A novel hierarchical dynamic group decision-based fuzzy ranking approach to evaluate the green road construction suppliers

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Abstract

In recent years, sustainable development and environmental protection are getting more attention in construction projects. Hence, green road construction (GRC) supplier selection problem is the main key for organizations to grow their environmental and economical performances. Accordingly, a new hierarchical group decision fuzzy ranking framework is presented based on dynamic interval-valued hesitant fuzzy numbers (DIVHFN) and last aggregation approach to select the most appropriate GRC supplier. Thereby, DIVHFN theory and last aggregation concept could decrease the judgmental errors and data loss, respectively. Moreover, the weight of each criterion is obtained by proposing a new dynamic interval-valued hesitant fuzzy maximize deviation from ideal decision (DIVHF-MD$_f$ID) method. Furthermore, the experts' weight is determined by presenting a dynamic interval-valued hesitant fuzzy preference assessment (DIVHF-PA) method. Besides, to reach precise weights the opinions of experts are included in criteria/sub-criteria weights computations. Meanwhile, an actual case regarding GRC supplier evaluation and selection problem for a construction project is provided to detect the implementation process of the proposed approach. Finally, some comparative and sensitivity analysis are performed to confirm the validation and verification of the presented DIVHF-hierarchical group decision (DIVHF-HGD) approach.

***Keywords*:** Construction projects; GRC supplier selection; Dynamic fuzzy sets; Group decision analysis; Environmental competencies.

1. Introduction

Environmental management is a main issue for construction projects to increase the stockholders' satisfaction includes organizational stakeholders, employees, customers, governments, communities, and competitors [1]. Meanwhile, some plans/frameworks as life cycle assessment, green supply chain management, ISO 14000 standards, and total quality environmental management are designed to appropriately analyze the environmental process for avoiding the environmentally nonconformity [2]. In this respect, the companies/organizations should consider the environmental competencies in primary levels of construction projects to prevent the costs of irregularities [3]. Therefore, these companies should focus on the green road construction (GRC) that meets the environmental standards/regulations [4]. Furthermore, selecting an appropriate GRC project can play a main role for their successfulness in long-term performances regarding the environmental competencies.

On the other hand, assessing and selecting the candidate GRC suppliers is inherently complex group decision problems. Accordingly, choosing the most appropriate GRC project should be determined during the assessment of candidate GRC suppliers under important conflicted attributes according to environmental competencies [5]. Thus, one of the most powerful tools that could deal with GRC supplier evaluation and selection problems is decision making approach [6]. Consequently, the evaluating and ranking process of the GRC suppliers problems could be considered as a decision making issue that includes both objective and subjective factors [7]. In this respect, establish a group of decision makers/experts could assist the users to reach a reliable/precise solution regarding the comprehensive analysis of the problem. Therefore, this perspective of addressing the evaluation and selection problem is leaded to utilize the group decision-making approach [8].

Furthermore, in some practical applications, the uncertainty of group decision problems under complex situations is high, in which decision makers could assigned their opinions based on incomplete information [9]. Indeed, assessing the candidate GRC suppliers based on deterministic information is intangible and should express under uncertainty environment. To address the issue, one the main tool which could be considered is the fuzzy set theories and their extensions. Hence, some authors focused on construction projects problems regarding to decision making approaches under complete/incomplete information.

Meanwhile, Lu et al. [10] elaborated a group decision-making technique conforming to the fuzzy hierarchical to assess and rank a set of product prototypes. Tsai [11] surveyed on selecting and evaluating criteria for GRC based on fuzzy decision making tool. Oh et al. [12] presented a decision technique under fuzzy conditions to deal with project portfolio management problem. Hence, Cho and Lee [13] recognized the success factors of construction projects in commercialization opportunities field and then evaluated based on Delphi and fuzzy analytic hierarchy process (AHP) framework. Driessen et al. [14] extended an integrative model for GRC regarding the recent literature and to implement the proposed approach in real-life problem. In addition, Marmier et al. [15] tailored an integral procedure regarding the comprise design, risk management and project management for taking a strategic decision in construction projects. Lin et al. [16] proposed an aggregated multi-stage construction project framework by means of fuzzy interpretive structural modeling, fuzzy analytic network process, quality function deployment, fuzzy failure mode and effects analysis (FFMEA), and goal programming model.

Furthermore, Büyüközkan and Güleryüz [17] manipulated an aggregated methodology using evaluating group decision, AHP methodology, and TOPSIS approach to deal with the construction projects selection issue under intuitionistic fuzzy conditions. Akhavan et al. [18]

developed a mathematical fuzzy bi-objective programming model by aims of maximizing the expertise of construction project team members and optimizing the knowledge sharing, simultaneously. In addition, Afrouzy et al. [19] proposed a fuzzy stochastic multi-objective model for multi-period supply chain configuration regarding construction problems. Relich and Pawlewski [20] presented a novel technique for portfolio selection based on fuzzy average approach and artificial neural network to rank the construction projects and to predict their performance, respectively. Abu et al. [21] identified the barriers and critical success factors for GRC implementation among the small and medium enterprise firms. Thereby, Oliveira et al. [22] recognized 16 green and lean enablers for GRC operations that are assessed by means of AHP and fuzzy TOPSIS techniques. Pun et al. [23] implemented a fuzzy integrated FFMEA to minimize the NPD risks and shorten time to market in high tech industry. However, to demonstrate recent researches trends and detect the literature gap, the literature review is briefed and presented in Table 1.

{Please insert here Table 1}

One of the powerful tools that could cope with uncertain situation among fuzzy sets theories is dynamic interval-valued hesitant fuzzy numbers (DIVHFN). DIVHFN that is originally presented by Peng and Wang [39], allows the decision makers to assigned interval-values to a criterion in each period to decrease the judgmental errors. In this research, a new group decision making approach is designed via using DIVHF information to address the GRC supplier evaluation and selection issue. In addition, the weight of each decision maker and criterion is obtained via the proposed dynamic interval-valued hesitant fuzzy preference assessment (DIVHF-PA) and dynamic interval-valued hesitant fuzzy maximize deviation from ideal decision (DIVHF-MD$_f$ID) methods, respectively. Hence, decision makers' opinions about the GNPD projects assessment are aggregated in final step to avoid the data loss that is called last aggregation process. In sums, the advantages and merits of this research regarding the literature are represented as following:

- Considers the hierarchical structure in GRC suppliers evaluation;
- Proposes DIVHF-MD$_f$ID method to compute the criteria weights;
- Presents DIVHF-PA method to detect the weight of each expert;
- Ranks the candidates based on proposed DIVHF-hierarchical group decision (DIVHF-HGD) method;
- Considers the experts' judgments last aggregation to prevent the data loss.

The structure of this paper is as following: in part 2, the proposed DIVHF-HGD approach is presented for evaluation and selection of the GRC suppliers problem. Then, a real case study about the GRC supplier evaluation and selection in construction projects is presented in section3, to confirm the verification and application of the proposed method. In part 4, the proposed approach is compared with literature to demonstrate the credibility of the introduced DIVHF-HGD method. In addition, a sensitivity evaluation is provided in section 5 to carry out the robustness and sensitiveness of the obtained results. Eventually, concluding consideration and suggestions for future studies are provided in part 6.

2. Introduced DIVHF-HGD method

In this segment, an assessment technique is proposed conforming to the expert system approach and then the output of the presented expert system, that is DIVHF decision matrix, is prepared as ranking's input data. Meanwhile, the experts' weights and criterions' importance are computed according to the extended approaches under IVHFN. Afterwards, the potential options are selected conforming to a developed ranking approach under imprecise information. The visualization of the introduced technique is visualized in Figure 1.

2.1. Introduced appraisal method

In this segment, an extended expert system technique is presented for assessing the green road construction supplier selection problems. In this respect, a team of experts $\left(DM_k, k=1,2,...,K\right)$ is founded for evaluating the green road construction suppliers $\left(S_i, i=1,2,....,m\right)$ according to the selected criteria $\left(Q_J, J=1,2,....,n\right)$ and sub-criteria $\left(Q_j, j=1,2,....,n'\right)$. Moreover, the preferences experts' opinions in each period are defined based on linguistic terms, which are provided as inputs parameters of working memory. Hence, the experts' opinions to evaluate the importance of each criterion and the grading the options are expressed conforming to the linguistic variables in Tables 2 and 3, respectively.

{Please insert here Figure 1}

{Please insert here Table 2}

{Please insert here Table 3}

Moreover, an assessment module based on rule-based approach for designing the expert system is presented. Herby, the potential candidates are evaluated based on selected helpful factors and sub-factors, which are expressed in Table 4. Moreover, the hierarchical structure of the defined criteria and sub-criteria is depicted in Figure 2.

{Please insert here Table 4}

{Please insert here Figure 2}

2.2. Proposed ranking approach

A novel ranking approach is presented in this section includes of determining the experts' weights, computing the criteria weights and rank the candidates. In this sake, the extended technique under DIVHFS environment is shown as follows:

Step 1. The DIVHF group decision matrix (DIVHF-GDM) is established according to the Introduced appraisal method as below:

$$F^{p}=\begin{matrix} \\ A_1 \\ \vdots \\ A_m \end{matrix}\overset{\begin{matrix} C_1 & \cdots & C_n \end{matrix}}{\begin{bmatrix} \left\{\left[\mu_{11}^{L1p},\mu_{11}^{U1p}\right],\left[\mu_{11}^{L2p},\mu_{11}^{U2p}\right],\dots,\left[\mu_{11}^{Lkp},\mu_{11}^{Ukp}\right]\right\} & \cdots & \left\{\left[\mu_{1n}^{L1p},\mu_{1n}^{U1p}\right],\left[\mu_{1n}^{L2p},\mu_{1n}^{U2p}\right],\dots,\left[\mu_{1n}^{Lkp},\mu_{1n}^{Ukp}\right]\right\} \\ \vdots & \ddots & \vdots \\ \left\{\left[\mu_{m1}^{L1p},\mu_{m1}^{U1p}\right],\left[\mu_{m1}^{L2p},\mu_{m1}^{U2p}\right],\dots,\left[\mu_{m1}^{Lkp},\mu_{m1}^{Ukp}\right]\right\} & \cdots & \left\{\left[\mu_{mn}^{L1p},\mu_{mn}^{U1p}\right],\left[\mu_{mn}^{L2p},\mu_{mn}^{U2p}\right],\dots,\left[\mu_{mn}^{Lkp},\mu_{mn}^{Ukp}\right]\right\} \end{bmatrix}_{m\times n}} \quad \forall p=1,2,\dots,P \tag{1}$$

where the DIVHF-GDM in period p is defined as F^{p} and $\left[\mu_{mn}^{Lk},\mu_{mn}^{Uk}\right]$ indicated the kth expert' judgments which assign to mth potential candidate under the nth selected criterion.

Step 2. The DIVHF-GDM should be normalize based on definition 10.

Step 3. The weights of sub-criteria are specified by using the introduced DIVHF maximize deviation from ideal decision (DIVHF-MDID) method and the preferences experts' opinions concerning criteria and sub-criteria importance. The process of the final sub-criteria weights is explained according to the following:

Step 3.1. Establish the normalized DIVHF-GDM for sub-criteria $\left(T_j^{p}\right)$ by:

$$T_j^{p}=\begin{matrix} \\ A_1 \\ \vdots \\ A_m \end{matrix}\overset{\begin{matrix} DM_1 & DM_2 & \cdots & DM_K \end{matrix}}{\begin{pmatrix} \left[\mu_{1j}^{L1p},\mu_{1j}^{U1p}\right] & \left[\mu_{1j}^{L2p},\mu_{1j}^{U2p}\right] & \cdots & \left[\mu_{1j}^{Lkp},\mu_{1j}^{Ukp}\right] \\ \vdots & \vdots & \ddots & \vdots \\ \left[\mu_{mj}^{L1p},\mu_{mj}^{U1p}\right] & \left[\mu_{mj}^{L2p},\mu_{mj}^{U2p}\right] & \cdots & \left[\mu_{mj}^{Lkp},\mu_{mj}^{Ukp}\right] \end{pmatrix}_{m\times k}} \quad \forall j,p \tag{2}$$

Step 3.2. The decision matrix of positive ideal $\left(\xi_p^{*}\right)$ is specified based on following matrix:

$$\xi_p^{*}=\left(\left[\mu_{ip}^{*Lk},\mu_{ip}^{*Uk}\right]\right)_{m\times k}=\begin{matrix} \\ A_1 \\ \vdots \\ A_m \end{matrix}\overset{\begin{matrix} DM_1 & DM_2 & \cdots & DM_K \end{matrix}}{\begin{pmatrix} \left[\mu_{1p}^{*L1},\mu_{1p}^{*U1}\right] & \left[\mu_{1p}^{*L2},\mu_{1p}^{*U2}\right] & \cdots & \left[\mu_{1p}^{*LK},\mu_{1p}^{*UK}\right] \\ \vdots & \vdots & \ddots & \vdots \\ \left[\mu_{mp}^{*L1},\mu_{mp}^{*U1}\right] & \left[\mu_{mp}^{*L2},\mu_{mp}^{*U2}\right] & \cdots & \left[\mu_{mp}^{*LK},\mu_{mp}^{*UK}\right] \end{pmatrix}_{m\times k}} \quad \forall p \tag{3}$$

where Yue [49] expressed that the positive ideal decision in real world should be determined based on the average of individual preferences experts' judgments. Thus, the elements of positive ideal decision matrix are specified as: $\mu_{ip}^{*Lk}=\frac{1}{n}\sum_{j=1}^{n}\mu_{ij}^{Lkp}\ \ \forall i,k,p$ and $\mu_{ip}^{*Uk}=\frac{1}{n}\sum_{j=1}^{n}\mu_{ij}^{Ukp}\ \ \forall i,k,p$.

Step 3.3. The decision matrices of left negative ideal $\left(\zeta_p^{\ell-}\right)$ and the right negative ideal $\left(\zeta_p^{R-}\right)$ are established according to following relations:

$$\zeta_p^{\ell-}=\left(\left[\mu_{ip}^{-\ell Lk},\mu_{ip}^{-\ell Uk}\right]\right)_{m\times k}=\begin{array}{c} \\ A_1 \\ \vdots \\ A_m\end{array}\begin{array}{c}\begin{array}{cccc} DM_1 & DM_2 & \cdots & DM_K\end{array}\\ \begin{pmatrix}\left[\mu_{1p}^{-\ell L1},\mu_{1p}^{-\ell U1}\right] & \left[\mu_{1p}^{-\ell L2},\mu_{1p}^{-\ell U2}\right] & \cdots & \left[\mu_{1p}^{-\ell LK},\mu_{1p}^{-\ell UK}\right]\\ \vdots & \vdots & \ddots & \vdots\\ \left[\mu_{mp}^{-\ell L1},\mu_{mp}^{-\ell U1}\right] & \left[\mu_{mp}^{-\ell L2},\mu_{mp}^{-\ell U2}\right] & \cdots & \left[\mu_{mp}^{-\ell LK},\mu_{mp}^{-\ell UK}\right]\end{pmatrix}_{m\times k}\end{array}\quad \forall p \tag{4}$$

$$\mu_{ip}^{-\ell Lk}=\min_j\left\{\mu_{ij}^{Lkp}\in T_j^{\,p}\mid \mu_{ij}^{Lkp}\le\mu_{ip}^{*Lk}\right\}\quad \forall i,k,p \tag{5}$$

$$\mu_{ip}^{-\ell Uk}=\max_j\left\{\mu_{ij}^{Ukp}\in T_j^{\,p}\mid \mu_{ij}^{Ukp}\le\mu_{ip}^{*Uk}\right\}\quad \forall i,k,p \tag{6}$$

$$\zeta_p^{R-}=\left(\left[\mu_{ip}^{-RLk},\mu_{ip}^{-RUk}\right]\right)_{m\times k}=\begin{array}{c} \\ A_1 \\ \vdots \\ A_m\end{array}\begin{array}{c}\begin{array}{cccc} DM_1 & DM_2 & \cdots & DM_K\end{array}\\ \begin{pmatrix}\left[\mu_{1p}^{-RL1},\mu_{1p}^{-RU1}\right] & \left[\mu_{1p}^{-RL2},\mu_{1p}^{-RU2}\right] & \cdots & \left[\mu_{1p}^{-RLK},\mu_{1p}^{-RUK}\right]\\ \vdots & \vdots & \ddots & \vdots\\ \left[\mu_{mp}^{-RL1},\mu_{mp}^{-RU1}\right] & \left[\mu_{mp}^{-RL2},\mu_{mp}^{-RU2}\right] & \cdots & \left[\mu_{mp}^{-RLK},\mu_{mp}^{-RUK}\right]\end{pmatrix}_{m\times k}\end{array}\quad \forall p \tag{7}$$

$$\mu_{ip}^{-RLk}=\min_j\left\{\mu_{ij}^{Lkp}\in T_j^{\,p}\mid \mu_{ij}^{Lkp}\ge\mu_{ip}^{*Lk}\right\}\quad \forall i,k,p \tag{8}$$

$$\mu_{ip}^{-RUk}=\max_j\left\{\mu_{ij}^{Ukp}\in T_j^{\,p}\mid \mu_{ij}^{Ukp}\ge\mu_{ip}^{*Uk}\right\}\quad \forall i,k,p \tag{9}$$

Step 3.4. The separation measure from decision matrices of positive ideal $\left(\gamma_j^{*p}\right)$, left negative ideal $\left(\gamma_j^{\ell p}\right)$, and right negative ideal $\left(\gamma_j^{Rp}\right)$, respectively, are determined as follows:

$$\gamma_j^{*p}=\sqrt{\frac{1}{2l_{x_i}}\sum_{i=1}^{m}\sum_{k=1}^{K}\sum_{\lambda=1}^{l_{x_i}}\left(\left|\mu_{ip}^{Lk\sigma(\lambda)}-\mu_{ip}^{*Lk\sigma(\lambda)}\right|^2+\left|\mu_{ip}^{Uk\sigma(\lambda)}-\mu_{ip}^{*Uk\sigma(\lambda)}\right|^2\right)}\quad \forall j,p \tag{10}$$

$$\gamma_j^{\ell p}=\sqrt{\frac{1}{2l_{x_i}}\sum_{i=1}^{m}\sum_{k=1}^{K}\sum_{\lambda=1}^{l_{x_i}}\left(\left|\mu_{ip}^{Lk\sigma(\lambda)}-\mu_{ip}^{-\ell Lk\sigma(\lambda)}\right|^2+\left|\mu_{ip}^{Uk\sigma(\lambda)}-\mu_{ip}^{-\ell Uk\sigma(\lambda)}\right|^2\right)}\quad \forall j,p \tag{11}$$

$$\gamma_j^{Rp}=\sqrt{\frac{1}{2l_{x_i}}\sum_{i=1}^{m}\sum_{k=1}^{K}\sum_{\lambda=1}^{l_{x_i}}\left(\left|\mu_{ip}^{Lk\sigma(\lambda)}-\mu_{ip}^{-RLk\sigma(\lambda)}\right|^2+\left|\mu_{ip}^{Uk\sigma(\lambda)}-\mu_{ip}^{-RUk\sigma(\lambda)}\right|^2\right)}\quad \forall j,p \tag{12}$$

Step 3.5. The relative closeness coefficient of each sub-criterion $\left(C_j^{\,p}\right)$ regarding to separation measures are obtained based on following relations:

$$C_j^{\,p}=\frac{\gamma_j^{\ell p}+\gamma_j^{Rp}}{\gamma_j^{\ell p}+\gamma_j^{Rp}+\gamma_j^{*p}}\quad \forall j,p \tag{13}$$

Step 3.6. Aggregate the opinions of experts for relative importance of sub-criteria in each period $\left(\omega_j^{p}\right)$ by using definition 8 as below:

$$\omega_j^p = \frac{1}{2}\left(\prod_{k=1}^{K} (\omega_j^{Lkp})^{\frac{1}{K}} + \prod_{k=1}^{K} (\omega_j^{Ukp})^{\frac{1}{K}} \right) \quad \forall j, p \tag{14}$$

Step 3.7. The sub-criteria weights in every period $\left(\varpi_j^p\right)$ and in scheduling horizon $\left(\varpi_j\right)$ are obtained by means of closeness coefficient and experts' judgments for importance of sub-criteria regarding to proposed DIVHF-MDID method, as follows:

$$\varpi_j^p = \frac{\omega_j^p C_j^p}{\sum_{j=1}^{n} \omega_j^p C_j^p} \quad \forall j, p \tag{15}$$

$$\varpi_j = \frac{\prod_{p=1}^{P} \left(\omega_j^p C_j^p\right)^{\frac{1}{P}}}{\sum_{j=1}^{n} \left(\prod_{p=1}^{P} \left(\omega_j^p C_j^p\right)^{\frac{1}{P}} \right)} \quad \forall j \tag{16}$$

Step 3.8. Specify the final weights of sub-criteria in each period (ϖ_j^{fp}) and in the scheduling horizon (ϖ_j^f) according to the criteria's weight in every period (w_J^p), which are determined by experts' opinions.

$$w_J^p = \frac{1}{2}\left(\prod_{k=1}^{K} (w_J^{Lkp})^{\frac{1}{K}} + \prod_{k=1}^{K} (w_J^{Ukp})^{\frac{1}{K}} \right) \quad \forall J \tag{17}$$

$$\varpi_j^{fp} = \frac{w_J^p \varpi_j^p}{\sum_{j=1}^{n'} w_J^p \varpi_j^p} \quad \forall J\ R\ \ j, p \tag{18}$$

$$\varpi_j^f = \frac{\prod_{p=1}^{P} \left(\varpi_j^{fp}\right)^{\frac{1}{P}}}{\sum_{j=1}^{n'} \left(\prod_{p=1}^{P} \left(\varpi_j^{fp}\right)^{\frac{1}{P}} \right)} \quad \forall j \tag{19}$$

Step 4. Determine the decision-makers' weights by using the proposed DIVHF-PA technique by using the following steps:

Step 4.1. Form the normalized DIVHF-GDM for each expert $\left(Q_k^p\right)$ based on definition 10.

$$Q_k^p = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ A_1 & \left[\upsilon_{11}^{Lkp}, \upsilon_{11}^{Ukp}\right] & \left[\upsilon_{12}^{Lkp}, \upsilon_{12}^{Ukp}\right] & \cdots & \left[\upsilon_{1n}^{Lkp}, \upsilon_{1n}^{Ukp}\right] \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & \left[\upsilon_{m1}^{Lkp}, \upsilon_{m1}^{Ukp}\right] & \left[\upsilon_{m2}^{Lkp}, \upsilon_{m2}^{Ukp}\right] & \cdots & \left[\upsilon_{mn}^{Lkp}, \upsilon_{mn}^{Ukp}\right] \end{matrix}_{m \times n} \quad \forall k, p \tag{20}$$

Step 4.2. specify the DIVHF preference variation amount $\left(\partial_k^p\right)$ by:

$$\partial_k^p = \sqrt{\frac{1}{2l_{x_i}}\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{\lambda=1}^{l_{x_i}}\left|\upsilon_{ij}^{Lkp\sigma(\lambda)} - \bar{\upsilon}_k^{Lp\sigma(\lambda)}\right|^2 + \left|\upsilon_{ij}^{Ukp\sigma(\lambda)} - \bar{\upsilon}_k^{Up\sigma(\lambda)}\right|^2} \quad \forall k, p \tag{21}$$

where the mean of normalized amount $\left(\bar{\upsilon}_k^p = \left[\bar{\upsilon}_k^{Lp}, \bar{\upsilon}_k^{Lp}\right]\right)$ is computed by means of:

$$\bar{\upsilon}_k^{Lp} = \frac{1}{2mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\upsilon_{ij}^{Lkp} \quad \forall k, p \tag{22}$$

$$\bar{\upsilon}_k^{Up} = \frac{1}{2mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\upsilon_{ij}^{Ukp} \quad \forall k, p \tag{23}$$

Step 4.3. Compute the DIVHF overall preference deviation value $\left(\pi_k^p\right)$ for each expert.

$$\pi_k^p = \frac{1 - \frac{\partial_k^p}{\sum_{k=1}^{K}\partial_k^p}}{\sum_{k=1}^{K}\left(1 - \frac{\partial_k^p}{\sum_{k=1}^{K}\partial_k^p}\right)} \quad \forall k, p \tag{24}$$

Step 4.4. Specify the final experts' weights $\left(\lambda_k\right)$ according to the following relation:

$$\lambda_k = \frac{\prod_{p=1}^{P}\left(\pi_k^p\right)^{\frac{1}{P}}}{\sum_{k=1}^{K}\left(\prod_{p=1}^{P}\left(\pi_k^p\right)^{\frac{1}{P}}\right)} \quad \forall k \tag{25}$$

Step 5. Form the weighted normalized DIVHF-GDM $\left(\Re_{k(ij)}^p = \left[\Re_{k(ij)}^{Lp}, \Im_{k(ij)}^{Up}\right]_{m\times n}\right)$ by using the final sub-criteria importance in each period.

$$\Re_k^p = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ A_1 & \varpi_1^{fp}\left[\mu_{11}^{Lkp}, \mu_{11}^{Ukp}\right] & \varpi_2^{fp}\left[\mu_{12}^{Lkp}, \mu_{12}^{Ukp}\right] & \cdots & \varpi_n^{fp}\left[\mu_{1n}^{Lkp}, \mu_{1n}^{Ukp}\right] \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & \varpi_1^{fp}\left[\mu_{m1}^{Lkp}, \mu_{m1}^{Ukp}\right] & \varpi_2^{fp}\left[\mu_{m2}^{Lkp}, \mu_{m2}^{Ukp}\right] & \cdots & \varpi_n^{fp}\left[\mu_{mn}^{Lkp}, \mu_{mn}^{Ukp}\right] \end{matrix}_{m\times n} \quad \forall k, p \tag{26}$$

Step 6. Found the DIVHF positive ideal solution (DIVHF-PIS) and negative ideal solution (DIVHF-NIS) as follows:

$$A_{jk}^{*p} = \left\{h_{1k}^{*p}, h_{2k}^{*p}, \ldots, h_{nk}^{*p}\right\} \tag{27}$$

$$h_{jk}^{*p} = \begin{cases} \left\{ x_j, \max_i \left\langle \Re_{k(ij)}^{p} \right\rangle \right\}, & \forall J, k, p \\ \left\{ x_j, \min_i \left\langle \Re_{k(ij)}^{p} \right\rangle \right\}, & \forall J', k, p \end{cases} \tag{28}$$

$$A_{jk}^{-p} = \left\{ h_{1k}^{-p}, h_{2k}^{-p}, \ldots, h_{nk}^{-p} \right\} \tag{29}$$

$$h_{jk}^{-p} = \begin{cases} \left\{ x_j, \min_i \left\langle \Re_{k(ij)}^{p} \right\rangle \right\}, & \forall J, k, p \\ \left\{ x_j, \max_i \left\langle \Re_{k(ij)}^{p} \right\rangle \right\}, & \forall J', k, p \end{cases} \tag{30}$$

where J and J' are expressed a set of benefit and cost criteria.

Step 7. Compute the distance amounts among the DIVHF-PIS $\left(\wp_i^{*kp}\right)$, and DIVHF-PIS $\left(\wp_i^{-kp}\right)$ by weighted normalized DIVHF-GDM $\left(\Re_k^p\right)$ as follows:

$$\wp_i^{*kp} = \sum_{j=1}^{n} \sqrt{\frac{1}{2l_{x_i}} \sum_{\lambda=1}^{l_{x_i}} \left(\left| \Re_{k(ij)}^{Lp} - A_{jk}^{*Lp\sigma(\lambda)} \right|^2 + \left| \Re_{k(ij)}^{Up} - A_{jk}^{*Up\sigma(\lambda)} \right|^2 \right)} \quad \forall i, k, p \tag{31}$$

$$\wp_i^{-kp} = \sum_{j=1}^{n} \sqrt{\frac{1}{2l_{x_i}} \sum_{\lambda=1}^{l_{x_i}} \left(\left| \Re_{k(ij)}^{Lp} - A_{jk}^{-Lp\sigma(\lambda)} \right|^2 + \left| \Re_{k(ij)}^{Up} - A_{jk}^{-Up\sigma(\lambda)} \right|^2 \right)} \quad \forall i, k, p \tag{32}$$

Step 8. Obtain the DIVHF closeness coefficient index to specify the relative weight of each option in each period $\left(\Im_i^p\right)$ and in scheduling horizon $\left(\Im_i\right)$.

$$\Im_i^p = \frac{\prod_{k=1}^{K} \left(\wp_i^{-kp}\right)^{\lambda_k}}{\prod_{k=1}^{K} \left(\wp_i^{*kp}\right)^{\lambda_k} + \prod_{k=1}^{K} \left(\wp_i^{-kp}\right)^{\lambda_k}} \quad \forall i, p \tag{33}$$

$$\Im_i = \frac{\prod_{p=1}^{P} \prod_{k=1}^{K} \left(\wp_i^{-kp}\right)^{\frac{\lambda_k}{P}}}{\prod_{p=1}^{P} \prod_{k=1}^{K} \left(\wp_i^{*kp}\right)^{\frac{\lambda_k}{P}} + \prod_{p=1}^{P} \prod_{k=1}^{K} \left(\wp_i^{-kp}\right)^{\frac{\lambda_k}{P}}} \quad \forall i \tag{34}$$

Step 9. Rank the potential candidates in decreasing order of the closeness coefficient indexes in scheduling horizon $\left(\Im_i\right)$.

3. Case study: Green suppliers evaluation in construction projects

3.1. Problem definition

Environmental awareness is a truth that increased attention to the green construction. In this respect, many various materials are included and procured in the construction projects. Indeed, materials are manufactured in different types of production procedure, and many of them or their materials are provided from various suppliers. Hence, a project manager requires to cooperate with some suppliers that can prepare green components based on the companies' environmental competencies. Therefore, the goal of this case study is to found a hierarchical dynamic group decision fuzzy logic approach in appraisal most suitable green supplier in this GRC project.

In this sake, three candidate green road construction suppliers (S_1, S_2, S_3) are assessed based on the preferences of three experts (k_1, k_2, k_3) under four conflicted criteria (Q_1, Q_2, Q_3, Q_4) and 16 sub-criteria (Q_{11}, Q_{12}, Q_{13}, Q_{14}, Q_{21}, Q_{22}, Q_{23}, Q_{31}, Q_{32}, Q_{33}, Q_{34}, Q_{41}, Q_{42}, Q_{43}, Q_{44}, Q_{45}) in two periods (p_1, p_2). Accordingly, the proposed expert evaluation system is applied to establish the DIVHF-GDM which is represented in Table 5. In addition, each criterion's relative importance and sub-criterion are obtained by the experts' opinions based on the linguistic variables and their converted IVHF element. Give the above statements about the relative importance of criteria and sub-criteria in Tables 6 and 7. Moreover, it is worthwhile to note that the simple additive weighting method is also executed to the case study to construct a comparative analysis and shows the feasibility of the proposed ranking module.

{Please insert here Table 5}

{Please insert here Table 6}

{Please insert here Table 7}

3.2. Obtained outcomes from the Introduced appraisal method

However, the normalized DIVHF-GDM according to the definition 10, is utilized for ranking procedure. Hence, the significant of sub-criteria is determined by using the introduced DIVHF-MDID method conforming to the preferences experts' judgments toward the criteria and sub-criteria weights. Based on this, the normalized DIVHF-GDM is established for sub-criteria via Eq. (19) and then the decision matrices of positive ideal (ξ_p^*),left negative ideal ($\zeta_p^{\ell-}$), and right negative ideal (ζ_p^{R-}) are determined according to Eqs. (20)-(26). Then, the separation measure from decision matrices of positive ideal (γ_j^{*p}), left negative ideal ($\gamma_j^{\ell p}$), and right negative ideal (γ_j^{Rp}) are obtained via Eqs. (10)-(12), respectively. Give the results in Table 8.

{Please insert here Table 8}

Therefore, the relative closeness coefficient of each sub-criterion $\left(C_j^p\right)$ regarding to Eq. (30) and the experts' views at the relative significance of sub-criteria are aggregated (ω_j^p) based on Eq. (14). In this sake, the sub-criteria weights in each period (ϖ_j^p) and in scheduling horizon (ϖ_j) are computed according to Eqs. (15) and (16). In addition, to consider the hierarchical structure in procedure of the introduced ranking approach, the criteria's importance in first layer must be regarded. Indeed, the relative importance of criteria which expressed by experts, are aggregated based on Eq. (17), and the final sub-criteria weights in each period (ϖ_j^{fp}) and in the scheduling horizon (ϖ_j^{f}) are determined by using the importance of criteria in each period (w_J^{p}) regarding to Eqs. (18) and (19), respectively. The outcomes of specifying the sub-criteria importance are expressed in Tables 9 and 10.

{Please insert here Table 9}

{Please insert here Table 10}

In process of the introduced approach, the importance of experts is not considered as a same value to decrease the errors. Thus, the DIVHF-PA technique is prepared to calculate the importance of experts. Hence, the normalized DIVHF-GDM for each expert (Q_k^p) is established, and then the DIVHF preference variation amount (∂_k^p) is specified via Eqs. (21)-(23). Then, the DIVHF overall preference deviation value (π_k^p) is computed via Eq. (24) and the final experts' importance are computed regarding to Eq. (25). The outcomes of specifying the importance of experts are depicted in Table 11.

{Please insert here Table 11}

Accordingly, the process of ranking approach is applied by considering the weights of sub-criteria and experts. That's why, the weighted normalized DIVHF-GDM is established by using the final importance of sub-criteria in each period and then the DIVHF-PIS and DIVHF-NIS are specified according to the Eqs. (27)-(30). In addition, as represented in Table 12, the distance among weighted normalized DIVHF-GDM ($\Re_k^p$) and DIVHF-PIS ($\wp_i^{*kp}$), and DIVHF-PIS ($\wp_i^{-kp}$) is calculated by considering the Eqs. (31) and (32), respectively. Also, the DIVHF closeness coefficient is regarded to obtain the relative significance of each candidate green road construction suppliers in each period ($\Im_i^p$) based on Eq. (50).

Eventually, the significant of each supplier in scheduling horizon ($\Im_i$) is calculated by according to Eq. (34). Consequently, the ranking outcomes display the best green road construction supplier. In this sake, Ervural et al. [50] approach as well as Çolak and Kaya [51] technique are executed in our case study to confirm the validity of the proposed ranking approach. Accordingly, the computed ranking outcomes from introduced technique and two other studies are compared and indicated the same ranking results. Give the aforementioned results in Table 13.

{Please insert here Table 12}

{Please insert here Table 13}

Although, three considered approaches provide a same ranking results, but elaborating the proposed approach of this study under the following merits and advantages could strength the presented approach in decision making problems: (1) presented an evaluation method by considering the expert system; (2) considered the hierarchical structure in green road construction supplier evaluation; (3) proposed a DIVHF maximize deviation from ideal decision method to compute the importance of criteria; (4) Presented a DIVHF preference assessment method to determine the weight of each expert; (5) ranked the candidates under hesitant situation and dynamic environment based on novel procedure; (6) prevent the loss of data by considered the last aggregation of preferences experts' judgments. However, the comparison results are discussed in details in the next section.

4. Discussion

4.1.Comparative analysis

In the present part, by considering 6 comparing factors, a comparative analysis is performed between the achieved results of the presented method and two recent researches. Thus, to indicate the validity and accuracy of the presented DIVHF-HGD framework, it is appraised to Ervural et al. [50] approach as well as Çolak and Kaya [51] method. In addition, for ranking the candidate energy strategies, a SWOT analysis by means of ANP and triangular fuzzy TOPSIS methodology was presented by Ervural et al. [50]. Meanwhile, for sorting the candidate renewable energies, an aggregated framework was proposed by Çolak and Kaya [51] that combines the interval type-2 fuzzy AHP technique and hesitant fuzzy TOPSIS method. As regards, both recent researches and the presented method are performed to the case study and the same ranking results are achieved (A1>A2>A3). Furthermore, a detailed analysis of the three approaches is performed using the 5 comparing factors that are presented in table 14.

{Please insert here Table 14}

Thus, according to the comparison in table 14, the presented hybrid method has four superiorities over the Ervural et al. [50] and Çolak and Kaya [51] approaches which are as follows: uncertainty modeling, experts’ importance, last aggregation technique, and standard deviation parameter. Accordingly, all three approaches are adequate considering the criteria weights factor. Moreover, the results of the comparison indicates that the time complexity of the presented method is higher than the time complexity of Ervural et al. [50] and Çolak and Kaya [51] approaches. Therefore, considering the aforementioned features, the presented hybrid adaptive approach could lead to authentic results.

4.2.Sensitivity analysis

In this part, to indicate the sensitiveness and robustness of the achieved results, a sensitivity analysis is performed via using two factors as changing the importance of criteria, and last aggregation technique. Meantime, changes in both criteria weights and last aggregation approach elimination would affect the DIVHF-HGD framework as a part of the presented method. In the subsequent, the aforementioned factors are discussed individually to check out their effects on the achieved results.

4.2.1. Criteria weights

In this segment, the importance of criteria and sub-criteria are transformed to examine the effect of relative importance of criteria and sub-criteria on outcomes of introduced method. That is why, the cost (Q_1), quality (Q_2), capability of supplier (Q_3), environmental competency (Q_4) criteria importance is increased to examine their effects on rankings of suppliers. The outcomes illustrate the sensitivity of rankings to all criteria unlike the quality criterion. Thus, the variation of outcomes according to the sensitivity analysis are depicted in Figure 3. The results according to the cost, environmental competency, and capability of supplier have changed. But, according to the quality criterion, the results are the same with the introduced technique.

{Please insert here Figure 3}

Furthermore, the weights of sub-criteria are increased for evaluating its effects of the supplier rankings. Among the 16 sub-criteria, 5 criteria (Q_{14}, Q_{31}, Q_{34}, Q_{44}, Q_{45}) have changed the final rankings of suppliers. Consequently, increasing the importance of C_{14}, C_{31}, and C_{34} changes the ranking results to $S_3>S_1>S_2$, and also increasing the weight of Q_{44} and Q_{45} leads the rankings to $S_1>S_3>S_2$.

4.2.2. Elimination of Consensus

Here, according to the last aggregation technique, the sensitiveness and robustness of suppliers' rankings are surveyed. As demonstrated in Table 15, the computed ranking outcomes are strong by using the last aggregation technique in return executing the introduced technique without last aggregation approach results the different outcomes. Meanwhile, examination of this procedure, illustrated that the last aggregation approach may raise the quality of outcomes. For this reason, the measure of standard deviation is utilized to calculate the DIVHF closeness coefficient using two scenarios (S_1, S_2). The outcomes of standard deviations demonstrate that the introduced technique with last aggregation approach (S_1) has more dispersal than without last aggregation approach (S_2). Thus, experts can easily choose the best alternative among the candidate alternatives because of more dispersal.

{Please insert here Table 15}

5. Concluding remarks and future studies

With growing worldwide concerning about the environmental issues, green evaluation of suppliers has received a significant attention in almost every construction projects. Thus, a suitable green road construction supplier assessment and selection approach in a dynamic regulatory and competitive condition can assist lessen the legal and environmental hazards. In this respect, this research proposed an expert system to evaluate the green road construction suppliers along the conflicted criteria to decrease the uncertainty of experts' judgments. Then, a hierarchical last aggregation group decision-making approach according to the DIVHF information is proposed to rank the candidate green road construction suppliers. The DIVHF information allows to specialists allocate interval-values for green road construction supplier selection versus the elected criteria in each period of scheduling horizon. Also, considering the last aggregation approach could decrease the errors by preventing the loss of data. Furthermore, the importance of criteria and specialists computed and considered in process of the introduced approach by presenting a DIVHF maximize deviation from ideal decision and DIVHF-PA methods, respectively. However, a real case study about the green supplier evaluation in a construction project is prepared to show the ability and efficiency of the introduced technique. Accordingly, the outcomes of the introduced approach in compare of simple additive weighting method and a technique on literature shows the same outcomes. With this in mind, introduced technique worked in a right procedure. For future studies, proposing an expert evaluation system for evaluating the relative significant of criteria could enhance the proposed approach. In addition, the proposed approach can be implemented in wide range problems such as bioenergy development [52], economy assessment [53], etc.

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Figures captions:

Figure 1. Visualization of the introduced technique
Figure 2. The hierarchical structure of decision criteria for green road construction supplier evaluation
Figure 3. The sensitivity analysis for criteria weights

Tables captions:

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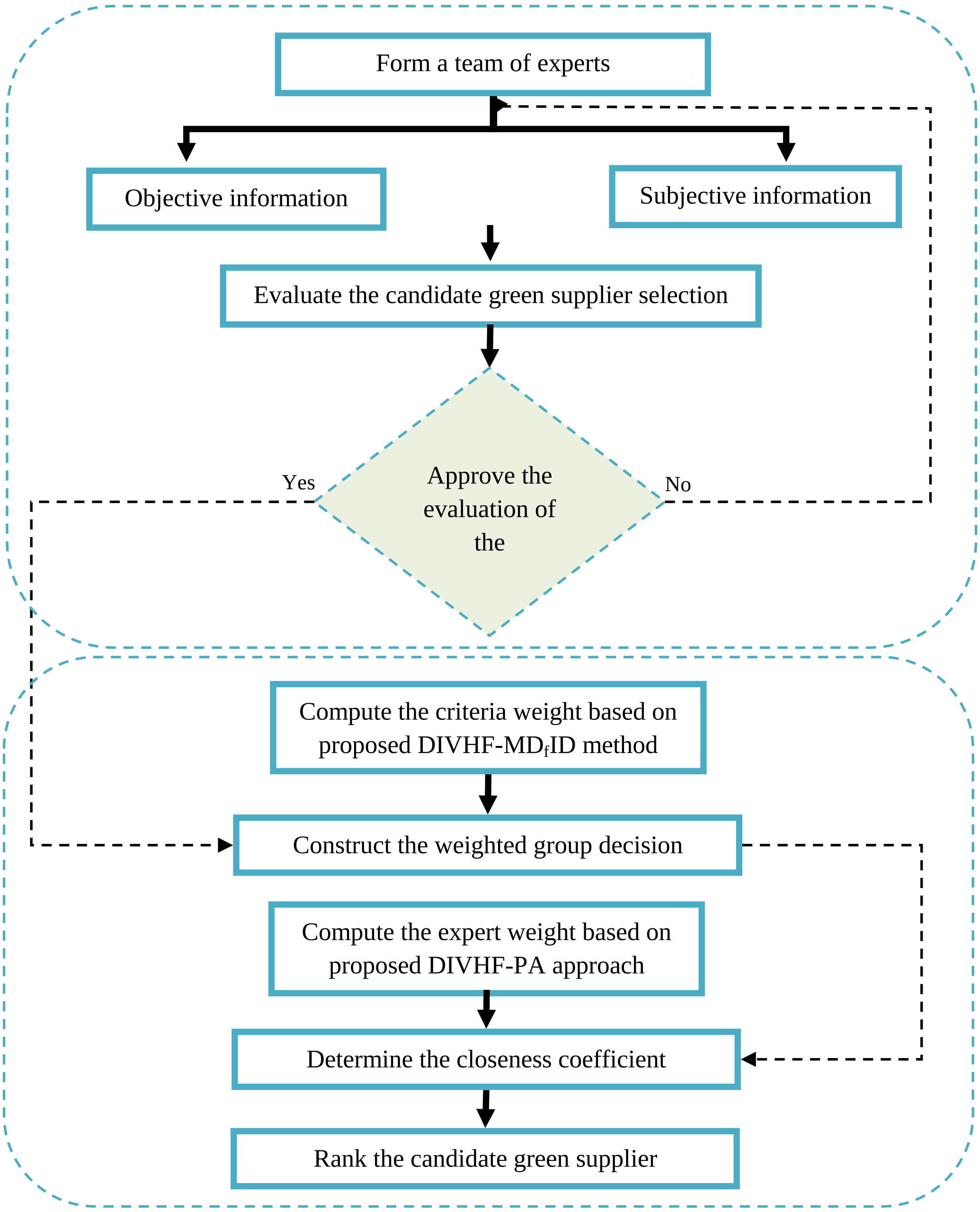

Figure 3. Visualization of the introduced technique

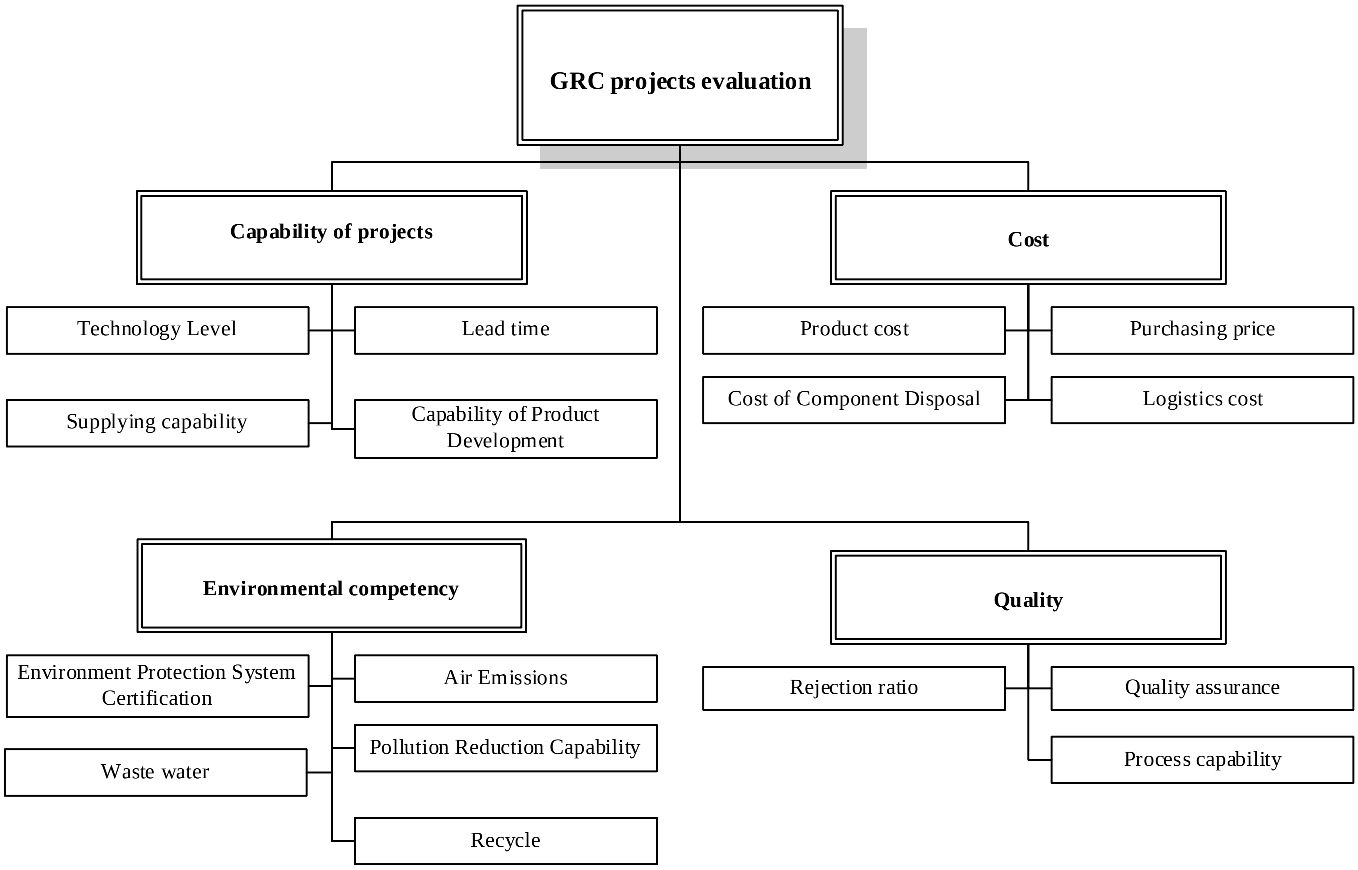

Figure 4. The hierarchical structure of decision criteria for green road construction supplier evaluation

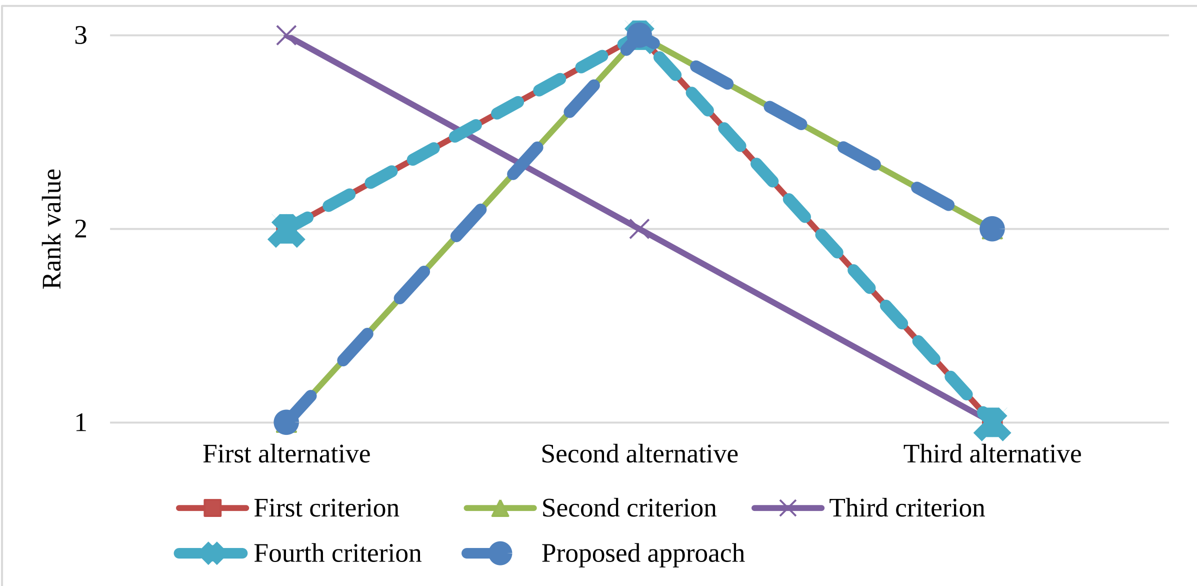

Figure 3. The sensitivity analysis for criteria weights

Table 1. The decision-making literature research gap

Authors	Fuzzy environment	Dynamic uncertainty	Weighting approaches		Group decision tool	Environmental competencies
			Experts	Criteria		
Chettibi and Chikhi [24]	√	√				
Mardani et al. [25]	√			√	√	
Mousavi et al. [26]	√		√	√	√	√
Büyüközkan and Güleryüz [27]	√			√	√	√
Jayaraman et al. [28]	√					
Wang et al. [29]	√			√	√	
Sindhu et al. [30]				√	√	√
Xiang [31]			√		√	
Gomes et al. [32]						√
Lu et al. [33]	√			√	√	√
Kofinas et al. [34]	√					
Jeong and Ramírez-Gómez [35]	√			√		√
Ren [36]	√			√	√	√
Fathipour and Saidi-Mehrabad [37]				√	√	√
Wang et al. [38]	√			√	√	
This article	√	√	√	√	√	√

Table 2. Linguistic terms for sub-criteria and criteria's weighting

Linguistic terms	IVHF equivalent
Very Significant (VS)	[0.90,0.90]
Significant (S)	[0.75, 0.80]
Medium (M)	[0.50, 0.55]
Insignificant (I)	[0.35, 0.40]
Very Insignificant (VI)	[0.10,0.10]

Table 3. Linguistic terms for rating of green road construction suppliers

Linguistic terms	IVHF equivalent
Extremely high (EH)	[1.00,1.00]
Very very high (VVH)	[0.90,0.90]
Very high (VH)	[0.80, 0.90]
High (H)	[0.70, 0.80]
Medium high (MH)	[0.60, 0.70]
Medium (M)	[0.50, 0.60]
Medium low (ML)	[0.40, 0.50]
Low (L)	[0.25, 0.40]
Very low (VL)	[0.10, 0.25]
Very very low (VVL)	[0.10,0.10]

Table 4. The factors and sub-factors for green road construction supplier evaluation

Criteria	**Sub-criteria**	**Definitions**
Cost (Q_1)	Cost of product (Q_{11})	The cost of processing, maintenance, and warranty that is considered as production cost for specifying the final price
	Buying price (Q_{12})	Lower price of product at the same quality level
	Cost of Component Disposal (Q_{13})	End of life of the products' processing cost (with increasing recycling, costs is reduced)
	Cost of logistics (Q_{14})	Total of unit variable and assigned constant transportation costs
Quality (Q_2)	Rejection proportion (Q_{21})	Ratio of materials rejected by quality control
	Quality assurance (Q_{22})	The achievement of quality assurance (QA) suchlike ISO certificates
	Process capability (Q_{23})	The process capability is a measurable property of a process to the specification, expressed as a process capability index
Capability of supplier (Q_3)	Level of technology (Q_{31})	Level of technology for meeting the current and future supplier demand
	Lead time (Q_{32})	Flexibility in time between the placement and the arrival of an order without compromising quality and cost.
	Supplying ability (Q_{33})	capability for delivering on time and quick reaction to the customer order
	Product Development capability (Q_{34})	Ability of development of new product in high speed
Environmental competency (Q_4)	Environmental protection certification (Q_{41})	Whether the supplier has environmental protection certificates, such as HSE-MS and ISO 14001
	Air pollution (Q_{42})	The control measures to reduce dangerous emission, for instance, SO2, NH3, CO and HC1
	Waste water (Q_{43})	The control measures to reduce waste water
	Pollution Reduction Capability (Q_{44})	Capability level of reducing the pollution
	Recycle (Q_{45})	Capability of reuse and reprocess of products

*Sources: [40-48].

Table 5. Dynamic interval-valued hesitant fuzzy group decision matrix

Criteria	Sub-criteria	Candidates	First period (p_1)			Second period (p_2)		
			Experts			Experts		
			E_1	E_2	E_3	E_1	E_2	E_3
Q_1	Q_{11}	S_1	L	M	M	ML	M	ML
		S_2	MH	MH	H	H	MH	MH
		S_3	MH	MH	M	M	MH	MH
	Q_{12}	S_1	VVH	H	H	VH	MH	VH
		S_2	M	M	MH	M	H	MH
		S_3	H	H	MH	M	MH	M
	Q_{13}	S_1	H	MH	M	VH	VH	H
		S_2	MH	H	M	MH	H	H
		S_3	VVH	VH	VH	VH	H	VH
	Q_{14}	S_1	H	H	VH	H	VH	VH
		S_2	L	ML	M	ML	L	L
		S_3	H	H	VH	VH	H	MH

Criteria	Sub-criteria	Candidates	First period (p_1)			Second period (p_2)		
			Experts			Experts		
			E_1	E_2	E_3	E_1	E_2	E_3
Q_2	Q_{21}	S_1	M	ML	M	H	MH	M
		S_2	VVL	VL	ML	VL	ML	L
		S_3	VL	L	L	L	VL	VL
	Q_{22}	S_1	H	MH	MH	H	MH	H
		S_2	VH	VH	H	H	H	VH
		S_3	VL	VVL	L	VL	L	L
	Q_{23}	S_1	MH	M	MH	M	M	MH
		S_2	H	H	VH	VH	H	VVH
		S_3	ML	L	ML	L	VL	VL
Q_3	Q_{31}	S_1	MH	M	MH	MH	H	VH
		S_2	H	MH	H	VH	H	VH
		S_3	ML	M	L	ML	L	VL
	Q_{32}	S_1	M	M	MH	H	MH	H
		S_2	VVL	VVL	VL	L	VL	L
		S_3	MH	H	MH	M	M	M
	Q_{33}	S_1	H	VVH	VH	VH	VH	VVH
		S_2	M	MH	M	M	MH	MH
		S_3	M	L	L	ML	L	VL
	Q_{34}	S_1	H	M	MH	M	MH	H
		S_2	ML	M	ML	M	ML	M
		S_3	M	MH	M	MH	M	M
Q_4	Q_{41}	S_1	MH	H	H	VH	H	MH
		S_2	VL	VL	VVL	L	VL	VL
		S_3	M	MH	M	MH	M	MH
	Q_{42}	S_1	ML	L	L	VL	VVL	VL
		S_2	MH	H	H	MH	MH	M
		S_3	M	H	H	MH	MH	H
	Q_{43}	S_1	L	L	VVL	ML	L	VVL
		S_2	MH	M	MH	M	H	H
		S_3	VL	L	VL	ML	ML	L
	Q_{44}	S_1	MH	MH	H	MH	H	M
		S_2	MH	H	H	H	MH	MH
		S_3	L	VVL	VL	VL	VVL	VVL
	Q_{45}	S_1	MH	M	M	MH	MH	H
		S_2	M	MH	M	MH	MH	M
		S_3	VL	L	VL	VVL	VL	VL

Table 6. Importance of criteria

Criteria	Periods	Experts		
		E_1	E_2	E_3
C_1	p_1	VS	M	VS
	p_2	S	M	VS
C_2	p_1	S	VS	M
	p_2	VS	S	M
C_3	p_1	M	S	VS
	p_2	S	S	VS
C_4	p_1	VS	VS	S
	p_2	M	VS	S

Table 7. Importance of sub-criteria

Criteria	sub-criteria	First period (p_1)			Second period (p_2)		
		Experts			Experts		
		E_1	E_2	E_3	E_1	E_2	E_3
C_1	C_{11}	M	S	M	S	M	M
	C_{12}	M	S	S	M	S	M
	C_{13}	S	M	VS	S	VS	S

	C_{14}	S	VI	S	VS	VS	S
C_2	C_{21}	M	M	M	VS	S	M
	C_{22}	S	S	VS	M	VS	S
	C_{23}	VS	S	VS	S	VS	S
C_3	C_{31}	S	S	M	S	VS	M
	C_{32}	S	M	M	VS	S	M
	C_{33}	VS	S	S	S	M	M
	C_{34}	S	VS	VS	M	S	VS
C_4	C_{41}	VS	S	S	S	VS	VS
	C_{42}	M	S	M	S	M	M
	C_{43}	S	VS	S	S	VS	VS
	C_{44}	S	M	M	M	S	S
	C_{45}	M	M	S	S	VS	VS

Table 8. Positive, right negative, and left negative ideals decision matrices

Sub-criteria	γ_j^{*p}		$\gamma_j^{\ell p}$		γ_j^{Rp}	
	p=1	p=2	p=1	p=2	p=1	p=2
Q_{11}	1.07079	0.97948	0.63738	0.67454	1.02835	1.03017
Q_{12}	0.70755	0.72118	0.62048	0.57879	1.30815	1.26541
Q_{13}	0.70777	0.87022	0.58737	0.53385	1.36976	1.51534
Q_{14}	0.68829	0.74042	0.69011	0.74330	1.27181	1.25250
Q_{21}	0.74948	0.85180	1.24900	1.17100	0.64323	0.83964
Q_{22}	0.63688	0.55250	1.13468	1.15271	0.89093	0.74330
Q_{23}	0.45190	0.57915	1.06829	1.08800	0.62650	0.88882
Q_{31}	0.38648	0.61614	1.01057	1.22780	0.59791	0.73739
Q_{32}	0.64481	0.61066	1.08915	0.87393	0.92871	0.94868
Q_{33}	0.52126	0.59656	1.09430	1.21347	0.68099	0.79294
Q_{34}	0.43445	0.42105	0.95917	0.99750	0.64517	0.61745
Q_{41}	0.82944	0.80706	1.02347	1.14401	1.09716	1.00000
Q_{42}	0.52455	0.60630	0.70178	1.07819	1.06243	0.94802
Q_{43}	0.83057	0.67182	1.25150	1.05475	0.77460	0.88530
Q_{44}	0.45717	0.55051	0.98043	1.00312	0.74330	1.01980
Q_{45}	0.34640	0.48115	0.76404	0.95525	0.90830	0.95851

Table 9. The relative closeness coefficient, aggregate the experts' views to the relative importance of sub-criteria, and the sub-criteria weights in each period

Sub-criteria	C_j^p		ω_j^p		ϖ_j^p	
	p=1	p=2	p=1	p=2	p=1	p=2
Q_{11}	0.60870	0.63509	0.59776	0.59776	0.04255	0.04345
Q_{12}	0.73160	0.71888	0.68063	0.59776	0.05822	0.04918
Q_{13}	0.73441	0.70192	0.71529	0.81451	0.06142	0.06543
Q_{14}	0.74029	0.72940	0.81451	0.85614	0.07050	0.07147
Q_{21}	0.71629	0.70242	0.51640	0.71529	0.04325	0.05750
Q_{22}	0.76079	0.77435	0.81451	0.71529	0.07246	0.06339
Q_{23}	0.78949	0.77341	0.85614	0.81451	0.07903	0.07210
Q_{31}	0.80627	0.76131	0.68063	0.71529	0.06417	0.06232
Q_{32}	0.75783	0.74904	0.59776	0.71529	0.05297	0.06132
Q_{33}	0.77302	0.77082	0.81451	0.59776	0.07362	0.05273
Q_{34}	0.78691	0.79320	0.85614	0.71529	0.07877	0.06493
Q_{41}	0.71884	0.72652	0.81451	0.85614	0.06846	0.07119
Q_{42}	0.77082	0.76969	0.59776	0.59776	0.05388	0.05266
Q_{43}	0.70925	0.74278	0.81451	0.85614	0.06755	0.07278
Q_{44}	0.79037	0.78608	0.59776	0.68063	0.05524	0.06123
Q_{45}	0.82841	0.79910	0.59776	0.85614	0.05790	0.07830

Table 10. Aggregate the experts' views to the relative importance of criteria and the final sub-criteria weights in each period and in the scheduling horizon

Criteria	w_J^p		Sub-criteria	ϖ_j^{fp}		ϖ_j^f
	p=1	p=2		p=1	p=2	
Q_1	0.75181	0.71529	Q_{11}	0.04173	0.04204	0.04200
			Q_{12}	0.05711	0.04759	0.05227
			Q_{13}	0.06025	0.06331	0.06192
			Q_{14}	0.06916	0.06916	0.06934
Q_2	0.71529	0.71529	Q_{21}	0.04036	0.05564	0.04751
			Q_{22}	0.06762	0.06134	0.06457
			Q_{23}	0.07376	0.06976	0.07192
Q_3	0.71529	0.81451	Q_{31}	0.05988	0.06867	0.06429
			Q_{32}	0.04943	0.06756	0.05794
			Q_{33}	0.06871	0.05810	0.06335
			Q_{34}	0.07351	0.07155	0.07271
Q_4	0.85614	0.71529	Q_{41}	0.07647	0.06888	0.07277
			Q_{42}	0.06018	0.05095	0.05552
			Q_{43}	0.07545	0.07042	0.07308
			Q_{44}	0.06171	0.05925	0.06062
			Q_{45}	0.06468	0.07576	0.07018

Table 11. The computational results of computing the importance of experts by using introduced DIVHF-PA technique

Experts	∂_k^p		π_k^p		λ_k
	p=1	p=2	p=1	p=2	
k=1	1.51223	1.53918	0.66681	0.68064	0.33688
k=2	1.50571	1.54554	0.66825	0.67932	0.33691
k=3	1.52075	1.73486	0.66494	0.64004	0.32621

Table 12. Separation measures and the significance of green road construction suppliers in each period

Periods	Candidates	$\wp_i^{*kp}$			$\wp_i^{-kp}$			$\Im_i^p$
		k=1	k=2	k=3	k=1	k=2	k=3	
p=1	S_1	0.11911	0.22661	0.23079	0.41809	0.38265	0.43881	0.69192
	S_2	0.30269	0.21202	0.27267	0.31433	0.31291	0.37726	0.56212
	S_3	0.36373	0.34318	0.36928	0.25122	0.31362	0.19134	0.40866
p=2	S_1	0.13932	0.16254	0.22210	0.42754	0.44002	0.48397	0.72459
	S_2	0.26053	0.22249	0.26645	0.41920	0.37483	0.39798	0.61463
	S_3	0.41071	0.47087	0.40337	0.31646	0.21419	0.18424	0.35233

Table 13. The relative significant of green road construction suppliers in scheduling horizon and comparative analysis

Candidates	$\Im_i$	Rank the candidate green suppliers by proposed approach	Ervural et al. [50]' technique		Çolak and Kaya [51] ' method	
			Ranking results	Prioritization of candidate	Ranking results	Prioritization of candidate
S_1	0.70807	1	0.96534	1	0.91645	1
S_2	0.58779	2	0.89873	2	0.85874	2
S_3	0.37945	3	0.80836	3	0.78346	3
Standard deviation	0.16626	---	0.07878	---	0.06668	---

Table 14. The comparative analysis results

Comparison factors	Comparisons results	Superiority checking of the proposed approach		
		Overcome	Adequate	Lose
Last aggregation technique	To prevent the data loss, the last aggregation concept is included in the presented method. However, the studies of Ervural et al. [50] and Çolak and Kaya [51] doesn't contain this concept. Considering this, the results of the presented method might be more authentic than the other two methods.	√		
Time complexity	The time complexity straightly depends on the data requirement, preprocessing, and computational size of approach. Comparing to the other two methods, the presented method required more information. Besides, there is a preprocessing mechanism to achieve a consensus solution. Hence the approaches from Ervural et al. [50] and Çolak and Kaya [51] studies can be accomplished faster than the presented hybrid adaptive method. Moreover, some factors in the presented method, as determining the experts and criteria importance, concept of ranking procedure, optimization modeling, and last aggregation would result in increasing the time complexity.			√
Criteria importance	The dynamic hesitant fuzzy entropy method is included in the presented approach to detect the relative significance of the criteria. Respectively, Ervural et al. [50] and Çolak and Kaya [51] introduced a fuzzy AHP and ANP methodology for computing the weights of criteria. So in determining the relative importance of criteria, the three methods are equal.		√	
Experts' importance	Considering or specifying the experience of DMs could result in increasing the quality of the achieved results concerning their preferences views to solve the group decision-making issues. In this research, for determining the experts' weights, an optimized model is presented via using maximizing deviation concept. Accordingly, this factor is not included in Ervural et al. [50] and Çolak and Kaya [51] studies.	√		
Uncertainty modeling	Both the presented method and the Çolak and Kaya [51] approaches tackle the uncertain group decision issue on hesitant fuzzy information. Thus, to deal with the uncertainty, Ervural et al. [50] considered the triangular fuzzy number. Thereby, although all these approaches have considered the fuzzy set theory to tackle with imprecise information, the Çolak and Kaya [51] as well as the presented method could properly deal with the uncertainty by allocating membership grades for an option under a set. However, the dynamic uncertainty considered in the presented method determine the issue in specific periods that could cover more uncertainty in scheduling horizon rather than the two other methods.	√		
Standard deviation	The standard deviation comparison parameter can help the users of the proposed approach to select the most suitable candidate, easily. As a result, an approach with higher standard deviation can rank candidates with more distance from each other. As indicated in Table 13, the proposed approach has higher standard deviation value over 100% in compared with two other studies.	√		

Table 15. The sensitivity analysis based on last aggregation approach

Candidates	$\Im_i$	
	S_1: with last aggregation approach	S_2: without last aggregation approach
S_1	0.70807	0.60791
S_2	0.58779	0.65037
S_3	0.37945	0.59387
Standard deviation	0.13575	0.02401

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