |
| A₄ | (0.0001, 0.407, 1.463, 4006.982) |
| A₅ | (0.0001, 0.107, 0.557, 1706.616) |

Table 11  
Final ranking of alternatives using PR.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>1/K-value</th>
<th>K-value</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁</td>
<td>1.000</td>
<td>1.000</td>
<td>1</td>
</tr>
<tr>
<td>A₂</td>
<td>0.737</td>
<td>1.321</td>
<td>3</td>
</tr>
<tr>
<td>A₃</td>
<td>0.403</td>
<td>2.160</td>
<td>4</td>
</tr>
<tr>
<td>A₄</td>
<td>0.848</td>
<td>1.179</td>
<td>2</td>
</tr>
<tr>
<td>A₅</td>
<td>0.361</td>
<td>2.770</td>
<td>5</td>
</tr>
</tbody>
</table>

The managers were left free to use multiplicative preference relation or fuzzy preference relation in their judgments. These 6 managers represented their preferences on the aforementioned criteria set \( C = \{c₁, c₂, c₃, c₄, c₅, c₆\} \) using linguistic terms of section (b) of Table 2 for multiplicative preference relations and/or fuzzy preference relations. The opinions of DMs have been summarized in Table 3. Table 3 represents the aggregation of DMs’ rating with respect to aforementioned sustainability criteria on Table 1 using linguistic terms of section (a) of Table 2 through Eq. (2) with \( K = 6 \). The investments are considered to be selected and implemented during a five years period with more than 1 million dollars of NPV. Details of DMs’ rating with respect to each criterion for all alternatives have been represented as table in Appendix A.

Table 4 is treated as input of stage 1 of proposed hybrid MCDM approach. The relative importance of DMs’ opinions and the relative importance of goals of (16)–(20) were set equally (i.e. 1/6 and 1, respectively). The model (16)–(20) has been modeled using Lingo 11.0 software and represented as Appendix B. The vector of relative importance of criteria, the deviation values of group consensus, and objective function value are represented in Table 5.

Using Table 4 and calculated relative importance according to Table 5, the results of applying stage 2 of proposed hybrid MCDM approach (i.e. steps of proposed fuzzy TOPSIS algorithm) are represented as Tables 6–11. It is notable that the second stage of proposed hybrid approach has been implemented using MS-Excel 12.0 and VB 6.0 which were applied to code Fuzzy TOPSIS algorithm and PR methodology, respectively. Fig. 4 represents the interface of developed application in VB 6.0 for PR.

6. Conclusion remarks

In this paper, a hybrid MCDM approach was proposed based on goal programming and modified fuzzy TOPSIS. The proposed approach was applied in a sustainable project selection problem.

First, through an exhaustive literature review, a comprehensive framework has been proposed for project selection problem. Although the economic analysis is the most common used criteria of project selection and capital investment problems in the classic procedures, sustainability which considers the balance of economic, social, and environmental effects of an investment, concurrently, is a modern paradigm. Moreover, other financial and non-financial criteria are assumed to have considerable effects on project selection. Six criteria have been selected for a comprehensive project selection framework. The economic, social, and environmental effects of an investment were assumed to be the main criteria of sustainability. A set of supportive criteria including strategic alliance, organizational readiness, and risk of investment were also considered in proposed framework.

The structure of proposed approach was as follows. The proposed approach had two main stages. In the first stage, several DMs had direct effect on calculation of importance of criteria for a typical MCDM problem. The conflictive DM’s preferences on criteria of MCDM problem gathered through linguistic terms, which were parameterized using TFS, in two different forms of multiplicative preference relations and fuzzy preference relations. A goal programming model supplied to achieve the relative importance of criteria based on in presence of conflictive DM’s preference. Goal programming model, in this stage, tried to achieve the relative importance of criteria in a way that deviations from collective DMs’ consensus were minimized.

Considering relative importance of criteria which were calculated through goal programming of first stage, a fuzzy TOPSIS method based on an efficient fuzzy distance measurement and preference ratio was supplied in second stage of proposed hybrid approach. The effects of DMs’ opinions were also apparent in construction of fuzzy decision matrix of second stage. DMs’ were asked to rate alternative of MCDM problem with respect to each criterion using predefined linguistic terms which were parameterized through TrFNs. Distances were calculated by an efficient fuzzy distance measurement, which was extended for TrFNs. So, the distances between fuzzy numbers were not crisp values, but they are fuzzy numbers. Moreover, preference ratio was effectively used for ranking fuzzy closeness coefficients of each alternative at final steps. Preference ratio has been applied in order to rank fuzzy numbers in a relative manner rather than absolute way. The aforementioned properties of proposed hybrid MCDM approach made it proper for real-life problem modeling.

Finally, the hybrid approach has been applied to rank a set of projects in form of investment chances considering sustainability and supportive criteria in a large Iranian financial and credit institute. A group of experts, with proper experience in the same field, were asked to validate the proposed framework, make pair-wise comparison of criteria, and rate alternatives with respect to criteria. The first and second stages of proposed hybrid approach were implemented and coded using Lingo 11.0, MS-Excel 12.0, and VB 6.0.

The results of application of proposed approach in sustainable investment selection were promising. The proposed approach yielded a general and efficient tool for MCDM problem using a group of DMs’ preferences, and considering multi-dimensional perspectives, concurrently.

Acknowledgement

The authors would like to thank the constructive comments of the reviewers which improved the quality of the paper.
Appendix A. Details of DMs' rating with respect to each criterion

See Table A.1.

Table A.1
DMs' rating of alternatives with respect to sustainability criteria.

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Appendix B. The result of codes of GP modeling in Lingo 11.0

MODEL:
SETS:
CRITERIA/L, 6/ W;
DM/1, 6/ LAMBDA;
LINK1 (CRITERIA, CRITERIA): ALPHA, BETA, DP, DN;
LINK2 (CRITERIA, CRITERIA, DM): PREFERENCE;
END SETS
DATA:
ALPHA, BETA, PREFERENCE, LAMBDA =
@OLE ('F:\A Hybrid Approach for Sustainable project selection\LINGO MODEL\PREFERENCE.XLS', 'ALPHA', 'BETA', 'PREFERENCE', 'LAMBDA');
@OLE ('F:\A Hybrid Approach for Sustainable project selection\LINGO MODEL\PREFERENCE.XLS', 'W', 'DP', 'DN') = W, DP, DN;
ENDDATA
SUBMODEL OBJECTIVE:
MAX= @SUM(CRITERIA/I): 
@SUM(CRITERIA(J) | J #NE# I: (ALPHA(I,J)*DP(I,J)+BETA(I,J)*DN(I,J)));
ENSUBMODEL
SUBMODEL CONSTRAINTS:
@FOR (CRITERIA/I):
@FOR (LINK3(L,K),I): L #NE# K:
@FOR (LINK2(L, K, A), I): L #NE# K:
{ @SUM (DM(A) | L #NE# K #AND# A #LE# 3: LAMBDA(A)*(W(L)-(PREFERENCE(L,K,A)*W(K)))) +
@SUM (DM(A) | L #NE# K #AND# A #GT# 3: LAMBDA(A)*(W(L)-(PREFERENCE(L,K,A)*W(L)+W(K)))) ) -DP(L,K)+DN(L,K) = 0
|);
@FOR (CRITERIA(I),W(I)) = 1;
@FOR (CRITERIA(I), W(I)) = 0;
|);
@FOR (LINK1(L,J)) # NE# J: DP(L,J) = 0;
|);
@FOR (LINK1(L,J)) # NE# J: DN(L,J) = 0;
|)
ENDSUBMODEL
CALC:
@SOLVE (OBJECTIVE, CONSTRAINTS);
ENDCALC
END MODEL

References


2 DN and DP were reserved for $d^+_n$ and $d^+_n$ in (16)–(20), respectively.


