EVALUATION OF INFRASTRUCTURE PROJECTS BY A DECISION MODEL BASED ON RPR, MABAC, AND WASPAS METHODS WITH INTERVAL-VALUED INTUITIONISTIC FUZZY SETS

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Abstract. Infrastructure projects (IPs) face numerous challenges to reach the predefined aims over their life-cycle. There are many difficulties in projects because of the variety of elements in project's tendency and the dependency of the project on mainly national factors. Due to these difficulties and their practices, the projects meet with uncertainty. In this paper, an interval-valued intuitionistic fuzzy set (IVIFS) is used at identifying ambiguity in IPs. Also, a new multi-criteria decision-making (MCDM) model is presented to evaluate and select the suitable alternative in IPs. Hence, a new IVIF-relative preference alternative-multi-attributive border approximation area comparison (IVIF-RPR-MABAC), and IVIF-weighted aggregated sum product assessment (IVIF-WASPAS) are proposed in order to obtain the weights of decision makers (DMs) and criteria, and a new IVIF-RPR-MABAC method is proposed to rank the alternatives. In this paper, a combination of the three mentioned approaches creates proposed new hybrid model to evaluate the main factors and the projects. Furthermore, a real case study is applied from the literature to validate the efficiency and performance of the proposed model. Afterward, a comparative analysis is presented to validate the proposed approach by comparing the hybrid proposed model with two IVIF-TOPSIS and IVIF-extended-VIKOR methods. The final results confirm the efficiency of the proposed model in ranking the main alternatives of an MCDM problem. Moreover, the sensitivity analysis is reported to determine the affection of parameters on the final weighting and ranking outcomes.

Keywords: infrastructure projects, multi-criteria decision-making (MCDM), interval-valued intuitionistic fuzzy sets (IVIFSs), relative preference alternative (RPR) method, multi-attributive border approximation area comparison (MABAC) method, weighted aggregated sum product assessment (WASPAS) method.

Introduction

Infrastructure projects (IPs) display an essential practice in construction conditions that links constructing and manufacturing projects to energy, water, and other topics to each other. The kinds of projection may develop distinctive scheming challenges because they may include the right to cross over another property adjustments, involve more basement construction than building or manufacturing projections, and may need more connection with the universe than other kinds of construction projects. An IP can be described as a megaproject, which comprises forwarding, transferring, distributing, collecting, or other abilities that support patronage or interaction of products, ministrations, or population (Bingham & Gibson, 2017); especially, an IP is horizontal in characters and practices as a vector that joins constructing and manufacturing depots within the manufacturing state. IPs may transmit persons, such as freeways, railways, and tunnels; they may extend liquids, such as tube lines, open channels, and pumping stations; or they may account for energy, such as transferring lines, electrical towers, and wayside (Construction Industry Institute, 2010).

The increasing world population rate and the need for growth IPs like transportation are straining existing and extending the requirement for megaprojects. Financial resources are rare and so should be allocated effectively. Correctly assessing transportation infrastructure in cost-benefit analysis will provide the most effective allocation of resources and do extra with fewer devices. Nevertheless, the elaborative and particular nature of IPs should be thoroughly managed (Taillandier et al., 2015). Likewise projects want detailed appraisement within the planning

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step for selection, comparison, and evaluation of proper projects alternatives. In project evaluation and selection process, which is classified as a strategic decision-making procedure, the decision maker (DM) is required to find a number of the most appropriate projects although considering the result of projects (Pires et al., 2018). Accordingly, there are various multi-criteria decision-making (MCDM) methods for assessing and selecting processes in IPs. Hence, there is no well-described approach that could be followed the decision-assisting process (Yazdani et al., 2011). The selection and evaluation of IP methodology are still under paper. The major case is to approximate and appraise a collection of options in kinds of indexes and inconsistent criteria (Mulliner et al., 2016). There are diverse measures for each index and criterion (Egilmez et al., 2016). One of the criticisms of MCDM approaches is that mixed methods can outcome multiple results when practical to the same subject. The DMs regard a suitable decision, which is nearest to the ideal, and options are assessed accordance with all demonstrate criteria (Chitsaz & Banihabib, 2015). It is essential to compare the MCDM approach for evaluation aims with a sensitivity analysis of the input information. It is also significant to experiment with the ability of different approaches by a particular kind of decision problem (Gan & Hill, 2009).

One of the other elements is related to an increasing extensive amount of ambiguity and uncertainty in most IPs, which usually occurs for evaluation and selection of suitable projects in complex decision-making problems by considering transferring process (Arshad et al., 2021). Accordingly, the fuzzy set (FS) is presented to reduce the probability lack of information by utilizing fuzzy numbers instead of numerical amounts to demonstrate the DMs' intuitive preferences. Still, it cannot reflect a well-known mental fact that the linguistic value is not consistently recognized with the rational term (Wu et al., 2014). In this regard, from the various higher levels of FSs, intuitionistic fuzzy sets (IFSs) proposed by Atanassov (1986) have been introduced to be extremely useful to cope with vagueness. The issue of IFSs is an extension of the FSs. The subject of vague sets proposed by Gau and Buehrer (1993) is another extension of FSs. However, Bustince and Burillo (1996) introduced that the notion of a vague set is the same as the IFSs. Due to the incrementing elaboration of the social and economic environments, the shortage of information about the problem, and expert's ability relevant to the information process, sometimes, an expert is hard to prioritize describing options with regard to criteria precisely but can give a value range. In this respect, for assessing an index, DM may be more comfortable to represent the value of criterion with satisfactory and dissatisfactory degrees by utilizing an interval value, respectively (Hashemi et al., 2013; Salimian & Mousavi, 2021). This point can be applied in the IFs environment, which creates the interval-valued intuitionistic fuzzy set (IVIFS) concept. The main advantage of IVIFSs is related to the capability of IVIFS to manage a non-membership degree in addition to the membership degree of fuzzy values that is a favored point

of this method over traditional fuzzy sets (Davoudabadi et al., 2019, 2020). Furthermore, IVIFS utilizes the interval values for determining the degrees instead of using a crisp value. Also, vague information can be managed adequately by employing IVIFSs in comparison with IFSs. By extending IFSs to IVIFSs, controlling uncertain and vague information becomes more successful due to the particular that the ambiguous, membership and non-membership degrees are represented as ranges of values instead of actual values (Davoudabadi et al., 2021).

For this reason, Gürbüz et al. (2012) presented an integrated MCDM method to select the ERP problem with a conflict criterion. Zhang et al. (2019) proposed the private-sector partner selection for the public-private partnership (3P) charging electric vehicles infrastructure problem. The study used the extended Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) method under the IFS condition. Turskis et al. (2019) generated the MCDM problem in the runway airport project. This paper applied the group decision-making (GDM) process to take an appropriate decision and select an effective alternative. Wang (2015) proposed weighting criteria approach by combining fuzzy quality function deployment with relative preference relation (RPR). The advantage of the RPR is that uncertainties of fuzzy values are kept during the ranking and weighting process, and another is related to control fuzzy pairwise comparisons by preference relation that is complex. Furthermore, the multi-attributive border approximation area comparisons (MABAC) methid has been proposed by Pamučar and Ćirović (2015) and categorized as a multi-attributes decision-making (MADM) approach to compute the criteria weights. The advantages of MABAC method are the simple calculation and durability in solution and the potential amounts of advantages and losses which to be considered in such a way that the final drawback can be extensive (Roy et al., 2016). Zavadskas et al. (2012) proposed the weighted aggregated sum product assessment (WASPAS) approach to evaluate the decision process in the complex problem. In addition, Chakraborty and Zavadskas (2014) introduced WASPAS method to compute the manufacturing decision-making process. Karsak and Dursun (2015) proposed the combination fuzzy MCDM approach to select and assess the supplier. Xue et al. (2016b) presented a combination linguistic MCDM approach to assess and select with incomplete weight data. Stević et al. (2018) proposed the MCDM method based on the WASPAS approach to evaluate location of the roundabout construction. The proposed WASPAS approach was created based on a new rough hamy aggregator. Navarro et al. (2020) introduced the sustainable lifecycle of the bridge construction project under MCDM technology. Baušys et al. (2020) focused on the residence plot for a family house in Vilnius using neutrosophic WASPAS method.

Brauers et al. (2008) proposed the MCDM approach to assess the road design problem. Fouladgar et al. (2012) introduced the combination AHP and complex proportional assessment (COPRAS) under fuzzy environments to select

the maintenance strategy. Turskis et al. (2015) presented integrated fuzzy AHP and WASPAS approach to select the construction site. Keshavarz Ghorabaee et al. (2016) generated the development WASPAS method to select the green supplier in type-2 fuzzy set conditions. Zavadskas et al. (2015) evaluated the sustainable alternative site of the waste burn factory with WASPAS method under netroustophic set. Zavadskas et al. (2016) introduced the WASPAS approach to select the optimal indoor environment. Yazdani et al. (2011) evaluated the supplier selection with QFD-MCDM structure in green environments. Mohagheghi et al. (2019) proposed a sustainable infrastructure selection multi-criteria group decision making (MCGDM) problem with MORAS method under interval type-2 fuzzy conditions. Mazher et al. (2018) introduced fuzzy integral–based risk-evaluation method for 3P-IPs. Stević et al. (2020) proposed the measurement of alternatives and ranking according to the compromise solution (MARCOS) approach to select the sustainable supplier in healthcare industry. Ranganath et al. (2020) proposed an application of fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) approach for risk assessment in extended and executed of solar park in India. Su and Li (2021) introduced project appropriation approach decision-making with Spearman rank similarity coefficient under uncertain situations. Bapat et al. (2021) proposed an application of combined fuzzy FCM-BIM-IoT for sustainable material choice and energy management of metro rail service box project in western India. Banihashemi et al. (2021) proposed an integrated fuzzy SWARA-TOPSIS method to evaluate the trade-off among time-cost-quality in construction project scheduling problems.

This paper proposes a new hybrid weighting and ranking model that includes IVIF-RPR-MABAC, IVIF-WASPAS, and new IVIF-RPR-MABAC approaches for solving the evaluation and selection problems of IPs. Therefore, integrating the RPR and MABAC methods is utilized to obtain the DMs weights. Also, the criteria weights are computed based on the WASPAS method. Eventually, a new hybrid assessment model based on RPR and MABAC methods is presented to compute the ranking of main alternatives for the IPs problems. Afterward, a case study is applied based on the literature to validate the performance of the introduced model, and this study compares the suggested method with two IVIF-TOPSIS and IVIF-extended-VIKOR (IVIF-E-VIKOR) approaches. The main innovations of the paper are examined below:

- Proposing a new DM' weighting method based on an IVIF-RPR-MABAC approach. This method uses the average, negative and positive ideal solutions distances to compute the DMs' weights.
- Introducing a criterion weighting method based on a new version of the IVIF-WASPAS approach.
- Proposing a new ranking method based on the MABAC and RPR concepts under IVIF conditions.
- Applying a case study to validate the introduced decision model.

The remaining part of this paper is turned out as follows. The based formulation of IVIF method is reviewed in Section 1. In Section 2, the proposed soft computing model is introduced. In Section 3, an empirical example is generated based on the literature. Section 4 investigates the sensitivity analysis. Eventually, the last section develops the conclusion and the future research suggestion.

1. Preliminary

This section describes the basic formulations of IVIFS and RPR method. These descriptions are shown below:

Definition 1. (Atanassov & Gargov, 1989). Let $Y = \{y_1, y_2, ..., y_n\}$ be a universe. An IVIFS $\tilde{P}$ in Y is defined from Eq. (1).

$$\tilde{P} = \left\{ y_i, \mu_{\tilde{P}}(u_i), v_{\tilde{P}}(u_i) \mid y_i \in Y \right\}, \tag{1}$$

where $\mu_{\tilde{P}}(y_i) = \left[\mu_{\tilde{P}}^l(y_i), \mu_{\tilde{P}}^u(y_i) \right], v_{\tilde{P}}(y_i) = \left[v_{\tilde{P}}^l(y_i), v_{\tilde{P}}^u(y_i) \right]$ and $\mu_{\tilde{P}}(y_i), v_{\tilde{P}}(y_i) \in [0,1]$. In these formulations, $\mu_{\tilde{P}}^l(y_i)$ is the infimum of the $\mu_{\tilde{P}}(y_i)$ and $\mu_{\tilde{P}}^u(y_i)$ is the supremum of the $\mu_{\tilde{P}}(y_i)$. Furthermore, this situation is done for $v_{\tilde{P}}(y_i)$, simultaneously.

$$\mu_{\tilde{P}}^u(y_i) + v_{\tilde{P}}^u(y_i) \leq 1 \qquad \forall y_i \in Y; \tag{2}$$

$$\pi_{\tilde{P}}(y_i) = \left[\pi_{\tilde{P}}^l(y_i), \pi_{\tilde{P}}^u(y_i) \right], \tag{3}$$

where $\pi_{\tilde{P}}^l(y_i) = 1 - \mu_{\tilde{P}}^u(y_i) - v_{\tilde{P}}^u(y_i)$ and $\pi_{\tilde{P}}^u(y_i) = 1 - \mu_{\tilde{P}}^l(y_i) - v_{\tilde{P}}^l(y_i)$ for $y_i \in Y$. Hence, if $\mu_{\tilde{P}}(y_i) = \mu_{\tilde{P}}^u(y_i) = \mu_{\tilde{P}}^l(y_i)$ and $v_{\tilde{P}}(y_i) = v_{\tilde{P}}^u(y_i) = v_{\tilde{P}}^l(y_i)$, IFS is created.

Definition 2. (Atanassov, 1999). Let $\tilde{Q}_1 = \left(\left[\mu_{\tilde{Q}_1}^l, \mu_{\tilde{Q}_1}^u \right], \left[v_{\tilde{Q}_1}^l, v_{\tilde{Q}_1}^u \right] \right), \tilde{Q}_2 = \left(\left[\mu_{\tilde{Q}_2}^l, \mu_{\tilde{Q}_2}^u \right], \left[v_{\tilde{Q}_2}^l, v_{\tilde{Q}_2}^u \right] \right),$ $\tilde{Q} = \left[\mu_{\tilde{Q}}^l, \mu_{\tilde{Q}}^u \right], \left[v_{\tilde{Q}}^l, v_{\tilde{Q}}^u \right]$. The major operations are demonstrated with Eqs (4)−(7).

$$\tilde{Q}_1 \otimes \tilde{Q}_2 = \left(\left[\mu_{\tilde{Q}_1}^l + \mu_{\tilde{Q}_2}^l - \mu_{\tilde{Q}_1}^l \mu_{\tilde{Q}_2}^l, \mu_{\tilde{Q}_1}^u + \mu_{\tilde{Q}_2}^u - \mu_{\tilde{Q}_1}^u \mu_{\tilde{Q}_2}^u \right], \right.$$
$$\left. \left[v_{\tilde{Q}_1}^l v_{\tilde{Q}_2}^l, v_{\tilde{Q}_1}^u v_{\tilde{Q}_2}^u \right] \right); \tag{4}$$

$$\tilde{Q}_1 \otimes \tilde{Q}_2 = \left(\left[\mu_{\tilde{Q}_1}^l \mu_{\tilde{Q}_2}^l, \mu_{\tilde{Q}_1}^u \mu_{\tilde{Q}_2}^u \right], \right.$$
$$\left. \left[v_{\tilde{Q}_1}^l + v_{\tilde{Q}_2}^l - v_{\tilde{Q}_1}^l v_{\tilde{Q}_2}^l, v_{\tilde{Q}_1}^u + v_{\tilde{Q}_2}^u - v_{\tilde{Q}_1}^u v_{\tilde{Q}_2}^u \right] \right); \tag{5}$$

$$E\tilde{Q} = \left(\left[1 - \left(1 - \mu_{\tilde{Q}}^l \right)^E, 1 - \left(1 - \mu_{\tilde{Q}}^u \right)^E \right], \left[v_{\tilde{Q}}^{lE}, v_{\tilde{Q}}^{uE} \right] \right); \tag{6}$$

$$\tilde{Q}^E = \left(\left[\mu_{\tilde{Q}}^{lE}, \mu_{\tilde{Q}}^{uE} \right], \left[1 - \left(1 - v_{\tilde{Q}}^l \right)^E, 1 - \left(1 - v_{\tilde{Q}}^v \right)^E \right] \right). \tag{7}$$

Definition 3. (Xue et al., 2016a). Euclidean distance is obtained from Eq. (8).

$$Dis\left(\tilde{Q}_1,\tilde{Q}_2\right) =$$

$$\sqrt{\frac{1}{4}\left(\left(\mu_{\widetilde{Q_1}}^l - \mu_{\widetilde{Q_2}}^l\right)^2 + \left(\mu_{\widetilde{Q_1}}^u - \mu_{\widetilde{Q_2}}^u\right)^2 + \left(v_{\widetilde{Q_1}}^l - v_{\widetilde{Q_2}}^l\right)^2 + \left(v_{\widetilde{Q_1}}^u - v_{\widetilde{Q_2}}^u\right)^2\right)}. \quad (8)$$

Definition 4. (Büyüközkan & Göçer, 2018). The normalized decision matrix is calculated from Eqs (9)–(12).

$$\mu_{ij}^l = \frac{\tilde{\mu}_{ij}^l}{\sqrt{\sum_{i=1}^{r}\left(\tilde{\mu}_{ij}^{l2} + \tilde{\mu}_{ij}^{l2}\right)}}; \quad (9)$$

$$\mu_{ij}^u = \frac{\tilde{\mu}_{ij}^u}{\sqrt{\sum_{i=1}^{r}\left(\tilde{\mu}_{ij}^{u^2} + \tilde{\mu}_{ij}^{u^2}\right)}}; \quad (10)$$

$$v_{ij}^l = \frac{\tilde{v}_{ij}^l}{\sqrt{\sum_{i=1}^{r}\left(\tilde{v}_{ij}^{l2} + \tilde{v}_{ij}^{l2}\right)}}; \quad (11)$$

$$v_{ij}^u = \frac{\tilde{v}_{ij}^u}{\sqrt{\sum_{i=1}^{r}\left(\tilde{v}_{ij}^{u^2} + \tilde{v}_{ij}^{u^2}\right)}}. \quad (12)$$

Definition 5. (Xu & Jian, 2007). The interval-valued intuitionistic fuzzy hybrid averaging (IVIFHA) approach is computed from Eq. (13).

$$IVIFHA_w = \left(\left[1-\prod_{j=1}^{h}\left(1-\mu_{\delta j}^u\right)^{w^j}, 1-\prod_{j=1}^{h}\left(1-\mu_{\delta j}^l\right)^{w^j}\right],\right.$$
$$\left.\left[\prod_{j=1}^{h}\left(v_{\delta j}^u\right)^{w^j}, \prod_{j=1}^{h}\left(v_{\delta j}^l\right)^{w^j}\right]\right). \quad (13)$$

Definition 6. (Jia et al., 2019). The approximation area matrix is computed from Eq. (14).

$$P_i = \left(\left[\prod_{j=1}^{h}\left(\mu_{ij}^l\right)^{\left(1/h\right)}, \prod_{j=1}^{h}\left(\mu_{ij}^u\right)^{\left(1/h\right)}\right],\right.$$
$$\left.\left[1-\prod_{j=1}^{h}\left(1-v_{ij}^l\right)^{\left(1/h\right)}, 1-\prod_{j=1}^{h}\left(1-v_{ij}^u\right)^{\left(1/h\right)}\right]\right). \quad (14)$$

2. Proposed soft computing model

This section determines a new model for decision-making process under IVIF conditions that is used in IP evaluation and selection problems. The weights of the DMs are computed from the new prescription of the combination RPR and MABAC methods, and the criteria weights are obtained from the WASPAS approach under IVIF situations. Also, a new ranking method is proposed based on the latest version of MABAC and RPR approaches under the IVIF state. In the model, some concepts based on the

recent papers are used for MCDM problems (i.e., Yue, 2012; Zavadskas et al., 2014; Mishra & Rani, 2018; Dorfeshan & Mousavi, 2020).

1. Creating a decision-making matrix based on e expert opinions $\left(D = \{D_1, D_2, ..., D_e\}\right)$.

This matrix is related to the DMs' judgments between criteria $i = \{R_1, R_2, ..., R_r\}$ and the alternatives $j = \{M_1, M_2, ..., M_h\}$. Also, decision-making matrix $\left(\varnothing_e\right)$ is determined below.

$$\varnothing_e = \left[\varnothing^e\right]_{ij} = \begin{bmatrix} \tilde{\varnothing}_{11}^e & \cdots & \tilde{\varnothing}_{1h}^e \\ \vdots & \ddots & \vdots \\ \tilde{\varnothing}_{r1}^e & \cdots & \tilde{\varnothing}_{rh}^e \end{bmatrix}, \quad (15)$$

where, $i \subseteq \{1,2,...,r\}$ and $j \subseteq \{1,2,...,h\}$ depict the quantity of the criteria and the alternatives. Furthermore, $E \subseteq \{1,2,...,e\}$ generates the quantity by the DMs.

2. Computing normalized decision matrix based on Definition 4.

This is determined in Eqs (16) and (17).

$$\eta_{ij}^e = \begin{bmatrix} \tilde{\eta}_{11}^e & \cdots & \tilde{\eta}_{1h}^e \\ \vdots & \ddots & \vdots \\ \tilde{\eta}_{r1}^e & \cdots & \tilde{\eta}_{rh}^e \end{bmatrix}; \quad (16)$$

$$\tilde{\eta}_{ij}^e = \left(\left[\frac{\tilde{\mu}_{ij}^{el}}{\sqrt{\sum_{j=1}^{h}\left(\tilde{\mu}_{ij}^{el^2} + \tilde{\mu}_{ij}^{el^2}\right)}}, \frac{\tilde{\mu}_{ij}^{eu}}{\sqrt{\sum_{j=1}^{h}\left(\tilde{\mu}_{ij}^{eu^2} + \tilde{\mu}_{ij}^{eu^2}\right)}}\right],\right.$$
$$\left.\left[\frac{\tilde{v}_{ij}^{el}}{\sqrt{\sum_{j=1}^{h}\left(\tilde{v}_{ij}^{el^2} + \tilde{v}_{ij}^{el^2}\right)}}, \frac{\tilde{v}_{ij}^{eu}}{\sqrt{\sum_{j=1}^{h}\left(\tilde{v}_{ij}^{eu^2} + \tilde{v}_{ij}^{eu^2}\right)}}\right]\right). \quad (17)$$

3. Computing the weights of the experts by introducing IVIF-RPR-based MABAC approach.

Meanwhile, in this study, Yue (2012) method is presented to show DMs weights based on the closeness to the average ideal solution, and the expert with higher closeness gets the high weight degree. In this regard, a new weighting DMs approach is computed based on utilizing a closeness to the average ideal solution with the following sub-steps:

3.1. Obtaining the border approximation area matrix based on Definition 6 with Eq. (18).

$$\bar{\xi}_{ij} = \begin{bmatrix} \bar{\bar{\xi}}_{11} & \cdots & \bar{\bar{\xi}}_{1h} \\ \vdots & \ddots & \vdots \\ \bar{\bar{\xi}}_{r1} & \cdots & \bar{\bar{\xi}}_{rh} \end{bmatrix}; \quad (18)$$

$$\bar{\bar{\xi}}_{rh} = \left(\left[\prod_{e=1}^{E}\left(\mu_{rh}^{el}\right)^{\left(1/e\right)}, \prod_{e=1}^{E}\left(\mu_{rh}^{eu}\right)^{\left(1/e\right)}\right],\right.$$
$$\left.\left[1-\prod_{e=1}^{E}\left(1-v_{rh}^{el}\right)^{\left(1/e\right)}, 1-\prod_{e=1}^{E}\left(1-v_{rh}^{eu}\right)^{\left(1/e\right)}\right]\right). \quad (19)$$

3.2. Computing the IVIF-RPR based on the border approximation area matrix with Eqs (20)–(26).

In this formulation, $\Delta_{P^*}\left(\tilde{\eta}_{rh}^e, \bar{\tilde{\xi}}_{ij}\right)$ determines a preference degree of the $\tilde{\eta}$ over $\bar{\tilde{\xi}}$. Also, Δ_P is a membership degree of fuzzy preference relation P.

$$\partial_e = \sum_{i=1}^{r}\sum_{j=1}^{h}\Delta_{P^*}\left(\tilde{\eta}_{ij}^e, \bar{\tilde{\xi}}_{ij}\right) = \frac{1}{2}\left[\Delta_{P^*}\left(\tilde{\eta}_{ij}^{le}, \bar{\tilde{\xi}}_{ij}^{l}\right) + \Delta_{P^*}\left(\tilde{\eta}_{ij}^{ue}, \bar{\tilde{\xi}}_{ij}^{u}\right)\right] =$$

$$\left(\begin{bmatrix}\frac{1}{2}\left[\frac{1}{2}\left(\frac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(\mu_{ij}^{le}-\bar{\mu}_{ij}^{l}\right)}{2\|T_\xi^{\mu l}\|}+1\right)+\frac{1}{2}\left(\frac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(\mu_{ij}^{ue}-\bar{\mu}_{ij}^{u}\right)}{2\|T_\xi^{\mu u}\|}+1\right)\right], \\ \frac{1}{2}\left[\frac{1}{2}\left(\frac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(v_{ij}^{le}-\bar{v}_{ij}^{l}\right)}{2\|T_\xi^{vl}\|}+1\right)+\frac{1}{2}\left(\frac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(v_{ij}^{ue}-\bar{v}_{ij}^{u}\right)}{2\|T_\xi^{vu}\|}+1\right)\right]\end{bmatrix}\right);$$

$$(20)$$

$$\|T_\xi^{\mu u}\| = \begin{cases} \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(t_{ij}^{+\mu u}-t_{ij}^{-\mu u}\right)}{2} & \text{if } t_{ij}^{+\mu u} \geq t_{ij}^{-\mu u} \\ \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(t_{ij}^{+\mu u}-t_{ij}^{-\mu u}\right)}{2}-2\left(t_{rh}^{+\mu u}-t_{11}^{+\mu u}\right) & \text{if } t_{ij}^{+\mu u} < t_{ij}^{-\mu u} \end{cases};$$

$$(21)$$

$$\|T_\xi^{\mu l}\| = \begin{cases} \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(t_{ij}^{+\mu l}-t_{ij}^{-\mu l}\right)}{2} & \text{if } t_{ij}^{+\mu l} \geq t_{ij}^{-\mu l} \\ \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(t_{ij}^{+\mu l}-t_{ij}^{-\mu l}\right)}{2}-2\left(t_{rh}^{+\mu l}-t_{11}^{+\mu l}\right) & \text{if } t_{ij}^{+\mu l} < t_{ij}^{-\mu l} \end{cases};$$

$$(22)$$

$$\|T_\xi^{vu}\| = \begin{cases} \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(t_{ij}^{+vu}-t_{ij}^{-vu}\right)}{2} & \text{if } t_{ij}^{+vu} \geq t_{ij}^{-vu} \\ \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(t_{ij}^{+vu}-t_{ij}^{-vu}\right)}{2}-2\left(t_{rh}^{+vu}-t_{11}^{+vu}\right) & \text{if } t_{ij}^{+vu} < t_{ij}^{-vu} \end{cases};$$

$$(23)$$

$$\|T_\xi^{vl}\| = \begin{cases} \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(t_{ij}^{+vl}-t_{ij}^{-vl}\right)}{2} & \text{if } t_{ij}^{+vl} \geq t_{ij}^{-vl} \\ \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(t_{ij}^{+vl}-t_{ij}^{-vl}\right)}{2}-2\left(t_{rh}^{+vl}-t_{11}^{+vl}\right) & \text{if } t_{ij}^{+vl} < t_{ij}^{-vl} \end{cases};$$

$$(24)$$

$$t_{ij}^{+\mu u}=\max_i \mu_{ij}^u, t_{ij}^{+\mu l}=\max_i \mu_{ij}^l, t_{ij}^{-\mu u}=\min_i \mu_{ij}^u, t_{ij}^{-\mu l}=\min_i \mu_{ij}^l;$$

$$(25)$$

$$t_{ij}^{+vu}=\max_i v_{ij}^u, t_{ij}^{+vl}=\max_i v_{ij}^l, t_{ij}^{-vu}=\min_i v_{ij}^u, t_{ij}^{-vu}=\min_i v_{ij}^l.$$

$$(26)$$

3.3. Calculating the distance between ∂_e and $\bar{\partial}$ based on Definition 3 with Eq. (27).

$$Dis\left(\partial_e, \bar{\partial}\right)=\sqrt{\frac{1}{2}\left(\left(\mu_{\partial_e}-\mu_{\bar{\partial}}\right)^2+\left(v_{\partial_e}-v_{\bar{\partial}}\right)^2\right)};$$

$$(27)$$

$$\bar{\partial}=\left[\prod_{e=1}^{E}\left(\mu^e\right)^{\left(1/e\right)}, 1-\prod_{e=1}^{E}\left(1-v^e\right)^{\left(1/e\right)}\right].$$

$$(28)$$

3.4. Computing the DMs' weights with Eq. (29) based on closeness to the average ideal solution.

Furthermore, Eq. (30) obtains the weight of each DM.

$$W^e=\frac{\sum_{e=1}^{E}Dis\left(\partial_e, \bar{\partial}\right)}{Dis\left(\partial_e, \bar{\partial}\right)};$$

$$(29)$$

$$w^e=\frac{W^e}{\sum_{e=1}^{E}W^e}.$$

$$(30)$$

4. Calculating the criteria weights with WASPAS method under IVIF condition.

4.1. Constructing the matrix based on the DMs' opinions and DMs' weights.

$$\tilde{\psi}_{ij}=\begin{array}{c} \\ R_1 \\ \vdots \\ R_r \end{array}\begin{array}{ccc} D_1 & \cdots & D_e \\ \begin{bmatrix} \tilde{\psi}_{11} & \cdots & \tilde{\psi}_{1e} \\ \vdots & \ddots & \vdots \\ \tilde{\psi}_{r1} & \cdots & \tilde{\psi}_{re} \end{bmatrix} \end{array}.$$

$$(31)$$

4.2. Computing the weighted sum model (WSM) and weighted product model (WPM) with Eqs (32) and (33), respectively.

$$\tilde{\varsigma}_i=\sum_{e=1}^{E}w^e\tilde{\psi}_{ie};$$

$$(32)$$

$$\tilde{\varphi}_i=\prod_{e=1}^{E}w^e\tilde{\psi}_{ie}.$$

$$(33)$$

4.3. Obtaining the aggregated measure of the WASPAS approach for each criterion with Eq. (34).

$$\tilde{\varrho}_i=\iota\times\tilde{\varphi}_i+\left(1-\iota\right)\times\tilde{\varsigma}_i,$$

$$(34)$$

where ι is the aggregating coefficient of decision accuracy. It is extended to approximate the precision of WASPAS based on primary criteria identity and when $\iota \in [0,1]$. In addition, when $\iota=0$, and $\iota=1$, WASPAS is changed to the WPM and the WSM, respectively. In this paper, ι equals 0.5.

5. Aggregating the normalized decision matrix with weights of the DMs based on Definition 5.

$$\tilde{\tau}_{ij}=\bigoplus_{e=1}^{E}w^e\eta_{ij}^e=$$

$$\left(\left[1-\prod_{e=1}^{E}\left(1-\mu_{ij}^{\eta el}\right)^{w^e}, 1-\prod_{e=1}^{E}\left(1-\mu_{ij}^{\eta eu}\right)^{w^e}\right], \left[\prod_{e=1}^{E}v_{ij}^{\eta el^{w^e}}, \prod_{e=1}^{E}v_{ij}^{\eta eu^{w^e}}\right]\right).$$

$$(35)$$

6. Computing the weighted normalized decision matrix with Eq. (36).

$$\tilde{\pi}_{ij}=\tilde{\varrho}_i\otimes\tilde{\tau}_{ij}=\begin{bmatrix} \tilde{\varrho}_1\otimes\tilde{\tau}_{11} & \cdots & \tilde{\varrho}_1\otimes\tilde{\tau}_{1h} \\ \vdots & \ddots & \vdots \\ \tilde{\varrho}_r\otimes\tilde{\tau}_{r1} & \cdots & \tilde{\varrho}_r\otimes\tilde{\tau}_{rh} \end{bmatrix}.$$

$$(36)$$

7. Calculating the border approximation area vector $\tilde{\chi}_i$ with Eq. (37).

$$\tilde{\chi}_i = \left[\tilde{\chi}_1, \ldots, \tilde{\chi}_r\right];\tag{37}$$

$$\tilde{\chi}_i = \left[\prod_{j=1}^{h}\left(\mu_{ij}^l\right)^{\left(1/h\right)}, \prod_{j=1}^{h}\left(\mu_{ij}^u\right)^{\left(1/h\right)}\right], \left[1 - \prod_{j=1}^{h}\left(1 - v_{ij}^l\right)^{\left(1/h\right)}, 1 - \prod_{j=1}^{h}\left(1 - v_{ij}^u\right)^{\left(1/h\right)}\right].\tag{38}$$

8. Calculating the IVIF-RPR of each alternative with Eqs (39)–(46).

$$A_{ij} = \begin{bmatrix} \Delta_{P^*}\left(\tilde{\pi}_{11}, \overline{\tilde{\chi}}_1\right) & \cdots & \Delta_{P^*}\left(\tilde{\pi}_{1h}, \overline{\tilde{\chi}}_h\right) \\ \vdots & \ddots & \vdots \\ \Delta_{P^*}\left(\tilde{\pi}_{r1}, \overline{\tilde{\chi}}_1\right) & \cdots & \Delta_{P^*}\left(\tilde{\pi}_{rh}, \overline{\tilde{\chi}}_h\right) \end{bmatrix};\tag{39}$$

$$Q_{ij} = \Delta_{P^*}\left(\tilde{\pi}_{ij}, \overline{\tilde{\chi}}_i\right) = \frac{1}{2}\left[\Delta_{P^*}\left(\tilde{\pi}_{ij}^l, \overline{\tilde{\chi}}_i^l\right) + \Delta_{P^*}\left(\tilde{\pi}_{ij}^u, \overline{\tilde{\chi}}_i^u\right)\right] =$$

$$\left(\begin{bmatrix} \frac{1}{2}\left[\frac{1}{2}\left(\frac{\left(\mu_{ij}^l - \overline{\mu}_{ij}^l\right)}{2\left\|R_\xi^{\mu l}\right\|} + 1\right) + \frac{1}{2}\left(\frac{\left(\mu_{ij}^u - \overline{\mu}_{ij}^u\right)}{2\left\|R_\xi^{\mu u}\right\|} + 1\right)\right], \\ \frac{1}{2}\left[\frac{1}{2}\left(\frac{\left(v_{ij}^l - \overline{v}_{ij}^l\right)}{2\left\|R_\xi^{v l}\right\|} + 1\right) + \frac{1}{2}\left(\frac{\left(v_{ij}^u - \overline{v}_{ij}^u\right)}{2\left\|R_\xi^{v u}\right\|} + 1\right)\right] \end{bmatrix}\right);\tag{40}$$

$$\left\|R_\xi^{\mu u}\right\| = \begin{cases} \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(r_{ij}^{+\mu u} - r_{ij}^{-\mu u}\right)}{2} & \text{if } r_{ij}^{+\mu u} \geq r_{ij}^{-\mu u} \\ \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(r_{ij}^{+\mu u} - r_{ij}^{-\mu u}\right)}{2} - 2\left(r_{rh}^{+\mu u} - r_{11}^{+\mu u}\right) & \text{if } r_{ij}^{+\mu u} < r_{ij}^{-\mu u} \end{cases};\tag{41}$$

$$\left\|R_\xi^{\mu l}\right\| = \begin{cases} \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(r_{ij}^{+\mu l} - r_{ij}^{-\mu l}\right)}{2} & \text{if } r_{ij}^{+\mu l} \geq r_{ij}^{-\mu l} \\ \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(r_{ij}^{+\mu l} - r_{ij}^{-\mu l}\right)}{2} - 2\left(r_{rh}^{+\mu l} - r_{11}^{+\mu l}\right) & \text{if } r_{ij}^{+\mu l} < r_{ij}^{-\mu l} \end{cases};\tag{42}$$

$$\left\|R_\xi^{v u}\right\| = \begin{cases} \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(r_{ij}^{+v u} - r_{ij}^{-v u}\right)}{2} & \text{if } r_{ij}^{+v u} \geq r_{ij}^{-v u} \\ \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(r_{ij}^{+v u} - r_{ij}^{-v u}\right)}{2} - 2\left(r_{rh}^{+v u} - r_{11}^{+v u}\right) & \text{if } r_{ij}^{+v u} < r_{ij}^{-v u} \end{cases};\tag{43}$$

$$\left\|R_\xi^{v l}\right\| = \begin{cases} \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(r_{ij}^{+v l} - r_{ij}^{-v l}\right)}{2} & \text{if } r_{ij}^{+v l} \geq r_{ij}^{-v l} \\ \dfrac{\sum_{i=1}^{r}\sum_{j=1}^{h}\left(r_{ij}^{+v l} - r_{ij}^{-v l}\right)}{2} - 2\left(r_{rh}^{+v l} - r_{11}^{+v l}\right) & \text{if } r_{ij}^{+v l} < r_{ij}^{-v l} \end{cases};\tag{44}$$

$$r_{ij}^{+\mu u} = \max_i \mu_{ij}^u, r_{ij}^{+\mu l} = \max_i \mu_{ij}^l, r_{ij}^{-\mu u} = \min_i \mu_{ij}^u, r_{ij}^{-\mu u} = \min_i \mu_{ij}^l;\tag{45}$$

$$r_{ij}^{+v u} = \max_i v_{ij}^u, r_{ij}^{+v l} = \max_i v_{ij}^l, r_{ij}^{-v u} = \min_i v_{ij}^u, r_{ij}^{-v u} = \min_i v_{ij}^l.\tag{46}$$

9. Obtaining the final value of each alternative with Eq. (47).

$$\rho_j = \sum_{i=1}^{r}\Delta_{P^*}\left(\tilde{\pi}_{ij}, \overline{\tilde{\chi}}_i\right).\tag{47}$$

10. Calculating the distance between ρ_j and $\overline{\rho}$ based on Definition 3 with Eq. (48).

$$Dis\left(\rho_j, \overline{\rho}\right) = \sqrt{\frac{1}{2}\left(\left(\mu_{\rho_j} - \mu_{\overline{\rho}}\right)^2 + \left(v_{\rho_j} - v_{\overline{\rho}}\right)^2\right)};\tag{48}$$

$$\overline{\rho} = \left[\prod_{j=1}^{h}\left(\mu^j\right)^{\left(1/h\right)}, 1 - \prod_{j=1}^{h}\left(1 - v^j\right)^{\left(1/h\right)}\right].\tag{49}$$

11. Computing the final value to rank alternatives with Eq. (50). Also, the alternatives are ranked in descending order.

$$C^j = \frac{\sum_{j=1}^{h}Dis\left(\rho_j, \overline{\rho}\right)}{Dis\left(\rho_j, \overline{\rho}\right)}.\tag{50}$$

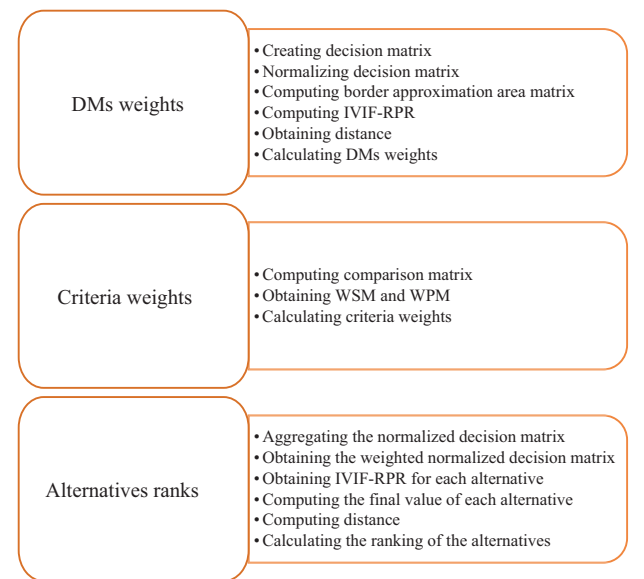Furthermore, the structure of the introduced method is presented in Figure 1.

Figure 1. Structure of the proposed IVIF decision-making model

3. Case study

This section examines a real-case study of the railway construction projects in Serbia based on the literature (Belošević et al., 2018) to show the performance of the introduced model in the selection and evaluation of the IP problem. This case is related to the railway of Pančevo-Vršac; this rail line is depicted in Figure 2. The railway line can be utilized to help people to transfer among two far nodes, and this line aids the persons to travel to the cities that are located among source and destination nodes easily. In this regard, this study applies 7 types of criteria, 3 DMs, and 4 different alternatives.
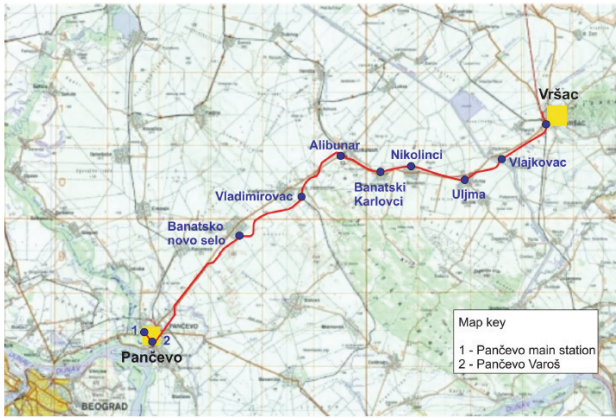
Figure 2. Railway line of Pančevo-Vršac

Hence, D_1 has an experience in railroad frameworks and alignment design, D_2 has an expertise in railway practice and transportation economics, and D_3 has a skill in spatial planning and environmental conservation. Also, the main criteria are included financial provisions (R_1), quality of the rail service (R_2), safety performance (R_3), risks of the project (R_4), transportation politics (R_5), economic impacts (R_6), and environmental effect (R_7). The first and fourth criteria have a cost nature and their others have a benefits nature. The first alternative (M_2) introduces setting all residual railroads equipped with signs and some type of safety tool. The second (M_3) alternative proposes setting all residual railroads equipped with obstacles and alarms as active traffic control systems. The third alternative (M_4) considers setting all railroads at a separated rating. The (M_1) is relevant to the lowest rank alternative

that is called the do-nothing alternative. Afterward, linguistic variables are applied to evaluate the alternatives in Table 1. This table provides the linguistic variables in five scales for judging the main alternatives of the problem based on three DMs' opinions. Moreover, the linguistic terms are considered in another scale to assess the problem criteria with an opinion of each DM in Table 2. For this reason, Table 2 provides these five measures to compute the assessment value of each criterion (Hajek & Froelich, 2019).

The decision matrix based on linguistic judgment is presented in Table 3. This table provides the decision matrix and rating of each alternative with respect to each criterion by DMs with the linguistic terms. Furthermore, the linguistic comparison between criteria and experts' judgment is given in Table 4. These are completed with the experts' opinions that are received from their experiences and knowledge. The judgments of Table 3 are provided from VW to VS, and the judgments based on DMs opinions in Table 4 are presented from VL to VH by five scales.

Table 1. Linguistic phrases for assessing the alternatives

Linguistic term	Value
Very strong (VS)	([0.73, 0.83], [0.00, 0.13])
Strong (S)	([0.63, 0.73], [0.10, 0.23])
Medium (M)	([0.43, 0.53], [0.30, 0.43])
Weak (W)	([0.15, 0.29], [0.45, 0.64])
Very weak (VW)	([0.00, 0.14], [0.60, 0.79])

Table 2. Linguistic values for assessing the criteria

Linguistic term	Value
Very high (VH)	([0.90, 0.90], [0.10, 0.10])
High (H)	([0.40, 0.76], [0.00, 0.21])
Medium (M)	([0.15, 0.51], [0.25, 0.46])
Low (L)	([0.00, 0.36], [0.40, 0.61])
Very low (VL)	([0.10, 0.10], [0.90, 0.90])

Table 3. Rating of alternatives with regard to criteria evaluated by DMs

Alternatives	DMs	R_1	R_2	R_3	R_4	R_5	R_6	R_7
M_1	D_1	W	VW	VW	S	W	W	W
M_2		VS	W	S	VS	VW	S	W
M_3		M	S	M	S	S	M	W
M_4		VW	VS	VS	VW	M	VS	VW
M_1	D_2	W	VW	W	S	W	VW	W
M_2		VS	W	W	S	W	W	S
M_3		S	S	S	M	VS	S	M
M_4		M	VS	VS	W	S	VS	W
M_1	D_3	M	W	M	S	W	W	VW
M_2		S	M	S	S	W	M	S
M_3		S	S	F	S	S	S	W
M_4		W	S	W	W	S	S	VW

Table 4. Importance of criteria evaluated by DMs

Criteria	D_1	D_2	D_3
R_1	VH	H	M
R_2	H	VH	M
R_3	H	VH	H
R_4	VH	M	VL
R_5	H	VH	M
R_6	M	VH	L
R_7	M	L	VH

Table 5. Normalized decision matrix

Alternatives	DMs	R_1	R_2	R_3	R_4	R_5	R_6	R_7
M_1	D_1	([0.17, 0.28], [0.56, 0.58])	([0.00, 0.12], [0.79, 0.75])	([0.00, 0.11], [0.88, 0.84])	([0.55, 0.55], [0.16, 0.27])	([0.19, 0.30], [0.55, 0.57])	([0.14, 0.23], [0.82, 0.79])	([0.58, 0.56], [0.46, 0.47])
M_2		([0.85, 0.80], [0.00, 0.12])	([0.15, 0.25], [0.59, 0.61])	([0.60, 0.59], [0.15, 0.25])	([0.63, 0.62], [0.00, 0.15])	([0.00, 0.15], [0.74, 0.70])	([0.59, 0.58], [0.18, 0.28])	([0.58, 0.56], [0.46, 0.47])
M_3		([0.50, 0.51], [0.37, 0.39])	([0.65, 0.63], [0.13, 0.22])	([0.41, 0.43], [0.44, 0.46])	([0.55, 0.55], [0.16, 0.27])	([0.81, 0.76], [0.12, 0.20])	([0.40, 0.42], [0.55, 0.53])	([0.58, 0.56], [0.46, 0.47])
M_4		([0.00,0.14], [0.74,0.71])	([0.75, 0.72], [0.00, 0.12])	([0.69, 0.67], [0.00, 0.14])	([0.00, 0.11], [0.97, 0.91])	([0.55, 0.55], [0.37, 0.38])	([0.68, 0.66], [0.00, 0.16])	([0.00, 0.27], [0.61, 0.58])
M_1	D_2	([0.14, 0.23], [0.82, 0.79])	([0.00, 0.12], [0.79, 0.75])	([0.15, 0.25], [0.70, 0.68])	([0.63, 0.61], [0.18, 0.27])	([0.15, 0.25], [0.70, 0.68])	([0.00, 0.12], [0.79, 0.75])	([0.19, 0.29], [0.63, 0.62])
M_2		([0.68, 0.66], [0.00, 0.16])	([0.15, 0.25], [0.59, 0.61])	([0.15, 0.25], [0.70, 0.68])	([0.63, 0.61], [0.18, 0.27])	([0.15,0.25], [0.70,0.68])	([0.15, 0.25], [0.59, 0.61])	([0.80, 0.74], [0.14, 0.22])
M_3		([0.59, 0.58], [0.18, 0.28])	([0.65, 0.63], [0.13, 0.22])	([0.64, 0.62], [0.16, 0.24])	([0.43, 0.44], [0.54, 0.51])	([0.74, 0.70], [0.00, 0.14])	([0.65, 0.63], [0.13, 0.22])	([0.54, 0.53], [0.42, 0.42])
M_4		([0.40, 0.42], [0.55, 0.53])	([0.75, 0.72], [0.00, 0.12])	([0.74, 0.70], [0.00, 0.14])	([0.15, 0.24], [0.80, 0.76])	([0.64, 0.62], [0.16, 0.24])	([0.75, 0.72], [0.00, 0.12])	([0.19, 0.29], [0.63, 0.62])
M_1	D_3	([0.43, 0.44], [0.54, 0.51])	([0.15, 0.24], [0.80, 0.76])	([0.48, 0.49], [0.48, 0.47])	([0.57, 0.56], [0.21, 0.31])	([0.16, 0.26], [0.69, 0.67])	([0.15, 0.24], [0.80, 0.76])	([0.00,0.17], [0.62,0.60])
M_2		([0.63, 0.61], [0.18, 0.27])	([0.43, 0.44], [0.54, 0.51])	([0.71, 0.67], [0.16, 0.25])	([0.57, 0.56], [0.21, 0.31])	([0.16, 0.26], [0.69, 0.67])	([0.43, 0.44], [0.54, 0.51])	([0.97, 0.90], [0.10, 0.18])
M_3		([0.63, 0.61], [0.18, 0.27])	([0.63, 0.61], [0.18, 0.27])	([0.48, 0.49], [0.48, 0.47])	([0.57, 0.56], [0.21, 0.31])	([0.69, 0.66], [0.15, 0.24])	([0.63, 0.61], [0.18, 0.27])	([0.23, 0.36], [0.47, 0.49])
M_4		([0.15, 0.24], [0.80, 0.76])	([0.63, 0.61], [0.18, 0.27])	([0.17, 0.27], [0.72, 0.70])	([0.14, 0.22], [0.93, 0.85])	([0.69,0.66], [0.15,0.24])	([0.63, 0.61], [0.18, 0.27])	([0.00, 0.17], [0.62, 0.60])

In this regard, Table 5 presents the normalized decision matrix that is computed with Eq. (17). In this formulation, the normalized decision matrix is computed based on the membership and non-membership degrees with lower bound and upper bound values separately. After that, a distance and a weight of DMs are computed with Eqs (27), (29), and (30) that are generated in Table 6. In this regard, the distance value, $Dis(\partial_e, \overline{\partial})$, is presented based on Euclidean distance formulation, and is computed from the opinion of the DMs. Further W^e more, w^e are the values of the normalized weights that are computed from each W^e value divided on the summation of W^e values. As can be seen, the second DM has a high priority than others, and the opinion is superior to others. This person has expertise in railway practice and transportation economics.

Also, the amounts of $\tilde{\varsigma}_i$, and $\tilde{\varrho}_i$ are presented in Table 7. The WSM is computed from the weighted decision matrix with aggregating opinions of the DMs. Therefore, the aggregation of WASPAS value $\tilde{\varrho}_i$ is obtained from integrating the WSM and WPM with a specific procedure. These are computed from Eqs (32) and (34). The IVIF criteria weights show that the third criterion with higher membership degree and lower non-membership value has a great value than other criteria. This criterion is related to safety performance.

In addition, the IVIF-RPR of each alternative (Q_{ij}) is depicted in Table 8 that is computed with Eq. (40). Afterward, final alternatives values (ρ_j), $Dis(\rho_j, \overline{\rho})$, and C^j are introduced in Table 9 that are obtained from Eqs (47), (48), and (50), respectively. The distance measure $(Dis(\rho_j, \overline{\rho}))$ aggregates the fuzzy values and changes them to the crisp quantity. In this respect, the distance computation formulation is presented from Euclidean procedure. Finally, the collective measure index (C^j) shows the ranking score of the alternatives.

Table 6. Weights of the DMs

DMs	$Dis(\partial_e, \overline{\partial})$	W^e	w^e
D_1	0.55	3.47	0.37
D_2	0.52	3.67	0.39
D_3	0.84	2.28	0.24

Table 7. Criteria weights

Criteria	$\tilde{\varsigma}_i$	$\tilde{\varrho}_i$
R_1	([0.52, 0.75], [0.10, 0.23])	([0.26, 0.38], [0.05, 0.12])
R_2	([0.53, 0.75], [0.10, 0.23])	([0.27, 0.38], [0.05, 0.11])
R_3	([0.59, 0.81], [0.04, 0.17])	([0.30, 0.42], [0.02, 0.08])
R_4	([0.41, 0.55], [0.35, 0.43])	([0.21, 0.28], [0.18, 0.22])
R_5	([0.53, 0.75], [0.10, 0.23])	([0.27, 0.38], [0.05, 0.11])
R_6	([0.41, 0.63], [0.23, 0.36])	([0.20, 0.32], [0.11, 0.18])
R_7	([0.27, 0.55], [0.27, 0.43])	([0.14, 0.28], [0.14, 0.22])

Table 8. Amount of Q_{ij}

Alternatives	R_1	R_2	R_3	R_4	R_5	R_6	R_7
M_1	[1.08, 1.07]	[1.03, 1.09]	[1.08, 1.05]	[1.11, 1.06]	[1.06, 1.07]	[1.03, 1.16]	[1.06, 1.03]
M_2	[1.19, 1.01]	[1.08, 1.06]	[1.15, 1.02]	[1.12, 1.03]	[1.04, 1.08]	[1.09, 1.08]	[1.13, 1.06]
M_3	[1.15, 1.03]	[1.17, 1.02]	[1.15, 1.02]	[1.10, 1.08]	[1.19, 1.01]	[1.12, 1.06]	[1.08, 1.11]
M_4	[1.06, 1.07]	[1.19, 1.01]	[1.17, 1.01]	[1.03, 1.24]	[1.16, 1.03]	[1.14, 1.02]	[1.03, 1.15]

Table 9. Ranking of the alternatives

Alternatives	ρ_j	$Dis\left(\rho_j,\bar{\rho}\right)$	C^j	Final ranking values
M_1	[7.45, 7.62]	9.254	3.950	4
M_2	[7.80, 7.35]	9.057	4.035	2
M_3	[7.96, 7.34]	9.054	4.037	1
M_4	[7.79, 7.53]	9.184	3.980	3

Table 10. Comparing the score values among three IVIF decision-making methods

Alternatives	Score of IVIF-E-VIKOR method	Score of IVIF-TOPSIS method	Score of the proposed approach
M_1	0.352	0.342	3.950
M_2	0.359	0.425	4.035
M_3	0.484	0.496	4.037
M_4	0.473	0.362	3.980

Table 9 determines that the third alternative has high priority than other options. This alternative is related to using the alarms and active traffic control systems in all residual railroads. The notable point is about the distance value of the alternatives that the higher distance has a lower score and has a lower rank in comparing other alternatives. The lower distance and higher score values are created from the higher membership and lower non-membership degrees in the final alternative values. Eventually, this table demonstrates that the higher membership degree has a lower non-membership value. Also, the higher degree of the membership value creates a lower distance, and the lower distance makes the high-rank value.

4. Discussion of results

This section examines the comparisons of IVIF-TOPSIS, IVIF-extended VIKOR (E-VIKOR) from the adapted case-study paper, and the proposed approach for validating the introduced model. The utilized IVIF-TOPSIS method is related to the original TOPSIS under IVIF conditions. The final values of the alternatives rank are determined in Table 10 and Figure 3. This figure is determined that the introduced model has a good performance and is validated to compute the complex problem. This figure depicts that the first alternative places in the fourth-ranking position in all decision methods. Afterward, the second alternative places in the third position by IVIF-E-VIKOR method, and locates the second position by two other computing methods. Moreover, the fourth alternative places in the second position by IVIF-E-VIKOR method, and places the third position by other approaches. Finally, the third alternative places in the first position by obtaining all three different methods.

In addition, the degree of the Δ_p has an important role in computing the weights of the DMs. For this reason, this value change from 0.1 to 0.9, and its impact on the final weights are depicted in Figure 4. This figure demonstrates that the final weights of the DMs change with the various values, but the second DM has high priority than others with a different degree. This point determines that the proposed approach is reliable. Also, this rate can be changed for the ranking proposed approach that is used in Eq. (40). The value of Δ_p changes among 0.1 to 0.9, and their influences are demonstrated in Figure 5. This figure present that the third alternative has a high priority than other with various amount of Δ_p. In this regard, the value of adjustment measure changes among interval values, and the final results denote that the third alternative has high priority and degree than other alternatives. The ranking method is compared in two ways, and all of them show that the proposed model is reliable and robust.
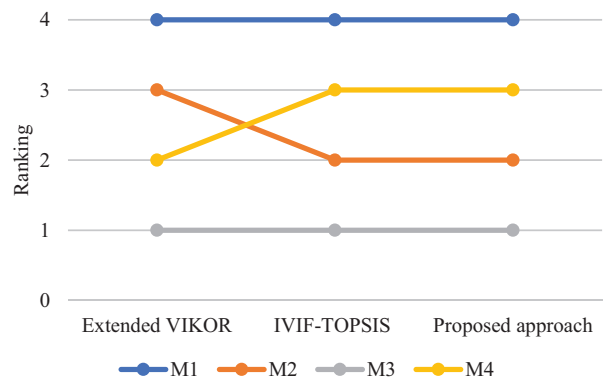

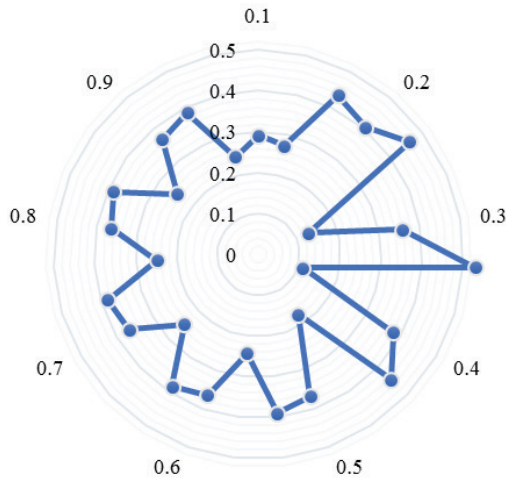Figure 3. Comparisons of the rankings among three IVIF decision methods

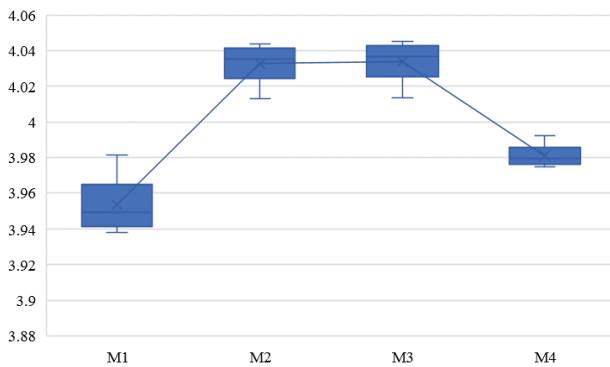Figure 4. Effect of changing Δ_p value in the weighting method

Figure 5. Effect of changing Δ_p value in the ranking approach

Conclusion and further suggestions

Infrastructure projects (IPs) are one of the most important issues that have fundamental effects on the quality of the lives of people in the community. In this way, the transportation system and the construction have a high position to transfer people. Introducing construction projects into infrastructure fields has been highly motivated by the government as an effective manner to evaluate and select a sustainable alternative. In this regard, multi-criteria decision-making (MCDM) techniques were developed to support the selection and evaluation alternatives in the IPs. This paper presented a new hybrid weighting and ranking approach to compute the decision makers (DMs) weights, criteria weights, and alternatives ranks, respectively. These formulations consisted of new relative preference relation-multi-attributive border approximation area comparison (RPR-MABAC), weighted aggregated sum product assessment (WASPAS), and new RPR-MABAC approaches. The first method was used to obtain the DMs' weights, and the second approach was utilized to obtain the criteria weights. The RPR was one of the computation approaches used in the border approximation area matrix. For this reason, the preference degree was obtained to

compute the RPR degree. Also, WASPAS method was the distance-based method that combined the weighted sum model (WSM) and the weighted product model (WPM). Afterward, new combination ranking approach was presented to rank alternatives. This method was developed based on using the RPR degree. Moreover, this decision approach was developed in interval-valued intuitionistic (IVIF) conditions for increasing real-world application situations. Hence, a real case study of Serbia railway was applied from the literature to validate the proposed model. The final results determined that the introduced approach had high performance to compute the complex project decision, and the third alternative had superior value to others. Finally, the comparative analysis was introduced to determine the performance of the proposed approach. For this reason, the proposed model was compared with two IVIF-TOPSIS method and IVIF-extended VIKOR approaches. The final results of these three methods were similar and confirmed the performance and validation of the proposed approach. Furthermore, the sensitivity analysis was introduced based on the study of the effect of Δ_p on the final weighting outcomes and final ranking results. The discussion of results demonstrated that the final result of the proposed model was reliable in various conditions. Also, all of the outcomes showed that the proposed approach had a high performance to take an appropriate decision by managers and DMs in the real complex IP problems.

For the managerial insights based on the case study, this paper denotes that managers and DMs can utilize this proposed approach to solve MCDM problems in various types under uncertainty. In complex decision-making concerns, when uncertainties require to be taken, this proposed model contains some advantages; they contain maintaining simple mathematical computations and constant outcomes, considering benefit and cost values for information in the model, and high accuracy of solving the decision problem by regarding conditions of uncertainty. Practical characteristics can be considered by the proposed decision model that include infrastructure problems, construction problems, investment project assessment, and other related topics. In typical usages, managers can choose suitable criteria relevant to their requirements and assess the performance values of alternatives. When the proposed model is utilized to demonstrate the criteria weights, linguistic values can better represent the selection data of DMs for criteria and find a compatible model via pairwise comparisons to get the proper weights of criteria. Also, the proposed method can enhance the decision-making precision when selecting the suitable alternative and is appropriate for complex types of problems under uncertainty.

For future suggestions, the presented approach can be developed by various types of extended fuzzy sets approaches, like hesitant fuzzy sets, to deal with uncertain situations. Furthermore, it can be implemented by a decision support system (DSS) in several positions for solving complex MCDM problems.

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Author contributions

S. Salimain and S. M. Mousavi designed the research, analyzed the data and the obtained results and developed the manuscript. J. Antuchevičienė provided extensive advice throughout the study regarding the research design, methodology and findings. All the authors have read and approved the final manuscript.

Disclosure statement

The authors declare that they have any competing financial, professional, or personal interests from other parties.

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