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Extended Intuitionistic Fuzzy VIKOR Method in Group Decision Making: The Case of Vendor Selection Decision

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Abstract**—**Vendor (supplier) selection is a group decision-making (GDM) process, in which, based on some predetermined criteria, the experts' preferences are provided in order to rank and choose the most desirable suppliers. In the real business environment, our attitudes or our choices would be made in an uncertain and indecisive situation could not be expressed in a crisp framework. Intuitionistic fuzzy sets (IFSs) could handle such situations in the best way. VIKOR method was developed to solve multi-criteria decision-making (MCDM) problems. This method, which is used to determine the compromised feasible solution with respect to the conflicting criteria, introduces a multi-criteria ranking index based on the particular measure of 'closeness' to the 'ideal solution'. Until now, there has been a little investigation of VIKOR with IFS, therefore we extended the intuitionistic fuzzy (IF) VIKOR to solve vendor selection problem under IF GDM environment. The present study intends to develop an IF VIKOR method in a GDM situation. Therefore, a model is presented to calculate the criterion weights based on entropy measure. Then, the interval-valued intuitionistic fuzzy weighted geometric (IFWG) operator utilized to obtain the total decision matrix. In the next stage, an approach based on the positive idle intuitionistic fuzzy number (PIIFN) and negative idle intuitionistic fuzzy number (NIIFN) was developed. Finally, the application of the proposed method to solve a vendor selection problem illustrated.

Keywords**—**Group decision making, intuitionistic fuzzy entropy measure, intuitionistic fuzzy set, vendor selection VIKOR.

I. INTRODUCTION

THE main purpose of this paper is to extend the VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) method based on IFS to develop a new method to solve vendor selection problems under a GDM environment.

Vendor selection is the process of choosing suppliers based on a number of criteria, which are compatible with a company's conditions. Supplier selection is one of the most important tasks of supply chain management in the competitive world; however, success in supply chain management (SCM) is the most important point for achieving growth and success in a competitive situation. Today, SCM has become an important area for both the factory owners and researchers. A variety of methods have been proposed for supplier selection, including the following: Saen [1], who employed the DEA model to evaluate technology suppliers in a nuclear power station concerning two outputs including electricity capacity and amount of know-how transfer; and one input (cost). An enhanced imprecise DEA model was proposed by Wu et al. [2] to choose supplier and to deal with the imprecise data for distinguishing efficient suppliers from other suppliers in an aviation electronics manufacturing company with respect to two inputs (cost and judgment) and two outputs (revenue and satisfaction) criteria. Talluri [3] introduced an integer linear programming to choose a group of bids in respect to a company's limitations. Hong et al. [4] proposed a mixed-integer linear programming model to supplier selection, based on maximizing the revenue. Muralidharan et al. [5] presented a five-step Analytic Hierarchy Process (AHP) model to supplier selection regarding nine criteria in a bicycle manufacturing company. Hou and Su [6] introduced decision support system (DSS) based on the AHP model to deal with the supplier selection problem in a printer manufacturing company regarding seven criteria. Sarkis and Talluri [7] applied Analytic Network Process (ANP) to evaluate the supplier and to choose them based on seven evaluation criteria in a high technology metal-based manufacturing company. Chen et al. [8] suggested a hierarchy model that utilized fuzzy set theory technique to deal with linguistic value. Bottani and Rizzi [9] presented integrated method including cluster analysis and the AHP method to evaluate and rank the alternative to select the suppliers. Choy and Lee [10] applied an overall model of case based reasoning CBR-system in a consumables manufacturing company. Three groups of criteria were used to evaluate the candidate alternatives including organizational profile, technical capability, and quality system. Choy et al. [11] presented the same method that was suggested by [10]. An integrated AHP and DEA method to supplier selection in a hypothetical case with respect to the four criteria, namely quality, technology, manufacturing cost, and after-sales service has been introduced by [12]. Other integrated methods used to handle supplier selection problem were integrated fuzzy and genetic algorithm methods [13]. A two-step model with regard to the five criteria which had been implemented in a automobile part manufacturing company, by using rating linguistic values to evaluate the weight of each criteria, and VIKOR, a Serbian name translated as multi-criteria optimization and compromise solution), to finally choose the supplier has been proposed by [14]. Deshang Dash Wu et al. [15] suggested a fuzzy multi objective programming (FMOP) model regarding risk factors to deal with the supplier selection

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process. They utilized a possibility approach to solve the FMOP model based on three levels by using the simulated historical quantitative and qualitative criteria. A MCDM approach based on fuzzy TOPSIS for evaluating environmental performance of suppliers has been developed by Awasthi et al. [16]. They utilized fuzzy set theory to deal with vagueness and used linguistic variables to represent decision maker preferences. Boran et al. [17] presented an IF multi-criteria GDM with TOPSIS method for supplier selection problem.

The literature analysis illustrates that the majority of researchers concentrated on vendor selection methods using probability distributions and some applied Fuzzy approach to enhance the results. Deploying IFS VIKOR as an extended method, which may contribute toward more precise results is still under question. Consequently, in this study, we are proposing such an innovative method for selecting the most appropriate vendor.

II. IFS and VIKOR Method

A. IFS

Fuzzy logic and fuzzy sets theory (FSs) proposed by [18] has represented a means for handling vagueness and impreciseness in the real life situations. Atanassov [19]-[21] introduced a generalization of Zadeh's fuzzy set called IFS. Each IFS is characterized by a membership function and non-membership function. IFS are useful in dealing with uncertainty and vagueness. Today, IFS has become one of the most applicable subjects in many various scientific fields, including medical diagnosis [22], [23], clustering [24], [25], pattern recognition [26]-[30] and IFS topology [31]-[34]. Gau and Buehrer [35] introduced the vague set, but Bustince and Burillo [36] showed that it is an equivalence of IFS. Many relations and operators related to IFS have been studied by researchers, such as distance measure [37]-[39], similarity measure [40]-[43], and IFS entropy [44]-[46]. Xu and Yager [47] developed some geometric aggregation based on IFS, such as the IFWG operator, the intuitionistic fuzzy ordered weighted geometric (IFOWG) operator, and the intuitionistic fuzzy hybrid geometric (IFHG) operator. Xu [48], moreover, developed the intuitionistic fuzzy ordered weighted averaging (IFOWA) operator and the intuitionistic fuzzy hybrid aggregation (IFHA) operator. Many investigations have been done on GDM with IFS by researchers. Atanassov et al. [49] used IFS to solve a multi-criteria, multi-person, and multi-measurement GDM problem. Li et al. [50] developed a fractional programming models based on TOPSIS to solve multi-attribute GDM problems using IFS. Some research has been conducted on aggregation operators of decision-making process. As an illustration, Wei [51] proposed two new aggregation operators: induced intuitionistic fuzzy ordered weighted geometric (I-IFOWG) operator and induced interval-valued intuitionistic fuzzy ordered weighted geometric (I-IVIFOWG) operator, and developed them to solve the MAGDM problems, in which both the attribute weights and the expert weights take the form of real numbers. Liu and Wang [52] presented a new method for solving the MCDM problem in an IF environment to measure the extent to which alternatives meet the decision-makers requirements. Boran et al. [17] combined TOPSIS method with IFS to select appropriate supplier in a GDM procedure. Xu and Yager [53] presented two new aggregation operators: dynamic intuitionistic fuzzy weighted averaging (DIFWA) operator and uncertain dynamic intuitionistic fuzzy weighted averaging (UDIFWA) operator and introduced some methods, including the basic unit-interval monotonic (BUM) function based method, normal distribution based method, exponential distribution based method, and average age method, to determine the weight vectors associated with these operators. They also investigated the dynamic multi-attribute decision making problems with IF information. Wei [54] introduced an optimization model based on the basic ideal of traditional grey relational analysis (GRA) method, by which the attribute weights can be determined. They investigated the multiple-attribute decision-making problems with IF information. In this model, the information concerning attribute weights are not fully known, and the attribute values take the form of IF numbers. Xu [55] also developed a method based on distance measure for GDM with interval valued IF matrices. Wu and Zhang [56] present the concept of the IF weighted entropy, which is a natural extension of the entropy for IFSs. They calculated the criteria weights according to the minimum entropy and use it to solve the MCDM. They also based it on IFS score function and accuracy function ranked the alternatives. Ye [45] proposed a method for MCDM based on entropy weight. He utilized IFS entropy measure to compute the criterion weights and ranked the alternative with respect to weighted correlation coefficients.

The most of mentioned IFS applications are utilized to deal with the decision-making problem with a scoring model and few studies used the compromising models. The VIKOR method is one of the credible compromising models.

B. VIKOR Method

VIKOR method was proposed by Opricovic and Tzeng [57]. Recently, it has gained much attention for its application to solve MCDM problems. VIKOR method focuses on ranking and selecting alternatives in the presence of conflicting criteria. This method is widely used in a variety of fields to solve MCDM problems. Cristóbal [58] employed VIKOR method in the selection of a Renewable Energy project corresponding to the Renewable Energy Plan launched by the Spanish Government. The method was combined with the AHP method to measure the importance of different criteria, allowing decision-makers to assign these values based on their preferences. Kuo and Liang [59] presented an effective approach to the evaluation of Northeast-Asian international airports service quality by conducting customer surveys. They combined the concepts of VIKOR and GRA, to propose a new fuzzy MCDM method that dealt with the evaluation of service quality problems in international airports. Bazzazi et al. [60] presented an evaluation model based on deterministic data, fuzzy numbers, interval numbers and linguistic terms. A combination of AHP and entropy method was applied for attribute weighting in this MADM method. Liou et al. developed a modified VIKOR method to improve service quality among domestic airlines in Taiwan. Chang and Hsu [61] utilized VIKOR to determine the most feasible) solution according to the selected criteria, including geographical and meteorological factors. It was also used by Chen and Wang [62] to provide a delivery approach for evaluating and assessing possible suppliers/vendors. Sayadi et al. [63] extended the method by using interval numbers**.** VIKOR method was extended even more by Opricovic and Tzeng [64] using a stability analysis to determine the weight stability intervals and trade-offs analyses. They compared their extended method with three MCDM methods: TOPSIS, PROMETHEE, and ELECTRE. Kaya and Kahraman [65] utilized an integrated VIKOR-AHP methodology to determine the best renewable energy alternative for Istanbul. They used the pairwise comparison matrices of AHP to determine the weights of the selection criteria. Devi [66] extended the VIKOR method under an IF environment to solve MCDM problems in which the weights of criteria and ratings of alternatives are taken as a triangular IFS.

VIKOR method, which is mainly used to determine the compromised feasible solution with respect to the conflicting criteria, is developed to solve MCDM problems. This method introduces multi-criteria ranking index based on the particular measure of “closeness” to the “ideal solution”, helping the decision makers to reach a final solution. It is one of the suitable methods due to its simple procedure; however, few studies ever apply this method based on IFSs. In real life situations, the decision making data are vague and the crisp sets fail to handle this situation; that is one of the reasons why we extended VIKOR based on IFSs.

III. Contribution

In this study, we extend the VIKOR method based on IFS in order to solve the vendor selection problem under GDM condition. Due to the multiplicity of decision makers (DMs) in the real world, they usually tend to give their preferences for each alternative based on a number of predetermined criteria in an uncertain situation. Thus, they are not confident enough about their preferences, and consequently, their attitudes are blended with some amount of uncertainty (hesitation) degree. This situation can be dealt with in the best way utilizing the IFS concept. Moreover, IFS allows DMs to assign the membership and non-membership degree to each alternative, and it also enables them to overcome the existing uncertainty. Furthermore, in most of GDM developments, the weights of criteria are not fully known. In addition, little investigation has been carried out on GDM with vague criteria weights. Thus, a method to determine the criterion weights for each decision-making matrix is utilized and a model to aggregate the calculated weights is proposed to compute the final entropy weights. On the other hand, the multiplicity of the above-mentioned VIKOR literature perfectly used crisp value and applied linguistic value using the fuzzy logic to solve MCDM problems. However, in reality, due to a lack of knowledge, and the expert’s limited experience in the problem domain, it is often the case that the experts show a tendency toward each alternative in an uncertain situation. They are not, therefore, confident enough about their preferences, and consequently, their attitudes are blended with some degrees of uncertainty. By using the IFS, this plight could completely be dealt with. Moreover, the IFS concept enables experts to assign a degree of membership and non-membership to each alternative based on their preferences according to some discrete criteria. It also enables them to determine the existing uncertainty (hesitation) degree in each preference (attitude). Keeping in mind the fact that little investigation of the VIKOR method has been carried out so far based on IFS, we have developed an intuitionistic fuzzy VIKOR method to solve a GDM problem, in which the preferences (rating) value are expressed in intuitionistic fuzzy number (IFN). The rest of this paper is organized as follows:

In Section II, the influences of criteria on supplier selection process are explored. Section III introduces the concept of IFSs and GDM model based on IFNs. Section IV develops VIKOR method with IFSs. The proposed method for vendor selection is introduced in Section V. Section VI illustrates the application of proposed method to solve a supplier selection problem. A discussion is given in Section VII.

IV. Criteria Selection in Vender Selection

Choosing criteria is a fundamental section in a vendor selection process. Companies tend to choose their vendors based on a number of criteria that are effective and related to the company's activities. The criteria are classified in to two groups, quantitative and qualitative. Some methods use one of them while others use both. In most cases, choosing a particular criterion depends on the special industrial area that each company specializes in, and the vendor selection model used by them. The most commonly used criteria for this purpose include quality, delivery, cost/price, manufacturing capability, service, management, technology, research, flexibility, finance, reputation, relationship, risk and safety, and environment [67]. In the hierarchy of the most important and most commonly used criteria and related sub-criteria in the vendor selection process is constructed. This hierarchical model includes four criteria and 11 sub criteria as follows:

Quality criteria (C_1): quality criteria, because of their direct effect on companies’ outputs are of critical importance to them.

- Six sigma programs (C_{11}): These are the most potent strategies developed to accelerate improvements in processes, products, and services, to reduce manufacturing and/or administrative costs radically, and to improve the quality.
- Total quality management (TQM) (C_{12}): Applying a management technique and an assuring-continuous-improvement approach to doing business through a new management model, it emphasizes the quality of the product or service predominates.
- Quality award (C_{13}): It refers to the number and the kind of quality awards, which the companies have achieved.

Cost and price (C_2):

- Direct cost (C_{21}): Direct cost is the cost, which is directly related to the company's product. Product cost is the overall price of products.
- Unit price (C_{22}): It refers to the price of the product per unit.
- Indirect cost (C_{23}): Indirect cost is the cost, which is not directly related to the products, such as the cost of machinery maintenance.

Delivery (C_3):

- Delivery condition (C_{31}): Refers to the agreed condition of the delivery of the products.
- Degree of closeness (C_{23}): It determines the distance measure between each supplier and manufacture.
- Delivery delays (C_{33}): This is related to the attending time for receiving the goods and services from the suppliers after request submission.
- On-time delivery (C_{34}): Shows the variance between the request submission time and delivery of goods and services time.

Company and technology ability (C_4):

- IT level (C_{41}): IT level indicates the degree to which the information technology is used in the organization, such as customer relation management (CRM) and electronic data interchange (EDI).
- Human resource technology (C_{42}): Refers to the skilled work force in the field of technology who work for the company.

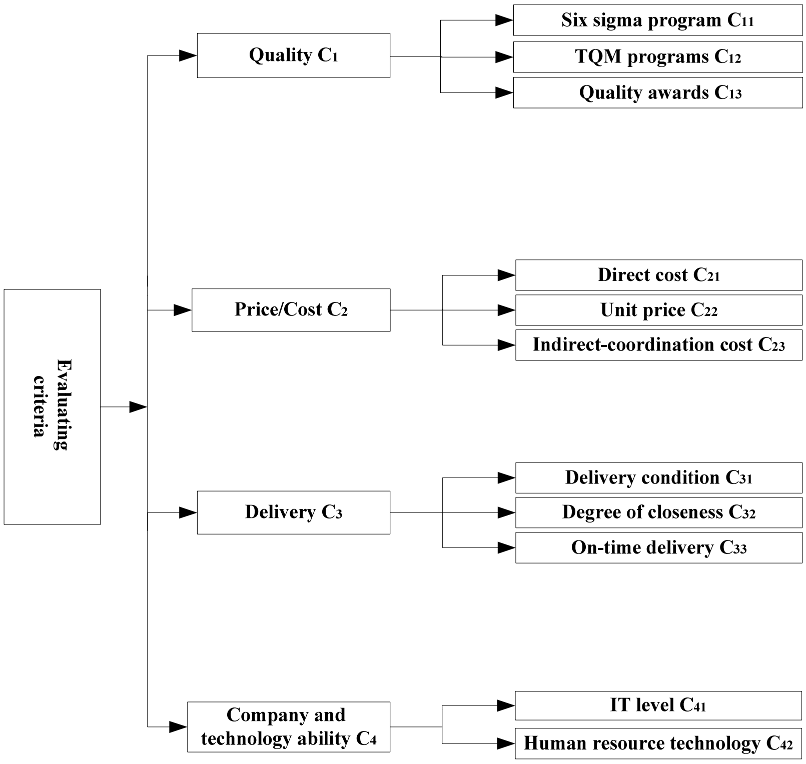

Fig. 1 Values for text Criteria influence in vendor selection process

V. PROPOSED METHOD FOR VENDOR SELECTION

A novel method extending VIKOR is proposed to solve the vendor selection problem under an IF environment. As we mentioned before, the criterion weights are not thoroughly defined; so, we propose a method based on the entropy measure of IFSs to find the criterion weights. The proposed method in this investigation consists of three main stages. The first stage deals with constructing decision matrix from each decision maker based on discreet criteria and candidate alternatives by using the IFN preferences. The second stage seeks the criterion weights based on IFS entropy measure, and in the third stage, the alternatives are ranked by using the proposed extended VIKOR method.

Step1. Construct the decision matrix for each decision maker based on discrete criteria and candidate alternatives (vendors) as follows.

Let $t_j = \{t_1, t_2, ..., t_m\}$ be a set of candidate alternatives, $D_i = \{D_1, D_2, ..., D_n\}$ be a set of decision makers (whose weight vector is $\varepsilon_i = (\varepsilon_1, \varepsilon_2, ..., \varepsilon_n)^T, \sum_{i=1}^{n} \varepsilon_i = 1$) and $C_k = \{C_1, C_2, ..., C_p\}$ be a discrete set of criteria with respect to the weight vector $\gamma_k = (\gamma_1, \gamma_2, ..., \gamma_p)^T$ where $\sum_{k=1}^{p} w_k = 1$). The decision makers D_i $(i = 1, 2, ..., n)$ give their preferences $\tilde{e}_{jk}^{(i)} = \left(\mu_{jk}^{(i)}, v_{jk}^{(i)}, \pi_{jk}^{(i)}\right)$ based on IVIFNs for each alternative A_j and discreet criterion

C_k. The decision matrix $\tilde{X}^{(i)} = \left(\tilde{e}_{jk}^{(i)}\right)_{m\times p}$ is constructed for ith decision maker D_i based on IFNs in Table I.

TABLE I
DECISION MATRIX $\tilde{X}^{(i)}$ WITH IFNS FOR EACH D_i

	C_1	⋯	C_p
t_1	$e_{11}^{(i)} = \left(\mu_{11}^{(i)}, v_{11}^{(i)}, \pi_{11}^{(i)}\right)$	⋯	$\tilde{e}_{1p}^{(i)} = \left(\mu_{1p}^{(i)}, v_{1p}^{(i)}, \pi_{1p}^{(i)}\right)$
t_2	$e_{21}^{(i)} = \left(\mu_{21}^{(i)}, v_{21}^{(i)}, \pi_{21}^{(i)}\right)$	⋯	$\tilde{e}_{2p}^{(i)} = \left(\mu_{2p}^{(i)}, v_{2p}^{(i)}, \pi_{2p}^{(i)}\right)$
⋮	⋮	⋯	⋮
t_m	$e_{m1}^{(i)} = \left(\mu_{m1}^{(i)}, v_{m1}^{(i)}, \pi_{m1}^{(i)}\right)$	⋯	$\tilde{e}_{mp}^{(i)} = \left(\mu_{mp}^{(i)}, v_{mp}^{(i)}, \pi_{mp}^{(i)}\right)$

Step2. Calculate the criteria weights based on entropy measure. Here, the weights of criteria are completely unknown. To obtain the weight of each criterion we use the following entropy weight model:

$$\gamma_k^{(i)} = \frac{1 - \tilde{E}_k^{(i)}}{p - \sum_{k=1}^{p} \tilde{E}_k^{(i)}} \quad \left(i = 1, 2, ..., n\right), \tag{1}$$

where $\gamma_k^{(i)} \in [0,1]$, $\sum_{k=1}^{p} \gamma_k^{(i)} = 1$ and $\tilde{E}_k^{(i)}$ is calculated by

$$\mathrm{E}_{jk}^{(i)} = \frac{1}{\mathrm{m}} \sum_{j=1}^{m} \left\{ \left\{ \sin \frac{\pi \times \left[1 + \mu_{jk}^{i}(x) - v_{jk}^{i}(x)\right]}{4} + \sin \frac{\pi \times \left[1 - \mu_{jk}^{i}(x) + v_{jk}^{i}(x)\right]}{4} - 1 \right\} \times \frac{1}{\sqrt{2} - 1} \right\} \tag{2}$$

or

$$E_{jk}^{(i)} = \frac{1}{m} \sum_{j=1}^{m} \left\{ \left\{ \cos \frac{\pi \times \left[1 + \mu_{jk}^{j}(x) - v_{k}^{j}(x)\right]}{4} + \cos \frac{\pi \times \left[1 - \mu_{jk}^{j}(x) + v_{jk}^{j}(x)\right]}{4} - 1 \right\} \times \frac{1}{\sqrt{2} - 1} \right\} \tag{3}$$

To calculate the total aggregated weight vector $\varpi_k = (\varpi_1, \varpi_2, ..., \varpi_p)$, the following operation is used:

$$\varpi_k = \sum_{i=1}^{n} \varepsilon_i \gamma_k^{(i)} \quad \left(k = 1, 2, ..., p\right). \tag{4}$$

Step3. Utilize $IFWG_{\varepsilon}$ to aggregate all given preferences for each alternative based on each criterion, and then construct the total collective decision matrix $F = \left(f_{jk}\right)_{m\times p}$ as Table II.

$$IFWG_{\varepsilon}\left(e_1, e_2, e_3, ..., e_n\right) = \prod_{i=1}^{n} e_i^{\varepsilon_i} = \left(\prod_{i=1}^{n} \mu_i^{\varepsilon_i}, 1 - \prod_{i=1}^{n} \left(1 - v_i\right)^{\varepsilon_i}\right) \tag{5}$$

Step4. Define the value f^* and f^- as follows:

$$f^* = (1, 0, 0) \tag{6}$$

$$f^- = (0, 1, 0) \tag{7}$$

TABLE II
TOTAL COLLECTIVE MATRIX F

	$C_1\left(\omega_1\right)$	⋯	$C_m\left(\omega_m\right)$
t_1	$f_{11} = \left(\mu_{11}, v_{11}, \pi_{11}\right)$	⋯	$f_{1m} = \left(\mu_{1m}, v_{1m}, \pi_{1m}\right)$
t_2	$f_{21} = \left(\mu_{21}, v_{21}, \pi_{21}\right)$	⋯	$f_{2m} = \left(\mu_{2m}, v_{2m}, \pi_{2m}\right)$
⋮	⋮	⋯	⋮
t_n	$f_{n1} = \left(\mu_{n1}, v_{n1}, \pi_{n1}\right)$	⋯	$f_{nm} = \left(\mu_{nm}, v_{nm}, \pi_{nm}\right)$

Step5. Compute the value S_j and R_j based on distance measure using following relations:

$$S_j = \sum_{j=1}^{m} w_j \left(1 - \mu_{ij}\right). \tag{8}$$

$$R_j = \max_j \{ w_j \left(1 - \mu_{ij}\right) \}. \tag{9}$$

Step6. Calculate the value Compute the value Q_j.

$$\mathrm{Q_i} = \mathrm{v}\left(\mathrm{S_i} - \mathrm{S}^*\right) / \left(\mathrm{S}^- - \mathrm{S}^*\right) + (1 - \mathrm{v}) \left(\mathrm{R_i} - \mathrm{R}^*\right) / \left(\mathrm{R}^- - \mathrm{R}^*\right), \tag{10}$$

$$S^* = \min\left(S_j\right), \ S^- = \max\left(S_j\right) \quad j = 1, 2, ..., m, \tag{11}$$

$$R^* = \min\left(R_j\right), \ R^- = \max\left(R_j\right) \quad j = 1, 2, ..., m. \tag{12}$$

Step7. Rank the alternative according to the values S, R and Q.

Step8. Choose the best vendors based on ranking results.

VI. CONCLUSION

Vendor selection is one of the most important problems in any type of company. In fact, as the main value proposed by businesses is directly dependent to the quality and price of inputs, effective and wise SCM is crucially important. The main expected role of SCM is selecting the best supplier to diminish product process cost and simultaneously reduce the risk while improving supply chain quality. Therefore, companies are expected to have a clear strategy for selecting their supplier, while they benefit from enhanced techniques. In real life situations, the vendor selection problem is often influenced by uncertainty in practice. The IFS concept, because of its conformity with real life, is the best choice to handle such situation. In this study, we propose a new method, the IF VIKOR method, to solve the vendor selection problem under an IF GDM condition in which the weights of criteria uncertain. Considering the ambiguity in the real business environment, we utilized IFNs to show the experts' attitude about each vendor based on each criterion. In the current investigation, the criterion weights are not defined completely. For this reason, we proposed a method by using IF entropy measure to calculate the criteria weights. So far, little investigation has been carried out on the IF VIKOR method; therefore, we extend the VIKOR method based on IFNs to rank the vendors. The main difference between our suggested method and the classic VIKOR is in the way we calculate *S, R,* and *Q* and rank IFN preferences to find f^* and f^-. We utilize distance measure and PIIFN and NIIFN to calculate *S, R, and Q*. In a future study, we implement the IF VIKOR method to rank the B2B e-business websites based on evaluating criteria. Moreover, we will also extended VIKOR method based on interval-valued IFS to solve GDM problems.

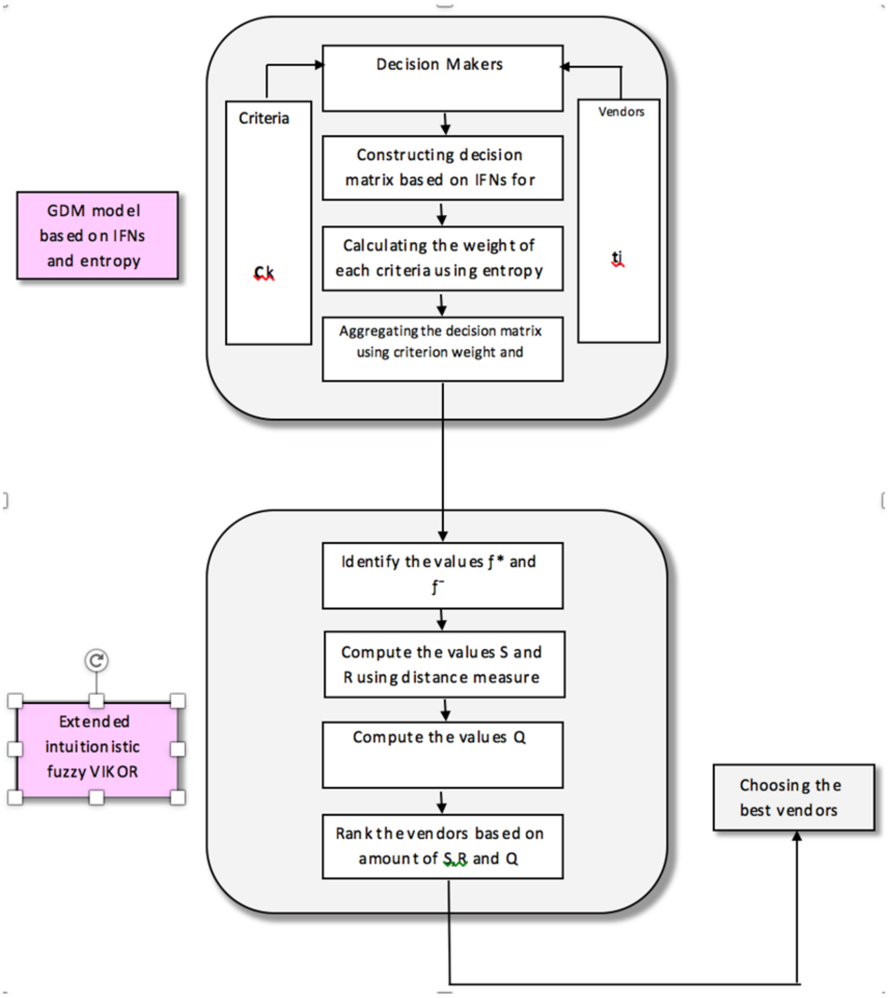

Fig. 2 The process of proposed method

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