Partner selection in Virtual enterprises using the Interval Neutrosophic fuzzy approach

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Abstract: With the rapid development of the Internet, information technology, and globalization of the economy, Some small and medium-sized companies know that they cannot compete with their limited capacity alone. As a result, they are beginning to seek collaboration and a collective approach to meet the dynamic needs of customers and increase their power for competition in the market. Virtual enterprise is a temporary platform for working with different companies that share their core tasks to meet customer's demand. Partner selection is a major issue in the formation of a virtual organization. This is especially difficult due to the uncertainties regarding information, market dynamics, customer expectations, and rapidly changing technology, with highly random decision making. As a generalization of fuzzy sets and intuitionistic fuzzy sets, Neutrosophic sets are created to show the uncertain, and inconsistent information available in the real world. The main purpose of this paper is to identify and select partners in the formation of Virtual Enterprises under uncertainty and contradictory factors using the extended VIKOR group decision making technique using the Interval Neutrosophic fuzzy approach. For this purpose, after identifying the factors affecting partner selection, the factors are weighted using the Maximizing deviation method and the partners are ranked using this method. Finally, a sensitivity analysis for assessing the validity of the method is also presented. The results show that the Willingness to share information criterion is the most important partner selection criterion in this enterprise.

Keywords: Virtual Enterprise, Partner Selection, Interval Neutrosophic Numbers, Group Decision Making, Uncertainty, VIKOR.

1. Introduction

With the globalization of the market and the economy, the rapid development of the use of the Internet and information technologies, faster product updates and market needs have become more uncertain and personalized [1]. Globally, companies are increasingly in need of the competence of other companies to meet growing customers' demands [2]. Therefore, it is difficult to adapt the traditional business model to the new market environment. At the same time, companies need to maintain lower costs and shorter delivery cycles, that this challenges old organizational form [3]. In fact, a enterprise cannot meet the rapid market changes by integrating internal resources and competencies alone [1]. As such, many companies are attracting partners to absorb opportunities in emerging markets to share costs, reduce development time, and utilize the effectiveness of design, production, and marketing skills within and outside companies [4]. With the rapid growth of competition in the global industry, a dynamic virtual enterprise (VE) approach will be needed to meet market needs for quality, responsiveness and customer satisfaction [5]. VE is created to address a specific opportunity in a fast-paced and simultaneous market, creating a collaborative work environment for managing and using a set of resources provided by companies. Business partners are all connected to share their skills, and take advantage of the rapidly changing opportunities in a dynamic network [6]. In fact, through the VE framework, each VE partner brings its expertise for implementing the original project, [7] and each partner focuses on its own core competence. This increases the ability of the organization to meet the unpredictable demands of customers [8]. Therefore, by maintaining the agility of the entire structure, this collaboration will deliver high quality products based on customer's specific needs [7]. In this alliance, the links are made easier by computer technology, [4] and eventually when the market opportunity is over, the VE will be dissolved [5].

Compared to the traditional organizational form, VE is considered a low cost, high responsive and adaptive organization and members of this alliance can share cost, risk, technology, and key competition with each other, through which members can gain win-win policy. However, many issues arise throughout the life cycle of a VE, including how we can find the right partners, which is a key issue for the core enterprise in the VE development phase, and this issue has been considered by many researchers [3]. As the VE environment continues to grow in size and complexity, the importance of managing such complexities increases [5]. In a virtual enterprise (VE), choosing a partner is very important because of the short life of these organizations (temporary alliances) and the absence of formal mechanisms (contracts) to ensure participants' responsibility [9].

The complexity of the partner selection process is reinforced by the fact that there are several centralized internal and external organizational factors that have both tangible and intangible characteristics and should be incorporated into the decision analysis for this selection process [8]. Like all decision-making issues, partner selection involves tangible and intangible paradox specifications under conflicting or incomplete information [10]. Therefore, it is important to select the most appropriate companies while there may be dozens of volunteer companies involved in the project [7]. The multitude of factors that are considered when choosing partners for a business opportunity such as cost, quality, trust and delivery time cannot be expressed by the same size or scale [11]. In practice, partner selection should consider higher levels of uncertainty and risk as a way of addressing uncontrolled factors: such as price or demand fluctuations, lack of enough knowledge sharing among VE members, resource constraints, and incomplete information about candidates and their performance [12].

The multi-attribute group decision making (MAGDM) approach is to provide a comprehensive solution by evaluating and ranking alternatives based on contrasting features based on decision makers' (DM) preferences [13]. Decision-making is often about the optimal choice between a set of options, considering the impact of many criteria. In the past five decades, Multi criteria decision making method (MCDM) has become one of the most important and key ways of solving complex decision problems, despite of various criteria and options. In MCDM problems, the characteristics of dependence, opposition, and interaction are ambiguous between decision criteria, which obscures the degree of membership [14]. In fact, it is difficult for DMs due to the uncertainty of the information and the many constraints such as time pressure, lack of awareness, and problems of data extraction and so on to express their preferences numerically in many complex realities [15]. The fuzzy set theories or the intuitionistic fuzzy theories are used to overcome this obstacle. However, these sets are not always suitable [14]. The fuzzy set (FS) has only one member and cannot display complex information and the intuitionistic fuzzy set, which includes membership and non-membership degree, can only manage incomplete information, and cannot deal with inconsistent information, and degree of indeterminate membership at IFS has always been ignored [16]. Smarandache recommended Neutrosophic set (NS) by adding an indefinite membership function based on IFS. In NS, the degree of accuracy, lack of reliability, and the degree of inaccuracy are completely independent [17].

The Neutrosophic set is becoming a scientific tool and has attracted the attention of many scientists and academic researchers to develop and improve the Neutrosophic method [14]. Abdel-Basset et al. (2020) considered inventory location problem, They applied the best-worst method (BWM) to find the weight of these criteria and propose a combination of plithogenic aggregation operations, and the BWM to solve MCDM problems [18]. Veerappan et al (2020) considered Multi-Aspect Decision-Making Process in Equity Investment Using Neutrosophic Soft Matrices [19]. Abdel-Basset and Mohamed (2020) proposed a combination of plithogenic multi-criteria decision-making approach based on the TOPSIS and Criteria Importance Through Inter-criteria Correlation (CRITIC) methods for sustainable supply chain risk management [20]. Abdel-Basset et al. (2020) provided a new hybrid neutrosophic MCDM framework that employs a collection of neutrosophic ANP, and TOPSIS under bipolar neutrosophic numbers for professional selection [21]. Edalatpanah and Smarandache proposed an input-oriented DEA model with simplified neutrosophic numbers and present a new strategy to solve it [22]. Abdel-Basset et al. (2020) applied a combination of quality function deployment (QFD) with plithogenic aggregation operations for Selecting Supply Chain Sustainability Metrics [23].

In this paper, we combine the Interval Neutrosophic Numbers (NS) set and the VIKOR method to select a partner in a virtual enterprise. One of the best ways to solve decision problems with inconsistent and unbelievable criteria is the VIKOR approach. VIKOR can be an effective tool for decision making when the decision maker is unable to identify and express the superiority of a problem at the time it is started and designed [24]. For this purpose, the criteria for selecting the partner were first identified by the experts and then their opinions about each of the candidate partners were collected according to the effective factors. Finally, partner rating and selection are performed using the VIKOR method, which is based on the concurrent planning of multivariate decision problems and evaluates issues with inappropriate, and incompatible criteria, in the Interval Neutrosophic environment. The innovation of this paper is that the Interval Neutrosophic set is used to express the evaluation of information, and partner selection in virtual enterprise will be implemented under an Interval Neutrosophic environment. Since the weight of the criteria varies with the mental state, and no specific information is available, in this paper the weight of the criteria is determined using the Maximizing deviation method under the Interval Neutrosophic environment.

2. Research literature and Related studies

The widespread development of Internet technologies in the late twentieth century has led to the dramatic formation and enhancement of the virtual environment in the employment sector, and virtual enterprises, virtual sectors and a series of virtual businesses have expanded. Information on so-called virtual companies was first provided in the early 1990s by Steven L. Goldman, Rocer N. Nagel and David B. Greenberger, and William H. Davidow and Michael S. Malone. The innovative technology market enables companies to form temporary partnerships, and the creation of such links through the Internet leads to the formation of Virtual Enterprises [25]. Member companies in such a virtual enterprise, rather than being independent companies and focusing on their own business goals, work together to share their information about their capabilities, programs and cost structures, to improve their technical, logistical, financial and other activities in order to compete [4]. The short-term goal of a VE is primarily to increase productivity, reduce inventory and total cycle time. The long-term goal is to increase customer satisfaction, market share, and profit levels for all members. Failure to cooperate may result in a delay in delivery, poor customer service, and inventory creation, and so on [26]. The success of this mission depends on all the organizations that work together as a unit. Because everyone gives its own core strengths or competencies to the virtual enterprise. In other words, the competitive advantage gained by a virtual enterprise depends on each other and their ability to integrate with each other. The key factor in forming a virtual enterprise is choosing agile, competent and consistent partners [27]. The life cycle of a VE consists of four stages: creation, operation, evolution, and dissolution [28]. In the creation phase, when an organization wins a large contract project and is unable to complete it with its proper capacity, it seeks out potential partners and negotiates with them through its information infrastructures and VE will be created. At the operation stage, after signing contracts between the partners, VE manages the process of production or execution of the project. At the development stage, the VE is configured to meet the resource requirements when the project is changed, and at the dissolution stage, when the project is completed, the VE will be eventually dissolved [29]. Obviously, the first step, namely the selection of partners, is crucial to the success of the VE [30]. The main difference between a regular supplier selection issue and a partner selection issue in a VE is the expected duration of the relationship. In fact, companies in a VE rarely have the time to implement, and develop all the features needed for successful relationships. They therefore emphasize on the fact that partner selection is definitely an important step in VE development [12]. Determining the right criteria and evaluating all of the influencing factors in partner selection is difficult. There are many factors that must be considered during decision making. Some are qualitative, such as friendship, credibility, and reliability, and others are quantitative, such as cost, and delivery time. It is very costly and time-consuming to evaluate each partner and identify the most desirable ones [26].

There is an extensive literature on partner selection in VE, each offering a new approach for evaluating and selecting the most appropriate partners among the set of organizations. Sha and Che (2004) develop a partner selection and production distribution planning problem with a new partner selection Model based on Analytical Hierarchy Process (AHP), multi-attribute utility theory (MAUT), and integer programming (IP), for Virtual integration (VI) with multiple criteria. The AHP and MAUT methods are used to evaluate and weight each partner's candidate, and the IP model applies this weigh to find the best potential partners and provide the right distribution plan for the selected partners [31]. Sarkis et al. (2007) present a practical paradigm that can be used by organizations to help form agile virtual companies using ANP method [8]. Ye and Li (2009) proposed two group decision models for spatial decision making to solve the problem of partner selection under incomplete information. The first model is a technique for preferring the order with similarity with ideal Solution (TOPSIS) for group decision making based on degree of deviation. The second approach is TOPSIS group decision-making based on risk factor [28]. Crispim and Sousa (2009) propose an exploratory process to help the decision maker to acquire knowledge about the network in order to identify the criteria and companies that provide the needs of a project very well. This process involves a multi-objective meta-heuristic search algorithm designed to find a good approximation of the PARETO front and a fuzzy TOPSIS algorithm to rank the configuration of VE options. Preliminary computational results clearly showed the potential of this approach for practical applications [9]. Ye (2010) investigated the problem of partner selection in partial and uncertain information environments and used the extended TOPSIS technique for group decision making with intuitive fuzzy numbers with interval values for problem solving [32].

Liu et al (2016) proposed a partner selection method based on distance multipliers preferences with approximate compatibility. In this paper, using a (n - 1) pairwise comparison, a new partner selection method is proposed, which introduces a new concept of approximate compatibility for multidimensional preferential relationships [27]. Nikghadam et al. (2016) designed a customer-based algorithm to select a partner in a virtual enterprise. In this study, customers were classified into three categories: passive, standard and assertive. Three different approaches; fuzzy logic-FAHP TOPSIS and ideal programming were used for each type of customer, respectively. The results confirm that adopting this algorithm not only helps VE to select the most appropriate partners based on customer preferences, but also adapts its model to each customer's attitude. As a result, the overall flexibility of the system significantly improves [7]. Polyantchikov et al. (2017) performed virtual enterprise formation in the context of a sustainable partner network using methodologies such as Analytical Hierarchy Process (AHP), fuzzy AHP approach and TOPSIS method [33]. Huang et al. (2018) studied the problem of partner selection for virtual production companies facing an uncertain environment and using the gray system theory studied uncertainty at the start of a project, in the completion time, in shipping time, and also studied the cost. They used the chaotic particle swarm optimization (CPSO) algorithm to solve the problem [30].

Meng et al. (2019) in their paper presented Interval Neutrosophic Preferred Relations and examined its application with numerical examples in virtual partner selection. The algorithm presented in this paper is based on group decision-making based on INPRs which can be applied to address incomplete and inconsistent INPRs [3]. Chen and Goh (2019) sought a cooperative partner selection mechanism from the perspective of dual-factor theory. They proposed a new framework for problem solving and cooperative partner selection. This framework uses the degree of compatibility of the triangular fuzzy soft set (TFSS) to measure the level of participation, and a broad TODIM based on TFSS to measure the degree of influence on the individual level [34]. Ionescu (2020) reviews the most prominent approaches to solving partner selection problems and discuss some of the most documented methods and algorithms for VO creation and reconfiguration [35]. Zhao et al. (2020) studied a multi-objective virtual enterprise partner selection model with relative superiority parameter in fuzzy environment. In this paper, the completion time and delivery time were fuzzily processed [36] . Wan and Dong (2020) applied the group decision making (GDM) problems with interval-valued Atanassov intuitionistic fuzzy preference relations (IV-AIFPRs) and developed a novel method for solving a virtual enterprise partner selection problem [37].

These papers use different methods and techniques to select partners in virtual enterprises. Many of these studies make use of fixed weights of the criteria, and consider a limited set of uncertainties. They do not make sensitivity analysis to examine solutions, and are, in general, very time-consuming or too complex to be understood by the DM. However, in practice, there are multiple uncertainties in the VE partner selection problem and to assign precise weights to criteria becoming more critical when the number of criteria increases and when the VE life cycle is rather short. In this paper, the weight of the criteria is determined using the maximizing deviation method under the Interval Neutrosophic environment. and combine the Interval Neutrosophic Numbers (NS) set and the VIKOR method have considerable potential to this problem. Neutrosophic sets are very powerful and successful in overcoming situations and cases in uncertainty, vagueness, and imprecision. This model is easy to understand and use, and flexible, and tolerant with inconsistent and inaccurate information. Additionally, the procedure proposed in this work overcomes some of the shortcomings of decision-support tools and provides automatic sensitivity analysis on the results.

On the other hand, many factors should be taken into consideration when selecting partners of a VE By studying the research literature, the most important factors influencing partner selection in Virtual Enterprises can be classified according to Table 1. These factors are the most popular and most influential factors in choosing a partner in a virtual enterprise.

Table 1. Criteria for partner selection

Criteria	Reference
Cost	[28], [9], [32],[12], [4],[27], [30], [10], [38], [2], [39]
Time	[28], [32], [12], [10], [2]
Trust	[28], [32], [10], [34], [3]
Risk	[28], [32], [12], [9] ,[10], [40]
Quality	[28], [9], [33], [27], [10], [26], [38], [39], [6]
Productivity & Performance history	[9], [33], [7], [26], [2]
Market entrance capability	[9], [12]
Knowledge and managerial experience	[9], [33], [34]
Age of the organisation	[9], [12]
Competency & technical expertise	[9], [33], [3]
Information and communication technology resources	[9], [33]
Price	[12], [33], [7], [26], [6]
Delivery	[12], [33], [7], [30], [26], [39]
Customer service	[12], [7], [27], [26], [38], [2], [6]
Geographical location	[33], [26], [34]
The financial stability	[27], [34], [38], [6]

Willingness to share information	[12], [34]
Tardiness penalty	[4], [27]
Technology capability	[34], [26], [38], [34],
Reputation and position in industry	[3], [26], [38], [33]
IT infrastructure	[38], [26]

3. Methedology

This research is applied in terms of purpose and quantitative in terms of variables. In the partner selection process, decision makers are usually unsure of their preferences [41]. Because information about candidates and their performance is incomplete and unclear. In terms of data collection, selecting and evaluating partners is difficult due to the complex interactions between different entities, and because of their preferences they may be inaccessible based on incomplete or partial information. To address this issue under a multi-criteria perspective, several types of information (numerical, interval, qualitative and binary) are used to facilitate the expression of preferences or the evaluation of stakeholders in decision making [12]. In this paper, Interval Neutrosophic numbers are used to express the preferences of experts. In this regard, First, the effective criteria influencing the choice of partner are selected, and then experts express their opinion about candidates with the competence of linguistic terms according to the effectiveness criteria. After converting the experts' opinions to Interval Neutrosophic numbers, the weight of the criteria is calculated using the maximum deviation method. In the second step, expert opinions on each company integrate using the interval neutrosophic weighted average operator. Finally, rankings of companies perform by using the Vikor fuzzy interval neutrosophic method. The general framework of proposed method presented in Fig 1.

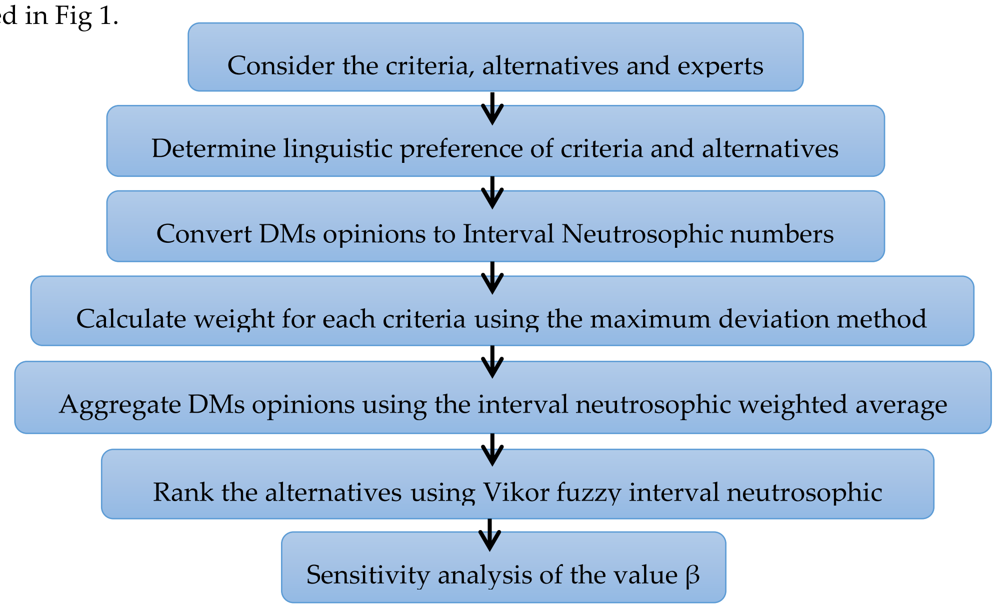

Fig 1. A general framework of proposed method

3.1. Interval Neutrosophic fuzzy set

In the real world, decision information is often incomplete, uncertain, and inconsistent. In order to process this type of information, Smarandache introduced Neutrosophic set (NS) from a philosophical perspective by adding independent indeterminacy-membership, which is an extension of the fuzzy set (FS), the fuzzy set with interval values, the intuitionistic fuzzy set, and so on [42]. Smarandache believed that these types of sets not only had the degree of membership and the degree of non-membership, but also consider the degree of non-determination and lack of compatibility [16]. The new theory of Neutrosophic sets allows to work with the "Knowledge of neural thought". In fact, Neutrosophic sets are generalizations of fuzzy logic and allow to deal with more complex uncertainty models. In "classical" fuzzy sets, each element is defined by a degree of membership, and the available methods are controlled by fuzzy sets [43]. The fuzzy set cannot express neutral state, meaning neither support nor opposition. To overcome this defect, Atanassov introduced the concept of the Intuitionistic Fuzzy Set (IFS). Compared to The fuzzy set, the intuitionistic fuzzy set can simultaneously express three modes of support, opposition, and neutrality. Although the FS and IFS have been developed and publicized, they cannot address the uncertain and inconsistent issues of real decision-making. To solve this problem, Neutrosophic (NS) sets have been suggested [44]. Unlike The intuitionistic fuzzy sets, which depend on the degree of uncertainty on membership and non-membership, by the Neutrosophic logic the value of the indeterminate membership is independent of the degree of truth and falsehood [43]. Neutrosophic logic is flexible and tolerant with inconsistent and inaccurate data. This logic is based on natural language and is made up of specialized knowledge. The concept of the Neutrosophic set provides an alternative approach in the case of inaccuracies in the decisions made by deterministic sets or traditional fuzzy sets, and where the information provided is inadequate for finding it inaccurate [45]. Neutrosophic sets are powerful and successful in overcoming situations and in an inadequate information environment, uncertainty, ambiguity and inaccuracy [14]. A Neutrosophic set A with an A value in X is expressed by 1.

$$\boldsymbol{A} = \{\boldsymbol{x}(\boldsymbol{T_A}(\boldsymbol{x}), \boldsymbol{I_A}(\boldsymbol{x}), \boldsymbol{F_A}(\boldsymbol{x})) | \boldsymbol{x} \in \boldsymbol{X}\} \quad (1)$$

With Neutrosophic set logic, every aspect of the problem is represented by the degree of the truth membership ($T_A(x)$), the degree of the indeterminate membership ($I_A(x)$) and the degree of the false membership ($F_A(x)$) according to 1.

For each x, $T_A(x) + I_A(x) + F_A(x) \in [0,1]$ and the sum of these memberships is less than or equal to three [46]. Thus, Neutrosophic sets provide a means of expressing DM preferences and priorities, and fully determine membership performance in situations where DM comments are subject to the indeterminate membership or lack of information [14].

$$\boldsymbol{0} \leq \boldsymbol{T_A}(\boldsymbol{x}) + \boldsymbol{I_A}(\boldsymbol{x}) + \boldsymbol{F_A}(\boldsymbol{x}) \leq \boldsymbol{3} \quad (2)$$

Sometimes the degree of truth, falsehood, and uncertainty of a particular sentence is not precisely defined in real terms, but is determined by several possible interval values [47]. Thus, the Interval Neutrosophic Set (INS) was introduced by Wang et al (2005). [48]. As a special case of Neutrosophic sets, the Interval Neutrosophic Set (INS) can be used to address uncertain and inconsistent information in decision making [3]. Wang et al showed Interval Neutrosophic (INS) assemblages with distance membership, the degree of non-membership, and degree of hesitant (The indeterminate membership) as follows.

$$\boldsymbol{x} = ([\boldsymbol{T^L}, \boldsymbol{T^u}], [\boldsymbol{I^L}, \boldsymbol{I^u}], [\boldsymbol{F^L}, \boldsymbol{F^u}]) \quad (3)$$

The Interval Neutrosophic set can be simpler to express incomplete, uncertain, and contradictory information [49], and is flexible and practical for dealing with decision problems. Compared to other fuzzy set expansions, INS has the following advantages. (A) Compared to The fuzzy set, INS can simultaneously express positive, negative, and hesitant judgments of DM using membership degree, non-membership degree, and degree of hesitation. (B) Compared with The Intuitionistic fuzzy sets, INS independently express the degree of positive, negative, and uncertain judgments. That DMs have more flexibility to express their uncertain and contradictory information [3].

3.2. Interval Neutrosophic Fuzzy VIKOR Method

VIKOR is an effective decision making method that selects the optimal option with group utility maximization and individual regret minimization. And it is used as one of the applied MCDM techniques to solve a discrete decision problem with disproportionate criteria with different and conflicting units of measurement [50]. This method was proposed by Opricovic (1998) to solve the problem of multi-criteria decision making in an incompatible and inconsistent criteria environment [43]. VIKOR is an efficient tool for finding the compromise solution from a set of conflicting criteria. Where compromise means an agreement made with mutual concessions [51]. That can help decision makers to make a final decision [52]. The VIKOR method is based on the specific property of being close to the ideal solution. One of the features of this method is that the options are evaluated according to all defined criteria (performance matrix) and the stability analysis of the intervals shows the stability of the weight [53]. The effectiveness of this approach becomes more apparent when the decision maker is not able to express his/her preferences and uses agreed solutions to solve the problems. An agreed solution is a justified solution that is close to the ideal solution and that decision makers accept because of the maximum utility of the group [50].

Suppose the rating of options $P_i = \{p_1, p_2, \dots, p_m\}$ is given as f_{ij} with respect to criteria of $C_j = \{c_1, c_{2,}, \dots, c_n\}$. $w_j = \{w_1, w_2, \dots, w_n\}$ is the weight vector of the criteria. The formula for measuring distance on P_i options is based on equation (4).

$$\boldsymbol{L_{\alpha,i}} = \left(\sum_{j=1}^{n}\left(\boldsymbol{w_j}\frac{\boldsymbol{f_j^* - f_{ij}}}{\boldsymbol{f_j^* - f_j^-}}\right)^{\alpha}\right)^{\frac{1}{\alpha}}, \boldsymbol{1 \le \alpha \le \infty}, \qquad \boldsymbol{i = 1, 2, \dots, m} \tag{4}$$

where $f_j^* = max_i f_{ij}$ and $f_j^- = min_i f_{ij}$ are the ideal and anti-ideal points, respectively [53].

Let $W = \{w_1, w_2, \dots, w_n\}$ be the weight of the criteria, $0 \le W_j \le 1$ and $\sum_1^n W_j = 1$. If the set of decision makers be $E = \{E_1, E_2, \dots, E_t\}$ and the weight of decision makers be $\sigma = \{\sigma_1, \sigma_2, \dots, \sigma_t\}$, $0 \le \sigma_k \le 1$ and $\sum_{k=1}^{t} \sigma_k = 1$.

Suppose that $\tilde{R}_k = (\tilde{r}_{ij}^k)_{m\times n} = \left(\left[T_{ij}^{L(k)}, T_{ij}^{R(k)}\right], \left[I_{ij}^{L(k)}, I_{ij}^{R(k)}\right], \left[F_{ij}^{L(k)}, F_{ij}^{R(k)}\right]\right)_{m\times n}$ is the Matrix of decision of Interval Neutrosophic Numbers, $e_k \in E$.

$$\left[T_{ij}^{L(k)}, T_{ij}^{R(k)}\right], \left[I_{ij}^{L(k)}, I_{ij}^{R(k)}\right], \left[F_{ij}^{L(k)}, F_{ij}^{R(k)}\right] \subseteq [0,1], \tag{5}$$

$$0 \le T_{ij}^{R(k)} + I_{ij}^{R(k)} + F_{ij}^{R(k)} \le 3\,, \tag{6}$$

$$i = 1,2, \dots, m, \qquad j = 1,2, \dots, n, \qquad k = 1,2, \dots, t \tag{7}$$

The steps of the VIKOR method for multi-criteria group decision-making problems of the Interval Neutrosophic set are as follows [13].

Step 1. Convert Evaluation Information to the Interval Neutrosophic Number Set

Step 2. Calculate the weight of the criteria

Since the weight of the benchmarks may be completely unknown, the benchmark weight is calculated using the Maximizing deviation method. According to this view, if the criterion values of all alternatives to a particular attribute are quantitative deviations, quantitative weight can be assigned to this criterion. Otherwise, the criterion that causes the deviation to be greater should be weightier. In particular, if the criterion values of all the different options are equal to a given property, the weight of such a criterion may be zero [49]. The weight of the criteria is thus calculated using the equation (8) [48].

$$w_j = \frac{\sum_{k=1}^{t}\sigma_t \sum_{i=1}^{m}\sum_{s=1}^{m}(\Delta_{upv})}{\sum_{j=1}^{n}\sum_{k=1}^{t}\sigma_t \sum_{i=1}^{m}\sum_{s=1}^{m}(\Delta_{upv})} \tag{8}$$

$$\Delta_{upv} = \left|T_{ij}^{L} - T_{sj}^{L}\right| + \left|I_{ij}^{L} - I_{sj}^{L}\right| + \left|F_{ij}^{L} - F_{sj}^{L}\right| + \left|T_{ij}^{R} - T_{sj}^{R}\right| + \left|I_{ij}^{R} - I_{sj}^{R}\right| + \left|F_{ij}^{R} - F_{sj}^{R}\right| \tag{9}$$

Step 3. Using $\widetilde{\mathrm{R}}_{\mathrm{k}}$ and calculating the interval neutrosophic number weighted averaging (INNWA) operator [47]

$$\begin{aligned} &INNWA_{\sigma}(E_1, E_2, \dots, E_t) = \\ &\langle\left[1 - \prod_{i=1}^{t}\left(1 - T_{E_i}^{L}\right)^{\sigma_i}, 1 - \prod_{i=1}^{t}\left(1 - T_{E_i}^{R}\right)^{\sigma_i}\right], \\ &\left[\prod_{i=1}^{t}\left(I_{E_i}^{L}\right)^{\sigma_i}, \prod_{i=1}^{t}\left(I_{E_i}^{R}\right)^{\sigma_i}\right], \left[\prod_{i=1}^{t}\left(F_{E_i}^{L}\right)^{\sigma_i}, \prod_{i=1}^{t}\left(F_{E_i}^{R}\right)^{\sigma_i}\right]\rangle \end{aligned} \tag{10}$$

Step 4. Define the solution of positive and negative ideals (R^+ and R^-)

$$\tilde{R}^{+} = \left(\left[T_j^{L+}, T_j^{R+}\right], \left[I_j^{L+}, I_j^{R+}\right], \left[F_j^{L+}, F_j^{R+}\right]\right) \tag{11}$$

$$\tilde{R}^{-} = \left(\left[T_j^{L-}, T_j^{R-}\right], \left[I_j^{L-}, I_j^{R-}\right], \left[F_j^{L-}, F_j^{R-}\right]\right) \tag{12}$$

For positive and incremental criteria

$$\begin{aligned} &\left(\left[T_j^{L+}, T_j^{R+}\right], \left[I_j^{L+}, I_j^{R+}\right], \left[F_j^{L+}, F_j^{R+}\right]\right) \\ &= \left(\left[max_i T_{ij}^{L}, max_i T_{ij}^{R}\right], \left[min_i I_{ij}^{L}, min_i I_{ij}^{R}\right], \left[min_i F_{ij}^{L}, min_i F_{ij}^{R}\right]\right) \end{aligned} \tag{13}$$

$$\begin{aligned} &\left(\left[T_j^{L-}, T_j^{R-}\right], \left[I_j^{L-}, I_j^{R-}\right], \left[F_j^{L-}, F_j^{R-}\right]\right) \\ &= \left(\left[min_i T_{ij}^{L}, min_i T_{ij}^{R}\right], \left[max_i I_{ij}^{L}, max_i I_{ij}^{R}\right], \left[max_i F_{ij}^{L}, max_i F_{ij}^{R}\right]\right) \end{aligned} \tag{14}$$

For negative and decreasing criteria

$$\begin{aligned} &\left(\left[T_j^{L+}, T_j^{R+}\right], \left[I_j^{L+}, I_j^{R+}\right], \left[F_j^{L+}, F_j^{R+}\right]\right) \\ &= \left(\left[min_i T_{ij}^{L}, min_i T_{ij}^{R}\right], \left[max_i I_{ij}^{L}, max_i I_{ij}^{R}\right], \left[max_i F_{ij}^{L}, max_i F_{ij}^{R}\right]\right) \end{aligned} \tag{15}$$

$$\begin{aligned} &\left(\left[T_j^{L-}, T_j^{R-}\right], \left[I_j^{L-}, I_j^{R-}\right], \left[F_j^{L-}, F_j^{R-}\right]\right) \\ &= \left(\left[max_i T_{ij}^{L}, max_i T_{ij}^{R}\right], \left[min_i I_{ij}^{L}, min_i I_{ij}^{R}\right], \left[min_i F_{ij}^{L}, min_i F_{ij}^{R}\right]\right) \end{aligned} \tag{16}$$

Step 5. Calculate the indicators of maximum group utility (Γ_i) and minimum individual regret (Z_i)

$$\Gamma_i = \sum_{j=1}^{n} \frac{w_j \times d\left(\left(\left[T_j^{L+}, T_j^{R+}\right], \left[I_j^{L+}, I_j^{R+}\right], \left[F_j^{L+}, F_j^{R+}\right]\right), \left(\left[T_j^{L}, T_j^{R}\right], \left[I_j^{L}, I_j^{R}\right], \left[F_j^{L}, F_j^{R}\right]\right)\right)}{d\left(\left(\left[T_j^{L+}, T_j^{R+}\right], \left[I_j^{L+}, I_j^{R+}\right], \left[F_j^{L+}, F_j^{R+}\right]\right), \left(\left[T_j^{L-}, T_j^{R-}\right], \left[I_j^{L-}, I_j^{R-}\right], \left[F_j^{L-}, F_j^{R-}\right]\right)\right)} \tag{17}$$

$$\mathrm{Z}_i = max_j \left\{ \frac{w_j \times d\left(\left([T_j^{L+}, T_j^{R+}], [I_j^{L+}, I_j^{R+}], [F_j^{L+}, F_j^{R+}]\right), \left([T_j^{L}, T_j^{R}], [I_j^{L}, I_j^{R}], [F_j^{L}, F_j^{R}]\right)\right)}{d\left(\left([T_j^{L+}, T_j^{R+}], [I_j^{L+}, I_j^{R+}], [F_j^{L+}, F_j^{R+}]\right), \left([T_j^{L-}, T_j^{R-}], [I_j^{L-}, I_j^{R-}], [F_j^{L-}, F_j^{R-}]\right)\right)} \right\} \tag{18}$$

$$d(A,B) = \frac{1}{6}\left(|T_A^L - T_B^L| + |I_A^L - I_B^L| + |F_A^L - F_B^L| + |T_A^R - T_B^R| + |I_A^R - I_B^R| + |F_A^R - F_B^R|\right) \tag{19}$$

Step 6. Calculate VIKOR Index (Q_i)

$$Q_i = \beta \frac{(\Gamma_i - \Gamma_i^*)}{(\Gamma_i^- - \Gamma_i^*)} + (1-\beta) \frac{(\mathrm{Z}_i - \mathrm{Z}_i^*)}{(\mathrm{Z}_i^- - \mathrm{Z}_i^*)} \tag{20}$$

$$\Gamma_i^* = min_i \Gamma_i, \qquad \Gamma_i^- = max_i \Gamma_i \tag{21}$$

$$\mathrm{Z}_i^* = min_i \mathrm{Z}_i, \qquad \mathrm{Z}_i^- = max_i \mathrm{Z}_i \tag{22}$$

Step 7. Rank the options based on Q_i, Γ_i and Z_i in accordance with the classic VIKOR ranking rule
Step 8. The compromise solution must meet one of the following conditions:
(A) Acceptable advantage in the sense that a compromise solution must be significantly different from its next solution: $\mathrm{Q}(\mathrm{A}^2) - \mathrm{Q}(\mathrm{A}^1) \geq \mathrm{DQ} = \frac{1}{\mathrm{m}-1}$ Where A^1 and A^2 are the first and second choices in the ordered list and m is the number of options.
(B) Acceptable consistency in the decision-making process means that the adaptive solution chosen must have Group utility maximization and at least individual impact: A^1 should be the best rank in Γ_i and Z_i. This is the compromise solution throughout the decision-making process.
If the above conditions for a compromise solution are not met, a set of adaptation strategies is provided instead of one.
Step 9. A set of compromise solutions is obtained if one of the conditions is not satisfied.
A^1 and A^2 are compromise solutions if only condition 2 is not met. Or A^1, A^2 and ... A^M are compromise solutions if condition 1 is not fulfilled, by the constraint $\mathrm{Q}(\mathrm{A}^{\mathrm{M}}) - \mathrm{Q}(\mathrm{A}^1) < \mathrm{DQ}$ decides for maximum M [54].

4. Case study

A company in the online sales of various products has been selected as the numerical example of this research. The company supplies products to various suppliers and sends them to its customers. Due to limited resources and limited resources, the company cannot independently complete the entire project. Therefore, the company intends to select an optimal partner from the project candidates for the transport sector of the company and create a dynamic virtual enterprise alliance to collectively complete the entire project. In the issue of partner selection, first by studying the research literature, the most important criteria affecting partner selection in different domains were identified in accordance with Table (1). Then, 8 experts from the company with expertise in virtual enterprise and partner selection and with over 5 years' experience were selected 13 criteria of the most important partner selection criteria in the transport sector of the company according to Table (2).

Table 2. Criteria linguistic assessments for partner selection by experts

Criteria		Partner 1				Partner 2			
		E_1	**E_2**	**E_3**	**E_4**	**E_1**	**E_2**	**E_3**	**E_4**
Cost	C_1	VH	H	VH	VH	H	VH	VH	VH
Delivery	C_2	H	L	H	M	L	M	L	M
Trust	C_3	VH	H	VH	M	H	H	VH	M
Risk	C_4	L	VL	M	VL	M	M	M	VL
Quality	C_5	H	H	H	VH	H	H	VH	H
Reputation and position in industry	C_6	H	VH	VH	H	VH	H	VH	VH
Customer service	C_7	H	M	M	VH	H	VH	M	VH
Knowledge and managerial experience	C_8	H	H	M	H	H	L	M	L
Technology capability	C_9	M	VL	L	VL	M	VL	L	L
Information and communication technology resources	C_{10}	VH	H	VH	H	H	VH	VH	H
Willingness to share information	C_{11}	M	M	L	VL	M	VL	H	L
Competency & technical expertise	C_{12}	M	H	M	M	VH	H	VH	H
IT infrastructure	C_{13}	VH	H	H	H	VH	M	H	M

After defining effective criteria in the Partner selection of the transport sector, 4 experts of the company expressed their opinion about the 4 candidates with the competence of linguistic terms according to the effective criteria. Table (2) gives some examples of expert opinions.

4.1. Findings

After gathering the experts' opinions in the form of linguistic terms, they first converted to Interval Neutrosophic numbers using Table 3.

Table 3. Transformations between numerical ratings and INSs

Linguistic terms	INSs
VH	{[0.9,1],[0,0.1],[0,0.1]
H	{[0.75,0.85],[0.05,0.15],[0.15,0.25]}
M	{[0.55,0.65],[0.15,0.25],[0.35,0.45]}
L	{[0.35,0.45],[0.25,0.35],[0.55,0.65]}
VL	{[0.15,0.25],[0.35,0.45],[0.75,0.85]

Next, using these observations, the weighting of the criteria was calculated using the maximum deviation and correlation technique (8) according to Table (4). The results show that the Willingness to share information criterion with a weight of 0.113 is the most important partner selection criterion in this company. This illustrates the importance of the quality of information shared. As such, it is important for Virtual Enterprises to collaborate effectively with the information sharing organization for optimal collaboration. And keeping in touch with other partners, such as finding out where and when to deliver the goods, and keeping the customer informed of the delivery and planning process of the company to ship other products will ultimately lead to better overall company performance. Competency & technical expertise is ranked second and reflects the importance of technical and practical expertise from the point of view of company experts in choosing a virtual partner. Reputation and position in the industry are of third importance for the company and the background, reputation and position of the company in the industry and among the competitors can be an effective choice. The notable point in this company is that the cost criterion (lowest-weighted) is the last priority. This indicates the importance of other criteria for cost, and the company tends to be more costly in choosing the optimal partner.

Table 4. Weight of criteria

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
Weight	0.048	0.095	0.051	0.086	0.049	0.096	0.084	0.085	0.056	0.067	0.113	0.098	0.071

Given the group decision-making of choosing a virtual partner, it is necessary to integrate expert opinions on each company. For this purpose, using the Interval Neutrosophic Weighted Average Operator for each candidate company, the relation of 10 decision matrices of consensus of expert opinions is calculated. The Consensus Decision Matrix of Business Partner 1 is in the form of Interval Neutrosophic Numbers as shown in Table 5. The same applies to other business partners.

Table 5. The decision matrix $\tilde{R}_1$

	T^+	T^-	I^+	I^-	F^+	F^-
C_1	0.874257	1	0	0.110668	0	0.125743
C_2	0.632293	0.743461	0.098399	0.210643	0.256539	0.367707
C_3	0.816858	1	0	0.139158	0	0.183142
C_4	0.321982	0.426361	0.260341	0.364845	0.573639	0.678018
C_5	0.801182	1	0	0.13554	0	0.198818
C_6	0.841886	1	0	0.122474	0	0.158114
C_7	0.733258	1	0	0.174982	0	0.266742
C_8	0.710427	0.81461	0.065804	0.170433	0.18539	0.289573
C_9	0.321982	0.426361	0.260341	0.364845	0.573639	0.678018
C_{10}	0.841886	1	0	0.122474	0	0.158114
C_{11}	0.421652	0.525878	0.210643	0.314985	0.474122	0.578348
C_{12}	0.611497	0.716813	0.113975	0.220028	0.283187	0.388503
C_{13}	0.801182	1	0	0.13554	0	0.198818

Finally, the VIKOR fuzzy Interval Neutrosophic method and the equations of 10 to 23 rankings of the four transport companies were performed. After calculating the performance and distance from the ideal level of options and obtaining the indicators of maximum group utility (G_i) and minimum individual regret (Z_i) and the value of VIKOR index (Q_i), the final ranking of options was done according to Table 5. Accordingly, the least Q value is chosen as the best option.

Table 6. Sorting results

Partner	Partner 1	Partner 2	Partner 3	Partner 4	The ranking order
Γ_i	0.383959	0.355709	0.471911	0.666381	$P_2>P_1>P_3> P_4$
Z_i	0.100536	0.085379	0.113432	0.098186	$P_2>P_4> P_1>P_3$
Q_i	0.31562	0	0.687017	0.728261	$P_2>P_1>P_3> P_4$

Thus Business Partner 2 with $Q_2 = 0$ is selected as the best virtual partner. This result is now examined by two conditions. $0.31562 - 0 < \mathrm{DQ} = \frac{1}{4-1} = 0.333$ Hence the first condition is not applicable. Since option A_2 has the best rank in G_i and Z_i ($\beta = 0.5$), so the second condition holds. Since only the second condition is in place, the options are rated $P_2 \sim P_1> P_3> P_4$, and both A_2 and A_1 are eventually selected and get top rankings.

In the relationships of the Neutrosophic fuzzy VIKOR method, β is defined as the weight of most criteria strategy, or most group utility, and is usually considered to be 0.5. However, the β value may affect the value of the VIKOR index. For this purpose, calculations for different values of β are performed according to Table 7, and the applicability and stability of the proposed method are investigated.

Table 6. Sensitivity analysis of the value β

β	Q_1	Q_2	Q_3	Q_4	Rank order
0	0.540309	0	1	0.456522	$P_2> P_4>P_1>P_3$
0.2	0.450433	0	0.874807	0.565217	$P_2>P_1 >P_4>P_3$
0.4	0.360558	0	0.749613	0.673913	$P_2>P_1> P_4>P_3$
0.5	0.31562	0	0.687017	0.728261	$P_2>P_1>P_3> P_4$
0.6	0.270682	0	0.62442	0.782609	$P_2>P_1>P_3> P_4$
0.8	0.180807	0	0.499227	0.891304	$P_2>P_1>P_3> P_4$
1	0.090931	0	0.374034	1	$P_2>P_1>P_3> P_4$

Weight sensitivity analysis of the majority (β) strategy indicates that the firm manager can select the appropriate group (β) value to reflect the decision maker priority. If the manager prefers to eliminate Group utility maximization, it supports β = 1 and uses the G marker. Conversely, if the decision maker pays more attention to regret thinking, then β = 0 and the value of Z is accepted. Figure (2) shows the effect of changing β on Q_i. In different values of β, trading partner 2 and 1 are ranked first and second, respectively, with values below 0.5 third partner and values above 0.5 partner 4 last.

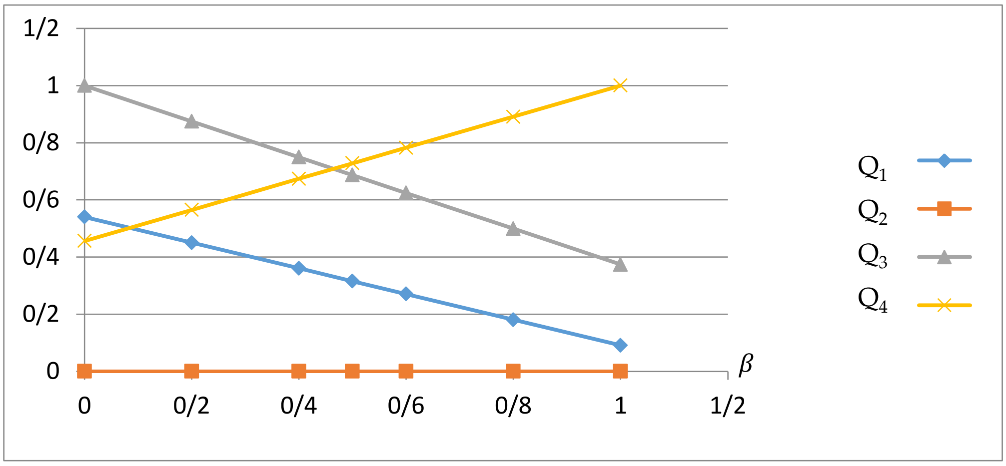

Fig 2. Sensitivity analysis of the value β for each alternative with INSs

Figure 3 shows the spider diagram of the sensitivity analysis and the effect of the β parameter change on the VIKOR index. Partner rankings in this chart are centered outward, and Partner 2 in the chart is ranked first in all β values, and Partner 2 is not second only to value β = 0. This chart shows the gap between the partners. At point β = 0, business partner 4 ranks second. While in other values of β the first partner is at this rank. The spider diagram shows that the distance between these two partners is very small at this point, and the Q value of Partner 1 is only slightly different from Partner 4, and the stability of this ratio can be confirmed. But for the third and fourth partner the subject is slightly different and when the β value is greater than 0.5 the rating changes and the distance between the two graphs is noticeable indicating the influence of individual views of the group. Accordingly, when the group views are more important, the third partner is ranked third and in the smaller values of β the individual opinions are more important. The fourth partner ranks third. The impact of the importance of group versus individual views on this ranking is clearly illustrated by the decrease and increase in the distance between the third and fourth partner graphs in Figure 3.

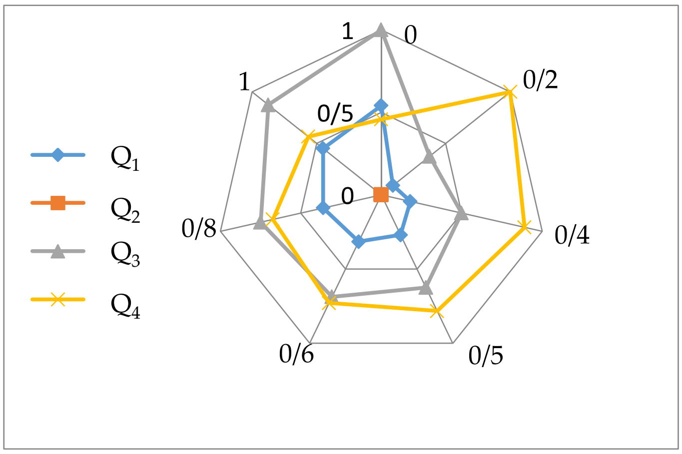

Fig 3. Spider chart of the value β for each alternative with INSs

Sensitivity analysis showed that the value of the parameter β did not significantly influence the results of the selection of the best partner. Therefore, the ranking results obtained using the proposed method for INS are reliable and effective.

5. Conclusions

In today's business environment, competition is focused on innovation, speed, and flexibility. A new business model is needed to help companies gain competitive benefit in the volatile market [55]. Increasing complexity has allowed any business to reconfigure itself to meet its needs, and opportunities and remain in a highly competitive environment, because they do not have all the skills and resources needed to meet new market demand. Virtual enterprise (VE) has been proposed as a new organizational approach to meet the requirements of low cost, high quality, fast responsiveness, and greater customer satisfaction to be adapted with this rapidly changing environment [56]. The criteria for choosing a partner in Virtual Enterprises vary depending on the type of activity. In this paper, firstly, by studying the research literature and using the experts' opinions, 13 criteria affecting the selection of a partner in the transport sector of virtual enterprise were identified. How to choose the right partners for success in Virtual Enterprises (VE) is very important and has received a great deal of attention from researchers and experts. Given the different types of uncertainty in the real environment, decision makers are usually not sure when choosing a partner because the information on the candidates is incomplete and unclear. In addition, some of the features of decision making are subjective and qualitative. In many cases decision makers are unable to express their decisions about candidates in precise quantities. For this purpose, in the second step, the partner selection problem with VIKOR method is used to form a VE under Interval Neutrosophic environment. The VIKOR method considers the boundary rationality of decision makers, and makes more rational decisions. Interval Neutrosophic Numbers are used to address problems with uncertain, incomplete and inconsistent information. This method helps to reduce the mentality of decision makers. In this paper, the method of weighting the maximum deviation in the Neutrosophic environment is used in the absence of benchmark information, which can be very useful in deciding issues with inconsistent and uncertain criteria. The Partner Selection Process In this paper, we have designed a new combination and comprehensive classification of partner evaluation criteria in the context of the virtual enterprise. The proposed approach can effectively reduce the subjectivity and uncertainty of the multi-criteria decision-making problem and rely on the underlying data to make the evaluation result more objective and reliable. Also, by improving the existing method of weight calculation, the Maximizing deviation method can effectively guarantee the consistency of the judgments and simplify the weighting function in cases where the information is incomplete or there is no metric weight information. Expanding the VIKOR method to Interval Neutrosophic numbers can effectively counteract uncertainty assessment information. Without increasing mental states, it retains more decision information and makes Partner selection in the virtual enterprise more scientific. The results of the weight sensitivity analysis of the group utility strategy (β) show that the business firm is selected as the best partner for all β values according to the identified effective factors. Ranked second in trading partner 1 for all values of β, with only zero for trading partner 4. The β parameter is determined by the degree of agreement of the decision maker, and the larger the β, the greater the group's views (too much agreement) and the smaller the β, the greater the individual's opinions (little agreement). In this paper, the rankings are slightly different for the smaller β values as illustrated in Fig. 2, with the trading partner 4 being ranked second and the trading partner 3 last. But one still remains the top partner.

In the actual decision making, there is much qualitative information that can be expressed by uncertain linguistic variables. Interval Neutrosophic numbers can easily express uncertain and contradictory information in the real world, and by combining multi-criteria decision-making techniques to make the paradoxical features more scientific and reasonable. In this paper, the VIKOR method is developed to deal with uncertain linguistic information in the Interval Neutrosophic environment. In this method, the criterion values are presented as Interval Neutrosophic numbers. Neutrosophic set with interval value is used to express incomplete knowledge of the expert group and to prevent loss of information. However, the approach proposed for selecting the best partner in Virtual Enterprises has advantages in terms of selection criteria. But the main limitation is the lack of quantitative data and the limited number of respondents in the study. With increasing awareness of Virtual Enterprises, effective benchmarks should be developed according to the field of business activity, and other weighting techniques such as AHP, ANP and artificial intelligence techniques can be used in combination with VIKOR. Other ranking methods such as AHP and TOPSIS can be used in combination with the Neutrosophic environment. Optimization techniques can also be applied to partner selection in Virtual Enterprises. The proposed model can be applied to other decision-making issues such as supplier selection, risk assessment. Also, comparison of model results with other uncertainty modeling techniques can be suggested. Finally, the robustness of the proposed model can be tested through scenario analysis and uncertainty analysis.

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