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Solving New Product Selection Problem by a New Hierarchical Group Decision-making Approach with Hesitant Fuzzy Setting

S. M. Mousavi[*]

Department of Industrial Engineering, Faculty of Engineering, Shahed University, Tehran, Iran

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ABSTRACT

Selecting the most suitable alternative under uncertainty is considered as a critical decision-making problem that affects the success of organizations. In the selection process, there are a number of assessment criteria, considered by a group of decision makers, which often could be established in a multi-level hierarchy structure. The aim of this paper is to introduce a new hierarchical multiple criteria group decision-making (HMCGDM) approach in hesitant fuzzy setting based on the concept of compromise solutions. Motivated by hesitant fuzzy sets, Hamming distance measure is utilized in the process of the proposed hierarchical method, namely HF-HMCGDM, and also hesitant fuzzy weighted averaging operator is used to aggregate the judgments of experts or decision makers. Firstly, for assessing weights of criteria, a hesitant fuzzy hierarchical weighting method is developed. To rank the possible alternatives, a new hesitant fuzzy extension of the classical compromise solution method is then proposed. Furthermore, a case study in the new product ideas problem from the recent literature is provided to illustrate the proposed HF-HMCGDM approach, and finally a comparative analysis is given to demonstrate the capability.

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1. INTRODUCTION

Developing a new product (s) is an important activity that drives the competitive merit of manufacturing companies' success. A company should be able to extend an innovative product that attracts the customer and then could be able to produce it in a large amount in order to gain a mass market benefit [1, 2].

NPD can often be of very high risk and costly in nature [3]. Because of the inherent characteristics of NPD, its relevant planning definitely takes numerous uncertainties that may lead to negative consequences [4]. This is specifically significant since the failure rate of new products is high. A recent study shows that 97 percent of new product ideas never enter the market successfully [5]. Therefore, reassessment of product idea and selection is one of the most effective tasks in manufacturing companies [6].

New problem regarding the selection of product ideas needs multiple perspectives from various experts, such as sales managers, marketers, and research and development (R&D) engineers. Experts may have various understandings of the same information and various preferences as well as experiences in the NPD environment. Thus, a solution preferred by the group is the most reliable decision of the group of experts as a whole. It has been shown that the combination of GDM and multiple decision-making (MADM) methods leads to multiple attributes group decision-making (MAGDM) that is a very effective methodology to increase the overall satisfaction level for the final decision in the evaluation and selection of decision-making problems [7].

In this respect, Sarı and Kahraman [8] utilized fuzzy Monte Carlo simulation approach for new product to prioritize the investment alternative. Guo et al. [9] proposed an integrated approach based on fuzzy AHP and GE matrix to solve the new product selection of manufacturing enterprises. Lin and Yang [10] indicated a holistic approach by a fuzzy weighted average to

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[*]Corresponding Author's Email: sm.mousavi@shahed.ac.ir (S. M. Mousavi)

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compute a fuzzy possible-attractiveness performance and regarding both favourable and unfavourable factors for measuring the new product attractiveness in portfolio selection problem. Relich and Pawlewski [11] designed a multi-agent approach for assessing new products and selecting product portfolio. Li and Lin [12] investigated how exporters diffused new products and how importers specified new product adoptions to offshore markets by extending the product innovation adoption. Suresh [13] presented a complex proportional assessment approach regarding grey relations method to select the best Clay-Pot-Refrigerator model as a new product selection problem. Kłos [14] developed an ERP model based on decision support system and the AHP methodology for the selection of the best prototypes. Bingham [15] presented a new product implementation model to reduce the important risk inherent in new product ventures for an industrial marketplace. Mohagheghi et al. [16] introduced a new decision-making procedure based on the concept of preference selection index and intuitionistic fuzzy sets (IFSs) to solve the best product end-of-life scenario selection problem.

Furthermore, many scholars focused on group decision analysis tools under uncertainty to solve the decision-making problems focusing on the NPD. Reviewing decision-making tools which have been developed under fuzzy environments, could help to identify the literature gap. Meanwhile, hesitant fuzzy sets (HFSs) as a new development of traditional fuzzy sets [17] have been first introduced by Torra and Narukawa [18] and Torra [19]. The HFSs theory is known as a powerful tool in the literature and is applied in dubious situations. In this case, Farhadinia [20] as well as Yu et al. [21] expressed that HFSs can be considered in the practical applications of MCDM problems to prevent privacy, anonymity and psychic contagion of experts. Wang et al. [22] mentioned that consideration of HFSs were useful in handling MCDM problems expressed in an imprecise situation where decision-makers are among several values before assigning their preferences. Zhang et al. [23] denoted that HFS provided an effective way of relating to decision-making problems when some member values are possible for an object or criterion. Hence, Rodríguez et al. [24] provided an overview on theory of HFSs by the aims of preparing an obvious perspective on different tools, concepts, and trends according to this extensions of fuzzy sets theory. Also, in complex and hesitant situations, decision makers (DMs) evaluate the preferences by assigning some membership values to an element under a set [25, 26]. Thus, for dealing with hesitant conditions, the objects are not always defined as crisp number but may be considered as fuzzy numeral.

In the decision theory, MCDM methods are regarded as the important part of studies. In real-world, in fuzzy situations some DMs should be considered that evaluate the decision problem by their judgments. In this condition, the multi-criteria group decision-making (MCGDM) problems are taken into account. In this respect, Liu and Wang [27] developed some new group decision-making methods based on intuitionistic linguistic numbers. Vahdani et al. [28] proposed a fuzzy compromise solution approach based on group decision analysis to solve the contractor selection problem. Meng and Zhang [29] defined two induce continuous Choquet integral operators based on the MCGDM. The uncertain generalized probabilistic weight averaging was introduced by Merigo et al. [30] respecting to the MCGDM. Also, regarding the HFS, some researchers applied this set in the MCGDM problems; for instance, Rodríguez et al. [31] proposed a linguistic group decision model for rich linguistic expressions. Vahdani et al. [32] presented a fuzzy modified technique for order of preference by similarity to ideal solution (TOPSIS) for evaluating the robot and selecting rapid prototyping process.

In addition, Chen et al. [33] extended the interval-valued of HFSs and then indicated their application in clustering. For extending the HFSs, some distance and aggregation operators have been proposed. Xu and Xia [34] based on the corresponding similarity measures provided some distance measures for the HFSs. Xia and Xu [35] extended some aggregation operators for the HFSs based on the relationship between IFSs and HFSs. Some other researchers developed distance measures or aggregation operators [36-38]. Liao and Xu [39] as well as Zhang and Wei [40] focused on VIKOR method to extend a decision making method based on hesitant fuzzy information. Xu and Zhang [41] developed the TOPSIS method based on hesitant fuzzy information and interval-valued hesitant fuzzy setting information by developing a maximizing deviation method to cope with incomplete weight information. Wei and Zhang [42] developed the VIKOR method based on Shapley value and hesitant fuzzy information to manage the correlative decision making problems. Meanwhile, Liao et al. [43] designed the VIKOR method by regarding hesitant fuzzy linguistic term sets by defining the hesitant fuzzy linguistic individual regret measure, the hesitant fuzzy linguistic group utility measure, and the hesitant fuzzy linguistic compromise measure. Wu et al. [44] proposed an integrated analytical model for obtaining the importance of ratings of engineering characteristics in quality function deployment by combining the decision-making trial and evaluation laboratory (DEMATEL) technique and VIKOR method under hesitant fuzzy environment. Ren et al. [45] developed the traditional VIKOR method by regarding dual hesitant fuzzy information and group decision analysis approach. In their study, the extended method was established based on fuzzy measure and a new comparison method. Further, some additional investigations existed which focused on group decision-making tools to solve complex evaluation and selection problems (e.g., [25, 46-48]).

To cope with the complex decision problems in the NPD environment, we focus on the MCGDM evaluations in this paper. In the multi-criteria analysis, there are not solutions that satisfy all conflicting criteria concurrently. In this respect, for the problem by conflicting criteria a compromise solution could help the DMs to recognize an acceptable answer [49-51]. Furthermore, the existing techniques and tools do not suggest sufficient insights for investigators and practitioners. For the structure of assessments in the decision problems for multi-level hierarchy, large-sized decision problems is regarded particularly under an uncertain environment.

This paper aims at introducing a new hesitant fuzzy hierarchical multiple criteria group decision-making (HF-HMCGDM) approach based on the compromise ratio (VIKOR). The pair-wise comparisons are firstly taken into account to assist the NPD DMs or experts for obtaining their opinions by hesitant fuzzy linguistic terms. To drive criteria weights, a hesitant fuzzy hierarchical weighting method is extended. All DMs' opinions are defined in the form of the HFSs and to make the decision respecting both expectations and needs of customers and companies. Then, for ranking the possible alternatives in terms of conflicting criteria, a new HF-HVIKOR method is proposed. The classical VIKOR method is a well-known and effective decision-making tool that is able to achieve a compromise solution for complex decision problems. This method has been widely utilized in different fields to obtain compromise ranking in the problems [52]. Also, the proposed hesitant fuzzy group decision approach is capable to solve the problems in a multi-level hierarchy consisting indicators, criteria, main criteria and alternatives, by hesitant fuzzy Hamming distance measure and hesitant fuzzy weighted averaging operator. In addition, for indicating the detail of the proposed HF-HMCGDM approach, a real application is presented from the recent literature for the new product ideas problem.

In brief statements, main specifications of the proposed HF-HMCGDM approach based on VIKOR method are as follows: (1) By extending a hesitant fuzzy weighting method, the proposed method in a multi-level hierarchy structure is capable to solve the large-sized problems under uncertainty; (2) A new hesitant fuzzy version of the VIKOR method with risk preferences of the DMs is introduced by an effective and simple distance measure metric; (3) By an aggregation group decision-making method, a new hesitant fuzzy ranking index is extended; (4) The weight of each DM is computed and considered in the HF-HMCGDM approach; and (5) By hesitant fuzzy Hamming distance, hesitant fuzzy compromise, hesitant fuzzy individual, and hesitant fuzzy group utility measures are taken into account. Finally, a three-stage hybridization of hierarchical VIKOR and hierarchical weighting method is introduced in hesitant fuzzy group decision-making situations.

The structure of paper is organized as follows: in section 2, some basic operations and basic concepts are defined. In section 3, the proposed HF-HMCGDM approach based on the VIKOR method is illustrated. In section 4, we utilize a real application example to show the efficiency of the proposed HF-HMCGDM approach; in addition, some remarkable conclusions are reported in section 5.

2. PRELIMINARIES

In this section, the preliminary concepts and preliminary operations of the HFSs are given.

Definition 1 [35]. Let X be a reference set, then a HFS as E on X is described as a function $h_E(x)$ that is applied to X returns to a subset of [0, 1].

$$E = \{< x, h_E(\mathrm{x}) >| \mathrm{x} \in \mathrm{X}\} \tag{1}$$

where $h_E(x)$ is describing as set of possible membership degrees of an element, in [0,1], $x \in X$ to E.

Definition 2 [35]. Let h, h_1, and h_2 be HFSs, then the following relations are defined respecting to the relation between the HFS and IFS:

$$h_1 \oplus h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} \{\gamma_1 + \gamma_2 - \gamma_1.\gamma_2\} \tag{2}$$

$$h_1 \otimes h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} \{\gamma_1.\gamma_2\} \tag{3}$$

$$h^\lambda = \cup_{\gamma \in h} \{\gamma^\lambda\} \tag{4}$$

$$\lambda h = \cup_{\gamma \in h} \{1 - (1-\gamma)^\lambda\} \tag{5}$$

Definition 3 [35]**.** Distance measure between two HFSs should be satisfied by the following properties; let M and N be two HFSs on X, then:

$$0 \le d(M,N) \le 1 \tag{6}$$

$$d(M,N) = 0 \quad \textit{if and only if } M = N \tag{7}$$

$$d(M,N) = d(N,M) \tag{8}$$

Definition 4 [34]. Some different distance measures are proposed; in this paper the Hamming distance measure is used. Let h_M and h_N two HFSs, then the Hamming distance between them is as follows:

$$d\left(h_M, h_N\right) = \frac{1}{l_{x_i}} \sum_{\lambda=1}^{l_{x_i}} \left| h_M^{\sigma(\lambda)} - h_N^{\sigma(\lambda)} \right| \tag{9}$$

The λth largest value in h_M and h_N are indicated as $h_M^{\sigma(\lambda)}$ and $h_M^{\sigma(\lambda)}$.

Definition 5 [35]. The hesitant fuzzy weighted averaging (HFWA) operator is defined. Let $h_j\left(j=1,2,...,n\right)$ be some of HFE, then:

$$HFWA\left(h_1, h_2, ..., h_n\right) = \underset{j=1}{\overset{n}{\oplus}} \left(w_j h_j\right)$$
$$= \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, ..., \gamma_n \in h_n} \left\{1 - \prod_{j=1}^{n} \left(1-\gamma_j\right)^{w_j}\right\} \tag{10}$$

3. PROPOSED HESITANT FUZZY-HIERARCHICAL GROUP DECISION-MAKING APPROACH

Let $A=\{A_1, A_2, ..., A_m\}$ be a set of possible alternatives, $I=\{I_1, I_2, ..., I_n\}$ be a set of indicators in the first level, $C=\{C_1, C_2, ..., C_{n'}\}$ be a set of criteria in the second level and $MC=\{MC_1, MC_2, ..., MC_{n''}\}$ be a set of main criteria in the third level. Also, suppose that characteristics of each possible alternative according to each criterion are represented by A_i^{MCk}, where index MC and k demonstrate the main criteria level and the number of the DMs, respectively; also, they are presented by HFSs as below:

$$A_i^{MCk} = \left\{ \begin{array}{l} \left(\mu_{i1}^{MC1}, \mu_{i1}^{MC2}, ..., \mu_{i1}^{MCK}\right), \\ \left(\mu_{i2}^{MC1}, \mu_{i2}^{MC2}, ..., \mu_{i2}^{MCK}\right), ..., \\ \left(\mu_{in''}^{MC1}, \mu_{in''}^{MC2}, ..., \mu_{in''}^{MCK}\right) \end{array} \right\} \quad \forall i \tag{11}$$

Respecting to the above-statements, the structure of the proposed HF-HMCGDM approach by regarding the VIKOR method is depicted in Figure 1.

Step 1. Determine the weight of each DM (λ_k).

$$\lambda_k = \frac{\sum_{i}^{m} \sum_{j}^{n} \mu_{ij}^{k}}{\sum_{k}^{K} \sum_{i}^{m} \sum_{j}^{n} \mu_{ij}^{k}} \tag{12}$$

$$\sum_{k=1}^{K} \lambda_k = 1$$

Step 2. Determine the weight of main criteria, sub-criteria and indicators (w_J^*).

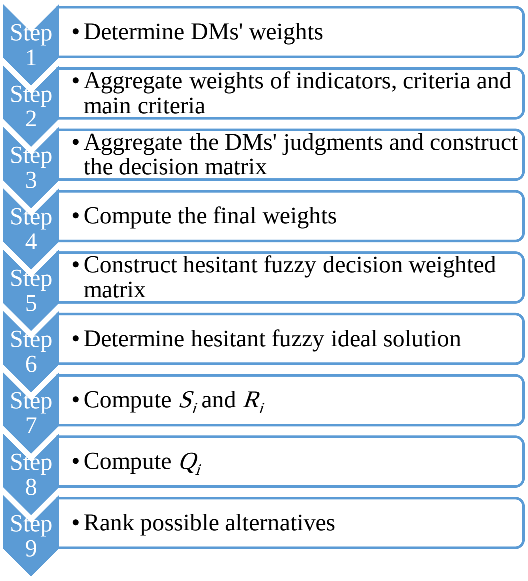

Figure 1. Structure of proposed HF-HMCGDM approach based on VIKOR method

Based on definition 5, the HFWA is utilized as follows:

$$w_J^* = HFWA\left(\varpi_J^{(1)}, \varpi_J^{(2)}, ..., \varpi_J^{(k)}\right) = \underset{k=1}{\overset{K}{\oplus}} \left(\lambda_k \varpi_J^{(k)}\right)$$
$$= \cup_{\varpi_J^{(k)} \in w_J^{(k)}} \left\{1 - \prod_{k=1}^{K} \left(1-\varpi_J^{(k)}\right)^{\lambda_k}\right\} \quad \forall J \approx j', j'', j''' \tag{13}$$

$$w_J = \frac{w_J^*}{\sum_{J} w_J^*} \quad \forall J \approx j', j'', j''' \tag{14}$$

where $w^I = \left[w_1^I, w_2^I, ..., w_n^I\right]$ as the weight of indicators, $w^C = \left[w_1^C, w_2^C, ..., w_{n'}^C\right]$ as the weight of criteria and $w^{MC} = \left[w_1^{MC}, w_2^{MC}, ..., w_{n''}^{MC}\right]$ as the weight of main criteria.

Step 3. Construct hesitant fuzzy decision matrix by aggregating opinions of the DMs.

Determine the aggregation hesitant fuzzy sets for each alternative according to each main criterion. Based on definition 5, the HFWA operator is used for the decision problem as below:

$$r_{ij}^{MC} = HFWG\left(\tilde{h}_1^{MC}, \tilde{h}_2^{MC}, ..., \tilde{h}_K^{MC}\right)$$
$$= \left(\underset{k=1}{\overset{K}{\oplus}} \left(\tilde{h}_K^{MC}\right)^{\psi_j^k}\right)$$
$$= \cup_{\gamma_1 \in h_1^{MC}, \gamma_2 \in h_2^{MC}, ..., \gamma_K \in h_K^{MC}} \left\{1 - \prod_{k=1}^{K} \left(1-\mu_{ij}^{MCk}\right)^{\psi_j^k}\right\} \quad \forall i, j \tag{15}$$

$$\psi_j^k = \lambda_k \otimes w_j, \quad \forall j, k \tag{16}$$

$$R^{MC}=\begin{bmatrix}\mu_{A_1}^{MC}(x_1) & \mu_{A_1}^{MC}(x_2) & \cdots & \mu_{A_1}^{MC}(x_{n'''})\\ \mu_{A_2}^{MC}(x_1) & \mu_{A_2}^{MC}(x_2) & \cdots & \mu_{A_2}^{MC}(x_{n'''})\\ \vdots & \vdots & \ddots & \vdots\\ \mu_{A_m}^{MC}(x_1) & \mu_{A_m}^{MC}(x_2) & \cdots & \mu_{A_m}^{MC}(x_{n'''})\end{bmatrix} \tag{17}$$

Step 4. Aggregate the weight of main criteria level according to all-level weights and specify the final aggregation weights of main criteria.

$$w_j = w_{j'} . w_{j''} \quad \forall j' \text{and} j'' \tag{18}$$

$$w_{j'} = w_{j''} . w_{j'''} \quad \forall j'' \text{and} j''' \tag{19}$$

Step 5. Construct hesitant fuzzy decision-weighted matrix (R^T) as below.

$$R^{T}=\begin{bmatrix}w_1.\mu_{A_1}^{MC}(x_1) & w_2.\mu_{A_1}^{MC}(x_2) & \cdots & w_n.\mu_{A_1}^{MC}(x_{n'''})\\ w_1.\mu_{A_2}^{MC}(x_1) & w_2.\mu_{A_2}^{MC}(x_2) & \cdots & w_n.\mu_{A_2}^{MC}(x_{n'''})\\ \vdots & \vdots & \ddots & \vdots\\ w_1.\mu_{A_m}^{MC}(x_1) & w_2.\mu_{A_m}^{MC}(x_2) & \cdots & w_n.\mu_{A_m}^{MC}(x_{n'''})\end{bmatrix} \tag{20}$$

Step 6. Determine hesitant fuzzy ideal solution (r_j^*) for all main criteria. In addition, the J_1 and J_2 are considered as benefit and cost criteria, respectively. Then, r_j^* is obtained as below:

$$r_j^*=\begin{pmatrix}\left(\max_i \mu_{R_{ij}^T}(x_j) \mid j\in J_1\right),\\ \left(\min_i \mu_{R_{ij}^T}(x_j) \mid j\in J_2\right)\end{pmatrix} \tag{21}$$

Step 7. Calculate a hesitant fuzzy average group score value S_i and a hesitant fuzzy worst group score value R_i for each possible alternative A_i as follows:

$$S_i=\sum_{j=1}^{n} w_j \times d\left(R_{ij}^T, r_j^*\right), \quad \forall i$$

$$S_i=\sum_{j=1}^{n} w_j \left|R_{ij}^T - r_j^*\right| \qquad \forall i \tag{22}$$

$$S_i=\sum_{j=1}^{n}\frac{w_j}{l_{x_i}}\sum_{\lambda=1}^{l_{x_i}}\left|R_{ij}^{T\sigma(\lambda)} - r_j^{*\sigma(\lambda)}\right| \qquad \forall i$$

$$R_i=\max_j\left(w_j \times d\left(R_{ij}^T, r_j^*\right)\right) \quad \forall i$$

$$R_i=\max_j\left(w_j\left|R_{ij}^T - r_j^*\right|\right) \quad \forall i \tag{23}$$

$$R_i=\max_j\left(\frac{w_j}{l_{x_i}}\sum_{\lambda=1}^{l_{x_i}}\left|R_{ij}^{T\sigma(\lambda)} - r_j^{*\sigma(\lambda)}\right|\right) \quad \forall i$$

here, w_j is final aggregated weight of all levels. In this sake, the hesitant fuzzy average group score value (Equation (22)) is developed regarding the utility index concept and could determine the usefulness of each alternative along the selected criteria. Moreover, the hesitant fuzzy worst group score value (Equation (23)) is extended regarding the regret index concept and could specify the worst condition of each alternative in terms of the criteria.

Step 8. Calculate the proposed hesitant fuzzy ranking index Q_i for $i=1,2,...,m$ as below:

$$Q_i = \nu.d\left(S_i, S^*\right)+(1-\nu).d\left(R_i, R^*\right) \quad \forall i$$

$$\nu = HFWA(\nu_1,\nu_2,...,\nu_k)= \\ \bigoplus_{k=1}^{K}(\lambda_k \nu_k)=\cup_{\nu_k\in\tilde{\nu}}\left\{1-\prod_{k=1}^{K}(1-\nu_k)^{\lambda_k}\right\} \tag{24}$$

$$Q_i=\left(1-\prod_{k=1}^{K}(1-\nu_k)^{\lambda_k}\right)\left|S_i - S^*\right| \\ +\left(\prod_{k=1}^{K}(1-\nu_k)^{\lambda_k}\right)\left|R_i - R^*\right|$$

$$Q_i=\frac{1}{l_{x_i}}\begin{pmatrix}\left(1-\prod_{k=1}^{K}(1-\nu_k)^{\lambda_k}\right)\sum_{\lambda=1}^{l_{x_i}}\left|S_i^{\sigma(\lambda)} - S^{*\sigma(\lambda)}\right|\\ +\left(\prod_{k=1}^{K}(1-\nu_k)^{\lambda_k}\right)\sum_{\lambda=1}^{l_{x_i}}\left|R_i^{\sigma(\lambda)} - R^{*\sigma(\lambda)}\right|\end{pmatrix} \quad (24) \tag{25}$$

$$S^*=\min_i\left(\mu_{S_i}\right) \tag{26}$$

$$R^*=\min_i\left(\mu_{R_i}\right) \tag{27}$$

Step 9. Sort decreasing each Q_i value and rank each alternative.

4. APPLICATION EXAMPLE

4. 1. Problem Description

In this section, an industrial application is presented to denote the suitability of the proposed HF-HMCGDM approach based on the VIKOR method for appraising new product ideas. To create a set of new product ideas, a committee is considered consisting five DMs. For the selection process, six indicators are selected. Also, these indicators are divided to five main criteria. Finally, four alternatives as new product ideas (*NPI*$_i$) are considered for this problem. Four NPI$_i$ are offered as possible alternatives for the industrial selection problem. The indicators and main criteria are defined as follows [52]:(C_1) project resource compatibility, (C_2) product superiority and uniqueness, (C_3) technology complexity and magnitude,(C_4) market need, growth and size, (C_5) maintenance of market share and sunk cost, (C_6) project risks, (C_{61}) financial risks, (C_{62}) managerial risks, (C_{63}) envisioning risks, (C_{64}) design risks, and (C_{65}) execution risks.

4. 2. Implementation As indicated in Table 1, the linguistic variables for rating the importance of criteria are in an interval form. The DMs' risk preferences can be considered. If the DMs are pessimist, the lower bound of hesitant interval-valued fuzzy elements (HIVFEs) is considered and if the DMs are optimist, the upper bound of HIVFEs is selected (See Table 2). In addition, if the risk preferences of DMs are considered as moderate, the average of HIVFEs is chosen. In the selection problem, DM$_1$ and DM$_2$ are pessimist, DM$_3$ is moderate and DM$_4$ and DM$_5$ are optimists.

Herein, the proposed HF-HMCGDM approach based on the VIKOR procedure is presented for the industrial case study. In this real practical example, four types of possible alternatives as new product ideas are taken to be estimated according to ten attributes. The criteria and alternatives evaluations are measured by using hesitant linguistic terms. The evaluations are made by five DMs and the proposed HF-HMCGDM approach can be applied in the new product idea selection problem. The hesitant linguistic terms for the assessment of the performance ratings regarding the four new product ideas with respect to the criteria are obtained. Also, the rating of the relative importance of indicators are provided. In addition, the rating importance of the main criteria is determined.

TABLE 1. Hesitant linguistic variables for rating the importance of attributes

		DMs' risk preferences		
Hesitant linguistic variables	**Hesitant interval-value fuzzy elements**	**Pessimist**	**Moderate**	**Optimist**
Very important (VI)	[0.40,0.50]	0.40	0.45	0.50
Important (I)	[0.30,0.40]	0.30	0.35	0.40
Medium (M)	[0.20,0.30]	0.20	0.25	0.30
Unimportant (U)	[0.10,0.20]	0.10	0.15	0.20
Very unimportant (VU)	[0.10,0.10]	0.10	0.10	0.10

As mentioned earlier, the five DMs expressed their judgments for indicators' weights, main criteria' weights, and possible alternatives by using hesitant linguistic terms. By Equation (12), the importance of each DM is determined that is presented in Table 3. The normalized aggregated weight of indicators and weight of main criteria with respect to the DMs' weights are computed by Equations (13) and (14). Also, the final normalized weight of main criteria is calculated by Equations (18)-(19). The corresponding results are then given in Table 4. In addition, to obtain the weighted decision matrix, the data is applied and provided in Tables 3 and 4; the hesitant fuzzy ideal solution are then achieved by Equation (21). The results are presented in Table 5.

There may be a conflict between the Q_i value and NPD DMs' preferences (i.e., v value) [53]. Therefore, for deriving v value, a new aggregate group approach is proposed by a hesitant fuzzy value. Table 6 illustrates the value of the v in the hesitant fuzzy environment. By the weighted decision matrix in Table 5 and the final normalized weight of main criteria in the last column of Table 4, an overall fuzzy preference value for each possible alternative can be obtained.

TABLE 2. Hesitant fuzzy values for the rating alternatives

		DMs' risk preferences		
Hesitant linguistic variables	**Hesitant interval-value fuzzy sets**	**Pessimist**	**Moderate**	**Optimist**
Extremely high (EH)	[0.95,0.95]	0.95	0.95	0.95
Very very high (VVH)	[0.90,0.90]	0.90	0.90	0.90
Very high (VH)	[0.80,0.90]	0.80	0.85	0.90
High (H)	[0.70,0.80]	0.70	0.75	0.80
Medium high (MH)	[0.60,0.70]	0.60	0.65	0.70
Medium (M)	[0.50,0.60]	0.50	0.55	0.60
Medium low (ML)	[0.40,0.50]	0.40	0.45	0.50
Low (L)	[0.25,0.40]	0.25	0.325	0.40
Very low (VL)	[0.10,0.25]	0.10	0.175	0.25
Very very low (VVL)	[0.10,0.10]	0.10	0.10	0.10

TABLE 3. Weights of five DMs with respect to their judgments to preferences of attributes

	DM$_1$	**DM$_2$**	**DM$_3$**	**DM$_4$**	**DM$_5$**
DMs' weight	0.153846	0.17004	0.206478	0.226721	0.242915

TABLE 4. Normalized aggregated weights of attributes in all levels

	Normalized aggregated indicators' weights	**Normalized aggregated main criteria' weights**	**Final normalized weights of main criteria**
C_1	0.089707		0.089707121
C_2	0.142117		0.142116561
C_3	0.211516		0.211515921
C_4	0.175965		0.175965031
C_5	0.089707		0.089707121
C_6	0.290988		
C_{61}		0.23867	0.069450103
C_{62}		0.221573	0.064475049
C_{63}		0.069087	0.020103455
C_{64}		0.155619	0.045283292
C_{65}		0.076382	0.022226242

The $\tilde{S}_i$ and $\tilde{R}_i$ values are computed by Equations (22)-(23) and the calculative results are given in Table 7. Also, in this table, the Q_i values are calculated by selecting the hesitant fuzzy value of the v. The DMs' preferences for rating the v are aggregated by Equation (24) and the Q_i value is calculated by Equation (25). Moreover, the computational results are given in Table 7; it shows that A_2 (NPI$_2$) has attained the first rank whereas A_4 (NPI$_4$) has been the last one. Therefore, for the investment of new product, the NPI$_2$ is the first recommendation. Finally, comparative results between the proposed HF-HMCGDM approach and the recent method of the literature are also provided in Table 7.

As indicated in Table 7, the proposed HF-HMCGDM approach is compared with a conventional VIKOR method, and same ranking results are obtained.

So, some merits and advantages are elaborated in proposing the HF-HMCGDM method. In this respect, the proposed approach evaluates the alternatives based on a group of NPD experts' judgments regarding risk preferences of the NPD DMs to consider their expertise and experience for precise results. Furthermore, the weight of each expert is computed and manipulated in process of the proposed approach. In addition, a hierarchical approach is provided in procedure of the proposed approach to assess the group decision-making problems under different aspects. However, one of the main advantages of this study is uncertainty modelling which could provide the linguistic assessments, qualitative variables, and reliable incomplete information in procedure of the group decision-making evaluation. Consequently, the proposed approach is established based on three-stage hybridization of hierarchical VIKOR and hierarchical weighting method in hesitant fuzzy group decision-making situations that is capable and reliable to solve the large-sized problems under uncertainty versus the conventional methods.

TABLE 5. Weighted decision matrix

Criteria / **Alternatives**	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
NPI$_1$	0.044854	0.113693	0.169213	0.123176	0.044854
NPI$_2$	0.071766	0.08527	0.12691	0.070386	0.022427
NPI$_3$	0.062795	0.056847	0.148061	0.158369	0.062795
NPI$_4$	0.035883	0.071058	0.105758	0.123176	0.062795
r_j^*	0.071766	0.113693	0.105758	0.158369	0.022427
Criteria / **Alternatives**	**C_{61}**	**C_{62}**	**C_{63}**	**C_{64}**	**C_{65}**
NPI$_1$	0.04167	0.045133	0.010051728	0.022642	0.015558
NPI$_2$	0.05556	0.038685	0.008041382	0.018113	0.013336
NPI$_3$	0.034725	0.02579	0.014072419	0.031698	0.017781
NPI$_4$	0.05556	0.045133	0.016082764	0.02717	0.013336
r_j^*	0.034725	0.02579	0.008041382	0.018113	0.013336

TABLE 6. Hesitant fuzzy value of *v*

Decision makers ***v* value**	**DM$_1$**	**DM$_2$**	**DM$_3$**	**DM$_4$**	**DM$_5$**
Hesitant fuzzy linguistic terms	M	I	I	M	I
Hesitant fuzzy values	0.20	0.30	0.35	0.30	0.40
Aggregated opinion of DMs	0.322184				

5. CONCLUSIONS AND FUTURE RESEARCHES

In the process of developing new products (NPD), there are different attributes of the evaluation by a group of experts that often can be established in a hierarchy of multiple levels. The selection of the best possible alternative under uncertainty is a complex decision problem, which includes risks in nature.

TABLE 7. Values of S_i , R_i , Q_i and ranking the alternatives

Values **Alternatives**	S_i	R_i	Q_i	**Ranked by the proposed HF-HMCGDM approach**	**Ranked by conventional VIKOR method**
NPI$_1$	0.026065	0.013422	0.006116756	2	2
NPI$_2$	0.026274	0.015482	0.007580422	1	1
NPI$_3$	0.022288	0.008948	0.001867424	3	3
NPI$_4$	0.022358	0.006193	0.000022585	4	4

To address this situation, the multiple perspectives from several professional NPD DMs from different departments in organizations are needed. Therefore, it is necessary to have a credible decision approach in the NPD environment to obtain and distinguish the right alternative in terms of contradictory criteria. In this paper, a new hybrid three-stage approach was proposed regarding a powerful hesitant fuzzy hierarchical weighting method and a new hesitant fuzzy VIKOR method under the hesitant fuzzy environment in order to make the best decisions in NPD-selection problems. Motivated by hesitant fuzzy Hamming distance measure and hesitant fuzzy weighted averaging, this paper has utilized them in the process of the proposed hesitant fuzzy-hierarchical multiple criteria group decision-making (HF-HMCGDM) approach. In addition, a set of linguistic terms has been used to help NPD DMs make judgments and evaluate each possible alternative according to qualitative criteria. In this respect, for margin of error, the DMs assigned their opinions under hesitant fuzzy sets (HFSs). Furthermore, at the end of the ranking process, the DMs' judgments have been aggregated as a group decision by utilizing the HFSs to reflect the inherent uncertainty involved in computing the strategy of the majority of criteria. Finally, the proposed HF-HMCGDM approach was applied to the real case study in new product ideas problem from the recent literature to illustrate the group decision process systematically. In addition, comparative analyses showed that the proposed HF-HMCGDM approach was verified, and it could be powerful in solving complex and large-sized decision-making problems in uncertain situations. For future directions, developing a new combined procedure for determining the weight of each expert could enhance the proposed HF-HMCGDM approach. Moreover, the proposed approach could be developed regarding dynamic uncertainty to assess the alternatives in different periods.

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Solving New Product Selection Problem by a New Hierarchical Group Decision-making Approach with Hesitant Fuzzy Setting

S. M. Mousavi

Department of Industrial Engineering, Faculty of Engineering, Shahed University, Tehran, Iran

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چکیده

انتخاب مناسب ترین آلترناتیو تحت شرایط عدم قطعیت به عنوان یک مسئله حیاتی تصمیم گیری در نظر گرفته می شود که بر موفقیت سازمانها تاثیر می‌گذارد. در فرآیند انتخاب، تعداد معیارهای ارزیابی با در نظر گرفتن گروهی از تصمیم گیرندگان وجود دارد که می‌تواند در یک ساختار سلسله مراتبی چند سطحی قرار گیرد. هدف از این مقاله معرفی یک رویکرد تصمیم گیری گروهی چندمعیاره گروهی سلسله مراتبی جدید است که براساس مفاهیم جواب توافقی با مجموعه های فازی تردیدی بنا نهاده شده است. برگرفته از مجموعه های فازی تردیدی، اندازه فاصله همینگ در فرآیند تصمیم گیری سلسله گروهی پیشنهادی استفاده می شود و نیز اپراتور میانگین وزنی فازی تردیدی برای ادغام نظرات خبرگان یا تصمیم گیرندگان بهره گرفته می شود. ابتدا برای وزندهی معیارهای ارزیابی، یک روش وزندهی سلسله مراتبی فازی تردیدی توسعه می یابد. سپس به منظور رتبه بندی گزینه های ممکن، یک روش توسعه یافته فازی تردیدی برمبنای حل توافقی سنتی ارائه می شود. علاوه بر این، یک مطالعه موردی برای مساله ایده تولید محصول جدید از ادبیات اخیر استفاده می شود تا رویکرد تصمیم گیری پیشنهادی تبیین گردد و سرانجام یک تحلیل مقایسه‌ای برای نمایش توانمندی مدل آورده می‌شود.

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