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Pythagorean interval 2-tuple linguistic VIKOR method for evaluating human factors in construction project management

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Abstract

In a construction project, there are many factors that affect the project quality, such as people, materials, machinery, environment, etc. Among them, people have the greatest influence on the project quality, whether people participate directly or indirectly. This paper mainly evaluates human factors in the process of construction project management, such as workers proficiency, workers safety awareness, technical workers quality, and workers emergency capacity, with the purpose of helping Chinas construction project to proceed smoothly. In this manuscript, a multi-attribute group decision-making (MAGDM) technique based on Pythagorean interval 2-tuple linguistic numbers (PI2TLNs) and VIKOR method is proposed to evaluate human factors in construction projects. PI2TLNs are used to represent performance assessments of decision makers. Relying on Pythagorean interval 2-tuple linguistic weighted averaging (PI2TLWA)/Pythagorean interval 2-tuple linguistic weighted geometric (PI2TLWG) operator, the evaluation information given by experts is fused into a group decision matrix. Combined with the essential VIKOR method, PI2TLN-VIKOR framework is established. The effectiveness of this method is verified by an example, and compared with two algorithms and PI2TLN-TODIM method.

Keywords: Multiple attribute group decision making (MAGDM), Pythagorean interval 2-tuple linguistic numbers (PI2TLNs), VIKOR method, construction project management.

1 Introduction

In the related projects of engineering construction, the management problems mainly involve safety management, it is closely related to people, things and environment. Safety management involved in engineering construction project management problems need to be eliminated or avoided in time to ensure that construction is completed on time to protect the personal safety and property safety of construction personnel. However, in engineering construction project management, human factors play a very important role, can effectively guide the construction project construction management results. In recent years, there have been a series of explorations and researches on capital construction management at home and abroad. Mete [40] proposed FMEA-based AHP-MOORA comprehensive evaluation method based on Pythagorean fuzzy sets (PFSs) for a natural gas pipeline construction project. Carr and Tah [5] used the language variables to describe the risks and their consequences in the construction industry, and fuzzy approximations and combinations were used to determine the relationship between risk sources and project performance evaluation results and to quantify them consistently. Dagdeviren and Yuksel [7] constructed the project construction behavior safety management evaluation model by using data fuzzy processing and analytic hierarchy process. Gupta and Thakkar [18] adopted TOPSIS method to prioritize risk and compared it with the results of quantitative risk analysis and shown that this approach can provide stronger results and contribute to the management control of project risks. On the basis of 2-tuple linguistic Pythagorean fuzzy Numbers (2TLPFNS) and Bonferroni mean (BM) operator, Deng, Wei,

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Gao and Wang [9] defined several operators and applied them to evaluate the safety management of construction projects. Lu [36] combined TOPSIS model and 2-tuple linguistic set to consider the fuzziness of evaluation in the field of building management and applied scientific ranking method to obtain the optimal solution. Biswas and Zaman [3] utilized the triangular fuzzy number to integrate expert assessment information and historical data for assessing the risks in construction projects. Wang, Wei and Lu [59] extended the original TODIM model to the context of the 2-tuple linguistic neutrosophic set. Wang, Zhang, Wang and Li [62] constructed a new VIKOR model with a picture fuzzy projection to determine the priority of risk factors in a building project. Roy, Das, Kar and Pamucar [49] extended CODAS into the interval value IFSs for the MADM problem with incomplete weight information.

The above scholars studied the safety evaluation, performance evaluation and risk management of construction projects from different perspectives and methods, but none of them involved the evaluation of human factors in construction projects. Therefore, this paper intends to adopt a fuzzy evaluation method to complete this task. The following are about PFSs and VIKOR. The PFSs is put forward by Yager and Abbasov [73] compared with intuitionistic fuzzy sets [1], which expanded the membership and the non-membership degree to meet the conditions of the sum of the squares less than or equal to 1. Since the introduction of PFSs, many scholars have done a lot of research and expansion on it. Zhang and Xu [79] proposed a sort optimization method based on similar ideal solution for MADM problem with PFSs. Liang, Zhang and Liu [30] proposed a concept based on interval Pythagorean fuzzy number (IVPFN) and innovated a method to deal with MAGDM problem. In order to better understand PFSs, Peng and Yang [45] redefined the division and subtraction operation of PFS and discussed their properties in detail. Garg [12] first pointed out the shortcomings of calculating the correlation coefficients of intuitionistic fuzzy sets (IFSs) and designed a new (weighted) correlation coefficient formula to measure the relationship between two PFSs. Garg [11] defined several operators of PFSs and studied the corresponding properties. In order to enrich the PFS theory, Gou, Xu and Ren [16] studied the basic properties of continuity, derivability and differentiability for PFSs. Ma and Xu [37] defined a new class of operators based on the given algorithm and compared with the existing operators for PFSs. Peng and Yang [46] studied the MAGDM problem of interval valued PFSs. Liang and Xu [29] combined PFSs with hesitating fuzzy sets, in which the membership and non-membership of PFS were expressed as hesitating fuzzy numbers and combined this new environment with the TOPSIS approach. Qin, Liu and Hong [47] studied the new distance measurement method for PFSs, and innovatively introduced the generalized Pythagorean fuzzy weighted averaging distance (GPFWAD) operator and generalized Pythagorean fuzzy ordered weighted averaging distance (GPFOWAD) operator. Bolturk [4] extended the CODAS method to the PFSs and considered the decision maker's hesitation. Wei, Gao, Wang and Huang [63] defined the TODIM method based on the Pythagorean 2-tuple linguistic fuzzy sets (P2TLSs) by combining PFSs [27, 58] with 2-tuple linguistic set. Ding and Liu [10] innovated a new method to apply to the example of emergency decision-making which firstly used the best-worst method to calculate the attribute weight. Liu, Quan, Shi and Guo [32] used the interval-valued Pythagorean uncertain linguistic sets to express the subjectivity and uncertainty of decision makers and used the QUALIFLEX technology to select the most suitable robot.

The VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method is put forward by Opricovic and Tzeng [43], which is a multi-attributes decision-making (MADM) method based on the ideal point method. Opricovic and Tzeng [44] popularized the VIKOR method by using a higher-level relationship. Compared with previous methods, such as ELECTRE [2], PROMETHEE [39], GRA[25], TOPSIS [22, 24, 35], TODIM [15, 59], MABAC [57, 60, 65, 78] and EDAS method [19, 28, 56], the advantage of this approach is that conflicts between attributes are considered, the best solution is the closest to the ideal solution, and a compromise with priority is obtained. Mete, Serin, Oz and Gul [41] provided the VIKOR method based on the PFSs for risk assessment of gas pipeline construction with a view to contributing to stakeholders in the energy industry. Muhammet Gul, M. Fatih Ak and Guneri. [17] put forward the VIKOR method to evaluate the overall safety level of underground mining under PFSs. Cui, You, Shi and Liu [6] established a Pythagorean fuzzy VIKOR model to solve the location problem of charging stations for electric vehicles. Zeng, Chen and Kuo [77] designed the MADM method based on novel score function of intuitionistic fuzzy values and modified VIKOR method. Wang, Xu, Wang and Ren [61] defined an interval MADM method by coupling interval DEMATEL and interval VIKOR. Wang, Sun and Zhou [55] designed an intuitionistic fuzzy MAGDM method with incomplete weight information based on improved VIKOR. Wu, Gao and Wei [68] proposed the VIKOR method for financing risk assessment of rural tourism projects under interval-valued intuitionistic fuzzy environment. Rani, Mishra, Pardasani, Mardani, Liao and Streimikiene [48] defined a novel VIKOR method based on entropy and divergence measures of PFSs to evaluate renewable energy technologies. Narayanamoorthy, Geetha, Rakkiyappan and Joo [42] proposed the interval-valued intuitionistic hesitant fuzzy entropy based-VIKOR algorithms for industrial robot selection. Wang, Pan and He [53] defined a novel interval Type-2 fuzzy VIKOR model for MADM. Wang, Song, Ren, Li, Duan and Wang [54] Selected the sustainable energy conversion technologies for agricultural residues by using a fuzzy AHP-VIKOR-based prioritization from life cycle point. Wu, Xu, Jiang and Zhong [71] developed two MAGDM methods based on hesitant fuzzy linguistic term sets along with VIKOR and TOPSIS method. Wu, Zhou, Chen and Chen [72] defined the integrated algorithms to green supplier selection with the interval type-2 fuzzy best-worst and extended VIKOR methods. Yang and Pang [74] proposed the hesitant interval-valued Pythagorean fuzzy VIKOR method. Gao, Ran, Wei, Wei and Wu [14] devised the VIKOR method to solve the MAGDM based on q-rung interval-valued orthopair fuzzy information for supplier selection of medical consumption products.

Although the previous studies involved the selection of construction projects, they did not mention the evaluation of human factors in the process of construction project management. Therefore, it is necessary to use relevant evaluation criteria to evaluate human factors. In this paper, we use PI2TLNs to extend the VIKOR approach to evaluate human factors in a construction project. The remainder of this article is mainly as follows: Section 2: some basic definitions of PI2TLNs; Section 3: the extending VIKOR method with PI2TLNs; Section 4: A case study of evaluating human factors in the process of construction project management and contrastive analysis; Section 5: conclusions.

2 Preliminaries

2.1 Pythagorean interval 2-tuple linguistic sets

Wei, Lu, Alsaadi, Hayat and Alsaedi [65]proposed the Pythagorean interval 2-tuple linguistic sets (PI2TLSs) based on the PFSs[75] and 2-tuple linguistic information [20].

Definition 2.1. [64] *A PI2TLS A in X is given*

$$A = \left\{ \left[\left(\varphi_{(x)}, \rho_{(x)} \right), \left(\phi_{(x)}, \sigma_{(x)} \right) \right], \left(u_A\left(x\right), \nu_A\left(x\right) \right), x \in X \right\}. \tag{1}$$

Where $\left[\left(\varphi_{(x)}, \rho_{(x)} \right), \left(\phi_{(x)}, \sigma_{(x)} \right) \right]$ *is an interval 2-tuple linguistic variable,* $\varphi_{(x)}, \phi_{(x)} \in S, S = \{S_0, S_1 \cdots S_T\}$ *is a linguistic term set and* $\rho_{(x)},\ \sigma_{(x)} \in [-0.5, 0.5)\,,\ u_A\left(x\right), \nu_A\left(x\right) \in [0,1]$ *represent the degree of membership and degree of non-membership of the element x to an interval 2-tuple linguistic* $\left[\left(\varphi_{(x)}, \rho_{(x)} \right), \left(\phi_{(x)}, \sigma_{(x)} \right) \right]$ *.Then for* $x \in X,\ \pi_A\left(x\right) = \sqrt{1 - \left(u_A\left(x\right)\right)^2 - \left(\nu_A\left(x\right)\right)^2}$. *When* $(\varphi_A, \rho_A) = (\phi_A, \sigma_A)$ *then the Pythagorean interval 2-tuple linguistic sets (PI2TLSs) reduce to Pythagorean 2-tuple linguistic sets(P2TLSs). For conveniences sake,* $A{=}\langle [(\varphi_A, \rho_A), (\phi_A, \sigma_A)], (u_A, v_A) \rangle$ *can be called a Pythagorean interval 2-tuple linguistic number (PI2TLN).*

Definition 2.2. [64] *Given* $\tilde{a} = \langle [(\varphi_a, \rho_a), (\phi_a, \sigma_a)], (u_a, v_a) \rangle$ *is a PI2TLN, the score function of PI2TLN can be depicted as follows:*

$$Sf(\tilde{a}) = \Delta \left(\frac{\Delta^{-1}\left(\varphi_a, \rho_a\right) + \Delta^{-1}\left(\phi_a, \sigma_a\right)}{2} \times \frac{1 + \left(u_a\right)^2 - \left(\nu_a\right)^2}{2} \right). \tag{2}$$

Definition 2.3. [64] *Given* $\tilde{a} = \langle [(\varphi_a, \rho_a), (\phi_a, \sigma_a)], (u_a, v_a) \rangle$ *is a PI2TLN, the accuracy function of PI2TLN can be depicted as follows:*

$$Af(\tilde{a}) = \Delta \left(\frac{\Delta^{-1}\left(\varphi_a, \rho_a\right) + \Delta^{-1}\left(\phi_a, \sigma_a\right)}{2} \times \frac{\left(u_a\right)^2 + \left(\nu_a\right)^2}{2} \right). \tag{3}$$

Definition 2.4. [64] *Given* $\tilde{a}_1{=}\langle [(\varphi_{a_1}, \rho_{a_1}), (\phi_{a_1}, \sigma_{a_1})], (u_{a_1}, v_{a_1}) \rangle$ *and* $\tilde{a}_2{=}\langle [(\varphi_{a_2}, \rho_{a_2}), (\phi_{a_2}, \sigma_{a_2})], (u_{a_2}, v_{a_2}) \rangle$ *are two PI2TLNs. Respectively, the scores of* $\tilde{a}_1$ *and* $\tilde{a}_2$ *are*

$$Sf\left(\tilde{a}_1\right) = \Delta \left(\frac{\Delta^{-1}\left(\varphi_{a_1}, \rho_{a_1}\right) + \Delta^{-1}\left(\phi_{a_1}, \sigma_{a_1}\right)}{2} \times \frac{1 + \left(u_{a_1}\right)^2 - \left(\nu_{a_1}\right)^2}{2} \right),$$

and

$$Sf\left(\tilde{a}_2\right) = \Delta \left(\frac{\Delta^{-1}\left(\varphi_{a_2}, \rho_{a_2}\right) + \Delta^{-1}\left(\phi_{a_2}, \sigma_{a_2}\right)}{2} \times \frac{1 + \left(u_{a_2}\right)^2 - \left(\nu_{a_2}\right)^2}{2} \right),$$

and let

$$Af(\tilde{a}_1) = \Delta \left(\frac{\Delta^{-1}\left(\varphi_{a_1}, \rho_{a_1}\right) + \Delta^{-1}\left(\phi_{a_1}, \sigma_{a_1}\right)}{2} \times \frac{\left(u_{a_1}\right)^2 + \left(\nu_{a_1}\right)^2}{2} \right),$$

and

$$Af(\tilde{a}_2) = \Delta \left(\frac{\Delta^{-1}\left(\varphi_{a_2}, \rho_{a_2}\right) + \Delta^{-1}\left(\phi_{a_2}, \sigma_{a_2}\right)}{2} \times \frac{\left(u_{a_2}\right)^2 + \left(\nu_{a_2}\right)^2}{2} \right),$$

be the accuracy degrees of $\tilde{a}_1$ *and* $\tilde{a}_2$*, then some operational laws of PI2TLNs can be defined as follows:*

$$\begin{array}{l}(1)\ \ if\, Sf\left(\tilde{a}_1\right) < Sf\left(\tilde{a}_2\right),\ then\, \tilde{a}_1 < \tilde{a}_2;\\ (2)\ \ if\, Sf\left(\tilde{a}_1\right) > Sf\left(\tilde{a}_2\right),\ then\, \tilde{a}_1 > \tilde{a}_2;\\ (3)\ \ if\, Sf\left(\tilde{a}_1\right) = Sf\left(\tilde{a}_2\right), Af\left(\tilde{a}_1\right) < Af\left(\tilde{a}_2\right),\ then\, \tilde{a}_1 < \tilde{a}_2;\\ (4)\ \ if\, Sf\left(\tilde{a}_1\right) = Sf\left(\tilde{a}_2\right), Af\left(\tilde{a}_1\right) > Af\left(\tilde{a}_2\right),\ then\, \tilde{a}_1 > \tilde{a}_2;\\ (5)\ \ if\, Sf\left(\tilde{a}_1\right) = Sf\left(\tilde{a}_2\right), Af\left(\tilde{a}_1\right) = Af\left(\tilde{a}_2\right),\ then\, \tilde{a}_1 = \tilde{a}_2;\end{array}$$

Definition 2.5. [64] *Given* $\tilde{a}_1 = \langle [(\varphi_{a_1}, \rho_{a_1}), (\phi_{a_1}, \sigma_{a_1})], (u_{a_1}, v_{a_1}) \rangle$ *and* $\tilde{a}_2 = \langle [(\varphi_{a_2}, \rho_{a_2}), (\phi_{a_2}, \sigma_{a_2})], (u_{a_2}, v_{a_2}) \rangle$ *are two PI2TLNs, the normalized Hamming distance (H_d) between* $\tilde{a}_1$ *and* $\tilde{a}_2$ *can be depicted below:*

$$H_d\left(\tilde{a}_1, \tilde{a}_2\right) = \frac{1}{4L}\left[\left|\begin{array}{l}\left(1 + \left(u_{a_1}\right)^2 - \left(v_{a_1}\right)^2\right) \cdot \left(\Delta^{-1}\left(\varphi_{a_1}, \rho_{a_1}\right) + \Delta^{-1}\left(\phi_{a_1}, \sigma_{a_1}\right)\right) - \\ \left(1 + \left(u_{a_2}\right)^2 - \left(v_{a_2}\right)^2\right) \cdot \left(\Delta^{-1}\left(\varphi_{a_2}, \rho_{a_2}\right) + \Delta^{-1}\left(\phi_{a_2}, \sigma_{a_2}\right)\right)\end{array}\right|\right], \tag{4}$$

where L represents the length of the language scale. It is a numerical value.

Definition 2.6. [64] *Given* $\tilde{a}_1 = \langle [(\varphi_{a_1}, \rho_{a_1}), (\phi_{a_1}, \sigma_{a_1})], (u_{a_1}, v_{a_1}) \rangle$ *and* $\tilde{a}_2 = \langle [(\varphi_{a_2}, \rho_{a_2}), (\phi_{a_2}, \sigma_{a_2})], (u_{a_2}, v_{a_2}) \rangle$ *are two PI2TLNs, then*

$$\begin{array}{l}\tilde{a}_1 \oplus \tilde{a}_2 = \left\langle \left[\begin{array}{c}\Delta\left(\Delta^{-1}\left(\varphi_{a_1}, \rho_{a_1}\right) + \Delta^{-1}\left(\varphi_{a_2}, \rho_{a_2}\right)\right),\\ \Delta\left(\Delta^{-1}\left(\phi_{a_1}, \sigma_{a_1}\right) + \Delta^{-1}\left(\phi_{a_2}, \sigma_{a_2}\right)\right)\end{array}\right], \left(\sqrt{\left(u_{a_1}\right)^2 + \left(u_{a_2}\right)^2 - \left(u_{a_1}\right)^2\left(u_{a_2}\right)^2}, \nu_{a_1}\nu_{a_2}\right)\right\rangle;\\ \tilde{a}_1 \otimes \tilde{a}_2 = \left\langle \left[\begin{array}{c}\Delta\left(\Delta^{-1}\left(\varphi_{a_1}, \rho_{a_1}\right) \times \Delta^{-1}\left(\varphi_{a_2}, \rho_{a_2}\right)\right),\\ \Delta\left(\Delta^{-1}\left(\phi_{a_1}, \sigma_{a_1}\right) \times \Delta^{-1}\left(\phi_{a_2}, \sigma_{a_2}\right)\right)\end{array}\right], \left(u_{a_1}u_{a_2}, \sqrt{\left(\nu_{a_1}\right)^2 + \left(\nu_{a_2}\right)^2 - \left(\nu_{a_1}\right)^2\left(\nu_{a_2}\right)^2}\right)\right\rangle;\\ \lambda\tilde{a}_1 = \left\langle \left[\begin{array}{c}\Delta\left(\lambda\Delta^{-1}\left(\varphi_{a_1}, \rho_{a_1}\right)\right),\\ \Delta\left(\lambda\Delta^{-1}\left(\phi_{a_1}, \sigma_{a_1}\right)\right)\end{array}\right], \left(\sqrt{1 - \left(1 - \left(u_{a_1}\right)^2\right)^\lambda}, \left(\nu_{a_1}\right)^\lambda\right)\right\rangle;\\ \left(\tilde{a}_1\right)^\lambda = \left\langle \left[\begin{array}{c}\Delta\left(\left(\Delta^{-1}\left(\varphi_{a_1}, \rho_{a_1}\right)\right)^\lambda\right),\\ \Delta\left(\left(\Delta^{-1}\left(\phi_{a_1}, \sigma_{a_1}\right)\right)^\lambda\right)\end{array}\right], \left(\left(u_{a_1}\right)^\lambda\sqrt{1 - \left(1 - \left(\nu_{a_1}\right)^2\right)^\lambda}\right)\right\rangle.\end{array}$$

Theorem 2.7. [64] *For any two PI2TLNs* $\tilde{a}_1 = \langle [(\varphi_{a_1}, \rho_{a_1}), (\phi_{a_1}, \sigma_{a_1})], (u_{a_1}, v_{a_1}) \rangle$ *and* $\tilde{a}_1 = \langle [(\varphi_{a_1}, \rho_{a_1}), (\phi_{a_1}, \sigma_{a_1})], (u_{a_1}, v_{a_1}) \rangle$*, According to the Definition 6, naturally, we can get the following properties of the operation laws:*

$$\begin{array}{l}\tilde{a}_1 \oplus \tilde{a}_2 = \tilde{a}_2 \oplus \tilde{a}_1,\\ \tilde{a}_1 \otimes \tilde{a}_2 = \tilde{a}_2 \otimes \tilde{a}_1,\\ k\left(\tilde{a}_1 \oplus \tilde{a}_2\right) = k\tilde{a}_1 \oplus k\tilde{a}_2, 0 \le k \le 1,\\ k_1\tilde{a}_1 \oplus k_2\tilde{a}_1 = \left(k_1 \oplus k_2\right)\tilde{a}_1, 0 \le k_1, k_2, k_1 + k_2 \le 1,\\ \tilde{a}_1^{k_1} \otimes \tilde{a}_1^{k_2} = \left(\tilde{a}_1\right)^{k_1 + k_2}, 0 \le k_1, k_2, k_1 + k_2 \le 1,\\ \tilde{a}_1^{k_1} \otimes \tilde{a}_2^{k_1} = \left(\tilde{a}_1 \otimes \tilde{a}_2\right)^{k_1}, k_1 \ge 0,\\ \left(\left(\tilde{a}_1\right)^{k_1}\right)^{k_2} = \left(\tilde{a}_1\right)^{k_1k_2},\end{array}$$

2.2 Pythagorean interval 2-tuple linguistic arithmetic aggregation operators

In this section, some arithmetic aggregation operators with Pythagorean interval 2-tuple linguistic information will be introduced[65], such as Pythagorean interval 2-tuple linguistic weighted averaging (PI2TLWA) operator and Pythagorean interval 2-tuple linguistic weighted geometric (PI2TLWG) operator.

Definition 2.8. [64] *Assume that* $\tilde{a}_j = \left\langle \left[\left(\varphi_{a_j}, \rho_{a_j}\right), \left(\phi_{a_j}, \sigma_{a_j}\right)\right], \left(u_{a_j}, v_{a_j}\right)\right\rangle$ $(j = 1, 2, ..., n)$ *is a collection of PI2TLNs. PI2TLWA operator can be depicted as follows:*

$$\mathrm{PI2TLWA}_\omega\left(\tilde{a}_1, \tilde{a}_2, ..., \tilde{a}_n\right) = \mathop{\oplus}_{j=1}^{n}\left(\omega_j\tilde{a}_j\right) = \left\langle \left[\begin{array}{c}\Delta\left(\sum\limits_{j=1}^{n}\omega_j\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right),\\ \Delta\left(\sum\limits_{j=1}^{n}\omega_j\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)\end{array}\right], \left(\sqrt{1 - \prod_{j=1}^{n}\left(1 - \left(u_{a_j}\right)^2\right)^{\omega_j}}, \prod_{j=1}^{n}\left(\nu_{a_j}\right)^{\omega_j}\right)\right\rangle, \tag{5}$$

where $\omega = (\omega_1, \omega_2, ..., \omega_n)^T$ *is the weight vector of* $\tilde{a}_j$ $(j = 1, 2, ..., n)$ *and* $\omega_j > 0$, $\sum\limits_{j=1}^{n}\omega_j = 1$.

Definition 2.9. [64] *Assume that* $\tilde{a}_j = \left\langle \left[\left(\varphi_{a_j}, \rho_{a_j} \right), \left(\phi_{a_j}, \sigma_{a_j} \right) \right], \left(u_{a_j}, v_{a_j} \right) \right\rangle (j = 1, 2, ..., n)$ *is a collection of PI2TLNs. PI2TLWG operator can be depicted as follows:*

$$\mathrm{PI2TLWG}_\omega \left(\tilde{a}_1, \tilde{a}_2, ..., \tilde{a}_n \right) = \overset{n}{\underset{j=1}{\otimes}} \left(\omega_j \tilde{a}_j \right) = \left\langle \begin{bmatrix} \Delta \left(\prod_{j=1}^{n} \Delta^{-1} \left(\varphi_{a_j}, \rho_{a_j} \right)^{\omega_j} \right), \\ \Delta \left(\prod_{j=1}^{n} \Delta^{-1} \left(\phi_{a_j}, \sigma_{a_j} \right)^{\omega_j} \right) \end{bmatrix}, \left(, \prod_{j=1}^{n} \left(u_{a_j} \right)^{\omega_j} \sqrt{1 - \prod_{j=1}^{n} \left(1 - \left(\nu_{a_j} \right)^2 \right)^{\omega_j}} \right) \right\rangle, \tag{6}$$

where $\omega = (\omega_1, \omega_2, ..., \omega_n)^T$ *is the weight vector of* $\tilde{a}_j$ $(j = 1, 2, ..., n)$ *and* $\omega_j > 0$, $\sum_{j=1}^{n} \omega_j = 1$.

3 VIKOR method for PI2TL MADM problems

Suppose that $\Theta_i = \{\Theta_1, \Theta_2, \dots \Theta_m\}$ and $\xi_j = \{\xi_1, \xi_2, \dots \xi_n\}$ are respectively m alternatives and n criteria. Let $\omega = \{\omega_1, \omega_2, \dots \omega_n\}$ be the criterias weighting vector which satisfies $\omega_j \in [0, 1]$ and $\sum_{j=1}^{n} \omega_j = 1$. Let $\Psi = \{\Psi_1, \Psi_2, \dots \Psi_k\}$ be the group of DMs, $w = \{w_1, w_2, \dots w_k\}$ be the weight of DMs, with $w = \{w_1, w_2, \dots w_k\}$ and $\sum_{t=1}^{k} w_t = 1$. Construct a decision matrix $R^{(t)} = \left(r_{ij}^{(t)} \right)_{m \times n}$, where $R^{(t)} = \left(r_{ij}^{(t)} \right)_{m \times n} = \left\langle \left[\left(\varphi_{r_{ij}}^{(t)}, \rho_{r_{ij}}^{(t)} \right), \left(\phi_{r_{ij}}^{(t)}, \sigma_{r_{ij}}^{(t)} \right) \right], \left(u_{r_{ij}}^{(t)}, v_{r_{ij}}^{(t)} \right) \right\rangle_{m \times n}$, means the performance of the alternative $\Theta_i \{i = 1, 2 \cdots, m\}$ with respect to criteria $\xi_j \{j = 1, 2 \cdots, n\}$ by expert $\Psi^{(t)} \{t = 1, 2, \dots k\}$ using a PI2TLN, $0 \le u_{r_{ij}}^{(t)} \le 1, 0 \le v_{r_{ij}}^{(t)} \le 1$ and $0 \le \left(u_{r_{ij}}^{(t)} \right)^2 + \left(v_{r_{ij}}^{(t)} \right)^2 \le 1, i = 1, 2 \cdots, m, j = 1, 2 \cdots, n, t = 1, 2 \cdots, k$.

According to the PI2TLNs theory and steps in the VIKOR method, a PI2TLN-VIKOR method is proposed to effectively deal with the MADM problem. The new model is as follows:

Step 1. Set up a decision-making group composed of several experts, choose the best attributes to measure alternatives, and finally get a series of PI2TL fuzzy decision matrix $R^{(t)} = \left(r_{ij}^{(t)} \right)_{m \times n}$ from each decision maker.

$$R^{(t)} = \left[r_{ij}^{(t)} \right]_{m \times n} = \begin{bmatrix} r_{11}^{(t)} & r_{12}^{(t)} & \dots & r_{1n}^{(t)} \\ r_{21}^{(t)} & r_{22}^{(t)} & \dots & r_{2n}^{(t)} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1}^{(t)} & r_{m2}^{(t)} & \dots & r_{mn}^{(t)} \end{bmatrix}, \tag{7}$$

where $r_{ij}^{(t)}$ denotes the fuzzy performance value of $i-th$ alternative ($i = 1, 2, \dots, m$) with respect to $j-th$ criterion($j = 1, 2, \dots, n$) and decision-maker($t = 1, 2, \dots, k$).

Step 2. Utilize PI2TLWA operator or PI2TLWG operator to fuse assessment information, then the group PI2TL fuzzy decision matrix $R = (r_{ij})_{m \times n}$ can be obtained by the calculation.

$$R = [r_{ij}]_{m \times n} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}, \tag{8}$$

$$\begin{aligned} r_{ij} &= \overset{k}{\underset{t=1}{\oplus}} r_{ij}^{(k)} = \mathrm{PI2TLWA}(r_{ij}^{(1)}, r_{ij}^{(2)}, ..., r_{ij}^{(k)}) \\ &= \left\langle \begin{bmatrix} \Delta \left(\sum_{t=1}^{k} \omega_t \Delta^{-1} \left(\varphi_{r_{ij}}^{(t)}, \rho_{r_{ij}}^{(t)} \right) \right), \\ \Delta \left(\sum_{t=1}^{k} \omega_t \Delta^{-1} \left(\phi_{r_{ij}}^{(t)}, \sigma_{r_{ij}}^{(t)} \right) \right) \end{bmatrix}, \left(\sqrt{1 - \prod_{t=1}^{k} \left(1 - \left(u_{r_{ij}}^{(t)} \right)^2 \right)^{w_t}}, \prod_{t=1}^{k} \left(\nu_{r_{ij}}^{(t)} \right)^{w_t} \right) \right\rangle, \end{aligned} \tag{9}$$

or

$$\begin{aligned} r_{ij} &= \overset{k}{\underset{t=1}{\otimes}} r_{ij}^{(k)} = \mathrm{PI2TLWG}(r_{ij}^{(1)}, r_{ij}^{(2)}, ..., r_{ij}^{(k)}) \\ &= \left\langle \begin{bmatrix} \Delta \left(\prod_{t=1}^{k} \Delta^{-1} \left(\varphi_{r_{ij}}^{(t)}, \rho_{r_{ij}}^{(t)} \right)^{\omega_t} \right), \\ \Delta \left(\prod_{t=1}^{k} \Delta^{-1} \left(\phi_{r_{ij}}^{(t)}, \sigma_{r_{ij}}^{(t)} \right)^{\omega_t} \right) \end{bmatrix}, \left(\prod_{t=1}^{k} \left(u_{r_{ij}}^{(t)} \right)^{w_t}, \sqrt{1 - \prod_{t=1}^{k} \left(1 - \left(\nu_{r_{ij}}^{(t)} \right)^2 \right)^{w_t}} \right) \right\rangle, \end{aligned} \tag{10}$$

where r_{ij} means the average fuzzy performance value of $i-th$ alternative in relative to $j-th$ criterion.

Step 3. Determine the positive ideal solutions R_j^+ and R_j^- negative ideal solutions

$$R_j^+ = \left\{ \left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^+, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^+ \end{array} \right], \left(u_{a_j}^+, v_{a_j}^+\right) \right\}, \tag{11}$$

$$R_j^- = \left\{ \left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^-, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^- \end{array} \right], \left(u_{a_j}^-, v_{a_j}^-\right) \right\}, \tag{12}$$

For all benefit criteria:

$$\left\{ \left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^+, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^+ \end{array} \right], \left(u_{a_j}^+, v_{a_j}^+\right) \right\} = \left\{ \left[\begin{array}{c} \max\left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right), \\ \max\left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right) \end{array} \right], \left(\max\left(u_{a_j}\right), \min\left(v_{a_j}\right)\right) \right\}, \tag{13}$$

$$\left\{ \left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^-, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^- \end{array} \right], \left(u_{a_j}^-, v_{a_j}^-\right) \right\} = \left\{ \left[\begin{array}{c} \min\left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right), \\ \min\left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right) \end{array} \right], \left(\min\left(u_{a_j}\right), \max\left(v_{a_j}\right)\right) \right\}. \tag{14}$$

For all cost criteria:

$$\left\{ \left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^+, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^+ \end{array} \right], \left(u_{a_j}^+, v_{a_j}^+\right) \right\} = \left\{ \left[\begin{array}{c} \min\left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right), \\ \min\left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right) \end{array} \right], \left(\min\left(u_{a_j}\right), \max\left(v_{a_j}\right)\right) \right\}. \tag{15}$$

$$\left\{ \left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^-, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^- \end{array} \right], \left(u_{a_j}^-, v_{a_j}^-\right) \right\} = \left\{ \left[\begin{array}{c} \max\left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right), \\ \max\left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right) \end{array} \right], \left(\max\left(u_{a_j}\right), \min\left(v_{a_j}\right)\right) \right\}. \tag{16}$$

Step 4. Calculate S_i and P_i values using the following equations:

$$S_i = \sum_{j=1}^{n} \omega_j \frac{H_d\left(\left(\left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^+, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^+ \end{array} \right], \left(u_{a_j}^+, v_{a_j}^+\right)\right), \left(\left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right), \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right) \end{array} \right], \left(u_{a_j}, v_{a_j}\right)\right)\right)}{H_d\left(\left(\left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^+, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^+ \end{array} \right], \left(u_{a_j}^+, v_{a_j}^+\right)\right), \left(\left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^-, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^- \end{array} \right], \left(u_{a_j}^-, v_{a_j}^-\right)\right)\right)}, \tag{17}$$

$$P_i = \max\left\{ \omega_j \frac{H_d\left(\left(\left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^+, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^+ \end{array} \right], \left(u_{a_j}^+, v_{a_j}^+\right)\right), \left(\left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right), \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right) \end{array} \right], \left(u_{a_j}, v_{a_j}\right)\right)\right)}{H_d\left(\left(\left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^+, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^+ \end{array} \right], \left(u_{a_j}^+, v_{a_j}^+\right)\right), \left(\left[\begin{array}{c} \left(\Delta^{-1}\left(\varphi_{a_j}, \rho_{a_j}\right)\right)^-, \\ \left(\Delta^{-1}\left(\phi_{a_j}, \sigma_{a_j}\right)\right)^- \end{array} \right], \left(u_{a_j}^-, v_{a_j}^-\right)\right)\right)} \right\}, \tag{18}$$

here d denotes the normalized Hamming distance and ω_j means the weight of attributes with these $0 \leq \omega_j \leq 1$ $\sum_{j=1}^{n} \omega_j = 1$

Step 5. Compute Q_i values as follows:

$$Q_i = v\frac{S_i - S_i^*}{S_i^- - S_i^*} + (1 - v)\frac{P_i - P_i^*}{P_i^- - P_i^*}. \tag{19}$$

Where

$$S_i^* = \min_i S_i, S_i^- = \max_i S_i. \tag{20}$$

$$P_i^* = \min_i P_i, P_i^- = \max_i P_i. \tag{21}$$

Where v can be described as the decision-making mechanism coefficient. If $v > 0.5$, then it denotes the maximum group utility. If $v < 0.5$, then it denotes the minimum regret, and if $v = 0.5$, denotes equality.

Step 6. According to Q_i values, rank alternatives and the optimal decision is the alternative with the minimum Q value.

4 Numerical example and comparative analysis

4.1 Numerical example

There are many factors that affect the quality of construction projects. In the theory of quality control of construction projects, human factors are the leading, key and the first factor, and also the most difficult to control. Therefore, the evaluation of human factors is conducive to improving the overall quality of construction projects. The issue of evaluating human factors in construction project management is a classical MAGDM issue [18, 32, 53, 62, 66, 69, 71, 72].

In this section, we shall provide a numerical example to evaluate human factors in the process of construction project management by using PI2TL-VIKOR model. Assume that five possible construction projects $\Theta_i\ (i = 1, 2, 3, 4, 5)$ to be selected and four evaluation criteria $\xi_j\ (j = 1, 2, 3, 4)$ to evaluate these construction projects:
(1) ξ_1 is the workers proficiency;
(2) ξ_2 is the workers safety awareness;
(3) ξ_3 is the technical workers quality;
(4) ξ_4 is the workers emergency capacity.

The five possible construction projects $\Theta_i\ (i = 1, 2, 3, 4, 5)$ are to be evaluated through using PI2TLNs with the four criteria by three experts Ψ^k (experts weight $w = (0.35, 0.37, 0.28)$, attributes weight $\omega = (0.28, 0.29, 0.23, 0.20)^T$).

Step 1. Construct the evaluation matrix $R^{(3)} = \left(r^3_{ij}\right)_{5\times 4}\ (i = 1, 2, \ldots, 5, j = 1, 2, \ldots, 4)$ of each decision-maker as in Table 1-3. Based on table 1-3 and Equations (9), the group Pythagorean interval 2-tuple linguistic fuzzy decision matrix is computed. Table 4 shows the results.

Table 1: Rating alternatives on each criterion by Ψ_1

	ξ_1	ξ_2
Θ_1	$<[(S2,0),(S4,0)],(0.3,0.7)>$	$<[(S5,0),(S2,0)],(0.6,0.3)>$
Θ_2	$<[(S3,0),(S2,0)],(0.8,0.3)>$	$<[(S3,0),(S4,0)],(0.6,0.5)>$
Θ_3	$<[(S4,0),(S3,0)],(0.5,0.6)>$	$<[(S1,0),(S0,0)],(0.3,0.8)>$
Θ_4	$<[(S3,0),(S2,0)],(0.6,0.1)>$	$<[(S2,0),(S4,0)],(0.2,0.9)>$
Θ_5	$<[(S1,0),(S3,0)],(0.3,0.6)>$	$<[(S2,0),(S5,0)],(0.5,0.7)>$
	ξ_3	ξ_4
Θ_1	$<[(S5,0),(S2,0)],(0.8,0.5)>$	$<[(S1,0),(S3,0)],(0.5,0.1)>$
Θ_2	$<[(S5,0),(S3,0)],(0.8,0.7)>$	$<[(S3,0),(S4,0)],(0.7,0.4>$
Θ_3	$<[(S3,0),(S1,0)],(0.9,0.1)>$	$<[(S3,0),(S2,0)],(0.2,0.4)>$
Θ_4	$<[(S5,0),(S6,0)],(0.1,0.3)>$	$<[(S5,0),(S3,0)],(0.6,0.5)>$
Θ_5	$<[(S2,0),(S4,0)],(0.5,0.1)>$	$<[(S3,0),(S4,0)],(0.7,0.1)>$

Table 2: Rating alternatives on each criterion by Ψ_2

	ξ_1	ξ_2
Θ_1	$<[(S1,0),(S5,0)],(0.2,0.3)>$	$<[(S2,0),(S4,0)],(0.3,0.5)>$
Θ_2	$<[(S3,0),(S4,0)],(0.4,0.5)>$	$<[(S1,0),(S3,0)],(0.6,0.5)>$
Θ_3	$<[(S4,0),(S3,0)],(0.6,0.5)>$	$<[(S3,0),(S2,0)],(0.8,0.5)>$
Θ_4	$<[(S3,0),(S3,0)],(0.6,0.8)>$	$<[(S1,0),(S6,0)],(0.1,0.5)>$
Θ_5	$<[(S4,0),(S2,0)],(0.2,0.9)>$	$<[(S5,0),(S4,0)],(0.2,0.3)>$
	ξ_3	ξ_4
Θ_1	$<[(S1,0),(S4,0)],(0.7,0.3)>$	$<[(S3,0),(S4,0)],(0.1,0.8)>$
Θ_2	$<[(S2,0),(S2,0)],(0.7,0.8)>$	$<[(S4,0),(S4,0)],(0.4,0.7)>$
Θ_3	$<[(S5,0),(S6,0)],(0.9,0.6)>$	$<[(S3,0),(S5,0)],(0.1,0.6)>$
Θ_4	$<[(S4,0),(S3,0)],(0.6,0.4)>$	$<[(S2,0),(S6,0)],(0.4,0.3)>$
Θ_5	$<[(S2,0),(S1,0)],(0.2,0.2)>$	$<[(S3,0),(S5,0)],(0.4,0.8)>$

Table 3: Rating alternatives on each criterion by Ψ_3

	ξ_1	ξ_2
Θ_1	$<[(S2,0),(S2,0)],(0.8,0.6)>$	$<[(S3,0),(S4,0)],(0.5,0.7)>$
Θ_2	$<[(S5,0),(S2,0)],(0.7,0.3)>$	$<[(S5,0),(S2,0)],(0.1,0.4)>$
Θ_3	$<[(S3,0),(S5,0)],(0.7,0.6)>$	$<[(S5,0),(S4,0)],(0.2,0.4)>$
Θ_4	$<[(S2,0),(S3,0)],(0.4,0.6)>$	$<[(S4,0),(S5,0)],(0.5,0.6)>$
Θ_5	$<[(S1,0),(S4,0)],(0.3,0.1)>$	$<[(S1,0),(S3,0)],(0.7,0.5)>$
	ξ_3	ξ_4
Θ_1	$<[(S2,0),(S3,0)],(0.8,0.4)>$	$<[(S2,0),(S4,0)],(0.1,0.2)>$
Θ_2	$<[(S1,0),(S1,0)],(0.4,0.4)>$	$<[(S2,0),(S5,0)],(0.6,0.4)>$
Θ_3	$<[(S5,0),(S4,0)],(0.8,0.3)>$	$<[(S3,0),(S1,0)],(0.4,0.1)>$
Θ_4	$<[(S3,0),(S2,0)],(0.8,0.8)>$	$<[(S1,0),(S4,0)],(0.3,0.5)>$
Θ_5	$<<[(S5,0),(S1,0)],(0.5,0.6)>$	$<[(S1,0),(S2,0)],(0.4,0.5)>>$

Table 4: Rating alternatives on each criterion by Ψ_4

	ξ_1	ξ_2
Θ_1	$<[(S2,-0.37),(S4,-0.19)],(0.533,0.5552)>$	$<[(S3,0.33),(S3,0.3)],(0.4877,0.7002)>$
Θ_2	$<[(S4,-0.44),(S3,-0.26)],(0.676,0.5523)>$	$<[(S3,-0.18),(S3,0.07)],(0.5262,0.5987)>$
Θ_3	$<[(S4,-0.28),(S4,-0.44)],(0.6043,0.6707)>$	$<[(S3,-0.14),(S2,-0.14)],(0.587,0.5987)>$
Θ_4	$<[(S3,-0.28),(S3,-0.35)],(0.5562,0.798)>$	$<[(S2,0.19),(S5,0.02)],(0.3064,0.6707)>$
Θ_5	$<[(S2,0.11),(S3,-0.09)],(0.268,0.5047)>$	$<[(S3,-0.17),(S4,0.07)],(0.5122,0.5275)>$
	ξ_3	ξ_4
Θ_1	$<[(S3,-0.32),(S3,0.02)],(0.7684,0.4956)>$	$<[(S2,0.02),(S4,-0.35)],(0.3189,0.5867)>$
Θ_2	$<[(S3,-0.23),(S2,0.07)],(0.6934,0.7124)>$	$<[(S3,0.09),(S4,0.28)],(0.5885,0.6781)>$
Θ_3	$<[(S4,0.3),(S4,-0.31)],(0.8791,0.5909)>$	$<[(S3,0),(S3,-0.17)],(0.2542,0.4344)>$
Θ_4	$<[(S4,0.07),(S4,-0.23)],(0.6045,0.6693)>$	$<[(S3,-0.23),(S4,0.39)],(0.4679,0.5275)>$
Θ_5	$<[(S3,-0.16),(S2,0.05)],(0.4222,0.4778)>$	$<[(S2,0.44),(S4,-0.19)],(0.5428,0.7583)>$

Step 2. Determine the and by Equations (13) and (14).

$$R_j^+ = \left\{ \begin{array}{c} \langle [(S_4,-0.28),(S_4,-0.19)],(0.676,0.5047)\rangle \\ \langle [(S_3,0.33),(S_5,0.02)],(0.587,0.5275)\rangle \\ \langle [(S_4,0.3),(S_4,-0.23)],(0.8791,0.4778)\rangle \\ \langle [(S_3,0.09),(S_4,0.39)],(0.5885,0.4344)\rangle \end{array} \right\}.$$

$$R_j^- = \left\{ \begin{array}{c} \langle [(S_2,-0.37),(S_3,-0.35)],(0.268,0.798)\rangle \\ \langle [(S_2,0.19),(S_2,-0.14)],(0.3064,0.7002)\rangle \\ \langle [(S_3,-0.32),(S_4,0.05)],(0.4222,0.7124)\rangle \\ \langle [(S_2,0.02),(S_3,-0.17)],(0.2542,0.7583)\rangle \end{array} \right\}.$$

Step 3. Compute S_i and P_i values by Equation (17) and (18).

$$S_1 = 0.5807, S_2 = 0.4863, S_3 = 0.4238, S_4 = 0.5948, S_5 = 0.6136.$$

$$P_1 = 0.1772, P_2 = 0.1919, P_3 = 0.1908, P_4 = 0.2119, P_5 = 0.1935.$$

Step 4. Calculate Q_i values as follows (Let $v = 0.4$):

$$Q_1 = 0.3305, Q_2 = 0.3863, Q_3 = 0.2345, Q_4 = 0.9604, Q_5 = 0.6827.$$

Step 5. According to the order of Q_i values, the smaller the Q_i values, the better the evaluation of human factors of the construction project. Therefore the ranking is $\Theta_3 > \Theta_1 > \Theta_2 > \Theta_5 > \Theta_4$ and Θ_3 is the best.

4.2 Comparative analyses

In this part, we compare the proposed PI2TLN-VIKOR model with other methods, the PI2TLWA and PI2TLWG operators [64]and PI2TL-TODIM method proposed by Wei, Gao, Wang and Huang [64].

The comparison results of different methods are as follows.

Table 5: Rank of Alternatives

Methods	Order
PI2TLWA	$\Theta_3 > \Theta_2 > \Theta_1 > \Theta_4 > \Theta_5$
PI2TLWG	$\Theta_3 > \Theta_2 > \Theta_1 > \Theta_4 > \Theta_5$
PI2TLN-TODIM	$\Theta_3 > \Theta_2 > \Theta_4 > \Theta_1 > \Theta_5$
PI2TLN-VIKOR	$\Theta_3 > \Theta_1 > \Theta_2 > \Theta_5 > \Theta_4$

Discussion:

From the above comparison results, we can draw two conclusions. First, the comparison with PI2TLWA/PI2TLWG, the two original operators, shows that the ranking results of the alternatives are slightly different, but the best alternative is the same. Θ_3 is considered to be the best performance in human factor evaluation among the five construction projects, which verifies the stability and accuracy of this method. Second, compared with the traditional PI2TL-TODIM, although the ranking results are slightly inconsistent, the best alternative is also the same. We analyze the difference between the two methods, PI2TL-VIKOR method can reflect the alternatives and the proximity of the positive and negative ideal solution, and at the same time can take the group utility maximization and individual regret minimization into consideration, can fully considering the subjective preferences of decision makers, thus make decisions more reasonable, and PI2TL-TODIM is used to depict the decision-maker of the psychological behavior of the risk, so the PI2TL-VIKOR is more suited for evaluation of human factors in construction project evaluation.

5 Conclusions

In the total quality management of construction projects, human factors not only play a leading role in the factors affecting quality, but also the most basic and core factors in the quality assurance system. Therefore, it is particularly important to evaluate human factors in construction projects. The evaluation of human factors in engineering projects is a multi-attribute decision making problem. Therefore, the use of PI2TLNs to express the evaluation information of experts can reflect the uncertain or fuzzy information. Then, a new decision-making method was obtained by combining PI2TLNs with VIKOR, which was applied to the evaluation of human factors of five construction projects to find the construction project with the best performance. The comparative study shows that it is a feasible and effective decision-making method. In the future, this method can be used to deal with other practical decision-making problems, such as the selection of green suppliers [8, 13, 23, 26, 31, 34, 66, 67, 75] and the location of waste disposal station, and so on [38, 50, 76].

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