Research Article

Supply Chain Partner Selection under Cloud Computing Environment: An Improved Approach Based on BWB and VIKOR

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The wide application of cloud computing technology makes supply chain partner share information effectively and increase corporate profits. However, in cloud computing environment, the evaluation process of supply chain partner selection is dynamic and fuzzy, and its evaluation index is uncertain. To solve these problems, this paper proposes a new method combed with rough number, best-worst multicriteria decision-making method (BWM), and compromise ranking method (VIKOR). Firstly, Rough number is used to integrate data from different evaluation matrix. Secondly, rough number improves a new method, BWB, to get RBWB criteria weight methods. Thirdly, the rough numbers are introduced into VIKOR and combined with RBWB to evaluate and sort the supply chain partners. Finally, an example is given to demonstrate the rationality and feasibility of the method.

1. Introduction

With the development of economic globalization, the real competition is no longer the competition between enterprises and enterprises, but the competition between supply chain and supply chain. Supply chain management (SCM) can not only effectively promote the production, distribution, and logistics of enterprises, but also become an important strategy for modern enterprises in the fierce market competition [1]. As each firm has an inherent participation in one or more supply chains, so an effective supply chain is very important [2–4]. One of the major challenges for focal firm in supply chain is partner selection [5–7]. In a long term relationship, selecting a right partners is one of the key success factors in the supply chain management process [8]. Hence, the scientific selection of suitable supply chain partners for focal firm has a significant impact on the overall supply chain performance.

In the supply chain partner selection problem, information technology (IT) is inevitable to take into account. Nowadays, more and more interenterprise cooperation depends on efficient information systems of real-time information sharing and process collaboration [1, 9–11]. IT becomes a key

issue for focal firm to select appropriate supply chain partner [12–14]. However, due to the rigid technology infrastructure and high cost of traditional IT, the supply chain enterprises cooperation may be impeded [15–17]. This situation has been mitigated by the emergence of a new important information technology, cloud computing. In the field of information technology, cloud computing is one of the latest innovations, which refers to an IT service pattern in which both software and hardware services are implemented to deliver on need of customers over the network [18, 19]. Cloud computing is a technology application model which completely different from traditional IT. Compared with the traditional IT, cloud computing has the characteristics of pay per use, shared environment, scalability, and elasticity [20], so as to make IT solutions more economical and flexible. Cloud computing is also the development trend of the next generation of IT technical architecture [21], which make it easier to share information in the context of supply chain integration and truly realize the improvement of supply chain performance under the integration of supply chain [22]. Therefore, there might be great changes for supply chain partner selection problem under cloud computing environment, which makes a lot of sense to study this kind of problem.

In the last decades, many multiattribute group decision-making (MAGDM) approaches are proposed to evaluate and select appropriate partners. For example, Liao and Kao [23] proposed ideal solutions (TOPSIS) and multiple choice goal programming (MCGP) for supplier selection in supply chain management. Li et al. [24] proposed a research method of supplier selection combining axiomatic fuzzy sets and TOPSIS. Flynn et al. [25] put forward a theoretical concept in the uncertainty of supply chain and the influence of supply chain selection. Luthra and Govindan and Sivakumar [26] put forward new evaluation methods, including economic evaluation, environmental assessment, and social evaluation and adopt the combination of AHP and VIKOR to supply chain selection. Rostamzadeh *et al.* [27] proposed a hierarchical multicriteria decision (MCD) model that integrates fuzzy sets and VIKOR in the green supply chain.

However, through literature review we find that there are still limitations in supply chain partner selection problem. For example, first, the studies that research the supply chain partner selection problem under cloud computing environment are limited. Second, many criteria linguistic variables are difficult to describe and sort accurately in the existing studies, especially under the new cloud computing technology environment. Third, the existing approaches may lead to the deviation of the evaluation results thanks to some methodological flaws, such as the subjectivity of expert cognition and the complexity of the pairwise comparison [28]. Therefore, in order to fill the research gap, we focus on the supply chain partner selection problem under cloud computing environment and propose a new novel method which combine rough number, the best-worst-order multicriteria decision method (BWM), and the compromise ranking method (VIKOR) to solve it. Example analysis proves the practicability of our method.

The structure of this paper is as follows: the second section is literature review; Section 3 proposes the evaluation criteria of partner selection in supply chain under cloud computing environment. The proposed method is introduced in Section 4. Section 5 is the illustrative example and Section 6 concludes the paper.

2. Literature Review

The selection of partner is a common issue in the daily operation of an enterprise, and it is an important decision that impacts its operation success. In addition, it is a time-consuming and resource intensive process that should be carefully managed [7, 29].

Taluri and Baker [30] did early work on the partner selection problem; they put forward a two-stage approach to select a best partner. The first stage uses data envelopment analysis to identify effective alternatives, and the second stage resolves the 0–1 goal program. Hereafter, many scholars have studied the partner selection problem in various environment. Afterwards “supplier selection” becomes one of the principles of partner selection in general context [31].

In the supply chain area, many techniques are used to evaluate suitable partners, such as [8, 29, 32]. One of the most common techniques used in partner selection

is MAGDM (Multiattribute Group Decision-Making), such as Analytic Hierarchy Process (AHP) [6, 33], Analytical Network Process (ANP) [34, 35], fuzzy AHP [5, 36, 37], fuzzy TOPSIS [6, 26, 38], Data Envelopment Analysis (DEA) [39–41], and integrated methods such as AHP and linear programming [42], AHP and multiobjective mixed integer programming [43], TOPSIS and goal programming [44], rough set and grey system [31], and multiobjective decision-making methods [45, 46]. In the MAGDM approach on the partner selection problem mentioned above, BWM (the best-worst multicriteria decision-making method) and VIKOR (Vlsekriterijumska optimizacija I kompromisno resenje) are the two most critical methods.

As the newest MAGDM approach, Rezaei proposed the best-worst multicriteria decision-making method (BWM) in 2015 based on pairwise comparison, in which the alternatives and weights of criteria under different criteria can be obtained, and less comparative data is needed [47]. At the same time, BWM can effectively compensate for the inconsistency from pairwise comparisons. Unlike AHP, BWM uses a scale of 1 to 9 for pairwise comparisons. In addition, particularly unlike AHP, BWM only performs reference comparison, which indicates that it only needs the number of 1 to 9 to obtain the preference of the best criteria and the worst criteria among all criteria. This process does not perform second comparisons; hence it is more precise, less redundant, and much easier [48]. This approach has been applied to many real problems, for instance evaluating energy efficiency barriers [49], the outside factors of oil and gas industry [50], technical innovation [51], choosing suppliers [52], choosing transportation mode [48], quality evaluation of scientific output [53], and the measurement of the efficiency of the PhD project in the university [54].

VIKOR (Vlsekriterijumska optimizacija I kompromisno resenje) is a representative method of evaluating and ranking a range of alternative plans based on many possible noncomparable and conflicting criteria [55]. The classical VIKOR approach has been used in many fields. Wang *et al.* [56] researched the choice of low-temperature stage change energy storage materials by the method of VIKOR. Yazdani and Payam [57] compared Ashby, VIKOR, and TOPSIS methods in order to select suitable electrostatic material systems. Tiwari *et al.* [58] integrated VIKOR and rough sets to optimize the concept of product design. At the same time, the classical VIKOR has been developed to various uncertain and fuzzy situations, and also there are many extended VIKOR methods which have been put forward. For example, Liao and Xu [59] proposed a hesitant fuzzy linguistic VIKOR approach to deal with the conflicting criteria in MAGDM. Liao *et al.* [60] proposed a method to solve hesitant fuzzy linguistic MAGDM problems. This method is based on hesitant fuzzy linguistic TOPSIS and hesitant fuzzy linguistic VIKOR. You *et al.* [61] presented an extended VIKOR approach based on interval 2-tuple linguistic information for supplier selection problem.

Reviewing the literature reveals that there are still limitations in supply chain partner selection problem: (1) There are limited studies that research the supply chain partner selection problem under cloud computing environment.

Although cloud computing has been considered as the next generation of IT infrastructure for supply chain information systems [62–64], the current studies have generally acknowledged the fact that companies in supply chains using cloud computing will face a lot of problems besides cost, such as technology usefulness, managerial skills, strategies, and competitive pressure [65–67]. Therefore, firms should use scientific decision tools to judge which cloud computing vendor is more suitable by considering both cost and other related factors. (2) Many criteria linguistic variables are difficult to describe and sort accurately. The existing methods based on interval numbers and fuzzy numbers need to use prior knowledge to make the evaluation results subjective. (3) Due to the subjectivity of expert cognition and the complexity of the pairwise comparison [28], the inconsistent judgment matrix leads to the deviation of the evaluation results. By the above description, these limitations will make the conclusion unreasonable.

Therefore, in order to fill the research gap, this paper introduces the selection of supply chain partners under cloud computing environment with the combination of rough number, the best-worst-order multicriteria decision method (BWM), and the compromise ranking method (VIKOR). We introduce a rough number into multicriteria group decision-making problems and integrate data from different evaluation matrices. Then, rough number improves a new method, RBWM, obtains the RBWM criterion weight method. The rough numbers are introduced into VIKOR and combined with RBWM to evaluate and sort the supply chain partners. Finally, we give an illustrative example and verify the validity and advantage of this method by comparing with other decision methods.

The reason why we integrate rough numbers, BWM and VIKOR in our proposed approach, is mainly because of the following reasons: (1) Rough numbers can handle the ambiguities and uncertainties in supply chain partner selection problems. (2) Compared with a full pairwise comparison matrix approaches, BWM requires less pairwise comparison data. Besides, with the comparison with other MAGDM approaches, the results obtained by BWM are more consistent. Using a full pairwise comparison matrix is also a key reason for why we used BWM in this study. (3) VIKOR adopts the multicriteria ranking index and considers the subjective preferences of experts, leading to a more reasonable decision result. Hence, based on the above analysis, the integration of rough numbers, BWM and VIKOR, is recommended because it is well suited to supply chain partner selection problems under cloud computing environment

3. The Evaluation Criteria of Supply Chain Partner Selection under Cloud Computing Environment

Albeit the number of studies on partner selection in cloud computing is limited, e.g., [15, 17, 68, 69]. Nevertheless, the current researches focus solely on the organization itself, ignoring the supply chain situation. At present, a bit more enterprise networks or supply chains are replacing single

enterprises as competitive units in many fields of industry. Efficient management of cooperation and resources among partners in the supply chains has become very important. More and more enterprises begin to coordinate distribution and production networks and cooperate with partners rather than manage internal resources separately [70]. Besides, academia and business reach the consensus that a unified information system should be built through the supply chain to improve supply chain integration [71–73]. Cloud computing is considered to be the next generation of information system infrastructure [16, 18, 63]. Therefore, firms need scientific decision-making tools to help them to select appropriate supply chain partners under cloud computing environment.

In the present study, we use four primary criteria to analyze the performance of supply chain partners under cloud computing environment, according to studies [6, 15, 68, 69]. These four criteria, respectively, are economics, credibility, quality, and technology. Among them, economics and credibility are mainly reflect economic and business reputation issues of alternative supply chain partners under cloud computing environment [6, 68]. Moreover, quality and technology are efficient to reflect the alignment degree of alternative supply chain partners' information system architecture and cloud computing. Therefore, based on the above analysis, the proposed criteria can effectively reflect the impact factors involved in the selection of supply chain partners under cloud computing environment.

3.1. Economics. Economics is the major consideration of a firm to select appropriate supply chain cooperation partners [6, 8, 13, 14, 74], especially under cloud computing environment. Because cloud computing has the features of elasticity, scalability, and pay per use [18, 75], businesses do not need to invest or hire employees on their servers to take care of them; in contrast, they only need to pay on need [76]. The use of cloud computing services can convert fixed costs into variable costs, saving a lot of time and money [77]. Therefore, the information system architecture based on cloud computing is completely different from the traditional information system. If alternative supply chain partner's traditional IS is too expensive to convert to cloud, then focal firm may reconsider the suitability for this supply chain partner.

3.2. Credibility. Credibility is the basis and prerequisite of enterprise cooperation [78]. Corporate reputation and customer satisfaction are the foundation of enterprise survival and development [79]. It assesses the ability to provide solutions/services/products of highest quality with less cost to customers, leading to higher customer satisfaction [80]. Cloud computing will permit customers to obtain resources without prior capital investment. This enables corporations to extend services and reduce innovation barriers. In addition, cloud computing based system is totally different from traditional IT based system, all supply chain cooperation partners' data will be stored on cloud. If the credibility of an alternative supply chain partner is not good, which may damage the whole supply chain reputation due to the characteristics of "shared environment" and "data concentration" of cloud

computing [16, 19, 75], hence, we consider credibility as an organizational factor on the supply chain partner selection problem under cloud computing environment.

3.3. Quality. In the life cycle of an enterprise, quality is considered as an important factor. Product quality is an important index to measure the competitiveness of enterprises. Improving the quality of delivery is a powerful tool for enterprises to open up the market [81]. Quality management is the soul of production technology and plays an important role in enterprise management [82]. Cloud computing based supply chain system requires all participants' data and software applications are architecture in the "cloud" [16] that means the focal firm must strictly control the information quality of supply chain partners, especially the interconnection of data between supply chain partners. Hence, we consider quality as a significant influence factor on the information system integration among supply chain partners, which should be regarded as a key issue on the supply chain partner selection problem under cloud computing environment.

3.4. Technology. To select the right supply chain partner under cloud computing environment, both technical and managerial attributes must be considered by focal firm. Technology can reflect the technological innovation and research productivity of enterprises [82] and also can greatly enhance the comprehensive competitiveness of enterprises. For technology, focal firm requires to evaluate whether the alternative supply chain partner's IT infrastructure is easily to integrate with the whole cloud based supply chain information system. The information systems integration between focal firm and supply chain partners involves many factors, such as data interface, underlying IT architecture, and web server, and any technical problem may cause system mismatch problems, which may also affect the cooperation between supply chain partners. Therefore, technology issues are also not negligible aspects in the assessment of supply chain partners under cloud computing environment.

4. Research Methodology

The research method proposed in this paper has the following three steps: the first step is the preparatory stage, the data of different evaluation matrices are integrated by rough numbers. The second step is the gathering stage; we use rough numbers to improve BWM and determine the attribute weights based on RBWM. The third step is the selection stage, we introduce RVIKOR to evaluate and sort the supply chain partners based on S, R, and Q on the environment of cloud computing. The conceptual framework of the proposed approach is shown in Figure 1.

4.1. Presentation of the Problem. Let $M = \{1, 2, \dots, m\}$, $N = \{1, 2, \dots, n\}$, $K = \{1, 2, \dots, t\}$. The MAGD can be described as follows.

Let $A = \{A_1, A_2, \dots, A_m\}$ ($m \geq 2$) be the set of discrete feasible sets, $C = \{C_1, C_2, \dots, C_n\}$ is a finite set of attributes, and $w = \{w_1, w_2, \dots, w_n\}$ is the weight of attributes, where $\sum_{j=1}^n w_j = 1$, $j \in N$ and $0 \leq \lambda_k \leq 1$, $D = \{D_1, D_2, \dots, D_n\}$ is a

group of experts. The evaluation information of alternative A_i based on the attribute u_j provided by the expert D_k is $r_{ij}^k = (a_{ij}^k)$, ($i \in M, j \in n, k \in K$). Hence, the expert D_k decision matrix is denoted as $R_k = (r_{ij}^k) = (a_{ij}^k)$.

Each expert provides his/her decision matrix as follows:

$$R_k = (r_{ij}^k) = \begin{bmatrix} a_{11}^k & a_{12}^k & \cdots & a_{1n}^k \\ a_{21}^k & a_{22}^k & \cdots & a_{2n}^k \\ \cdots & \cdots & \ddots & \cdots \\ a_{m1}^k & a_{m2}^k & \cdots & a_{mn}^k \end{bmatrix} \quad (1)$$

4.2. Weighting for Attributes Based on RBWM. Through expert discussion, the best criterion C_B and the worst criterion C_W are determined. If no agreement can be reached, a new criterion widely recognized by experts is added as the best (worst) criterion. After experts score, we get two comparison vectors A_B and A_W . The k th expert scores two vectors, which are

$$A_B^k = (a_{B1}^k, a_{B2}^k, \dots, a_{Bn}^k), \quad (2)$$

$$A_W^k = (a_{1W}^k, a_{2W}^k, \dots, a_{nW}^k). \quad (3)$$

Among them, $1 \leq k \leq m$, $1 \leq j \leq n$, n is the number of guidelines, and M is the number of experts.

Construct the integrated comparison vector, which are as follows:

$$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}), \quad (4)$$

$$A_W = (a_{1W}, a_{2W}, \dots, a_{nW}). \quad (5)$$

Among them, $a_{Bj} = \{a_{Bj}^1, a_{Bj}^2, \dots, a_{Bj}^m\}$ are the sets of experts' scoring for the best criterion C_B compared with the preference degree of the standard c_j . In the same way, we can know the meaning of a_{jW} . We construct a rough comparison vector and use (1)–(5) to transform elements in the vector into rough number.

$$RN(a_{Bj}^k) = [\underline{a_{Bj}^k}, \overline{a_{Bj}^k}] \quad (6)$$

$$RN(a_{jW}^k) = [\underline{a_{jW}^k}, \overline{a_{jW}^k}] \quad (7)$$

The rough sequence can be expressed as

$$RN(a_{Bj}) = \left\{ [\underline{a_{Bj}^1}, \overline{a_{Bj}^1}], [\underline{a_{Bj}^2}, \overline{a_{Bj}^2}], \dots, [\underline{a_{Bj}^m}, \overline{a_{Bj}^m}] \right\} \quad (8)$$

$$RN(a_{jW}) = \left\{ [\underline{a_{jW}^1}, \overline{a_{jW}^1}], [\underline{a_{jW}^2}, \overline{a_{jW}^2}], \dots, [\underline{a_{jW}^m}, \overline{a_{jW}^m}] \right\} \quad (9)$$

We calculate the average roughness of the fuzzy sequence.

$$\overline{RN}(a_{Bj}) = [\underline{a_{Bj}}, \overline{a_{Bj}}] = \frac{1}{m} \sum_{k=1}^m [\underline{a_{Bj}^k}, \overline{a_{Bj}^k}] \quad (10)$$

$$\overline{RN}(a_{jW}) = [\underline{a_{jW}}, \overline{a_{jW}}] = \frac{1}{m} \sum_{k=1}^m [\underline{a_{jW}^k}, \overline{a_{jW}^k}] \quad (11)$$

FIGURE 1: The conceptual framework of the proposed approach.

Finally, we get two fuzzy comparative vectors:

$$RA_B = ([\underline{a}_{B1}, \overline{a}_{B1}], [\underline{a}_{B2}, \overline{a}_{B2}], \dots, [\underline{a}_{Bn}, \overline{a}_{Bn}]) \quad (12)$$

$$RA_W = ([\underline{a}_{1W}, \overline{a}_{1W}], [\underline{a}_{2W}, \overline{a}_{2W}], \dots, [\underline{a}_{nW}, \overline{a}_{nW}]) \quad (13)$$

We calculate the fuzzy weight of each criterion $([\omega_1], [\omega_2], \dots, [\omega_n])$. The weight of the optimal interval number should be satisfied

$$\begin{aligned} \frac{[\omega_B]}{[\omega_j]} &= [a_{Bj}], \\ \frac{[\omega_j]}{[\omega_W]} &= [a_{jW}] \end{aligned} \quad (14)$$

That is,

$$\frac{[\omega_B, \overline{\omega}_B]}{[\omega_j, \overline{\omega}_j]} = [a_{Bj}, \overline{a}_{Bj}] \quad (15)$$

$$\frac{[\omega_j, \overline{\omega}_j]}{[\omega_W, \overline{\omega}_W]} = [a_{jW}, \overline{a}_{jW}] \quad (16)$$

In order to calculate the rough weight, it uses the mathematical programming to seek $[\omega_j]$ that satisfy all the minimum maximum weights of $h([\omega_B]/[\omega_j], [a_{Bj}])$ and $h([\omega_j]/[\omega_W], [a_{jW}])$,

$$\begin{aligned} \min \max_j & \left\{ h\left(\frac{[\omega_B]}{[\omega_j]}, [a_{Bj}]\right), h\left(\frac{[\omega_j]}{[\omega_W]}, [a_{jW}]\right) \right\}; \\ \text{s.t. } & \overline{\omega}_B = 1, \\ & \overline{\omega}_j > \underline{\omega}_j \geq 0, \quad \forall j. \end{aligned} \quad (17)$$

Among them, $h([a], [b]) = \sqrt{(\underline{a} - \underline{b})^2 + (\overline{a} - \overline{b})^2}$ is the similarity between $[a]$ and $[b]$. And $[\omega_B]$ is the weight of the optimal criterion. $\omega_B = 1$ as a condition of standardization. It guarantees any criteria weights of j that meet $[\omega_j] \subseteq [0, 1]$. In order to solve conveniently, the mathematical programming can be rewritten into $\min \xi$,

$$\text{s.t. } \sqrt{\left(\frac{\omega_B}{\omega_j} - \underline{a}_{Bj}\right)^2 + \left(\frac{\overline{\omega}_B}{\overline{\omega}_j} - \overline{a}_{Bj}\right)^2} \leq \xi \quad (18)$$

$$\sqrt{\left(\frac{\omega_j}{\omega_W} - \underline{a}_{jW}\right)^2 + \left(\frac{\overline{\omega}_j}{\overline{\omega}_W} - \overline{a}_{jW}\right)^2} \leq \xi \quad (19)$$

$\overline{\omega}_B = 1, \overline{\omega}_j > \underline{\omega}_j \geq 0$, for all j .

Get rough weight $[\underline{\omega}_1, \overline{\omega}_1], [\underline{\omega}_2, \overline{\omega}_2], \dots, [\underline{\omega}_n, \overline{\omega}_n]$.

4.3. Rough VIKOR for Alternative Evaluation. Both the VIKOR and TOPSIS methods are based on the idea of "closest to the ideal solution". The TOPSIS method does not consider the weight of the distance between the evaluation object and the positive and negative ideal solution in the calculation process. The optimal solution obtained by this method is not necessarily the closest solution to the ideal point. However, the VIKOR method is a good multiattribute decision-making method, by maximizing the group benefit and minimizing the individual regret and getting the compromise solution accepted by the decision-makers.

Build a rough number decision matrix. The experts score and integrate the performance of each alternative on each criterion. We can get the group decision matrix and convert it into a rough number matrix by using the fuzzy method.

$$A = [\underline{x}_{ij}, \overline{x}_{ij}]_{m \times n} \quad (20)$$

Among them, m is the number of alternatives and n is the number of criteria.

Determine the positive ideal solution $X^+ = (x_1^+, x_2^+, \dots, x_n^+)$ and negative ideal solution $(x_1^-, x_2^-, \dots, x_n^-)$; it is defined as

$$x_j^+ = \left\{ \max_i \bar{x}_{ij}, j \in T_1; \min_i \underline{x}_{ij}, j \in T_2 \right\}, \quad (21)$$

$$x_j^- = \left\{ \min_i \underline{x}_{ij}, j \in T_1; \max_i \bar{x}_{ij}, j \in T_2 \right\} \quad (22)$$

T_1 collection is efficiency standards set; T_2 collection is cost standards set.

Calculate the values $[S_i, \bar{S}_i]$ and $[R_i, \bar{R}_i]$

$$S_i = \sum_{j \in T_1} \frac{\omega_j (x_j^+ - \bar{x}_{ij})}{(x_j^+ - x_j^-)} + \sum_{j \in T_2} \frac{\omega_j (x_{ij} - x_j^+)}{(x_j^- - x_j^+)} \quad (23)$$

$$\bar{S}_i = \sum_{j \in T_1} \frac{\bar{\omega}_j (x_j^+ - \underline{x}_{ij})}{(x_j^+ - x_j^-)} + \sum_{j \in T_2} \frac{\bar{\omega}_j (\bar{x}_{ij} - x_j^+)}{(x_j^- - x_j^+)} \quad (24)$$

$$R_i = \max_j \begin{cases} \frac{\omega_j (x_j^+ - \bar{x}_{ij})}{(x_j^+ - x_j^-)} & | j \in T_1 \\ \frac{\omega_j (x_{ij} - x_j^+)}{(x_j^- - x_j^+)} & | j \in T_2 \end{cases} \quad (25)$$

$$\bar{R}_i = \max_j \begin{cases} \frac{\bar{\omega}_j (x_j^+ - \underline{x}_{ij})}{(x_j^+ - x_j^-)} & | j \in T_1 \\ \frac{\bar{\omega}_j (\bar{x}_{ij} - x_j^+)}{(x_j^- - x_j^+)} & | j \in T_2 \end{cases} \quad (26)$$

Calculate the aggregative indicator values $[Q_i, \bar{Q}_i]$

$$Q_i = \frac{\nu (S_i - S^+)}{(S^- - S^+)} + \frac{(1 - \nu) (R_i - R^+)}{(R^- - R^+)} \quad (27)$$

$$\bar{Q}_i = \frac{\nu (\bar{S}_i - S^+)}{(S^- - S^+)} + \frac{(1 - \nu) (\bar{R}_i - R^+)}{(R^- - R^+)} \quad (28)$$

Under the condition $S^+ = \min_i S_i$, $S^- = \max_i \bar{S}_i$, $R^+ = \min_i R_i$, and $R^- = \max_i \bar{R}_i$.

The coefficient of ν is the largest group of utility decision strategy. At the time of $\nu > 0.5$, according to the opinion of most people, the strategy is formulated in a way that maximizes the proportion of the population in the largest proportion; at the time of $\nu = 0.5$, the strategy is formulated according to the equilibrium situation; in $\nu < 0.5$, according to the situation of opposition, it is to minimize the proportion of individual regrets to make up a large proportion of the formulation strategy. In this paper, $\nu = 0.5$ is set to choose the best supply chain partners in a balanced way. According to the ranking of S , R , and Q from small to large, we get three sorting sequences.

Determine a compromise solution. A_1 is the first ranked supplier ranked by Q (minimum). If it satisfies the following two conditions, supplier A_1 is the best compromise solution.

Condition 1. Acceptable advantages are as follows:

$$\sqrt{\frac{1}{2} [(\bar{Q}(A_2) - \bar{Q}(A_1))^2 + (Q(A_2) - Q(A_1))^2]} \geq \frac{1}{(n-1)} \quad (29)$$

Under the condition A_2 is the second supplier ranked by Q .

Condition 2. The stability of the decision-making process is acceptable. A_1 must be the first ranked supplier ranked by S and R .

When the above two conditions are not satisfied, a set of compromise solutions is obtained:

(a) If only Condition 2 is not satisfied, both A_1 and A_2 are compromise solutions.

(b) If the Condition 1 is not satisfied, the maximum i , A_1 , $A_2, \dots, A_i$ are close to the ideal solution that is determined by

$$\sqrt{\frac{1}{2} [(\bar{Q}(A_i) - \bar{Q}(A_1))^2 + (Q(A_i) - Q(A_1))^2]} \geq \frac{1}{(i-1)} \quad (30)$$

4.4. The Main Steps of the Proposed Method. The main steps of the proposed method are shown as follows.

Step 1. We establish the decision matrix by using the worst index score of design concept and the best index of design concept.

Step 2. We integrate the score vector and construct the comparison vector.

Step 3. D_B and D_W are converted to RDM_B and RDM_W as rough vector.

Step 4. We get the optimal interval weight vector by constructing mathematical programming and solving by Matlab. Five experts rated each alternative according to different scoring criteria.

Step 5. We transform the matrix into a rough number matrix.

Step 6. Based on the rough matrix, we determine every index of the worst optimal value and determine the positive and negative ideal solutions.

Step 7. According to (23)-(26), calculate the values S , R

Step 8. According to (27)-(28), calculate the aggregative indicator values Q .

Step 9. We plan in sequence according to the value of S , R , and Q .

TABLE 1: The worst indicator scores.

Experts	C_1	C_2	C_3	C_4
D_1	1	7	5	9
D_2	1	5	7	9
D_3	1	7	4	9
D_4	1	5	5	9
D_5	1	7	5	7

TABLE 2: The best indicator scores.

Experts	C_1	C_2	C_3	C_4
D_1	9	5	5	1
D_2	9	3	4	1
D_3	9	3	2	1
D_4	9	5	3	1
D_5	9	3	3	1

5. Illustrative Example and Discussion

5.1. Illustrative Example. This paper takes the partner selection of a company's supply chain as an example. According to the study of the supply chain partners under the cloud computing, four attributes are considered in the selection of four potential suppliers (A_1, A_2, A_3, A_4): C_1 -credibility, C_2 -technological, C_3 -quality, and C_4 -cost. And according to the existing 5 experts D_i ($i=1, 2, 3, 4, 5$), based on their views and judgments to score the criteria and alternatives, the evaluation process is divided into two parts: weight calculation and Scheme sorting.

According to the BWM method, 5 experts are invited to score the importance of the criteria. Then the RBWM method is used to calculate the rough weight vector of each criterion, and the objective vector of the criteria is obtained.

Step 1. Table 1 shows the worst indicator scores of the design concept and Table 2 shows the best indicator scores of the design concept.

According to the table of experts, five experts all agree that the best criterion is C_1 and the worst criterion is C_4 .

Step 2. Integrate score vector and integrate comparative vector construction.

$$\begin{aligned}
 DM_B &= (\{9, 9, 9, 9, 9\}, \{5, 3, 3, 5, 3\}, \{5, 4, 2, 3, 3\}, \\
 &\quad \{1, 1, 1, 1, 1\}) \\
 DM_w &= (\{1, 1, 1, 1, 1\}, \{7, 5, 7, 5, 7\}, \{5, 7, 4, 5, 5\}, \\
 &\quad \{9, 9, 9, 9, 7\})
 \end{aligned} \quad (31)$$

Step 3. D_B and D_w converted to RDM_B and RDM_w as rough vector.

TABLE 3: Evaluation data.

Alternatives	Experts	Evaluation criteria			
		C_1	C_2	C_3	C_4
A_1	DM1	95	7	5	7
	DM2	99	9	7	7
	DM3	98	9	5	7
	DM4	97	7	7	5
	DM5	93	7	3	7
A_2	DM1	93	9	7	5
	DM2	95	9	5	7
	DM3	90	7	7	3
	DM4	91	7	5	5
	DM5	90	9	7	5
A_3	DM1	88	7	7	9
	DM2	93	9	7	9
	DM3	92	7	7	9
	DM4	86	7	9	7
	DM5	91	7	7	9
A_4	DM1	89	7	5	9
	DM2	93	5	5	7
	DM3	90	5	7	7
	DM4	88	5	5	7
	DM5	92	7	7	9

$$\begin{aligned}
 RDM_B &= ([8.28, 8.92], [3.32, 4.28], [2.74, 4.08], [1, 1]) \\
 RDM_w &= ([1, 1], [5.72, 6.68], [4.69, 5.74], [8.28, 8.92])
 \end{aligned} \quad (32)$$

Step 4. We construct the mathematical programming and use Matlab to solve it and get the best interval value weight vector.

$$\bar{W} = ([0.83, 1], [0.16, 0.22], [0.20, 0.27], [0.07, 0.09]) \quad (33)$$

Under the condition $\xi = 0.3$.

The five experts grade each alternative on different criteria and score in Table 3.

Step 5. We transform the score matrix into a rough matrix:

$$\begin{aligned}
 R &= \begin{bmatrix} [7.08, 7.72] & [7.32, 8.28] & [4.49, 6.28] & [5.72, 6.68] \\ [4.49, 6.28] & [7.72, 8.68] & [5.72, 6.68] & [4.30, 5.70] \\ [7.32, 8.28] & [7.08, 7.72] & [7.08, 7.72] & [8.28, 8.92] \\ [5.72, 6.68] & [5.32, 6.28] & [5.32, 6.28] & [7.32, 8.28] \end{bmatrix} \\
 &= \begin{bmatrix} [7.08, 7.72] & [7.32, 8.28] & [4.49, 6.28] & [5.72, 6.68] \\ [4.49, 6.28] & [7.72, 8.68] & [5.72, 6.68] & [4.30, 5.70] \\ [7.32, 8.28] & [7.08, 7.72] & [7.08, 7.72] & [8.28, 8.92] \\ [5.72, 6.68] & [5.32, 6.28] & [5.32, 6.28] & [7.32, 8.28] \end{bmatrix} \quad (34)
 \end{aligned}$$

Step 6. According to the rough matrix, identify each index of the optimal values of the worst and determine the positive ideal solution and negative ideal solution. As shown in Table 4, the efficiency standards set is $T_1 = \{C_2, C_3\}$, and the cost type standards set is $T_2 = \{C_1, C_4\}$.

TABLE 4: The criterion of ideal solution.

	C_1	C_2	C_3	C_4
x_j^+	4.49	8.68	7.72	4.30
x_j^-	8.28	5.32	4.49	8.92

TABLE 5: The value $[S_i, \bar{S}_i]$.

	S_i	$\bar{S}_i$	$[S_i, \bar{S}_i]$	rank
A_1	0.697	1.247	[0.697, 1.247]	3
A_2	0.064	0.626	[0.064, 0.626]	1
A_3	0.725	1.178	[0.725, 1.178]	4
A_4	0.549	0.889	[0.549, 0.889]	2

TABLE 6: The value $[R_i, \bar{R}_i]$.

	R_i	$\bar{R}_i$	$[R_i, \bar{R}_i]$	rank
A_1	0.620	0.852	[0.574, 1]	3
A_2	0.064	0.472	[0.215, 0.515]	1
A_3	0.620	1	[0.063, 0.369]	4
A_4	0.269	0.578	[0.086, 0.370]	2

TABLE 7: The aggregative indicator value $[Q_i, \bar{Q}_i]$.

	Q_i	$\bar{Q}_i$	$[Q_i, \bar{Q}_i]$	rank
A_1	0.581	0.952	[0.581, 0.952]	3
A_2	0	0.47	[0, 0.47]	1
A_3	0.594	1	[0.549, 1]	4
A_4	0.327	0.645	[0.327, 0.645]	2

Step 7. We calculate the values S, R according to (23)-(26).

Step 8. We calculate the comprehensive index value Q according to (27)-(28).

Step 9. It plans in order for $A_2 < A_4 < A_1 < A_3$ based on the values S, R, Q , as shown in Tables 5, 6, and 7. A_3 is a compromise solution; namely, A_2 is the best choice.

5.2. Discussion. In this section, we discuss the proposed method's advantages compared with other MAGDM methods in the existing partner selection studies, e.g., [27, 83–85]. Specifically the proposed method has three advantages.

(1) The results of the evaluation are more objective and reliable. Solving uncertain problems is challenging for traditional multicriteria decision-making method. When we introduce interval numbers and rough numbers, we need a priori knowledge. In this method, fuzzy membership function is introduced, in which the fuzzy number widens the scope and increases the fuzziness [27, 85]. In order to effectively reduce the subjectivity and uncertainty of the problem, we use rough sets to collect expert evaluation. In addition, because the evaluation process is entirely dependent on the original data, so the evaluation results are more objective and reliable.

(2) This method improves the existing weight calculation method. If FAHP and RAHP do not reach the consistency requirement of the judgment matrix, the relevant experts need to modify them [84]. And the second grade is time-consuming and error prone. RBWM simplifies the calculation process of rough numbers by reducing the number of comparisons, which can effectively ensure consistency judgment and obtain accurate and reliable results.

(3) The improved method can solve uncertain evaluation information effectively. Rough set can reflect the positive and negative members' information and deal with the semantics of evaluation information of decision-makers. By calculating the similarity of rough set, the comprehensive index is received indirectly and is used to calculate the original data, thus avoiding the normalization of information loss data.

6. Conclusions

In the cloud computing environment, how to correctly select the supply chain partners becomes the key factor of competition. This paper proposes a supply chain partner selection model integrating rough BWM and rough VIKOR. Firstly, rough data is used to integrate data from different evaluation matrices. Secondly, we use the rough number to improve BWM and determine attribute weights based on RBWM. Thirdly, on the basis of cloud computing, RVIKOR is introduced to evaluate and sort the supply chain partners based on S, R , and Q . The method proposed in this study can also be applied to other group decision-making areas.

This paper makes contributes to the existing research from the following three points: (1) The evaluation results are more objective and reliable. It can effectively reduce the subjectivity and uncertainty of the multicriteria decision problem with fuzziness and responsiveness, and it relies on the original data to make the evaluation result more objective and reliable. (2) Improving the existing method of weight calculation, RBWM can effectively guarantee consistency judgment and simplify the operation process of rough numbers by reducing the number of comparisons. (3) Rough set which improved VIKOR can effectively deal with uncertainty evaluation information. Without increasing the subjective conditions, this paper retains more decision-making information and makes supply chain partner selection more scientific.

Besides, our work also extend the theory of existing MAGDM in two ways: (1) We made the best use of the experience and knowledge of experts. The proposed method integrates rough numbers to help experts easily to express the assessment comments directly, transforming the expert's experience and knowledge into visual data, so the decision system can make the best use of the expert's experience and knowledge and gives more scientific assessment comments on alternatives. (2) Our approach offers universality and scalability in practice. Theoretical and numerical results demonstrate the versatility and scalability of the approach in partner selection. This method can be extended to other approaches and applied to all kinds of decision systems, such as supplier segmentation, risk assessment, and supplier selection.

Finally, for future research, it is meaningful to conduct empirical researches on the criteria put forward by other scholar, which was going to be more appropriate for enterprises operation in practice. Besides, the proposed method can be used in many other practical fields, such as supplier selection, information retrieval, risk evaluation and supplier segmentation, etc. Particularly in the application areas of supplier segmentation, the proposed method can help focal firm to scientific categorize numerous suppliers by their similarities through modification and improvement.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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