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A mathematical modeling approach for high and new technology-project portfolio selection under uncertain environments

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Abstract. High and new technology-project as a tool to achieve productive forces through scientific and technological knowledge is characterized as knowledge based with high risk and returns. Often conflicting objectives of these projects have complicated their assessment and selection process. This paper offers a novel approach of high technology-project portfolio selection in two main parts. In the first part, a new risk reduction compromise decision-making model is proposed that applies a new approach in determining the weights of experts and in avoiding information loss. The objective function of a new interval type-2 fuzzy sets (IT2Fs) based mathematical model of project portfolio selection is formed by the outcome. To depict model's applicability, data from case study of high technology-project selection in the literature is used to present the efficacy of the model.

Keywords: High and new technology-projects, project portfolio selection, compromise solutions, mathematical modeling, interval type-2 fuzzy sets

1. Introduction

Large high-tech mega-projects are referred to projects that require research and development and/or application of technology in addition to a substantial infrastructure and multi-million or even billion dollar budgets. Additionally, their time-horizons are measured in at least years [18]. Ability of decision makers (DMs)' to flawlessly analyze projects is weakened by high risk of uncertainty or inadequacy of project data

[11, 21–24, 31]. This complication and vagueness is intensified in high-technology [16].

High-tech mega-projects have high levels of risk, vagueness and uncertainty. At the initial phases, uncertainty mostly affects performance expectations, political environments, goals, motivations, and potentials [25, 11]. Thomas and Mengel [10] stated that complex projects have vagueness and ambiguity of the not-yet-known that occur as events that crucially reframe meaning, interpretation, and social significance emerge.

Due to lack of adequate historical data, vagueness and high influence of experts' judgments on project selection problems, fuzzy sets theory has been referred to as a welcomed approach in considering

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42 project uncertainty [3, 27]. Most of the studies even
43 in the recent years are based on classic fuzzy sets.
44 Zadeh [13] expanded type-2 fuzzy sets (FSs). Type-
45 2 FSs have fuzzy membership functions (MFs) also
46 called “membership of membership”. In type-2 FSs
47 in contrast to type-1 FSs each membership value of
48 each element is expressed by fuzzy set in $[0, 1]$, rather
49 than using a crisp number in $[0, 1]$. Despite all these
50 positive points, unfortunately using T2FSs to model
51 the environment of high-tech project is still new.

52 Some of the main literature gaps that motivated
53 proposing this paper are as follows: (1) literature of
54 project selection and projects portfolio selection is
55 very weak when it comes to high-tech projects (2)
56 this problem contains very high levels of uncertainty
57 and vagueness and they are not yet well addressed; (3)
58 the existing decision-making methods do not compre-
59 hensively address risk of uncertainty and importance
60 of each DM’s judgment.

61 In order to fill the gaps of this practical decision-
62 making situation, this paper offers a novel two-part
63 model of high-tech project portfolio selection under
64 highly uncertain and vague conditions is proposed
65 that presents interval type-2 fuzzy sets (IT2FSs)
66 to model uncertainty. In the first part of the pre-
67 sented approach, a new IT2FSs based-risk reduction
68 compromise decision-making process is presented
69 that avoids information loss in designating weights
70 to DMs. Employing IT2FSs gives the model with
71 high power of uncertainty modeling and calculat-
72 ing. Moreover, each DM receives a weight based on
73 the judgments received in the process. In the second
74 part, a new mathematical model of project portfolio
75 selection with IT2F-constraints is proposed to find
76 the optimal portfolio of projects. Eventually, in this
77 paper the basic concept of IT2FSs is improved by
78 presenting a novel method of interval type-2 fuzzy
79 number (IT2FN)-ranking.

80 The following illustrates the remainder of this
81 paper. In Section 2, the relevant literature on com-
82 promise decision making problems is reviewed.
83 Section 3 displays the introduced model. Model’s
84 application is illustrated in Section 4 and eventually
85 Section 5 presents the conclusion remarks.

86 2. Literature review

87 Most of the project selection related studies apply
88 the concept of multi-criteria decision-making and
89 multi-criteria analysis [1]. Actually, since project
90 evaluation and selection is a group decision-making

91 process that is affected by different project aspects,
92 applying multi criteria decision-making methods
93 could be a useful approach. On the other hand,
94 one aspect that highly influences project evalua-
95 tion and selection studies especially in case of high
96 technology-projects is uncertainty. Over the years, a
97 large number of fuzzy multi-criteria decision mak-
98 ing (FMCDM) methods have been introduced. All
99 approaches are mainly concerned with conduct-
100 ing the decision-making process better informed
101 and more structured. Through reviewing previous
102 studies, FMCDM can be categorized as a fuzzy
103 multi-objective decision-making (FMODM) and
104 fuzzy multi-attribute decision-making (FMADM)
105 approach.

106 A practical solution in highly uncertain environ-
107 ments is applying type-2 FSs. The development made
108 by Wu and Mendel [2] was based on using words
109 for interval type-2 fuzzy hierarchical MADM. The
110 model was applied to assess a weapon system. Dereli
111 and Alton [26] used IT2FSs to present a framework
112 that evaluated technologies. Dereli and Alton [25]
113 further investigated the problem of candidate tech-
114 nology assessment with the help of a fuzzy inference
115 system that used type 2 fuzzy sets. Qin et al. [9] devel-
116 oped a decision model integrating VIKOR method
117 and prospect theory. To illustrate the applicability of
118 their method, they used case study of a high-tech risk
119 evaluation.

120 Another approach in using IT2FSs in project envi-
121 ronment is employing these sets in mathematical
122 modeling and programming. To the best of our knowl-
123 edge, this approach in project and project portfolio
124 selection is new and only a small number of studies
125 have used this approach. For instance, Mohagheghi
126 et al. [28] presented a model of project cash flow pre-
127 diction that could also be applied in project evaluation
128 and appraisal. Mohagheghi et al. [29] applied IT2FSs
129 to evaluate R&D project evaluation and project
130 portfolio selection. As mentioned earlier employ-
131 ing type-2 FSs in mathematical modeling for project
132 selection problems is new and most of the IT2FS-
133 based approaches apply different MCDM techniques.

134 Since this paper offers a new method of IT2F-
135 ranking, a brief review of ranking methods is
136 presented. Mitchell [4] presented one of the first type-
137 2 fuzzy-ranking methods. The method was based on
138 random inputs and the randomness involved in the
139 process would affect the final results. Qin and Liu
140 [9] used operators of arithmetic average, geometric
141 average and harmonic average (HA) to rank IT2FNs.
142 Kunda et al. [19] presented a model of interval type-2

fuzzy-ranking. The method was based on the concept of using relative preference index. Proposed ranking approaches are not totally satisfactory. Some of the reasons are as follows: lack of enough discrimination while differentiating similar IT2FNs, having inconsistent and sometimes counter-intuitive results under different situations, and requiring large computational effort under specific conditions.

As it was mentioned, any practical project evaluation process requires sophisticated consideration of uncertainty. Most of the existing literature of the project and project portfolio selection is based on classic fuzzy sets theory. In environments like high technology-project environments that have a very high level of uncertainty it is more practical to use type-2 FSs. Therefore, in this paper, a new model of project portfolio selection under an IT2F-environment that controls the risk of uncertainty in addition to avoiding information loss when giving weight to DMs is proposed.

3. Proposed approach

In this section, first a new effective ranking method is presented that is based on the concept of positive and negative ideal solutions. The project portfolio selection has two main parts. In the first part, a novel decision-making approach is presented that avoids information loss in addition to controlling uncertainty of soft computing. This part of the model results in ranking the candidate projects while considering the selection criteria. The second part includes a new mathematical model based on the concept of IT2FSs that uses the results of the previous part of the model to select the best portfolio of projects while considering conflicting and practical limitations and considerations. It should be noted that the applied IT2FS definitions and operators were taken from [6–8, 12, 15, 20].

3.1. Proposed ranking trapezoidal interval type-2 fuzzy numbers

In this section, a novel approach for comparing and ranking IT2FNs is presented. This approach is based on sensible use of concept of ideal solutions. Also, a distance-based similarity measure between IT2FNs is appropriately developed for effectively obtaining the overall performance for any given IT2FN ranking and comparing process. This method is based on the studies of Deng [5], Ren et al. [14], Mohagheghi et al.

[30] and Zhang and Zhang [34]. The step-by-step algorithm is introduced as follows:

1. Define the trapezoidal interval type-2 fuzzy positive ideal solution as \tilde{X}_{max} and the negative ideal solution as \tilde{X}_{min} .
2. Calculate the distance-based degree of similarity between each interval type-2 fuzzy number $\tilde{A}_i (i = 1, 2, \dots, n)$ and the positive interval type-2 fuzzy ideal solution (d_i^+) by applying Equation (1):

$$d_i^+ (\tilde{A}_i, \tilde{X}_{max}) = \sqrt{\sum_{i=1}^4 (a_i^U - x_i^U)^2 + \sum_{i=1}^4 (a_i^L - x_i^L)^2 + \sum_{i=1}^2 (H_i(\tilde{A}^U) - H_i(\tilde{X}^U))^2 + \sum_{i=1}^2 (H_i(\tilde{A}^L) - H_i(\tilde{X}^L))^2} \quad (1)$$

3. Calculate the distance-based degree of similarity between each interval type-2 fuzzy number $\tilde{A}_i (i = 1, 2, \dots, n)$ and the negative interval type-2 fuzzy ideal solution (d_i^-) by applying Equation (2):

$$d_i^- (\tilde{A}_i, \tilde{X}_{min}) = \sqrt{\sum_{i=1}^4 (a_i^U - x_i^U)^2 + \sum_{i=1}^4 (a_i^L - x_i^L)^2 + \sum_{i=1}^2 (H_i(\tilde{A}^U) - H_i(\tilde{X}^U))^2 + \sum_{i=1}^2 (H_i(\tilde{A}^L) - H_i(\tilde{X}^L))^2} \quad (2)$$

4. Determine the point $E (\min (d_i^+), \max (d_i^-))$, which is referred to as the optimized ideal reference point.
5. Calculate the distance from each alternative to point E by using the following:

$$ED_i = \sqrt{[d_i^+ - \min (d_i^+)]^2 + [d_i^- - \max (d_i^-)]^2}, \quad i = 1, 2, \dots, n \quad (3)$$

6. Rank the interval type-2 fuzzy numbers $\tilde{A}_i (i = 1, 2, \dots, n)$ in increasing order of ED_i . If two numbers happen to have the same value

Table 1
Linguistic terms and trapezoidal interval type-2 fuzzy numbers

Linguistic variables	Trapezoidal interval type-2 fuzzy numbers
Extreme High (EH)	((8,9,9,10; 1,1),(8.5,9,9,9.5;0.9,0.9))
Very High (VH)	((6,7,7,8; 1,1),(6.5,7,7,7.5;0.9,0.9))
High (H)	((4,5,5,6; 1,1),(4.5,5,5,5.5;0.9,0.9))
Medium High (MH)	((2,3,3,4; 1,1),(2.5,3,3,4.5;0.9,0.9))
M (Medium)	((1,1,1,1; 1,1),(1,1,1,1;0.9,0.9))
Medium Low (ML)	((0.25,0.33,0.33,0.5;1,1),(0.22,0.33,0.33,0.4;0.9,0.9))
Low (L)	((0.17,0.2,0.2,0.25; 1,1),(0.18,0.2,0.2,0.22;0.9,0.9))
Very Low (VL)	((0.13,0.14,0.14,0.17;1,1),(0.13,0.14,0.14,0.15;0.9,0.9))
Extreme Low (EL)	((0.1,0.11,0.11,0.13; 1,1),(0.11,0.11,0.11,0.12;0.9,0.9))

of ED_i , determine their ED_i by the following Equation and rank them in increasing order of ED_i .

$$ED_i = d_i^+ - \min(d_i^+) . \quad (4)$$

3.2. Proposed type 2-risk reduction compromise ratio model

In this section, a new risk reduction compromise ratio method based on trapezoidal IT2FSs and footprint of uncertainty (FOU) is developed that explores the impacts of the criteria used in the decision-making process. Linguistic variables were converted into trapezoidal interval type-2 fuzzy sets and are presented in Table 1. This novel method can be described in detail by means of the following.

First, decision information of each DM should be gathered, therefore:

$$\tilde{D}_K = (\tilde{D}_{ij}^K)_{m \times n} = \begin{bmatrix} \tilde{D}_{11}^K & \cdots & \tilde{D}_{1n}^K \\ \vdots & \ddots & \vdots \\ \tilde{D}_{m1}^K & \cdots & \tilde{D}_{mn}^K \end{bmatrix} \quad (5)$$

$$\tilde{W}_K = (\tilde{w}_1^k, \tilde{w}_2^k, \dots, \tilde{w}_n^k), K \in T \quad (6)$$

Where \tilde{D}_K is the decision matrix and \tilde{W}_K is the weight vector of attributes, m is the number of criteria, n is the number of alternatives compared and T denotes the group of experts. \tilde{w}_j is the weight vector of the criteria. Obviously, \tilde{D}_{ij}^K and \tilde{W}_K are trapezoidal IT2FSs.

The decision matrix should be normalized (\tilde{F}) using Equations (8 and 9).

$$\tilde{F} = \begin{bmatrix} \tilde{F}_{11} & \cdots & \tilde{F}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{F}_{m1} & \cdots & \tilde{F}_{mn} \end{bmatrix} \quad (7)$$

$$\begin{aligned} \tilde{F}_{ij} = & (f_{i1}^U, f_{i2}^U, f_{i3}^U, f_{i4}^U; (\min H_{i1}(D_1^U), H_1(d^*)), H_1(d^*)) \\ & (\min H_2(D_1^U), H_2(d^*)), f_{i1}^L, f_{i2}^L, f_{i3}^L, f_{i4}^L; \\ & (\min H_1(D_1^L), H_1(d^*)), (\min H_2(D_1^L), \\ & H_2(d^*))) \end{aligned} \quad (8)$$

where

$$f_{li}^T = \min \left(\frac{d_{ij1m}^T}{d^*}, \frac{d_{ij1m}^T}{d^*}, \frac{d_{ij1(5-m)}^T}{d^*}, \frac{d_{ij1(5-m)}^T}{d^*} \right),$$

$$T \in \{U, L\}, m \in \{1, 2\}$$

$$f_{lj}^T = \min \left(\frac{d_{ij1(5-n)}^T}{d^*}, \frac{d_{ij1(5-n)}^T}{d^*}, \frac{d_{ij1n}^T}{d^*}, \frac{d_{ij1n}^T}{d^*} \right),$$

$$T \in \{U, L\}, n \in \{3, 4\}$$

$$i = 1, 2, \dots, n, j \in B$$

$$\begin{aligned} \tilde{F}_{ij} = & (f_{i1}^U, f_{i2}^U, f_{i3}^U, f_{i4}^U; (\min H_{i1}(D_1^U), H_1(d^-)), \\ & (\min H_2(D_1^U), H_2(d^-)), f_{i1}^L, f_{i2}^L, f_{i3}^L, f_{i4}^L; \\ & (\min H_1(D_1^L), H_1(d^-)), (\min H_2(D_1^L), \\ & H_2(d^-))) \end{aligned} \quad (9)$$

where

$$f_{li}^T = \min \left(\frac{d^-}{d_{ij2m}^T}, \frac{d^-}{d_{ij2(5-m)}^T}, \frac{d^-}{d_{ij2m}^T}, \frac{d^-}{d_{ij2(5-m)}^T} \right),$$

$$f_{lj}^T = \min \left(\frac{d^-}{d_{ij2(5-n)}^T}, \frac{d^-}{d_{ij2n}^T}, \frac{d^-}{d_{ij2(5-n)}^T}, \frac{d^-}{d_{ij2n}^T} \right),$$

$$T \in \{U, L\}, n \in \{3, 4\}$$

$$i = 1, 2, \dots, n, j \in B$$

258 Where B denotes the group of benefit criteria and
 259 C represents the group of cost criteria. d^* and d^- are
 260 also obtained as follows:

$$261 \quad d^* = \max_i (d_{ij})_4^U \quad (10)$$

$$262 \quad d^- = \min_i (d_{ij})_1^U \quad (11)$$

263 The normalized weighted decision matrix is calcu-
 264 lated by employing Equation (12).

$$265 \quad \tilde{G} = \begin{bmatrix} \tilde{G}_{11} & \cdots & \tilde{G}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{G}_{m1} & \cdots & \tilde{G}_{mn} \end{bmatrix} \quad (12)$$

$$266 \quad \tilde{G}_{ij} = \tilde{F}_{ij} \times \tilde{w}_j$$

$$267 \quad = (g_{i1}^U, g_{i2}^U, g_{i3}^U, g_{i4}^U; (\min H_{i1}(G_1^U), H_1(F_1^U)),$$

$$268 \quad (\min H_{i1}(G_1^U), H_1(F_1^U)),$$

$$269 \quad g_{i1}^L, g_{i2}^L, g_{i3}^L, g_{i4}^L; (\min H_1(G_1^L), H_1(F_1^L)),$$

$$270 \quad (\min H_2(G_1^L), H_2(F_1^L))) \quad (13)$$

271 where

$$272 \quad g_{1i}^T = \min \left(\begin{array}{l} f_{ij_{1m}}^T w_{j_{2m}}^T, f_{ij_{1m}}^T w_{j_{2(5-m)}}^T, \\ f_{ij_{1(5-m)}}^T w_{j_{2m}}^T, f_{ij_{1(5-m)}}^T w_{j_{2(5-m)}}^T \end{array} \right),$$

$$273 \quad T \in \{U, L\}, m \in \{1, 2\}$$

$$274 \quad g_{1j}^T = \min \left(\begin{array}{l} f_{ij_{1(5-n)}}^T w_{j_{2(5-n)}}^T, \\ f_{ij_{1(5-n)}}^T w_{j_{2n}}^T, f_{ij_{1n}}^T w_{j_{2(5-n)}}^T, f_{ij_{1n}}^T w_{j_{2n}}^T \end{array} \right),$$

$$275 \quad T \in \{U, L\}, n \in \{3, 4\}$$

The ideal decisions of all individual decisions in mean sense should be the average of all individual decisions. A negative ideal decision should be of the maximum separation from the positive ideal decision [32]. Therefore, the best decision (G^*), the left negative ideal decision (G_l^-) and the right negative ideal decision (G_r^-) are calculated by applying the following equations:

$$276 \quad \tilde{G}^* = \begin{bmatrix} \tilde{\delta}_{11}^* & \cdots & \tilde{\delta}_{1n}^* \\ \vdots & \ddots & \vdots \\ \tilde{\delta}_{m1}^* & \cdots & \tilde{\delta}_{mn}^* \end{bmatrix} \quad (14)$$

where

$$276 \quad \tilde{g}_{ij}^* = \left(\frac{1}{t} \sum_{k=1}^t g_{ij1}^U, \frac{1}{t} \sum_{k=1}^t g_{ij2}^U, \frac{1}{t} \sum_{k=1}^t g_{ij3}^U \right.$$

$$277 \quad \left. \frac{1}{t} \sum_{k=1}^t g_{ij4}^U; (H_{i1}(G_1^U)), (H_{i2}(G_1^U)), \right.$$

$$278 \quad \left. \frac{1}{t} \sum_{k=1}^t g_{ij1}^L, \frac{1}{t} \sum_{k=1}^t g_{ij2}^L, \frac{1}{t} \sum_{k=1}^t g_{ij3}^L, \right.$$

$$279 \quad \left. \frac{1}{t} \sum_{k=1}^t g_{ij4}^L; (\min H_1(G_1^L), H_1(F_1^L)), \right.$$

$$280 \quad \left. (\min H_2(G_1^L), H_2(F_1^L))) \right.$$

$$281 \quad \tilde{G}_L^- = \begin{bmatrix} \tilde{g}_{l11}^- & \cdots & \tilde{g}_{l1n}^- \\ \vdots & \ddots & \vdots \\ \tilde{g}_{lm1}^- & \cdots & \tilde{g}_{lmn}^- \end{bmatrix} \quad (15)$$

where $\tilde{g}_{l_{ij}}^- = \min_{1 \leq k \leq t} \{\tilde{g}_{ij}^k\}$

$$282 \quad \tilde{G}_R^- = \begin{bmatrix} \tilde{g}_{r11}^- & \cdots & \tilde{g}_{r1n}^- \\ \vdots & \ddots & \vdots \\ \tilde{g}_{rm1}^- & \cdots & \tilde{g}_{rmn}^- \end{bmatrix} \quad (16)$$

where $\tilde{g}_{r_{ij}}^- = \max_{1 \leq k \leq t} \{\tilde{g}_{ij}^k\}$

283 The difference of each individual judgment from
 284 the ideal judgments including positive ideal decision,
 285 the left negative ideal decision and the right negative
 286 ideal decision are respectively denoted by d_k^* , d_l^- and
 d_r^- and are determined by the following Equations:

$$287 \quad d_l^* = \sqrt{\begin{array}{l} \sum_{p=1}^4 (g_{ijp}^{U^k} - g_{ijp}^{U^*})^2 + \sum_{p=1}^4 (g_{ijp}^{L^k} - g_{ijp}^{L^*})^2 \\ + \sum_{p=1}^2 (H_p(\tilde{G}_l^{U^k}) - H_p(\tilde{G}_l^{U^*}))^2 \\ + \sum_{p=1}^2 (H_p(\tilde{G}_l^{L^k}) - H_p(\tilde{G}_l^{L^*}))^2 \end{array}} \quad (17)$$

$k \in T$

$$d_l^- = \sqrt{\sum_{p=1}^4 (g_{ijp}^{U^k} - g_{ijp}^{U^l})^2 + \sum_{p=1}^4 (g_{ijp}^{L^k} - g_{ijp}^{L^l})^2 + \sum_{p=1}^2 (H_p(\tilde{G}_l^{U^k}) - H_p(\tilde{G}_l^{U^l}))^2 + \sum_{p=1}^2 (H_p(\tilde{G}_l^{L^k}) - H_p(\tilde{G}_l^{L^l}))^2} \quad (18)$$

$k \in T$

$$d_r^- = \sqrt{\sum_{p=1}^4 (g_{ijp}^{U^k} - g_{ijp}^{U^r})^2 + \sum_{p=1}^4 (g_{ijp}^{L^k} - g_{ijp}^{L^l})^2 + \sum_{p=1}^2 (H_p(\tilde{G}_l^{U^k}) - H_p(\tilde{G}_l^{U^r}))^2 + \sum_{p=1}^2 (H_p(\tilde{G}_l^{L^k}) - H_p(\tilde{G}_l^{L^r}))^2} \quad (19)$$

$k \in T$

The closeness coefficient of the individual decision (R_k) with respect to ideal decisions denoted by (CC_k) is achieved as follows:

$$CC_k = \frac{d_l^r + d_l^l}{d_l^r + d_l^r + d_l^*}, K \in T \quad (20)$$

It is considered that larger value of CC_k determines more importance on k th DM opinion, and bigger value of weight for k th DM [33]. The importance of an expert in his/her area of expertise is referred to as the individual importance and denoted by IM_k . Combination of the two DM importance considerations can be obtained as follows:

$$\pi_k = \alpha IM_k + (1 - \alpha) CC_k, K \in T \quad (21)$$

where α ($0 \leq \alpha \leq 1$) is the optimistic coefficient that indicates whose value can be chosen according to group's opinions, IM_k ($0 \leq IM_k \leq 1$) is the measure of importance of k th DM as an expert in his/her own area of expertise.

Eventually, the weights of DMs are obtained as follows:

$$\mu_k = \frac{\pi_k}{\sum_{k=1}^t \pi_k}, K \in T \quad (22)$$

The weighted (on attributes and DMs) decision matrix (S) for each DM is calculated by the following:

$$\tilde{S}_k = (s_{ij})_{m \times n} = (\mu_k \times g_{ij}^k)_{m \times n}$$

$$= \begin{bmatrix} \tilde{s}_{11}^k & \cdots & \tilde{s}_{1n}^k \\ \vdots & \ddots & \vdots \\ \tilde{s}_{m1}^k & \cdots & \tilde{s}_{mn}^k \end{bmatrix} \quad (23)$$

where

$$\tilde{s}_{ij} = (\mu_k g_{ij1}^U, \mu_k g_{ij2}^U, \mu_k g_{ij3}^U, \mu_k g_{ij4}^U; (H_{i1}(G_1^U), H_{i2}(G_1^U)), \mu_k g_{ij1}^L, \mu_k g_{ij2}^L, \mu_k g_{ij3}^L, \mu_k g_{ij4}^L; (H_{i1}(G_1^L), H_{i2}(G_1^L)))$$

The individual decision, which is weighted on attributes and DMs, is converted into the group decision, for each alternative. This is done by the following Equation:

$$\tilde{S}_i = (s_{kj})_{j \times n} = \begin{bmatrix} \tilde{s}_{11}^i & \cdots & \tilde{s}_{1n}^i \\ \vdots & \ddots & \vdots \\ \tilde{s}_{i1}^i & \cdots & \tilde{s}_{in}^i \end{bmatrix}, i \in M, \quad (24)$$

To manage the risk of uncertainty in the process the following mathematical model for each alternative is presented.

$$H_i = \max \left(\sum_{i=1}^M \tilde{q}Bi - \sum_{i=1}^M \tilde{q}Ci \right) \quad (25)$$

Subject to :

$$\tilde{q}Bi = \sum_{j \in B} \sqrt{\frac{1}{4} \left(((s_{ij})_1)^2 + ((s_{ij})_2)^2 + ((s_{ij})_3)^2 + ((s_{ij})_4)^2 \right)} \quad (26)$$

$$\tilde{q}Ci = \sum_{j \in C} \sqrt{\frac{1}{4} \left(((s_{ij})_1)^2 + ((s_{ij})_2)^2 + ((s_{ij})_3)^2 + ((s_{ij})_4)^2 \right)} \quad (27)$$

$$\tilde{S}_{ij} = (s_{ij_1}, s_{ij_2}, s_{ij_3}, s_{ij_4}) \quad (28)$$

$$s_{ij_1}^U \leq s_{ij_1} \leq s_{ij_1}^L, j = 1, \dots, m, i = 1, \dots, n \quad (29)$$

$$s_{ij_2}^U \leq s_{ij_2} \leq s_{ij_2}^L, j = 1, \dots, m, i = 1, \dots, n \quad (30)$$

$$s_{ij_3}^L \leq s_{ij_3} \leq s_{ij_3}^U, j = 1, \dots, m, i = 1, \dots, n \quad (31)$$

$$s_{ij_4}^L \leq s_{ij_4} \leq s_{ij_4}^U, j = 1, \dots, m, i = 1, \dots, n \quad (32)$$

$$\leq \frac{\beta}{\mu} \sum_{i=1}^N \begin{pmatrix} it2fi_1^U, it2fi_2^U, it2fi_3^U, it2fi_4^U; \\ H_1(it2fi_1^U), H_2(it2fi_1^U) \end{pmatrix}, \quad (40)$$

$$\sum_{i \in \text{long-term}} \begin{pmatrix} it2fi_1^U, it2fi_2^U, it2fi_3^U, it2fi_4^U; \\ H_1(it2fi_1^U), H_2(it2fi_1^U) \end{pmatrix},$$

$$\leq \frac{\gamma}{\mu} \sum_{i=1}^N \begin{pmatrix} it2fi_1^L, it2fi_2^L, it2fi_3^L, it2fi_4^L; \\ H_1(it2fi_1^L), H_2(it2fi_1^L) \end{pmatrix}.x_i \quad (41)$$

$$\alpha + \beta + \gamma = \mu \quad (42)$$

$$x_i \neq x_i'' \quad \text{for } i = 1, 2, \dots, n; (i, i'') \in K \quad (43)$$

$$x_i = 1 \quad \text{for } i = 1, 2, \dots, n; \forall i \in L \quad (44)$$

Equation (37) keeps the amount of investment in the feasible region. Equation (38) keeps the number of human resource of the entire selected portfolio in the practical area. Equations (39–41) can be added to the model to plan short, mid and long-term time horizons. Equation (43) indicates the mutual exclusiveness relationship of projects. Equation (44) makes inclusion of a certain project in the portfolio compulsory.

To solve the mathematical model with IT2FSs embedded in the constraints, the concept of expected value defined by Hu et al. [6] was used. In this approach, each IT2FN used in the model is transformed to crisp value. The following presents the applied approach of transformation:

$$E(A) = \frac{1}{2} \left(\frac{1}{3} \sum_{i=1}^3 a_i^L + a_i^U \right) \times \frac{1}{4} \left(\sum_{i=1}^2 (H_i(A^L) + H_i(A^U)) \right) \quad (45)$$

3.4. Procedure of the proposed project portfolio selection approach

In sum, the algorithm is provided by means of the following steps:

Step 1. Provide individual decision information for each DM. Each DM expresses his/her decision matrix. Their decision matrixes are gathered as expressed in Equations (5 and 6).

Step 2. Normalize the gathered decision matrixes by Equations (8 and 9).

Step 3. Construct the weighted (on attributes) individual decision by Equation (13).

Step 4. Determine the ideal decisions of all individual decisions. The best decision (G^*), the left negative ideal decision (G_l^-) and the right negative ideal decision (G_r^-) are calculated by Equations (14–16), respectively.

Step 5. Compute the separations of each individual judgment from the best judgment (G^*), the left negative ideal decision (G_l^-) and the right negative ideal decision (G_r^-) applying Equations (17–19), respectively.

Step 6. Decide the closeness coefficient of each individual judgment to supreme judgments by using Equation (20).

Step 7. Find the comprehensive closeness coefficient of each DM by employing Equation (21).

Step 8. Obtain the weights of DMs by using Equation (22).

Step 9. Create a decision matrix that is weighted on attributes and DMs for each DM by Equation (23).

Step 10. Convert the individual decision that is weighted on attributes and DMs into the group decision for each alternative by using Equation (24).

Step 11. Solve the mathematical model presented in Equations (25–34) for each alternative.

Step 12. Calculate the quantitative utility of each alternative by using Equation (35).

Step 13. Form the final objective function of the project portfolio selection model by using the obtained quantitative utility.

Step 14. Gather the data concerning the constraints and the limitations and form the final model.

Step 15. Solve the mathematical model to achieve the optimal portfolio of projects.

4. Proposed approach application

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In this part, an existing problem in the recent literature is adopted and solved using the proposed approach. Furthermore, the model is presented in two parts and each part is illustratively dealt with by the model.

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4.1. First part of the proposed model

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In this section, to display model's applicability in real-world problems, the data from the case study of Tavana et al. [16] is applied. The main objective of the studied organization is to find the most suitable projects for funding depending on the annual budget constraints.

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The following criteria were considered in the problem: Total cost (C_1), Production time (C_2), System safety (C_3), System reliability (C_4), Feasibility (C_5) and eventually, reusability (C_6). 5 projects (P_1) – (P_5) from the studied case are selected to be used in the proposed method. A group consisting of 5 experts have expressed their ideas.

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Since the calculations are too large to be fully displayed, partial calculations are presented as follows. The closeness coefficient of the individual judgment with respect to supreme judgments is obtained and displayed in Table 2. π_k is then calculated. It should be noticed that each DM was given the IM_k of 0.2 and α was equal to 0.5. π_k is also displayed in Table 2. Finally, the weights of DMs are calculated. They also are displayed in Table 2. The initial judgments are weighted by using Equation (23).

The weighted (on attributes and DMs) decision matrix (S) for each DM is aggregated before being used in the mathematical model. The aggregation is carried by applying the following:

$$\left(\begin{array}{c} \frac{\sum_{k=1}^K s_{kij1}^L}{K}, \frac{\sum_{k=1}^K s_{kij2}^L}{K}, \frac{\sum_{k=1}^K s_{kij3}^L}{K}, \frac{\sum_{k=1}^K s_{kij4}^L}{K}, \\ \min H_1(\tilde{S}_{kij}^L), H_2(\tilde{S}_{kij}^L), \\ \frac{\sum_{k=1}^K s_{kij1}^L}{K}, \frac{\sum_{k=1}^K s_{kij2}^L}{K}, \frac{\sum_{k=1}^K s_{kij3}^L}{K}, \frac{\sum_{k=1}^K s_{kij4}^L}{K}, \\ \min H_1(\tilde{S}_{kij}^L), H_2(\tilde{S}_{kij}^L), \end{array} \right) \quad (46)$$

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It should be mentioned that the aforementioned steps are carried out for all the gathered judgments. Eventually, the mathematical model for each alternative is solved. It should be noted that maximum level of uncertainty is set equal to 0.5. H_i , QU_i and the results of the existing literature are displayed

Table 2
The closeness coefficient, π_k and μ_k

Decision Maker	CC_k	π_k	μ_k
DM_1	0.65	0.42	0.18
DM_2	0.83	0.51	0.22
DM_3	0.67	0.43	0.18
DM_4	0.82	0.51	0.22
DM_5	0.67	0.43	0.18

Table 3
Final computational results

Projects	H_i	QU_i	Proposed approach ranking	Tavana et al. [16]
P_1	7.122591	100	1	1
P_2	6.102921	85.684	2	2
P_3	5.979368	83.94935	3	3
P_4	4.437909	62.30751	4	4
P_5	3.072105	43.13185	5	5

in Table 3. The results show the reliability if the proposed model in addition to its novelty in giving weights to each DM depending on the achieved judgments.

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4.2. The second part of the proposed approach

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Since the provided case study lacked the required data for this part of the model, in order to display application of this part, the problem is adapted and the required data is added. Table 4 displays the adapted data for each project. To demonstrate model's ability to handle problems under different scenarios, different levels of constraints are considered, and the model is solved under those different constraints. Table 5 displays the achieved results.

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4.3. Model's advantages over similar studies

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Applying the proposed model in the existing literature demonstrated several advantages. The most important implications of the model's application are as follows: (1) the model is based on type 2 FSs. This uncertainty-modeling tool gives the model a practical edge over the existing classic fuzzy models; (2) the model is in two main parts, and it means that the DM can easily observe the results of judgments on projects before choosing the portfolio. Furthermore, uncertain data concerning both quantifiable and unquantifiable can be applied in each part of the model; (3) each DM is given a weight that is based on the expertise and importance of the expert in any studying field, in addition to the data gathered from

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Table 4
Adapted data of the studied projects

Projects	IT2F investment (million dollars)	IT2F human resource (persons)
P_1	((160,180,210,230;1,1),(170,190,200,220;0.9,0.9))	((20,30,45,55;1,1),(25,35,40,50;0.9,0.9))
P_2	((260,280,310,330;1,1),(270,290,300,320;0.9,0.9))	((15,25,40,50;1,1),(20,30,35,45;0.9,0.9))
P_3	((110,130,160,180;1,1),(120,140,150,170;0.9,0.9))	((0,10,25,35;1,1),(5,15,20,30;0.9,0.9))
P_4	((60,80,110,130;1,1),(70,90,100,120;0.9,0.9))	((7,12,27,37;1,1),(7,17,22,32;0.9,0.9))
P_5	((210,230,260,280;1,1),(220,240,250,270;0.9,0.9))	((10,20,35,45;1,1),(15,25,30,40;0.9,0.9))

Table 5
Results of the second part of the model

Projects	Budget 0–100	Budget 100–200	Budget 200–300	Budget 0–500
	Human resource 0–30	Human resource 30–50	Human resource 50–70	Human resource 0–120
P_1	0	1	1	1
P_2	0	0	0	0
P_3	0	0	0	1
P_4	1	0	1	1
P_5	0	0	0	0
Objective	62.3	100	162.3	264.2

other experts; (4) the approach avoids information loss in the decision-making process.

5. Conclusions

New technology-project selection is one of the most important tasks of many organizations. Since high technology-projects are nowadays very crucial to advancements of science and technology, and they have not been comprehensively addressed in project selection literature, this paper proposed a novel approach of high technology-project selection. Moreover, the presented approach was in two main parts. In the first part, a new multi criteria decision-making model that avoids information loss was presented that was able to review and rank the projects. In the second part, a model of project portfolio selection was presented that simultaneously considered investments requirements and human resource requirements in finding the optimum portfolio of high technology-projects. To displays the model's application, a case study for the high technology-project selection problem from the existing literature was chosen and adopted properly to be solved by the model. Applying the approach provided several implications that were discussed. Finally, for further researches, integrating the proposed model in decision support systems could be a practical and interesting work.

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