Fuzzy Kano Integrated MCDM Approach for Supplier Selection Based on Must Be Criteria

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***Abstract*—Globalization of markets has compelled the industries to adopt new strategies of business to sustain in competitive markets. Therefore, industries are adopting innovative methods for selection of supply chain partners. Criteria of supplier selection should be based on industry need and type of product. In this work philosophy of Kano model has been applied for classification of criteria in to different sets. Fuzzification of Kano model overcomes the constraint of single response and allows respondent to express customer satisfaction feelings in form of multiple numeric values. In this work decision makers categorized thirty six criteria in to different sets and Must Be criteria are identified for supplier selection process. Further Step-wise Weight Assessment Ratio Analysis (SWARA) method and Range of Values (ROV) method has been applied for weight assignment of criteria and ranking of alternatives respectively. Researchers and industrial practitioners can apply this methodology to other industries by choosing a different set of criteria.**

***Keywords*—** *Supplier Selection, Selection Criteria, SWARA, ROV, Fuzzy Kano Model, MCDM*

1 Introduction

Dynamic and competitive market environment, changing customer expectations and required product varieties are forcing industries to adopt new and innovative methods for sustaining their market position. To remain competitive in market industries need to increase customer satisfaction by providing quality products at economic prices and in shortest lead time [1]. In supply chain management, Purchasing has been identified as one activity having great impact over quality, delivery time and cost of product. In literature authors have reported that major percentage of total manufacturing cost of product is because of cost of goods and raw materials procured by industries [2].

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Thus purchasing is a vital and critical activity which needs to be administered and monitored effectively to enhance performance level of supply chains and industries [3]. Supplier selection is important activity under purchasing. Supplier selection is a decision making process in which industry identifies potential suppliers, evaluates them on the basis of predefined criteria and lists them according to evaluation scores for the purpose of contract allocation. In literature several methodologies have been proposed by author for selecting reliable suppliers [4]–[11]. From these studies it is elicited that supplier selection process has four main objectives to achieve, (i) Determination of supplier selection criteria, (ii) Weight assignment to criteria, (iii) Assessment of alternatives (potential suppliers) over selection criteria and (iv) Determining Order of preference of alternatives.

Choosing correct set of criteria and assigning relative weights to selected criteria helps in alignment of purchasing decisions for achievement of strategic and performance objective of industry [12]. Further Dey et al., (2015) emphasised that criteria for supplier selection and evaluation are very significant from strategic perspective and should be chosen with agreement with business process and requirements of stakeholders. Also supplier selection criteria should be decided keeping in view factors like, type of industry, strategic planning of industry, customer satisfaction and product. Type of product being supplied is also a major variable in criteria selection. For example after sales services and repair can be a major criteria for selection of a computer peripheral supplier where as technical capability, knowledge sharing and mutual trust are vital criteria for supplier selection in new product development. Further choice of appropriate set of criteria for supplier selection is crucial owing to the fact that, improper choice of criteria will lead to selection of non-potential and non-reliable suppliers. This erroneous selection of suppliers will disturb whole supply chain and will adversely affect the performance of industry which ultimately effects customer's satisfaction.

In literature authors have considered criteria which belongs mainly to 'extreme importance' and 'considerable importance' category of criteria as suggested by Dickson (1966). Further criteria selection has been mainly done by authors. Decision makers from industry have mainly contributed in weight assignment to criteria and assessment of suppliers for ranking; they have little or no involvement in criteria selection phase of supplier selection process.

Hence there is a need of methodology for supplier selection that involves decision makers in selection of criteria according to need of industry. Secondly proposed methodology should provide decision makers with larger number of criteria to choose from and should have a simple and easy technique to categorize these criteria in to different sets on premise of level of significance. Considering these objectives a supplier selection frame work has been proposed which provides decision makers with thirty six criteria to choose from. Further philosophy of Kano model with fuzzification has been applied which facilitate decision makers to prioritize these criteria in different sets according to need of industry and type of product to be purchased. Fuzzification of Kano model allows to capture ambiguity of responses. Weight assignment to essential criteria has been accomplished by Step-wise Weight Assessment Ratio Analysis (SWARA) method which requires least number of pairwise comparisons. Finally order of preference of potential suppliers has been done by Range of values (ROV) MCDM method owing to simple computational procedure and its ability to produce reliable results.

Organization of paper is as follows: - next section covers fuzzy Kano model. Section three covers SWARA method and fourth section of paper covers ROV method. Proposed methodology is under section five. Application of proposed methodology is covered in section six. Conclusion has been presented in section seven.

2 Fuzzy Kano Model

Kano (1984) proposed a two-dimensional quality model that effectively analyzed the requirements of customer from a product or a service and level of customer satisfaction achieved form attributes of product. Kano model illustrates the relationship between customer satisfaction and performance of a product or a service. Model focuses on determining the attributes of a product and its effect on level of customer satisfaction and dissatisfaction. A questionnaire consisting of functional form and dysfunctional form of questions bssed on attributes is prepared and a 5 x 5 evaluation table is utilized for illustrating relationship of attributes and level of customer satisfaction perceived. Based over the customer satisfaction perceived from fulfillment of attributes, attributes are classified in to five sets as-

2.1 Must-be requirements (M): These are the essential requirements which customer need to have in the product. The fulfillment of these requirements will not increase the satisfaction level considerably; however their non-fulfillment increases the dissatisfaction level significantly.

2.2 One-dimensional requirements(O): Fulfillment of these requirements is proportional to the customer satisfaction level i.e. customer satisfaction increases if these requirements are fulfilled at higher level and vice versa.

2.3 Attractive requirements (A): Fulfillment of these requirements has highest level influence on the customer satisfaction where as non-fulfillment of these requirements does not increase dissatisfaction level.

2.4 In different requirements (I): Customer satisfaction level is not influenced by the achievement or non-achievement of these requirements.

2.5 Reverse requirements (R): Customers do not want these attributes in the product and absence of these attributes increases customer's satisfaction level.

In original Kano model, respondent is constrained to register a single response in questionnaire, reflecting his satisfaction level for that attribute (Table 1). Response in form of a single crisp choice is not able to capture the embedded uncertainty and ambiguity. To overcome this drawback of traditional Kano model questionnaire, fuzzy Kano questionnaire was proposed by Lee & Huang, (2009). Fuzzification of Kano model questionnaire allowed respondent to give multiple responses for each functional and dysfunctional for of questions (Table 2). Instead of single crisp response, respondent utilized membership function to express their level of satisfaction thus making evaluation process robust and consistent. Another advantage of fuzzy Kano model questionnaire is reduced degree of subjectivity of evaluation but on the other hand, analysis of response are complex as compared to traditional model.

Table 1. Traditional Kano model Questionnaire

	Like	Must Be	Neutral	Live with	Dislike
Functional form of question for an attribute	✓				
Dysfunctional form of question for an attribute				✓	

Table 2. Fuzzy Kano model Questionnaire

	Like	Must Be	Neutral	Live with	Dislike
Functional form of question for an attribute	40%	60%			
Dysfunctional form of question for an attribute			20%	20%	60%

$$R = \begin{pmatrix} 0 & 0 & 0.08 & 0.08 & 0.24 \\ 0 & 0 & 0.12 & 0.12 & 0.36 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Figure 1. Fuzzy relation matrix

In Table 1 sample response of traditional questionnaire has been presented and in Table 2 fuzzy questionnaire of Kano model has been depicted respectively. It is seen that in traditional questionnaire, response is single for each form of question and in fuzzy questionnaire multiple responses can be registered. Further if for example response of decision maker for an attribute is as per Table 2. For analysis, a row vector for response for functional form of question is established as {0.7, 0.3, 0, 0, 0}. Similarly a row vector for response of dysfunctional form of question is established as {0, 0, 0.2, 0.3, 0.5}. Multiplying transpose of functional vector with dysfunctional vector, a 5 x 5 fuzzy relation matrix is established (Figure 1.)

$$Kano = \begin{pmatrix} Q & A & A & A & O \\ R & I & I & I & M \\ R & I & I & I & M \\ R & I & I & I & M \\ R & R & R & R & Q \end{pmatrix}$$

Figure 2. Kano evaluation table

$$T = \left\{ \frac{0.36}{M}, \frac{0.16}{A}, \frac{0}{R}, \frac{0.24}{I}, \frac{0}{Q}, \frac{0.24}{O} \right\}$$

Further results of fuzzy relation matrix are interpreted with the help of Kano evaluation table (Figure. 2) and matrix T is established by adding values of respective categories. Value of must be category is largest among all other category values hence this criterion is categorized as Must Be criteria.

In supply chain management, suppliers are supplying various materials to industries and in supplier selection process decision makers of industry act as customers. Hence philosophy of Kano model and employment of fuzzy Kano model questionnaire is justified.

3 SWARA Method

It is elicited from literature that authors have applied SWARA method for weight assignment and ranking purpose in different areas of research such as rational decision making, architect selection, energy system, design of new product development, machine tool selection, priority decision of hi tech industry, sales branch performance evaluation and selection of packaging design [16]–[25] In present work SWARA method has been applied for determining relative weights of criteria. The choice of SWARA over AHP is made in present work as SWARA has following advantages [26].

i) For n number of criteria, in AHP method required number of pair wise comparisons are

$$\sum_{i=2}^{n}\sum_{j=2}^{i} j$$

Whereas pair wise comparisons in SWARA is n-1 which is comparatively less [26].

ii) In SWARA method respondents are free from scale and can express their response more freely. Respondent has to use a predefined ranking scale for AHP method proposed by Saaty (1980).

3.1 Steps of SWARA method are:

3.1.1 Arrangement of criteria in descending order of their expected significances.

3.1.2 Calculate Comparative importance of average value, sj. Starting from second criterion, for each criterion, respondent expresses its relative importance with respect to previous criterion.

3.1.3 Establish coefficient K_j as

$$k_j = 1 \quad \text{if} \quad j = 1 \tag{1}$$

$$k_j = S_j + 1 \quad \text{if } j>1 \tag{2}$$

3.1.4 Establish recalculated weight Q_j as

$$Q_j = 1 \quad \text{if} \quad j=1 \tag{3}$$

$$Q_j = \frac{k_{j-1}}{k_j} \quad \text{if } j > 1 \tag{4}$$

3.1.5 Determine relative weights of the evaluation criteria Wj

$$W_J = \frac{Q_j}{\sum_{k=1}^{n} Q_K} \tag{5}$$

4 Range of Values (ROV) method.

Range of values (ROV) method was developed by Yakowitz et al., (1993) [27]. Advantage of this method is that, decision maker has to provide only ordinal specification of criteria importance. This method is very useful in situations where assigning of quantitative weights is difficult [28]. ROV method has been used by authors due to its simple and easy computational procedure. Some of application of ROV in research areas includes selection of cutting fluid, ranking of non-traditional machining process [29], [30]. In this work ROV method has been applied for assessment of alternatives and finally ranks are awarded to alternatives based over their performance.

4.1 Steps of ROV method are

4.1.1 Establish criteria for evaluating available alternatives.

4.1.2 Establish a decision matrix

$$\text{Dmatrix} = [X_{ij}] = \begin{array}{c|cccccc} & C_1 & C_2 & - & - & C_n \\ \hline A_1 & x_{11} & x_{12} & - & - & x_{1n} \\ A_2 & x_{21} & x_{22} & - & - & x_{2n} \\ - & - & - & - & - & - \\ A_n & x_{m1} & x_{m2} & - & - & x_{mn} \end{array} \tag{6}$$

Where

A_i denotes the alternatives i, i=1…..m.

C_j denotes the jth criterion, j=1…….n related to i^{th} alternative. X_{ij} is the numerical value indicating the performance rating of each criterion A_i with respect to each criterion C_j.

4.1.3 Establish a Normalized decision matrix. In this step performance measure of alternatives are normalized (X_{ij}) and normalized decision matrix is established.

$$\left[\bar{X}_{IJ}\right]=\begin{bmatrix}\bar{X}_{11} & \bar{X}_{12} & - & - & \bar{X}_{1n}\\ \bar{X}_{21} & \bar{X}_{22} & - & - & \bar{X}_{2n}\\ - & - & - & - & -\\ - & - & - & - & -\\ \bar{X}_{m1} & \bar{X}_{m2} & - & - & \bar{X}_{mn}\end{bmatrix} \quad (7)$$

Normalization of performance measure (criteria) depends whether it's a beneficial criteria or non-beneficial criteria. For beneficial criteria, maximum values are preferred and for non-beneficial criteria minimum values are preferred.

(i) For beneficial criteria maximum values are preferred and normalization is done by applying linear transformation [28].

$$x_{ij}=\frac{x_{ij}-\min_{i=1}^{m}(x_{ij})}{\max_{i=1}^{m}\left(x_{ij}\right)-\min_{i=1}^{m}\left(x_{ij}\right)} \quad (8)$$

(ii) For non-beneficial criteria minimum values are preferred and normalization is done by applying linear transformation

$$x_{ij}=\frac{\max_{i=1}^{m}(x_{ij})-x_{ij}}{\max_{i=1}^{m}\left(x_{ij}\right)-\min_{i=1}^{m}\left(x_{ij}\right)} \quad (9)$$

4.1.4 In ROV method calculations for best and worst utility is performed for each alternative. It is achieved by maximization or minimization of a utility function. For linear additive model, for each alternative best utility (u_i^+) and worst utility (u_i^-) are calculated with help of following equations

Maximize: $$u_i^{+}=\sum_{j=1}^{n}\bar{x}_{ij}\cdot w_j \quad (10)$$

Minimize: $$u_i^{-}=\sum_{j=1}^{n}\bar{x}_{ij}\cdot w_j \quad (11)$$

Where w_j (j=1,.....,n) are weights of criteria which satisfy $\sum_{j=1}^{n}w_j=1$ and ≥ 0

If $u_i^+ < ui^-$ then alternative 'i' outperforms alternative 'i' regardless of the actual quantitative weights. If alternatives are not comparable using this rule then scoring can be attained from the midpoint. To calculate scoring following rule is applied [28], [29], [31].

$$u_i=\frac{u_i^{+}+u_i^{-}}{2} \quad (12)$$

4.1.5 In final step of method, on the basis of u_i complete ordinal ranking of alternatives are obtained. Alternative having highest u_i value is considered as best and awarded first rank and alternative having lowest u_i value is considered as worst choice and is ranked last.

5 Proposed Methodology

Proposed methodology consists of 8 steps. Steps of methodology are:

Step1: Identification of criteria for supplier selection from literature.
Step 2: Criteria classification by fuzzy Kano model
Step 3: Arrangement of criteria in decreasing order of significance.
Step 4: Establish coefficient K_j and recalculated weight Q_j.
Step5: Determine relative weights of evaluation criteria w_j.
Step 6: Establish decision matrix
Step 7: Establish normalized decision matrix.
Step 8: Calculate best and worst utility.
Step 9: Award final ranks to suppliers.

Flow chart of proposed methodology has been shown in Figure.3.

6 Application of proposed methodology in an Iron and Steel industry

Proposed methodology has been applied to an iron and steel industry located in central India. Steel plant manufactures steel products which are supplied to national and international customers. This iron and steel plant is facing tough competition from its counter parts due to globalization of markets and need to increase customer satisfaction to sustain its market position.

*Step 1:*Dickson (1966) reported twenty three criteria for supplier selection and categorized them over their importance. Further Thiruchelvam and Tookey, (2011) proposed thirteen more new criteria for supplier selection. In this work total thirty six criteria has been considered for supplier selection (Table 3).

Step 2: Based over these thirty six criteria, a fuzzy Kano model questionnaire has been prepared. In fuzzy questionnaire, functional and dysfunctional form of questions for each criterion has been framed. Unlike traditional questionnaire, in fuzzy questionnaire respondent is free to give multiple responses in form of numeric values for each form of question. This facilitate in capturing real feelings of respondents about customer satisfaction.

A team of decision makers, comprising of eight members from top and middle management has been formed. Team members have been selected from various departments such as materials management, finance, stores management and quality control. All team members are having ample experience of their field and possess a thorough knowledge of supplier selection process of industry. Details of decision makers has been presented in Table 4.

Decision makers were presented with questionnaire and filled questionnaire were received. Analysis of collected responses has been done and out of thirty six criteria, ten criteria has been designated as Must Be criteria's (Table 5).

Finalized ten criteria has been arranged in descending order individually by each decision maker on the basis of expected significance of criteria. Decision maker award's first rank to most significant criteria and award last rank to least significant criteria. Decision maker award's rank to criteria on basis of their experience in industry.

Based on the rank given to each criterion by decision makers, average for each criterion is calculated. Criterion with least value of average has been considered as most significant. Final ranking of criteria in descending order of their significance has been tabulated in Table 6.

Step 3: Experts start from second criterion and for each criterion, expresses its relative importance with respect to the previous criterion. Comparative Importance of Average Value (Sj) for all the criteria has been shown in column number two of Table 7.

Step 4: Coefficient Kj has been established and values are tabulated in fourth column of Table 7. Column number five of Table 7 shows recalculated weight Qj for each criterion. Final weights of the criterion are calculated and results have been tabulated in column number six of Table 7. It is observed that Quality criterion has highest weight and signifies that quality is still most important criterion. Delivery criterion is at second place which indicates that industry wants their suppliers to adhere strictly to their time schedule. It is observed that financial position of industry has been credited with least weight in Must Be category of criteria.

Step 5: Six potential suppliers have been considered as alternatives to which final ranks are to be awarded. Decision maker's asses the performance of these suppliers over ten finalized criteria. Decision maker present their response linguistically using options as very high (9), high (7), moderate (5), low (3) and very low (1). Based over responses from decision maker decision matrix has been established.

Step 6: For establishing normalized matrix, all ten criteria have been classified as beneficial and non-beneficial criteria. Quality, Delivery, Technical Capability, Procedural Compliance, Reputation and Position in Industry, Attitude, Reliability, Professionalism, and Commitment of supplier has been considered as beneficial criteria while Price has been considered as non-beneficial criteria. Normalized decision matrix for ROV method has been establishes in Table 8.

Step 7: With Eq. (10), u_i^+ has been calculated and with the help of Eq. (11), u_i^- has been calculated. Finally Eq. (12) has been applied to calculate values of u_i. All calculated values for u_i^+, u_i^- and u_i have been presented in Table 9. Based over calculated values final ranks has been given to all suppliers.

Table 3. Thirty six criteria for supplier selection

Quality	Labor relations record
Delivery	Geographical location
Performance history	Amount of past business
Warranties and claim policies	Training aid
Production facilities	Reciprocal arrangement
Net price	Reliability
Technical capability	Flexibility
Financial position	Process Improvement
Procedural compliance	Product Development
Communication system	Environment and Social Responsibility
Reputation and position in the industry	Occupational Safety And Health
Desire to do business	Integrity
Management and organization	Professionalism
Operating controls	JIT
Repair services	Commitment
Attitude	Economy Situation
Impression	Long Term Relationship
Packaging ability	Political Situation

Table 4. Decision makers' details

	Department	**Experience in**	**Designation**
Decision maker 1	Materials management	13	Senior manager
Decision maker 2	Materials management	21	Deputy general manager
Decision maker 3	Materials management	17	Assistant general manager
Decision maker 4	Materials management	9	Manager
Decision maker 5	Materials management	17	Assistant general manager
Decision maker 6	Finance	13	Senior manager
Decision maker 7	Stores management	17	Assistant general manager
Decision maker 8	Quality control	9	Manager

Step 8: All suppliers have been awarded rank based over calculated values of u_i. It is observed that supplier S4 tops the list and have been given first rank with supplier S5 with last rank. Ranking of suppliers in descending order is S4>S6>S1>S2>S3>S5.

7 Conclusion

In traditional Kano questionnaire response is in form of a single crisp answer. In this work fuzzy Kano questionnaire has been applied which allow multiple numeric value responses. Thus real and complete feeling of customer satisfaction is captured.

This work demonstrates use of Must be criteria in supplier selection process and results of this research work can be of interest to people from industry, academicians, researchers and decision makers.

Different MCDM techniques integrated with fuzzy and Kano philosophy which helps decision makers in identify Must Be criteria for supplier selection and facilitate in selection of optimal suppliers so as to have maximum level of customer satisfaction. Allocation of weights to different criteria is accomplished by SWARA method and ranks are provided to potential suppliers by using ROV method.

Finally decision makers can apply this methodology in different industries for selecting optimal suppliers by choosing different set of criteria and increase customer satisfaction and thus can sustain competitive advantage.

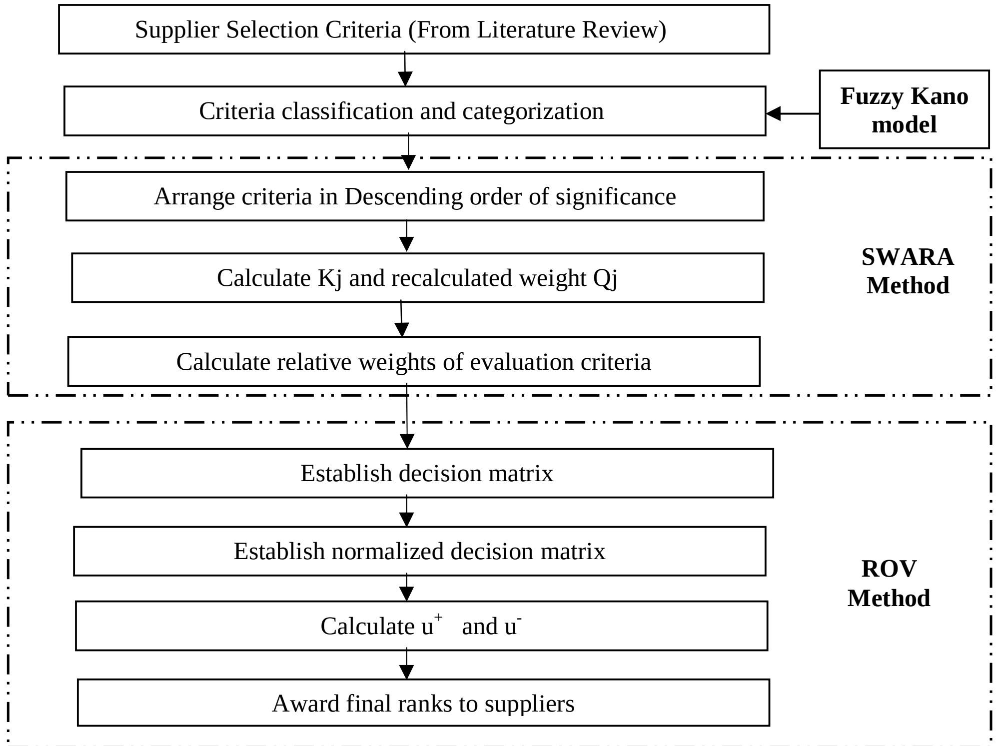

Figure 3. Flow chart of proposed methodology.

Table 5. Criteria of Must be Kano category

S. No	Criteria	Q	A	O	R	I	M
1	Delivery	0	0.12	0.18	0	0.28	0.42
2	Reliability	0	0.1125	0.337	0	0.1375	0.4125
3	Price	0	0.04	0.06	0	0.36	0.54
4	Commitment	0	0.08	0.12	0	0.32	0.48
5	Quality	0	0.16	0.24	0	0.24	0.36
6	Reputation and Position in Industry	0	0.12	0.21	0	0.28	0.49
7	Attitude	0	0.075	0.225	0	0.175	0.525
8	Technical Capability	0	0.135	0.165	0	0.315	0.385
9	Professionalism	0	0.08	0.1	0	0.32	0.4
10	Procedural Compliance	0	0.18	0.22	0	0.27	0.33

Table 6. Final Ranking of Criteria

S. No	Criteria	Rank
1	Quality	1
2	Delivery	2
3	Price	3
4	Technical Capability	4
5	Procedural Compliance	5
6	Reputation and Position in Industry	6
7	Attitude	7
8	Reliability	8
9	Professionalism	9
10	Commitment	10

Table 7. Final results of SWARA

S. No	Criteria	Comparative Importance of Average Value Sj	Coefficient Kj= Sj +1	Recalculated Weight $Wj=\frac{X_{J-1}}{K_J}$	Weight $Qj = \frac{W_J}{\sum W_J}$
1	Quality	0	1	1	0.172528
2	Delivery	0.171	1.171	0.853971	0.147334
3	Price	0.153	1.153	0.740651	0.127783
4	Technical Capability	0.143	1.143	0.647989	0.111796
5	Procedural	0.132	1.132	0.572428	0.09876
6	Reputation and	0.122	1.122	0.510186	0.088021
7	Attitude	0.156	1.156	0.441337	0.076143
8	Reliability	0.112	1.112	0.396886	0.068474
9	Professionalism	0.15	1.15	0.345118	0.059543
10	Commitment	0.2	1.2	0.287598	0.049619

Table 8. Normalized decision matrix for ROV method

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Supplier 1	0.0000	1.0000	0.3333	0.6667	0.0000	1.0000	0.3333	0.3333	0.5000	0.2500
Supplier 2	0.5000	0.5000	0.0000	1.0000	0.5000	0.5000	0.0000	0.0000	0.2500	0.5000
Supplier 3	0.2500	0.2500	0.3333	0.0000	0.7500	0.0000	1.0000	1.0000	0.0000	0.7500
Supplier 4	0.7500	0.7500	0.3333	0.6667	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000
Supplier 5	0.2500	0.0000	1.0000	0.3333	0.7500	0.0000	0.6667	0.0000	0.7500	0.0000
Supplier 6	1.0000	0.5000	0.5000	0.6667	1.0000	0.0000	0.6667	0.0000	0.5000	0.5000

Table 9. Computational details of ROV method

Suppliers	u_i^+	u_i^-	u_i	Ranks
Supplier 1	0.400268	0.042594	0.2214310	3
Supplier 2	0.404813	0	0.2024064	4
Supplier 3	0.335867	0.042594	0.1892305	5
Supplier 4	0.666966	0.042594	0.3547803	1
Supplier 5	0.249887	0.127783	0.1888348	6
Supplier 6	0.524829	0.063892	0.2943601	2

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