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A Hybrid Decision Analysis-based Soft Computing Approach to Solve 3P Project Selection Problem with Incomplete Information

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***Abstract** –Nowadays, governments are cooperating with the private sector under the name of public-private partnership (3P) projects to reduce the risks of projects and to achieve the ultimate goal, which is the construction and operation of the project. To help experts and managers make decisions in 3P projects, this article examines the financial challenges of projects in uncertain conditions using an intuitive fuzzy approach. The proposed intuitionistic fuzzy multi-criteria-based weighting and ranking model (IF-MCWR) method is based on the intuitionistic fuzzy values to compute the weights and ranking of the criteria. In the structure of the proposed IF-MCWR model, criteria weights are generated to reduce the errors. Also, criteria with optimal weights are obtained based on IF Hamming distance measure by using a developed maximizing deviation approach. Furthermore, judgments of decision makers (DMs) and experts are taken into account for calculating the criteria' weights. Nevertheless, the weights of DMs are presented using the proposed IF-TOPSIS method. Subsequently, a new IF index measure based on the Hamming distance is proposed to compute the relative closeness coefficient for ranking the alternatives. By doing this, project managers can make decisions with greater confidence. Finally, a case study examines the issue of urban development. It presents the option of constructing a highway project as the most important and highest-ranking among the projects that pose the greatest financial challenge.*

***Keywords**– Production projects, Group decision analysis, Financial challenges, Intuitionistic fuzzy sets, Urban development.*

I. INTRODUCTION

Recently, the rapid increase in population across societies has highlighted the growing importance of sustainable development. The construction and operation of large infrastructure projects are among the measures that have contributed significantly to this issue (Essounga & Njiei, 2021). For example, with the expansion of communication across communities and the use of cars to establish urban and interurban communication, transportation routes and roads have become a basic need of society. To this end, the construction of such projects is important (Kashef & El-Shafie, 2020). In addition to this example, we can mention the construction and operation of subways and public transportation systems, which require necessary measures to operate and develop the urban system (Yuan et al., 2020).

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In the meantime, governments have acted as the primary institution and the most important department responsible for the construction of these projects, their delivery, and operation (Tavana et al., 2021). In general, large infrastructure projects require significant financial, human, and equipment resources (Gitinavard, 2019; Gitinavard et al., 2017). In addition, there are project risks that could lead to failure in the project structure. Given the project's failure due to the risks involved, the government, as an important institution that has taken this type of action, will suffer, and all members of society will suffer from the damage to the government (Black et al., 2021). To that end, governments are partnering with the private sector to prevent losses and to stop construction and operation of projects (Kim, 2022).

The public-private partnership (3P) sector is one of the types of project construction that is very popular in today's world (Anwar et al., 2017). Accordingly, the government plays an oversight role and utilizes the private sector to supply financial support, specialized knowledge, design capabilities, and applied experience (Gitinavard et al., 2014). To ensure the sharing of risks, responsibilities, and benefits, as well as the synergy derived from resource mobilization, contracts embodying 3P requirements are executed between the public and private sectors (Mousavi & Gitinavard, 2019). In general, 3P is a long-term contract concluded between the private and public sectors. One of its most important threats was the risk of undermining the common goal of the two sectors, which was accompanied by the private sector's provision of services or infrastructure (Ghaderi et al., 2020).

The private sector, as a foreign investor, enters into negotiations with the public sector, which is typically a government-affiliated entity, and concludes a contract to build an infrastructure project. Here, the private sector is committed to completing the project from design to operation and to providing full financial, human, and equipment resources (Nezami et al., 2025). Under this framework, the private sector assumes the principal project risks, with the public sector serving as the oversight authority. Privatization is most effective when the public sector lacks the requisite advanced skills or when significant capital investment is needed. A successful 3P arrangement mandates shared objectives and reciprocal resource contributions, ensuring that the private and public sectors engage in a complementary manner in resource allocation (Boniotti, 2023). 3P allows the public sector to implement projects that it has not been allowed to look at to date. The government's use of private-sector financial pyramids as intermediaries is the main and influential variable in attracting private-sector participation and investment (Borujeni et al., 2025; Motshegwa & Molokwane, 2019).

Meanwhile, Ghasemi et al. (2023) proposed a mixed-integer linear mathematical model regarding the trade-off of cost, time, and quality with interval incomplete information. Kukah et al. (2023) extended a fuzzy synthetic evaluation methodology to assess risk factors and determine the overall risk level of public-private partnerships for power projects in Ghana. Jokar et al. (2023) developed a risk assessment and allocation model for PPP freeway projects in Iran, integrating AHP, TOPSIS, and DEMATEL methodologies. The model aims to critically assess risks, identify common threats, and determine the allocation and impact of these risks among various project elements. Moreover, Kukah et al. (2024) defined a fuzzy quantitative model, grounded in risk allocation principles, specifically designed to evaluate and prioritize the risk factors associated with PPP power projects. Du et al. (2025) presented a hybrid fuzzy multi-criteria framework that leverages geographic information systems to support the decision-making process for site selection in wind-photovoltaic hydrogen co-production facilities.

The 3P contracts pose different challenges to the project. One of the most important of these challenges is financial challenges. In this way, various project risks, whether internal or external, such as the laws governing a country's system, can have a significant impact on discussions of financial resources (Behzadipour et al., 2022). For example, when a developing country is building an infrastructure project, it faces a major financial challenge due to factors such as sanctions imposed by other countries, which can lead the project to continue failing. Therefore, identifying financial risks and challenges before the project and planning to address them is very important for managers and decision-makers on the project. Additionally, correctly ranking risks in each project can significantly help control the maximum risk and have a great impact on the project (Barzegar et al., 2016).

Another obstacle faced by managers and decision makers in various projects is related to the uncertainties in the project (Gitinavard et al., 2024; Jahangirzadeh et al., 2020). In the real world, uncertainty about the problem's basic parameters and the emergence of uncertain conditions can make decision-making difficult at the management level. For this purpose, uncertainty-based approaches can be used to help control and deal with these conditions. One of these methods is fuzzy programming, which can accurately model all uncertain conditions and has strong control over them (Tavana et al., 2018). Therefore, in this study, to address the problem's uncertainty and its inaccurate structure, the intuitionistic fuzzy (IF) approach is used (Solgi et al., 2021). This method is a new approach to control uncertain conditions and is structured according to the definitions of membership and non-membership functions, typical in intuitionistic fuzzy set theory. The purpose of this method is to control for uncertainty and help decision makers and managers make better, more accurate decisions in large infrastructure projects, where the main parameters and indicators are subject to high uncertainty (Ali et al., 2019).

This article is based on 3P projects designed to build infrastructure for urban development and seeks to identify the main indicators and basic financial challenges for the private sector to undertake such projects. In this study, a new multi-criteria group decision-making approach was employed to identify and prioritize the project's principal indicators, drawing on the expertise of multiple specialists. Also, to address the problem's uncertainty, the present paper has been examined under the conditions of intuitive fuzzy uncertainty. This article presents the new method of IF-multi-criteria weighting and ranking model (MCWR). Then, it uses a case study of urban development in Tehran to review and validate the model. Finally, upon validating the proposed model and methodology, the study concludes with key findings and offers recommendations for future research.

In Section 2, the preliminaries are reviewed; Section 3 introduces the proposed methodology; Section 4 presents the case study; and Section 5 provides the conclusions along with suggestions for future research.

II. PRELIMINARIES

The formulation herein establishes the necessary operators for the Intuitionistic Fuzzy Set (IFS), which is integral to the architecture of the proposed method.

Definition 1. Given *X* as the universe of discourse, the IFS *E* defined on *X* is represented by the expression found in Eq. (1).

$$E = \{\langle x, \rho_A(x), v_A(x), \pi_A(x)\rangle | x \in X\} \quad (1)$$

The membership function values $\rho_A: X \to [0,1]$ and non-membership function $v_A: X \to [0,1]$. Also, for each $x \in X$ exists $0 \le \rho_A(x) + v_A(x) \le 1, \pi_A = 1 - \rho_A - v_A$.

Definition 2. Let take the two IFSs *A* and *B* from set of *X*; then, the relations are defined in Eqs. (2) to (8) (Xu & Yager, 2006).

$$A \cup B = \left\{\langle x, max\left(\rho_A(x), \rho_B(x)\right), min(v_A(x), v_B(x)), \rangle | x \in A\right\} \quad (2)$$

$$A \cap B = \left\{\langle x, min\left(\rho_A(x), \rho_B(x)\right), max(v_A(x), v_B(x))\rangle | x \in A\right\} \quad (3)$$

$$\bar{A} = \{\langle x, v_A(x), \mu_A(x)\rangle | x \in A\} \quad (4)$$

$$\mathrm{A}\oplus\mathrm{B} = \{\langle x, \rho_A(x) + \rho_B(x) - \rho_A(x).\rho_B(x), v_A(x).v_B(x), 1 - \rho_A(x) - \mu_B(x) + \mu_A(x)\mu_B(x) - v_A(x)v_B(x)\rangle\} \quad (5)$$

$$A\otimes B = \{\langle x, \rho_A(x).\rho_A(x), v_A(x) + v_B(x) - v_A(x).v_B(x), 1 - \rho_A(x)\rho_B(x) - \rho_A(x) - \rho_B(x) + v_A(x)v_B(x)\rangle\} \quad (6)$$

$$A^{\lambda} = \{\langle x, \rho_A(x)^{\lambda}, 1-(1-v_A(x)^{\lambda}) | x \in A\rangle\}, \lambda > 0; \tag{7}$$

$$\lambda A = \{\langle x, 1-(1-\rho_A(x))^{\lambda}, v_A(x) | x \in A\rangle\}, \lambda > 0; \tag{8}$$

Definition 3. Hamming and Euclidean distances of two IFSs for $X = \{x_1, x_2, \dots, x_N\}$ obtain with Eqs. (9) and (10).

$$d_H(A,B) = \sum_{i=1}^{N} \frac{1}{2n} (|\rho_A(x_i) - \rho_B(x_i)| + |v_A(x_i) - v_B(x_i)| + |\pi_A(x_i) - \pi_B(x_i)|) \tag{9}$$

$$d(A,B) = \sqrt{\frac{1}{2n}\sum_{i=1}^{N}((\rho_A(x_i) - \rho_B(x_i))^2 + (v_A(x_i) - v_B(x_i))^2 + (\pi_A(x_i) - \pi_B(x_i))^2)} \tag{10}$$

Definition 4. The intuitionistic fuzzy weighted geometric (IFWG) is calculated from Eq. (11) (He et al., 2014).

$$IFWG(A(x_1), A(x_2), \dots, A(x_i)) = \langle \frac{2\prod_{i=1}^{N}(\rho_A(x_i))^{w_i}}{\prod_{i=1}^{N}(2-\rho_A(x_i))^{w_i} + \prod_{i=1}^{N}(\rho_A(x_i))^{w_i}}, \frac{\prod_{i=1}^{N}(1+v_A(x_i))^{w_i} - (1-v_A(x_i))^{w_i}}{\prod_{i=1}^{N}(1+v_A(x_i))^{w_i} + (1-v_A(x_i))^{w_i}} \rangle \tag{11}$$

Definition 5. The attribute weight is calculated for IF, when the attribute weight is completely unknown:

$$w_j^* = \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left(\left|\rho_{ij} - \rho_{kj}\right| + \left|v_{ij} - v_{kj}\right|\right)}{\sqrt{\sum_{j=1}^{n}\left[\sum_{i=1}^{m}\sum_{k=1}^{m}\left(\left|\rho_{ij} - \rho_{kj}\right| + \left|v_{ij} - v_{kj}\right|\right)\right]^2}} \tag{12}$$

To be normalized Eq. (12) is converted to Eq. (13):

$$w_j = \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left(\left|\rho_{ij} - \rho_{kj}\right| + \left|v_{ij} - v_{kj}\right|\right)}{\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m}\left(\left|\rho_{ij} - \rho_{kj}\right| + \left|v_{ij} - v_{kj}\right|\right)} \tag{13}$$

III. PROPOSED IF-MCWR APPROACH

This section is related to the proposed IF-MCWR method based on the weighting computation operator and ranking approach. For this reason, several computational steps are proposed to obtain the ranking of the criteria. These are the following:

Step 1. Generate the group decision matrix (*T*) in Eq. (14).

$$T = \begin{matrix} \\ A_1 \\ \vdots \\ A_m \end{matrix} \begin{matrix} C_1 & \cdots & C_j \\ \left[\begin{matrix} \{[\rho_{11}^1, v_{11}^1], [\rho_{11}^2, v_{11}^2], \dots, [\rho_{11}^k, v_{11}^k]\} & \cdots & \{[\rho_{1n}^1, v_{1n}^1], [\rho_{1n}^2, v_{1n}^2], \dots, [\rho_{1n}^k, v_{1n}^k]\} \\ \vdots & \ddots & \vdots \\ \{[\rho_{m1}^1, v_{m1}^1], [\rho_{m1}^2, v_{m1}^2], \dots, [\rho_{m1}^k, v_{m1}^k]\} & \cdots & \{[\rho_{mn}^1, v_{mn}^1], [\rho_{mn}^2, v_{mn}^2], \dots, [\rho_{mn}^k, v_{mn}^k]\} \end{matrix}\right]_{m\times n} \end{matrix} \quad \forall k \tag{14}$$

Step 2. Compute the weight of criteria with Definition 5. Also, this paper assumes that the weights of the criteria are completely unknown. For this reason, the optimal weight vector is computed from Hamming distance with Eq. (15).

The v_j is the weights of criteria that is developed with DMs. This measure is computed with Eq. (16) by decreasing error. The final normalized weight is obtained from Eq. (17).

$$w_j = \frac{\bar{v}_j \sum_{i=1}^{m} \sum_{k=1}^{K} \left(\frac{1}{2} \sum_{\lambda=1}^{l} \left(\left|h_{ij}^{\sigma(\lambda)} - h_{kj}^{\sigma(\lambda)}\right|\right)\right)}{\sqrt{\sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{k=1}^{K} \left(\frac{1}{2} \sum_{\lambda=1}^{l} \left(\left|h_{ij}^{\sigma(\lambda)} - h_{kj}^{\sigma(\lambda)}\right|\right)\right)}} \tag{15}$$

$$v_j = \left(\underset{k=1}{\overset{K}{\oplus}} \left(\widetilde{hwck}\right)^{\frac{1}{k}}\right) = \bigcup \gamma_{\widetilde{wc1}} \in \widetilde{hwc1}, \dots, \gamma_{\widetilde{wck}} \in \widetilde{hwck} \left\{\left[\prod_{k=1}^{K} (\gamma_{wck})^{\frac{1}{k}}\right]\right\} \tag{16}$$

$$w_j^* = \frac{w_j}{\sum_{j=1}^{n} w_j} \tag{17}$$

Step 3. The weight computation for individual DM is performed by employing the IF-TOPSIS framework.

Step 3.1. Develop the normalized IF-decision matrix based on DMs opinion in Eq. (18).

Step 3.2. The determination of the Positive Ideal Solution (PIS) (A^+) and the Negative Ideal Solution (NIS) (A^-) serves as the initial step. The best-ranked solution is then identified based on its proximity to $A^+$and its remoteness from A^-. The mathematical formalism for these calculations is explicitly delineated in Equations (19) to (24).

$$Q = \begin{matrix} \\ A_1 \\ \vdots \\ A_m \end{matrix} \begin{matrix} C_1 & \cdots & C_j \\ \left[\begin{matrix} [\rho_{11}^k, v_{11}^k] \\ \vdots \\ [\rho_{m1}^k, v_{m1}^k] \end{matrix}\right. & \begin{matrix} \cdots \\ \ddots \\ \cdots \end{matrix} & \left.\begin{matrix} [\rho_{1n}^k, v_{1n}^k] \\ \vdots \\ [\rho_{mn}^k, v_{mn}^k] \end{matrix}\right]_{m\times n} \end{matrix} \tag{18}$$

$$A^+ = \left([\rho_{ij}^+, v_{ij}^+]\right)_{m\times n} \tag{19}$$

$$A^- = \left([\rho_{ij}^-, v_{ij}^-]\right)_{m\times n} \tag{20}$$

$$\rho_{ij}^+ = \frac{1}{k} \sum_{k=1}^{K} \rho_{ij}^k \tag{21}$$

$$v_{ij}^+ = \frac{1}{k} \sum_{k=1}^{K} v_{ij}^k \tag{22}$$

$$\rho_{ij}^- = \min_k \left(\rho_{ij}^k\right) \tag{23}$$

$$v_{ij}^- = \min_k \left(v_{ij}^k\right) \tag{24}$$

Step 3.3. Obtain the separation measure of the PIS (S_k^+) and NIS (S_k^-) with IF-Euclidean distance measure. This computation is determined in Eqs. (25) and (26).

$$S_k^+ = \sqrt{\frac{1}{2} \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{\lambda=1}^{l} \left(\left|\rho_{ij}^{k\sigma(\lambda)}(x_i) - A_{ij}^{+\sigma(\lambda)}(x_i)\right|^2 + \left|v_{ij}^{k\sigma(\lambda)}(x_i) - A_{ij}^{+\sigma(\lambda)}(x_i)\right|^2\right)} \tag{25}$$

$$S_k^- = \sqrt{\frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{\lambda=1}^{l}\left(\left|\rho_{ij}^{k\sigma(\lambda)}(x_i) - A_{ij}^{-\sigma(\lambda)}(x_i)\right|^2 + \left|v_{ij}^{k\sigma(\lambda)}(x_i) - A_{ij}^{-\sigma(\lambda)}(x_i)\right|^2\right)} \tag{26}$$

Step 3.4. Calculate the relative closeness of the DMs (C_k) with Eq. (27).

$$C_k = \frac{S_k^-}{S_k^- + S_k^+} \tag{27}$$

Step 3.5. The weights of the DMs (W_k) compute from Eq. (28).

$$W_k = \frac{C_k}{\sum_{k=1}^{K} C_k} \tag{28}$$

Step 4. The opinions of the DMs aggregate (h_{pij}) with Eq. (29).

$$h_{pij} = \left(\underset{k=1}{\overset{K}{\oplus}} (W_k h_{pk})^{\frac{1}{k}}\right) = \bigcup[\rho_{p1}, v_{p1}] \in h_{p1}, \dots, [\rho_{pk}, v_{pk}] \in h_{pk}\left\{\left[\prod_{k=1}^{K}(W_k\rho_{pk})^{\frac{1}{k}}, \prod_{k=1}^{K}(W_k v_{pk})^{\frac{1}{k}}\right]\right\} \tag{29}$$

Step 5. The weighted normalized IF-decision matrix is computed with Eq. (30).

$$Q = \begin{pmatrix} w_1^* h_{11} & \cdots & w_n^* h_{1n} \\ \vdots & \ddots & \vdots \\ w_m^* h_{m1} & \cdots & w_n^* h_{mn} \end{pmatrix} \tag{30}$$

Step 6. The IF-relative closeness coefficient (C_i) is presented as follows:

$$C_i = \frac{\sum_{j=1}^{n}\left[\frac{1}{2n}\sum_{\lambda=1}^{n}\left(\left|Q_{ij}^{k\sigma(\lambda)} - \rho_{ij}^{-\sigma(\lambda)}\right|^2 + \left|Q_{ij}^{k\sigma(\lambda)} - v_{ij}^{-\sigma(\lambda)}\right|^2\right)\right]^{\frac{1}{2}}}{\sum_{j=1}^{n}\left[\frac{1}{2n}\sum_{\lambda=1}^{n}\left(\left|Q_{ij}^{k\sigma(\lambda)} - \rho_{ij}^{-\sigma(\lambda)}\right|^2 + \left|Q_{ij}^{k\sigma(\lambda)} - v_{ij}^{-\sigma(\lambda)}\right|^2\right)\right]^{\frac{1}{2}} + \sum_{j=1}^{n}\left[\frac{1}{2n}\sum_{\lambda=1}^{n}\left(\left|Q_{ij}^{k\sigma(\lambda)} - \rho_{ij}^{+\sigma(\lambda)}\right|^2 + \left|Q_{ij}^{k\sigma(\lambda)} - v_{ij}^{+\sigma(\lambda)}\right|^2\right)\right]^{\frac{1}{2}}} \quad \forall i \tag{31}$$

Step 7. The alternatives are ordered in descending sequence, governed by the specified degree of C_i.

IV. CASE STUDY

This section is constructed based on a case study of 3P urban development project and the proposed method in Iran. For this reason, we can use the four DMs (DM_1, DM_2, DM_3, DM_4) with 20 criteria ($C_1, C_2, \dots, C_{20}$). The description of the criteria is below:

- C_1: Capability to prepare convenience for banks
- C_2: Prohibit
- C_3: Computing a bank loan
- C_4: Effect of inflation on construction and operation
- C_5: Government patronage for the private section
- C_6: Failure by the government to pay bills on time
- C_7: Working fund of the firm
- C_8: Adequate familiarity with international law
- C_9: Permanent changes in public laws

- C_{10}: Suitable selection of the second hand contractors
- C_{11}: Complications of obtaining licenses
- C_{12}: Instability of financial organizations in relation to national laws
- C_{13}: Currency fluctuations
- C_{14}: Gaining the issue of the project
- C_{15}: Supply of raw material, machinery, and equipment
- C_{16}: Competition of governments and private sector
- C_{17}: Modify project priorities dynamically during runtime
- C_{18}: Potential risk associated with pursuing the rights of private companies through judicial channels
- C_{19}: The risk that the employer's obligations may not be fulfilled during the project's execution and operational phases
- C_{20}: The risk arising from senior managers' personal preferences influencing project alignment and execution

Also, this case is constructed based on four kinds of problems (A_1, A_2, A_3, A_4) that is made the alternatives of project. These are defined below:

- A_1: The surface water construction project
- A_2: The metro development project
- A_3: The highway construction project
- A_4: The bridge construction project

Furthermore, expert judgments are elicited to assess the relative importance of the identified criteria. Subsequently, the resulting table is transformed into IF values, and the criteria are ranked in accordance with the proposed methodology. Also, the linguistic values for the judgment of the DMs are inspired by Behzadipour et al. (2022).

Table I presents the evaluations provided by the DMs regarding the criteria and alternatives using linguistic variables. Subsequently, Table II presents the weights of the criteria as determined by expert judgment, expressed as linguistic variables.

Table I. Linguistic evaluation with DMs

Criteria	Alternatives	Decision makers			
		DM_1	DM_2	DM_3	DM_4
C_1	A_1	MH	ML	VVH	ML
	A_2	H	L	VVH	L
	A_3	M	L	VVH	ML
	A_4	H	VL	AH	M
C_2	A_1	L	M	H	ML
	A_2	VH	MH	VH	H
	A_3	VH	H	MH	H
	A_4	VVH	VH	VVH	VH
C_3	A_1	L	VH	VVH	ML
	A_2	ML	L	ML	L
	A_3	MH	H	M	MH
	A_4	MH	VH	H	M

Continue Table I. Linguistic evaluation with DMs

Criteria	Alternatives	Decision makers	Decision makers	Decision makers	Decision makers
		DM_1	DM_1	DM_1	DM_1
C_4	A_1	VH	H	VH	M
	A_2	MH	M	H	MH
	A_3	VL	VVH	ML	VH
	A_4	VVL	VVH	VVH	VVL
C_5	A_1	H	AH	H	MH
	A_2	VVH	VH	VH	H
	A_3	VH	VH	MH	H
	A_4	VH	VVH	MH	VH
C_6	A_1	MH	VH	M	M
	A_2	M	H	AH	H
	A_3	H	MH	H	MH
	A_4	H	VH	L	H
C_7	A_1	H	VVH	H	VH
	A_2	M	L	M	L
	A_3	MH	M	H	VH
	A_4	VH	H	H	M
C_8	A_1	VH	VH	AH	HH
	A_2	MH	VH	VH	MH
	A_3	VH	ML	VVL	VVH
	A_4	VVH	VH	VVL	AH
C_9	A_1	VVH	MH	VVH	VH
	A_2	VH	MH	VVH	VH
	A_3	VH	H	VH	H
	A_4	VVH	MH	VVH	VH
C_{10}	A_1	VVH	M	H	H
	A_2	H	VH	H	VH
	A_3	L	H	M	MH
	A_4	M	H	L	VH
C_{11}	A_1	H	ML	VVH	VVH
	A_2	M	VL	VH	ML
	A_3	VH	M	MH	M
	A_4	MH	L	VH	H
C_{12}	A_1	VVH	ML	VH	MH
	A_2	VH	M	H	VVH
	A_3	VH	VL	AH	VH
	A_4	AH	VL	MH	VH

Continue Table I. Linguistic evaluation with DMs

Criteria	Alternatives	Decision makers DM_1	Decision makers DM_1	Decision makers DM_1	Decision makers DM_1
C_{13}	A_1	VVH	VH	VL	VVH
	A_2	VVH	VVH	L	AH
	A_3	VH	AH	VL	VVH
	A_4	AH	MH	ML	VVH
C_{14}	A_1	M	H	AH	MH
	A_2	AH	M	H	VVH
	A_3	VH	H	L	VH
	A_4	VL	M	M	L
C_{15}	A_1	H	VVH	VH	VH
	A_2	M	VH	M	ML
	A_3	H	H	H	VH
	A_4	H	MH	H	ML
C_{16}	A_1	VVH	VH	VH	VH
	A_2	VH	VH	H	VH
	A_3	VVL	VH	ML	VL
	A_4	VL	AH	VH	VVL
C_{17}	A_1	VL	VVH	MH	ML
	A_2	L	AH	H	L
	A_3	ML	AH	M	L
	A_4	M	MH	H	VL
C_{18}	A_1	MH	VVH	L	M
	A_2	MH	VH	VH	MH
	A_3	M	ML	VH	H
	A_4	ML	ML	VVH	VH
C_{19}	A_1	VVH	VVH	L	VH
	A_2	VH	L	ML	L
	A_3	MH	H	MH	H
	A_4	H	H	MH	VH
C_{20}	A_1	VVH	MH	VH	H
	A_2	VH	H	MH	M
	A_3	VVH	VH	VL	VVH
	A_4	AH	VVH	VVL	VVH

Table II. The linguistic term of the criteria

Criteria	Decision- makers			
	DM_1	DM_2	DM_3	DM_4
C_1	VH	H	VH	H
C_2	VH	VH	H	VH
C_3	M	VL	L	L
C_4	VH	VH	VH	VH
C_5	H	M	VL	H
C_6	H	VH	VH	VH
C_7	M	L	M	M
C_8	M	VL	VL	VL
C_9	H	VH	VH	VH
C_{10}	L	L	L	M
C_{11}	VH	VH	VH	H
C_{12}	VH	VH	VH	VH
C_{13}	H	H	M	M
C_{14}	VH	M	H	H
C_{15}	VH	VH	VH	H
C_{16}	H	VH	VH	M
C_{17}	VH	M	H	VH
C_{18}	VH	VH	VH	VH
C_{19}	H	H	VH	VH
C_{20}	M	H	H	VH

In this context, Table III presents the aggregated criteria weights as well as the final weights derived from the DMs' evaluations. In accordance with Step 2, the proposed method integrates the DMs' opinions regarding the relative importance of the criteria (v_j). Subsequently, the final criteria weights (w_j^*) are calculated using the proposed extended maximizing deviation method, as formulated in Equation (17).

Table III. The aggregation of criteria's weight

Criteria	v_j	Average weight	Final weight
C_1	[3.45708E-06,1.88706E-05]	1.11638E-05	0.029151
C_2	[4.07683E-06,1.67063E-05]	1.03916E-05	0.045362
C_3	[3.4261E-08,2.17994E-07]	1.26127E-07	0.069064
C_4	[4.80769E-06,1.47903E-05]	9.799E-06	0.089361
C_5	[2.38607E-07,1.5182E-06]	8.78402E-07	0.014712
C_6	[4.07683E-06,1.67063E-05]	1.03916E-05	0.040049
C_7	[2.81383E-07,4.24219E-06]	2.26179E-06	0.057077

Continue Table III. The aggregation of criteria's weight

Criteria	v_j	Average weight	Final weight
C_8	[4.91944E-09,1.00578E-08]	7.48864E-09	0.066067
C_9	[4.07683E-06,1.67063E-05]	1.03916E-05	0.007492
C_{10}	[9.04153E-08,1.01488E-06]	5.52646E-07	0.053126
C_{11}	[4.07683E-06, 1.67063E-05]	1.03916E-05	0.046451
C_{12}	[4.80769E-06,1.47903E-05]	9.799E-06	0.036235
C_{13}	[1.11085E-06,1.44506E-05]	7.78072E-06	0.024792
C_{14}	[1.95966E-06,1.65134E-05]	9.23651E-06	0.08146
C_{15}	[4.07683E-06,1.67063E-05]	1.03916E-05	0.032829
C_{16}	[2.31097E-06,1.46195E-05]	8.46522E-06	0.090451
C_{17}	[2.31097E-06,1.46195E-05]	8.46522E-06	0.044272
C_{18}	[4.80769E-06,1.47903E-05]	9.799E-06	0.053262
C_{19}	[3.45708E-06,1.88706E-05]	1.11638E-05	0.064433
C_{20}	[1.95966E-06, 1.65134E-05]	9.23651E-06	0.054352

Furthermore, the computational weights of the DMs (W_k) evaluated in Table IV. To compute the weights of DMs, firstly, the separation measures of PIS (S_k^+) and NIS (S_k^-) are obtained based on Eqs. (25) and (26). After that, the relative closeness of the DMs (C_k) is calculated with Eq. (27), and the DMs' weights are computed with Eq. (28). Table V generates the aggregated decision matrix based on IF condition with the proposed method. Afterward, Table VI introduces the IF normalized decision matrix with Eq. (30).

Table IV. The obtaining DMs' weights

S_k^+		S_k^-		C_j		W_k	
S_1^+	0.75714	S_1^-	1.34070	C_1	0.63909	W_1	0.25109
S_2^+	0.74726	S_2^-	1.47421	C_2	0.66362	W_2	0.26073
S_3^+	0.97974	S_3^-	1.31678	C_3	0.57338	W_3	0.22528
S_4^+	0.68482	S_4^-	1.38498	C_4	0.66914	W_4	0.26290

Table V. Computation aggregated IF decision matrix with proposed method

Criteria	Alternatives			
	A_1	A_2	A_3	A_4
C_1	[0.01692,0.02581]	[0.00808,0.01378]	[0.0098,0.01715]	[0.01106,0.01800]
C_2	[0.00903,0.01575]	[0.03483,0.04274]	[0.03328,0.04093]	[0.04473,0.05304]
C_3	[0.01269,0.02015]	[0.00360,0.00766]	[0.02408,0.03328]	[0.02709,0.03638]
C_4	[0.03048,0.03976]	[0.02408,0.03328]	[0.00952,0.01612]	[0.00221,0.00240]
C_5	[0.03624,0.04354]	[0.04093,0.04871]	[0.03483,0.04274]	[0.03807,0.04654]

Continue Table V. Computation aggregated IF decision matrix with proposed method

Criteria	Alternatives			
	A_1	A_1	A_1	A_1
C_6	[0.02205,0.03234]	[0.03171,0.04050]	[0.02958,0.03744]	[0.01664,0.02379]
C_7	[0.03911,0.04664]	[0.00490,0.01000]	[0.02709,0.03638]	[0.02912,0.03807]
C_8	[0.04267,0.04970]	[0.03240,0.04084]	[0.00635,0.00806]	[0.01036,0.01152]
C_9	[0.03976,0.04852]	[0.03807,0.04654]	[0.03744,0.04473]	[0.03976,0.04852]
C_{10}	[0.03042,0.03969]	[0.03744,0.04473]	[0.01204,0.01935]	[0.01355,0.02115]
C_{11}	[0.02850,0.03782]	[0.00709,0.01316]	[0.02205,0.03234]	[0.01548,0.02274]
C_{12}	[0.02538,0.03466]	[0.03183,0.04145]	[0.01488,0.02209]	[0.01323,0.02021]
C_{13}	[0.01491,0.02257]	[0.02165,0.03001]	[0.01555,0.02303]	[0.02764,0.03687]
C_{14}	[0.02950,0.03870]	[0.03466,0.04410]	[0.01742,0.02485]	[0.00368,0.00800]
C_{15}	[0.04093,0.04871]	[0.01654,0.02632]	[0.03578,0.04283]	[0.02219,0.03048]
C_{16}	[0.04283,0.05087]	[0.03918,0.04672]	[0.00203,0.00329]	[0.00331,0.00470]
C_{17}	[0.00846,0.01475]	[0.00843,0.01406]	[0.01029,0.01750]	[0.00903,0.01548]
C_{18}	[0.01316,0.02107]	[0.03240,0.04084]	[0.02032,0.02961]	[0.01904,0.02821]
C_{19}	[0.01988,0.02821]	[0.00540,0.01028]	[0.02958,0.03744]	[0.03328,0.04093]
C_{20}	[0.03638,0.04456]	[0.02709,0.03638]	[0.01491,0.02257]	[0.0108,0.01201]

Table VI. Normalized decision matrix under IF situation

Criteria	Alternatives			
	A_1	A_2	A_3	A_4
C_1	[1.39222E-06,2.51459E-06]	[4.9502E-07,1.0446E-06]	[6.54622E-07,1.41878E-06]	[7.67891E-07,1.5182E-06]
C_2	[5.77975E-07,1.25933E-06]	[3.82544E-06,5.09535E-06]	[3.58955E-06,4.7944E-06]	[5.43019E-06,6.89238E-06]
C_3	[9.30663E-07,1.77815E-06]	[1.59503E-07,4.58742E-07]	[2.28174E-06,3.58955E-06]	[2.69078E-06,4.06556E-06]
C_4	[3.17316E-06,4.60471E-06]	[2.28174E-06,3.58955E-06]	[6.22126E-07,1.30105E-06]	[8.05045E-08,9.04681E-08]
C_5	[4.04405E-06,5.22824E-06]	[4.7944E-06,6.11776E-06]	[3.82544E-06,5.09535E-06]	[4.33274E-06,5.74051E-06]
C_6	[2.01706E-06,3.44752E-06]	[3.3545E-06,4.7248E-06]	[3.04387E-06,4.23305E-06]	[1.36018E-06,2.24385E-06]
C_7	[4.49876E-06,5.75643E-06]	[2.45596E-07,6.66724E-07]	[2.69078E-06,4.06556E-06]	[2.97749E-06,4.33274E-06]
C_8	[5.08243E-06,6.29326E-06]	[3.45708E-06,4.78115E-06]	[3.52655E-07,4.93007E-07]	[7.00899E-07,8.12299E-07]
C_9	[4.60471E-06,6.08539E-06]	[4.33274E-06,5.74051E-06]	[4.23305E-06,5.43019E-06]	[4.60471E-06,6.08539E-06]
C_{10}	[3.16439E-06,4.59304E-06]	[4.23305E-06,5.43019E-06]	[8.64616E-07,1.67996E-06]	[1.01962E-06,1.90275E-06]
C_{11}	[2.88832E-06,4.29228E-06]	[4.11753E-07,9.79275E-07]	[2.01706E-06,3.44752E-06]	[1.22921E-06,2.10549E-06]
C_{12}	[2.45604E-06,3.79935E-06]	[3.37234E-06,4.88134E-06]	[1.16344E-06,2.02218E-06]	[9.86575E-07,1.78541E-06]

Continue Table VI. Normalized decision matrix under IF situation

Criteria	Alternatives			
	A_1	A_1	A_1	A_1
C_{13}	[1.16639E-06,2.08389E-06]	[1.96579E-06,3.10577E-06]	[1.23647E-06,2.14367E-06]	[2.76702E-06,4.14314E-06]
C_{14}	[3.03149E-06,4.43345E-06]	[3.79935E-06,5.32305E-06]	[1.44957E-06,2.3847E-06]	[1.64175E-07,4.87834E-07]
C_{15}	[4.7944E-06,6.11776E-06]	[1.34835E-06,2.58432E-06]	[3.97202E-06,5.10947E-06]	[2.03475E-06,3.17316E-06]
C_{16}	[5.10947E-06,6.50177E-06]	[4.51123E-06,5.77105E-06]	[7.12757E-08,1.40611E-07]	[1.4166E-07,2.31677E-07]
C_{17}	[5.27551E-07,1.14872E-06]	[5.2476E-07,1.07457E-06]	[6.93949E-07,1.45948E-06]	[5.77975E-07,1.22921E-06]
C_{18}	[9.79275E-07,1.89268E-06]	[3.45708E-06,4.78115E-06]	[1.79872E-06,3.04762E-06]	[1.6418E-06,2.84805E-06]
C_{19}	[1.74486E-06,2.84805E-06]	[2.81383E-07,6.93123E-07]	[3.04387E-06,4.23305E-06]	[3.58955E-06,4.7944E-06]
C_{20}	[4.06556E-06,5.40146E-06]	[2.69078E-06,4.06556E-06]	[1.16639E-06,2.08389E-06]	[7.44895E-07,8.611E-07]

Furthermore, the ranking of the alternatives obtained through the proposed method is presented in Table VII. To evaluate the solution approach, a comparative analysis is conducted among the proposed method, the Simple Additive Weighting (SAW) technique, and the TOPSIS method, as illustrated in Fig. 1. The results indicate that the first alternative, corresponding to the metro development project, achieves the highest priority among all considered options. As depicted in Fig. 1, the final rankings from the three methods show high consistency, confirming the robustness and reliability of the proposed solution approach.

Table VII. Ranking of the alternatives with three methods

Alternatives	Final values of proposed method	Ranking alternatives with proposed method	SAW method	Ranking of SAW method	TOPSIS method	Ranking of the TOPSIS
A_1	0.60360	4	0.29812	4	0.047863	4
A_2	0.99249	1	0.62451	1	0.127954	1
A_3	0.74265	2	0.42876	2	0.107225	2
A_4	0.70880	3	0.31574	3	0.06773	3

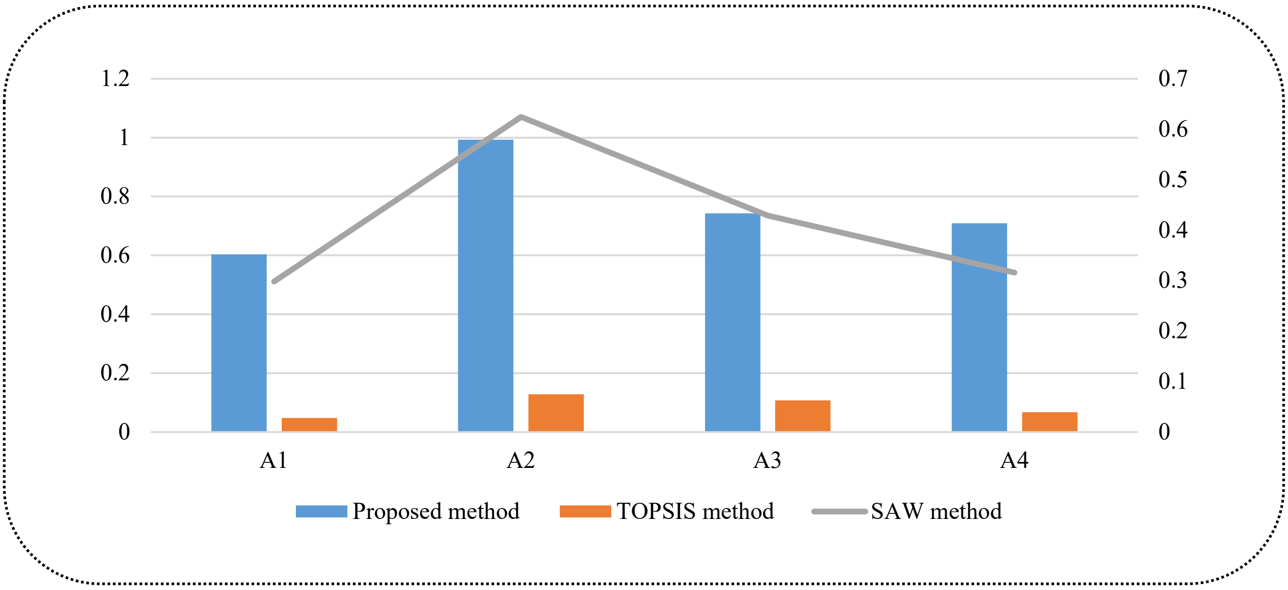

Fig 1. The comparison between three various types of the methods

V. CONCLUSIONS AND FUTURE DIRECTION

In contemporary urban development, one of the most critical factors influencing the enhancement of urban life and the expansion of city living is the implementation and advancement of major infrastructure projects. Projects such as the construction of highways and freeways, as well as the development of urban metro systems, serve to address the varied interests of people in society and ensure their satisfaction. However, there are various risk factors and challenges associated with these projects that can disrupt their activities. Accordingly, governments tend to implement infrastructure projects in close collaboration with the private sector to mitigate potential damage from various risks. 3P projects provide this to the government and deliver the projects in the best way. In this context, a significant challenge concerns the project's financial aspects, which are often compounded by its inherent uncertainty and subsequently affect managerial decision-making. The paper presents an approach to managing a 3P project under conditions of intuitionistic fuzzy uncertainty and calculates the weights of the indicators and their options and rankings. After presenting the proposed group decision-making method based on expert opinions, a case study of urban development was presented. After determining the indicators, options, and number of decision makers, the problem was solved using the proposed approach. It was found that highway construction projects, as the first option, pose the greatest financial challenge and are of higher importance for urban development. Finally, the issue under investigation was analyzed using two distinct methods, the results of which demonstrate the rationality and efficiency of the proposed approach relative to existing methods reported in the literature. To overcome the limitations of this study, an inferential search engine can be used in the fuzzy model of the problem and also, the issue can be solved by applying meta-heuristic techniques. Moreover, the current study can be developed using a machine learning approach to develop an intelligent framework as an assistant decision system (Behdinian et al., 2022; Gilani & Sahebi, 2025).

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