MULTI-CRITERIA DECISION APPROACH WITH AHP AND IF-TOPSIS METHODS FOR R&D PROJECT SELECTION PROCESS

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Abstract: In this study, we examined the project selection process in a mould manufacturing company. We ranked 12 criteria via Analytic Hierarchy Process (AHP) and evaluated the most important 8 criteria. Then we applied Intuitionistic Fuzzy TOPSIS (IF-TOPSIS) method, which is the extended version of the TOPSIS method in intuitionistic fuzzy environment. After expressing the decision makers' evaluations in linguistic terms, we turned them into intuitive fuzzy numbers. In the last step, we obtained the project rankings by calculating the closeness coefficient for 5 projects.

Keywords: analytic hierarchy process (AHP), intuitive fuzzy topsis (IF-TOPSIS), project selection, R&D project

1. INTRODUCTION

In today's competitive environment, the process of research and development (R & D) project selection is crucial for many firms, especially those that depend on innovation in order to maintain their competitiveness. The decision to develop and implement new products and processes is an important decision to be made within the framework of strategic management. Because resources that are limited during R & D activities should also be used efficiently. In this context, projects with high benefit value should be evaluated and selected. Because many factors are considered in this process, the problem is a Multi-Criteria Decision Making (MCDM). The decision-maker should evaluate the many factors affecting the decision-making process simultaneously [1, 2].

In decision environments where uncertainty, MCDM methods are used with fuzzy set theory. Because fuzzy set theory likens the uncertainty that emerges in the decision-making process to human inquisition. As fuzzy logic is very close to the logic of thinking of people, the decisions made in this way are more accurate. In the fuzzy approach, linguistic expressions are used when weighting criteria and evaluating alternatives [3].

Although fuzzy set theory is a good method for reflecting the assessment of decision-makers, it is not sufficient in some cases. Because it considers the sum of the degrees of belonging and not belonging of an element to a fuzzy cluster as 1. However, in real problems this value can be less than one. In addition, there may be hesitation in the decision-making process of the decision-maker. Therefore, Atanassov has proposed the intuitionistic fuzzy set (IFS) theory, which is the generalized version of fuzzy set theory. IFS theory, it is a more effective approach for uncertain processes because it is indicated by the degree of membership, non-membership and hesitation [4].

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In this study, we employed the R & D project selection process in a mould manufacturing company via Intuitionistic Fuzzy TOPSIS (IF-Technique for Order Preference by Similarity to Ideal Solution) method. Firstly, considering the similar studies in the literature, we identified 4 main criteria and 12 sub-criteria that should be considered in the selection of R & D project. Table 1 shows some of the criteria used in the selection of R & D projects in the literature. Then, we calculated weight of importance the 12 criteria via Analytic Hierarchy Process (AHP) which is one of the MCDM methods and eliminated 4 criteria which are small with regards to weight of importance. We asked the decision-makers (DM) to make the evaluation, and after expressing these evaluations in linguistic terms, then turned them into intuitive fuzzy numbers. We used the intuitionistic fuzzy weighted averaging (IFWA) operator to combine intuitive fuzzy numbers. Finally, we obtained the project rankings by calculating the closeness coefficient for 5 R & D projects.

Table 1. Criteria used in the selection of R & D projects.

Literature	Criteria
Osawa ve Murakami [5]	The strategic importance of the project, the technological impact of the project, applicability of the project, post-project sales, post-project profit, effectiveness of the project
Liang [6]	The contribution of the project to the business, the amount of investment of the project, the power of innovation of the project and the suitability of the project for the purposes of the enterprise
Tunç [7]	Technological uncertainty, working and test environment, system coverage, amount of resources
Wang et. al. [8]	Project's contribution to business and national economy, probability of success of the project, theoretical and technical contribution of the project, energy and material savings provided by the project, social impact of the project, commercial success of the project, impact of the project on development
Lawson vd. [9]	Technical risks of the project, legal regulations in force, post-project management, market share, feasibility of the project, commercial risk of the project, compliance with the business strategy of the project.
Tolga and Kahraman [10]	Production capacity, production facilities and equipment, workplace safety during production, production sensitivity to the environment, possibility of technical success, technical contribution, technical time, technical resources, marketing internal dynamics, marketing capacity, marketing trends
Ayan and Perçin [11]	Project cost, market share, payback period, expected return

The IFS is often used in the solution of MCDM problems. IF-TOPSIS is one of the methods developed by Boran et al. for this purpose [12]. Aloini et al. to select the appropriate machine tool [13], Büyüközkan and Güleryüz to select smartphones [14] and Aloini et al. for a structured partner in open innovation in a company operating in the advanced underwater systems sector used IF-TOPSIS [15]. Liu et al. determined the priorities of risk factors in failure mode and effects analysis (FMEA) with this method [16]. Dammak et. al used IFS-based TOPSIS, AHP and VIKOR in Human Capital Indicators (HCI) and compared the results [17]. Büyüközkan and Güleryüz used IF-AHP and IF-TOPSIS for product development partner selection [18]. Jaiswal et al. ranked 18 drivers in the adoption of lean production by utilizing IF-TOPSIS approach [19]. Büyüközkan and Göçer used the IF-TOPSIS method to support the evaluation and selection process of the most appropriate hazardous waste transportation company [20]. Tlig and Rebai have proposed a fuzzy TOPSIS method based on intuitionistic fuzzy values to evaluate and compare the service quality of the five largest airports in North Africa [21].

2. METHODS

2.1. Analytic Hierarchy Process (AHP)

AHP was first proposed by Saaty (1980). Based on the calculation of relative priorities according to the role of each criterion in achieving the objective, it is a method that is frequently applied both alone and in combination with other methods to solve MCDM problems [22]. When applying AHP, the problem is determined first. Then, the hierarchical structure is designed. There is the objective at the top level of the hierarchical structure. At a lower level, there are criteria that affect the quality of the decision. Other levels may be added to the hierarchy if these criteria have characteristics that may affect the target within themselves. At the bottom of the hierarchy there are alternatives. Pairwise comparisons are made in step 3. Decision-makers use the 1-9 comparison scale given in Table 2 when making judgments during the comparisons. This scale was developed by Saaty and many studies in the literature have benefited from this scale.

Table 2. The comparison scale as used by Saaty (1995) [23].

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of af. rmation
2, 4,6, 8	Intermediate values	When a compromise is needed

The consistency of these matrices should be explored after the pairwise comparison matrices are formed. If the matrices are consistent, weight of importance are calculated and finally the best alternative is determined [24].

2.2. Intuitionistic Fuzzy TOPSIS (IF-TOPSIS)

Let $A=\{A_1, A_2, A_3, \ldots, A_m\}$ be a set of alternatives and $C=\{C_1, C_2, C_3, \ldots, C_n\}$ be a set of criteria, the procedure for IF TOPSIS method is implemented as follows:

Step 1. Determine the weights of decision makers – Let $D_k=[\mu_k, v_k, \pi_k]$ be an IF number for rating of k^{th} decision maker. Then the weight of k^{th} decision maker can be obtained as equation (1).

$$\lambda_k=\frac{\left(\mu_k+\pi_k\left(\frac{\mu_k}{\mu_k+v_k}\right)\right)}{\sum_{k=1}^{l}\left(\mu_k+\pi_k\left(\frac{\mu_k}{\mu_k+v_k}\right)\right)} \quad \pi_k\geq 0,\ k=1,2,\ldots,l \text{ and } \sum_{k=1}^{l}\pi_k=1 \tag{1}$$

Step 2. Construct aggregated intuitionistic fuzzy decision matrix based on the opinions of decision makers – Let $R^{(k)}=\left(r_{ij}^{(k)}\right)_{mxn}$ is an IF decision matrix of each decision maker. $\lambda=\{\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_l\}$ is the weight of each decision maker and $\sum_{k=1}^{l}\pi_k=1,\ \lambda_k\in[0,1]$. In group decision-making process, all the individual decision opinions need to be fused into a group opinion to construct aggregated IF decision matrix. In order to do that, IFWA operator is used. $R=(r_{ij})_{mxn}$, where

$$\begin{aligned} r_{ij} &= IFWA_\lambda\left(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots, r_{ij}^{(l)}\right)=r_{ij}^{(1)}\lambda_1\oplus r_{ij}^{(2)}\lambda_2\oplus..\oplus r_{ij}^{(l)}\lambda_l \\ &= \left[1-\prod_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k},\ \prod_{k=1}^{l}\left(v_{ij}^{(k)}\right)^{\lambda_k},\ \prod_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}-\prod_{k=1}^{l}\left(v_{ij}^{(k)}\right)^{\lambda_k}\right] \end{aligned} \tag{2}$$

Here $r_{ij}=(\mu_{ij}, v_{ij}, \pi_{ij})$ (i=1,2,...,m; j=1,2,...,n). The aggregated IF decision matrix can be defined as equation (3)

$$R=\begin{bmatrix} (\mu_{11}, v_{11}, \pi_{11}) & \cdots & (\mu_{1n}, v_{1n}, \pi_{1n}) \\ \vdots & \ddots & \vdots \\ (\mu_{m1}, v_{m1}, \pi_{m1}) & \cdots & (\mu_{mn}, v_{mn}, \pi_{mn}) \end{bmatrix}=\begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \tag{3}$$

All criteria may not be assumed to be equal importance. W represents a set of grades of importance. In order to obtain w, all the individual decision maker opinions for the importance of each criteria need to be fused.

Let $w_j^{(k)}=[\mu_j^{(k)},v_j^{(k)},\pi_j^{(k)}]$ be an IF number assigned to criterion X_j by the k^{th} decision maker. Then the weights of the criteria are calculated by using IFWA operator as equation (4)

$$w_j=IFWA_\lambda\left(w_j^{(1)}, w_j^{(2)},\dots,w_j^{(l)}\right)=\lambda_1 w_j^{(1)}\oplus\lambda_2 w_j^{(2)}\oplus...\oplus\lambda_l w_j^{(l)} \tag{4}$$
$$= [1-\prod_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k},\ \prod_{k=1}^{l}\left(v_j^{(k)}\right)^{\lambda_k},\ \prod_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k}-\ \prod_{k=1}^{l}\left(v_j^{(k)}\right)^{\lambda_k}]$$

$W=\{w_1, w_2,w_3,\dots,w_j\}$ here $w_j=(\mu_j, v_j, \pi_j)$ (j=1, 2, ..., n)

Step 4. Construct aggregated weighted IF decision matrix - The aggregated weighted IF decision matrix is constructed according to equation (5) and equation (6)

$$R'=R\otimes W=\left(\mu'_{ij},v'_{ij}\right)=\left\{\langle x,\mu_{ij}.\mu_j,v_{ij}+v_j-v_{ij}.v_j\rangle|x\in X\right\} \tag{5}$$

$$\pi'_{ij}=1-v_{ij}-v_j-\mu_{ij}.\mu_j+v_{ij}.v_j \tag{6}$$

Then the aggregated weighted IF decision matrix can be defined as equation (7):

$$R'=\begin{bmatrix}(\mu_{11}',v_{11}',\pi_{11}') & \cdots & (\mu_{1n}',v_{1n}',\pi_{1n}')\\ \vdots & \ddots & \vdots \\ (\mu_{m1}',v_{m1}',\pi_{m1}') & \cdots & (\mu_{mn}',v_{mn}',\pi_{mn}')\end{bmatrix}=\begin{bmatrix}r_{11}' & \cdots & r_{1n}'\\ \vdots & \ddots & \vdots\\ r_{m1}' & \cdots & r_{mn}'\end{bmatrix} \tag{7}$$

Here $r'_{ij}=\left(\mu'_{ij}, v'_{ij}, \pi'_{ij}\right)$ (i=1, 2, …, m; j=1, 2, …, n) is an element of the aggregated weighted IF decision matrix.

Step 5. Obtain IF positive-ideal solution and IF negative-ideal solution - Let J_1 and J_2 be benefit criteria and cost criteria, respectively. A* is IF positive-ideal solution and A^- is IF negative-ideal solution. Then A* and A^- are obtained in equation (8) and equation (9).

$$A^*=\left(r_1'^*, r_2'^*, \dots,r_n'^*\right),\ r_j'^*=\left(\mu_j'^*,v_j'^*,\pi_j'^*\right),\ j=1\ ,2,\ \dots,\ n \tag{8}$$

$$A^-=\left(r_1'^-, r_2'^-, \dots,r_n'^-\right),\ r_j'^-=\left(\mu_j'^-,v_j'^-,\pi_j'^-\right),\ j=1\ ,2,\ \dots,\ n \tag{9}$$

where

$$\mu_j'^*=\left\{(\max_i\left\{\mu'_{ij}\right\}\mid j\in J_1),\ (\min_i\left\{\mu'_{ij}\right\}\mid j\in J_2)\right\} \tag{10}$$

$$v_j'^*=\left\{(\min_i\{v'_{ij}\}\mid j\in J_1),\ (\max_i\{v'_{ij}\}\mid j\in J_2)\right\} \tag{11}$$

$$\pi_j'^*=\left\{(1-\max_i\left\{\mu'_{ij}\right\}-(\min_i\{v'_{ij}\}\mid j\in J_1),\ (1-\min_i\left\{\mu'_{ij}\right\}-(\max_i\{v'_{ij}\}\mid j\in J_2)\right\} \tag{12}$$

$$\mu_j'^-=\left\{(\min_i\left\{\mu'_{ij}\right\}\mid j\in J_1),\ (\max_i\left\{\mu'_{ij}\right\}\mid j\in J_2)\right\} \tag{13}$$

$$v_j'^-=\left\{(\max_i\{v'_{ij}\}\mid j\in J_1),\ (\min_i\{v'_{ij}\}\mid j\in J_2)\right\} \tag{14}$$

$$\pi_j'^-=\left\{(1-\min_i\left\{\mu'_{ij}\right\}-(\max_i\{v'_{ij}\}\mid j\in J_1),\ (1-\max_i\left\{\mu'_{ij}\right\}-(\min_i\{v'_{ij}\}\mid j\in J_2)\right\} \tag{15}$$

Step 6. Calculate the separation measures - Differences between the alternatives and the positive IF ideal solution and the negative IF ideal solution calculate with equation (16) and equation (17). There are multiple distance measurements. In this study, we used normalized Euclidean distance.

$$S^{*}=\left(\frac{1}{2n}\sum_{j=1}^{n}\left[(\mu'_{ij}-\mu'^{*}_{ij})^{2}+(v'_{ij}-v'^{*}_{ij})^{2}+(\pi'_{ij}-\pi'^{*}_{ij})^{2}\right)^{1/2} \quad (16)$$

$$S^{-}=\left(\frac{1}{2n}\sum_{j=1}^{n}\left[(\mu'_{ij}-\mu'^{-}_{ij})^{2}+(v'_{ij}-v'^{-}_{ij})^{2}+(\pi'_{ij}-\pi'^{-}_{ij})^{2}\right)^{1/2} \quad (17)$$

Step 7. Calculate the relative closeness coefficient to the intuitionistic ideal solution - The relative closeness coefficient of an alternative A^{-} with respect to the intuitionistic fuzzy positive-ideal solution A* is defined as equation (18)

$$C_i^{*}=\frac{S_i^{-}}{S_i^{*}+S_i^{-}},\ 0\leq C_i^{*}\leq 1,\ i=1, 2, \ldots, m \quad (18)$$

Step 8. Rank the alternatives - Alternatives are ranked according to C_i^{*}'s [12].

3. CASE STUDY

In this study, we aimed to rank and select the R & D projects that a manufacturing enterprise can implement via AHP and IF-TOPSIS methods. We designed the hierarchical structure with 4 main criteria, 12 sub-criteria and 5 alternative projects. Assessments were made by 3 decision-makers (DM1, DM2 and DM3).

Alternative projects are; P1: Large Scale CMM Software, P2: 2. Hol Air Conditioning System Design project, P3: Team Management System Integration, P4: CNC Surface Grinding Machine Design and P5: Automatic Washing Machine Design. The evaluation criteria are shown in Table 3. Pairwise comparison matrices of the main criteria and sub-criteria of each main criterion are given in Table 4.

Table 3. Main and sub-criteria.

Main Criteria	Sub-Criteria
C1: Project	C11: Project Size
	C12: Product and Process Differentiation
	C13: Technical Contribution of the Project to the Enterprise
	C14: Internal Dynamics of the Project
C2:Risk	C21: Project Complexity
	C22: R & D Risk
	C23: Risk of Commercialization
C3: Conformity	C31: Experience in Similar Projects
	C32: Capacity
	C33: Required Equipment / Materials / Technology Availability
C4: Cost	C41: Outsourcing
	C42: Cost of the Project

Table 4. Main and sub-criteria.

Main Criteria	C1	C2	C3	C4
C1	1	3	3	3
C2	1/3	1	3	5
C3	1/3	1/3	1	1
C4	1/3	1/5	1	1
C1	C11	C12	C13	C14
C11	1	1/2	3	5
C12	2	1	1	4
C13	1/3	1	1	3
C14	1/5	1/4	1/3	1
C2	C21	C22	C23	

C21	1	1/3	1/5
C22	3	1	1/2
C23	5	2	1
C3	C31	C32	C33
C31	1	6	4
C32	1/6	1	1/3
C33	1/4	3	1
C4	C41	C42	
C41	1	4	
C42	1/4	1	

The weights of importance and rankings for each criteria are given in Table 5.

Table 5. Weights of importance and rankings.

Criteria	Weight of Importance	Ranking
C11	0.162	3
C12	0.164	2
C13	0.101	4
C14	0.033	9
C21	0.035	8
C22	0.098	5
C23	0.183	1
C31	0.080	7
C32	0.011	12
C33	0.026	10
C41	0.087	6
C42	0.022	11

We chose the most important 8 criteria by taking into consideration the number of criteria discussed in similar studies in the literature; C14, C32, C33, C42 criteria were eliminated. After this step, we applied the IF-TOPSIS method. The method steps are given below:

Step 1. In order to determine the weight of decision makers, linguistic terms are expressed in the IF numbers given in Table 6. equation (1) was used in the weight calculation of decision makers. The significance levels and weights of DM's are shown in Table 7.

Table 6. Linguistic Terms for rating the importance of DMs.

Linguistic Terms	Nonmember	Hesitant	Member
QI(Quite Important)	0.8	0.1	0.1
I(Important)	0.5	0.2	0.3
M(Medium)	0.5	0.5	0
UI(Unimportant)	0.3	0.5	0.2
QUI(Quite Unimportant)	0.2	0.7	0.1

Table 7. Evaluation of DM's.

	DM1	DM2	DM3
Linguistic Terms	QI	I	M
Weight	0.422	0.340	0.238

Step 2. The linguistic terms for the evaluation of alternatives by 3 DMs on the basis of criteria are defined in Table 8. The scores of the alternatives are given in Table 9.

Table 8. Linguistic terms for rating the alternatives

Linguistic terms	Intuitionistic Fuzzy Numbers
Extremely good (EG)/extremely high (EH)	[1.00, 0.00, 0.00]
Very very good (VVG)/very very high (VVH)	[0.90, 0.10, 0.00]
Very good (VG)/very high (VH)	[0.80, 0.10, 0.1]
Good (G)/high (H)	[0.70, 0.20, 0.1]
Medium good (MG)/medium high (MH)	[0.60, 0.30, 0.1]
Fair (F)/medium (M)	[0.50, 0.40, 0.1]
Medium bad (MB)/medium low (ML)	[0.40, 0.50, 0.1]
Bad (B)/low (L	[0.25, 0.60, 0.15]
Very bad (VB)/very low (VL)	[0.10, 0.75, 0.15]
Very very bad (VVB)/very very low (VVL)	[0.10, 0.90, 0.00]

Table 9. The ratings of the alternatives.

Criteria Type	Criteria	R&D Projects	DM1	DM2	DM3
Benefit	C11(Project Size)	A1	G	MG	VVG
		A2	VB	MB	B
		A3	MG	MB	G
		A4	MG	VVG	VVG
		A5	EG	MG	G
Benefit	C12(Product and Process Differentiation)	A1	MB	F	MB
		A2	MG	MB	MG
		A3	B	MB	F
		A4	MG	VG	G
		A5	MG	F	MB
Benefit	C13(Technical Contribution of the Project to the Enterprise)	A1	EG	G	F
		A2	MB	F	G
		A3	MG	VG	G
		A4	F	MB	VB
		A5	VB	MB	B
Cost	C21(Project Complexity)	A1	MH	M	VH
		A2	EH	G	MH
		A3	VL	L	MH
		A4	M	VH	H
		A5	EH	G	VVH
Cost	C22(R & D Risk)	A1	H	VH	VH
		A2	H	VH	VH
		A3	M	G	G
		A4	L	M	VL
		A5	VH	M	H
Cost	C23 (Risk of Commercialization)	A1	M	ML	M
		A2	L	ML	ML
		A3	MH	MH	G
		A4	MH	M	L
		A5	M	ML	ML
Benefit	C31 (Experience in Similar Projects)	A1	VH	G	MH
		A2	VVH	G	H
		A3	L	ML	ML
		A4	M	MH	H
		A5	MG	MH	M
Cost	C41(Outsourcing)	A1	VB	MB	B
		A2	VVH	G	H
		A3	MH	MH	G
		A4	M	MH	H
		A5	M	VH	H

In the group decision-making process, the DMs' ideas must be combined without any loss of information in order to achieve an aggregated IF decision matrix. Using IFWA we obtained aggregated IF decision matrix in Table 10.

Table 10. Aggregated IF decision matrix.

		Member	Nonmember	Hesitant			Member	Nonmember	Hesitant
C11	A1	0.745	0.195	0.060	C22	A1	0.763	0.134	0.103
	A2	0.249	0.620	0.131		A2	0.763	0.134	0.103
	A3	0.571	0.324	0.105		A3	0.628	0.268	0.104
	A4	0.820	0.159	0.021		A4	0.318	0.551	0.131
	A5	1.000	0.000	0.000		A5	0.699	0.189	0.112
C12	A1	0.436	0.463	0.100	C23	A1	0.468	0.432	0.100
	A2	0.541	0.357	0.102		A2	0.341	0.540	0.119
	A3	0.369	0.512	0.119		A3	0.626	0.272	0.101
	A4	0.705	0.187	0.108		A4	0.499	0.390	0.111
	A5	0.525	0.374	0.102		A5	0.444	0.455	0.101
C13	A1	1.000	0.000	0.000	C31	A1	0.729	0.164	0.106
	A2	0.522	0.373	0.106		A2	0.811	0.149	0.039
	A3	0.705	0.187	0.108		A3	0.341	0.540	0.119
	A4	0.388	0.501	0.111		A4	0.590	0.308	0.103
	A5	0.249	0.620	0.131		A5	0.578	0.321	0.101
C21	A1	0.676	0.215	0.109	C41	A1	0.249	0.620	0.131
	A2	1.000	0.000	0.000		A2	0.811	0.149	0.039
	A3	0.303	0.559	0.138		A3	0.626	0.272	0.101
	A4	0.676	0.212	0.113		A4	0.590	0.308	0.103
	A5	1.000	0.000	0.000		A5	0.676	0.212	0.113

Step 3. The linguistic terms used to calculate the weights of the criteria are defined in Table 11. Evaluation of the decision makers and calculated weights by using IFWA are given in Table 12.

Table 11. Linguistic terms and IF numbers for criteria.

Linguistic Terms	Intuitionistic Fuzzy Numbers
Very important (VI)	(0.90, 0.10, 0.00)
Important (I)	(0.75, 0.20, 0.05)
Medium (M)	(0.50, 0.45, 0.05)
Unimportant (U)	(0.35, 0.60, 0.05)
Very unimportant (VUI)	(0.10, 0.90, 0.00)

Table 12. Criteria evaluations and weights.

Criteria	DM1	DM2	DM3	Weights of Criteria
C11	I	VI	I	(0.817;0.158;0.025)
C12	I	I	M	(0.705;0.243;0.052)
C13	I	I	VI	(0.799;0.170;0.031)
C21	M	I	I	(0.665;0.281;0.053)
C22	VI	VI	I	(0.876;0.118;0.006)
C23	M	I	I	(0.665;0.282;0.053)
C31	I	I	M	(0.705;0.243;0.052)
C41	I	VI	M	(0.784;0.191;0.024)

Step 4. The aggregated weighted IF decision matrix was constructed using the multiplication operator defined in the intuitive fuzzy sets. This matrix was obtained in Table 13.

Table 13. Aggregated weighted IF decision matrix.

		Member	Nonmember	Hesitant			Member	Nonmember	Hesitant
C11	A1	0.609	0.322	0.069	C22	A1	0.668	0.236	0.096
	A2	0.204	0.680	0.117		A2	0.668	0.236	0.096
	A3	0.467	0.431	0.102		A3	0.550	0.354	0.096
	A4	0.670	0.292	0.038		A4	0.278	0.604	0.118
	A5	0.817	0.158	0.025		A5	0.612	0.285	0.103
C12	A1	0.307	0.594	0.099	C23	A1	0.311	0.592	0.097
	A2	0.381	0.513	0.106		A2	0.227	0.670	0.104
	A3	0.260	0.630	0.110		A3	0.417	0.477	0.106
	A4	0.497	0.385	0.118		A4	0.332	0.562	0.106
	A5	0.370	0.526	0.104		A5	0.296	0.609	0.096
C13	A1	0.799	0.170	0.031	C31	A1	0.514	0.367	0.119
	A2	0.417	0.479	0.104		A2	0.572	0.356	0.072
	A3	0.563	0.325	0.112		A3	0.240	0.652	0.108
	A4	0.310	0.586	0.104		A4	0.416	0.476	0.109
	A5	0.199	0.684	0.117		A5	0.408	0.486	0.106
C21	A1	0.450	0.436	0.115	C41	A1	0.195	0.693	0.112
	A2	0.665	0.282	0.053		A2	0.636	0.312	0.052
	A3	0.201	0.683	0.116		A3	0.491	0.412	0.097
	A4	0.449	0.434	0.117		A4	0.462	0.440	0.097
	A5	0.665	0.282	0.053		A5	0.530	0.363	0.107

Step 5. In the case study, C11, C12, C13 and C31 are the cost criteria; C21, C22, C23 and C41 are the profit criteria. A* positive IF ideal solutions using equation (8); A^- negative IF ideal solutions using equation (9) were calculated. The results are as shown in Table 14.

Table 14. A* and A-.

Criteria	A*	A-
C11	(0.670;0.292; 0.038)	(0.204; 0.680; 0.117)
C12	(0.497;0.385;0.118)	(0.260; 0.630; 0.110)
C13	(0.799; 0.170; 0.031)	(0.199; 0.684; 0.117)
C21	(0.201; 0.683; 0.116)	(0.665; 0.282; 0.053)
C22	(0.278; 0.604; 0.118)	(0.668; 0.236; 0.096)
C23	(0.227; 0.670; 0.104)	(0.417; 0.477; 0.106)
C31	(0.572; 0.356; 0.072)	(0.240; 0.652; 0.108)
C41	(0.195; 0.693; 0.112)	(0.636; 0.312; 0.052)

Step 6. The separation measures and closeness coefficients between the positive and negative IF ideal solutions for each alternative were calculated using equations 16, 17 and 18 and shown in Table 15. Alternative projects are ranked according to the magnitude of their closeness coefficients.

Table 15. S_i*, S_i^- and C_i*.

Projects	S_i*	S_i^-	C_i*	Rank
P1	0.179	0.309	0.633	1
P2	0.318	0.156	0.330	5
P3	0.220	0.228	0.509	3
P4	0.223	0.250	0.529	2
P5	0.303	0.222	0.423	4

4. RESULTS AND DISCUSSION

Project selection, which is one of the major problems for businesses, is a decision making problem that includes many evaluation criteria. It may be difficult for decision-makers to reflect their judgment in this type of decision-making problem. Although fuzzy set theory is a good method for decision makers to express their views, it may be inadequate in some cases. Because the decision making process may be hesitant. Intuitionistic fuzzy set theory; it is a more effective approach that reflects the choices of decision makers because it is indicated by membership, non-membership and hesitation degree.

In this study, a real project selection process of a business is discussed. Considering similar studies in the literature, the criteria determined as 12 were reduced to 8 by AHP method. 5 alternatives are ranked via IF-TOPSIS method. As a result, P1: Large CMM software project is selected. The last project is P2: 2.Hol Air Conditioning System Design project. It can be said that the decision-makers who are influential on the decision give importance to the field of software and programming.

As the method used in the study is an effective method for handle the hesitant in human thought, it can be applied to other selection problems such as supplier selection, investment problem, software selection, production system selection as an alternative to fuzzy MCDM methods.

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