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Application of SAW method and Fuzzy based VIKOR approach for Multi-Attribute Group Decision Making: a Case Study in Supplier Selection

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ABSTRACT

In today's competitive global markets, selection of a potential supplier plays an important role to cut production costs as well as material costs of the company and leads to successful survival and sustainability in a competitive marketplace. Therefore, evaluation and selection of an appropriate supplier has become an important part of supply chain management. The nature of the supplier selection process is a complex multi-attribute group decision making (MAGDM) problem which deals with both quantitative and qualitative factors may be conflicting in nature as well as contain incomplete and uncertain information. In order to solve such a kind of MAGDM problems, the development of an effective supplier selection model is evidently desirable. In this paper, an application of SAW method and VIKOR method combined with fuzzy logic has been used to solve supplier selection problems using five criteria which are qualitative and positive for selecting the best one amongst suppliers and also ranking them.

***Key words:* Supplier selection, SAW method, Fuzzy, VIKOR method.**

1. INTRODUCTION

In today's' competitive business scenario, supplier selection has become a major concern for every organizations. Supplier selection requires a wide conceptual and experimental framework to be carried out by the purchasing managers in a supply chain management. Therefore, it is considered to be one of the most important responsibilities in the philosophy of any organizational purchase management. In literature survey, an extensive work was found to be made by previous researchers in the area of supplier selection and they have solved a variety of supplier selection problems using different multi-criteria decision making (MCDM) methods like Performance Value Analysis (PVA), Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), Fuzzy logic, and TOPSIS approach. Apart from this, some hybrid and innovative approaches such as AHP-LP, ANP-TOPSIS and fuzzy-QFD are also being used to find a more precise decision towards the selection of a best alternative supplier from among a set of feasible alternatives. But, this is still limited to an extent because as there are many multi-attribute group decision making (MAGDM) methods which may yield very different results when they are applied on exactly the same data. MAGDM problems are one of the important phases of the multi-criteria decision making (MCDM) process in which three or more decision makers have been grouped together for ranking and selecting the best alternative in the decision making process. The literature depicts some extensive work has been made in the MCDM area as follows.

Roodhooft and Konings (1996) proposed an Activity Based Costing (ABC) approach for vendor selection and evaluation. This system helped to compute the total cost caused by the supplier in the production process, thereby increasing the objectivity in the selection process. Weber *et al.* (1998) developed a theory and methodology of non-cooperative negotiation strategies for vendor selection. Ghodsypour and ÓBrien (1998) proposed an integration of the Analytical Hierarchy Process and Linear Programming (AHP-LP) to consider both tangible and intangible factors in selecting the best vendor. Altinoz and Winchester (2001) focused on the implementation of rule based supplier selection methodology using fuzzy logic concepts. Tsai *et al.* (2003) applied grey relational analysis to the vendor selection model. Overall performance for each candidate vendor was evaluated; based on that, an optimum decision was taken. Kumar *et al.* (2004) developed a fuzzy goal programming approach to deal with the effect of vagueness and imprecision statement in the objectives of the vendor selection process and also highlighted how the quota allocation of vendors was changed with the uncertainty.

Saghafian and Hejazi (2005) presented a modified Fuzzy TOPSIS Technique (Order Performance by Similarity to Ideal Solution) for the Multi-Criteria Decision Making (MCDM) problem when there was a group of decision makers. Kubat and Yuce (2006) applied an integrated Fuzzy AHP and Genetic Algorithm (GA) approach to select the best supplier among the set of multiple suppliers deals with both subjective and objective criteria.

Bashiri and Badri (2011) presented a new group decision making tool when decision data were not crisp and the decision maker wanted to rank the alternatives during the fuzzy interactive linear programming process. Because of the existence of linguistic terms in the decision matrix and the weight of each criterion which could be expressed in trapezoidal fuzzy numbers; an interactive method was proposed for ranking an alternative with the best weight for each criterion. Shahanaghi and Yazdian (2009) proposed the fuzzy group TOPSIS approach to make more realistic decisions for vendor selection in a fuzzy multi-criteria decision making environment.

From the literature review, it has been observed that, choosing a suitable and efficient methodology to solve a multi-criteria decision making problem and selecting the best alternative is a great challenge to researchers as well as management practitioners due to the existence of conflicting and non-commensurable criteria associated with the supplier selection problem. The selection is based on a group of decision making processes which is involved with uncertainty and imperfect information processing to some extent, such as randomicity and fuzzy (Wu and Liu, 2011).

In order to tackle this kind of uncertainty in the decision-making process, in the present work, a fuzzy based VIKOR approach and SAW method has been attempted to evaluate the best supplier under multi-criteria decision making situations. The concept of fuzzy set theory has been applied in this paper to express decision-makers viewpoint in linguistic terms to overcome uncertainty on the estimation of qualitative factors. Linguistic judgment has been transformed to a corresponding fuzzy number. Then, a hierarchy MCDM model based on fuzzy sets theory and VIKOR has been used to deal with a supplier selection problem.

As a case study, the supplier selection problem in a spring manufacturing unit at Annathapur has been studied.

2. SAW method

Simple Additive Weighting (SAW) which is also known as weighted linear combination or scoring methods is a simple and most often used multi attribute decision technique. The method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria. The advantage of this method is that it is a proportional linear transformation of the raw data which means that the relative order of magnitude of the standardized scores remains equal. Process of SAW consist of these steps:

Step 1:

1) Construct a pair-wise comparison matrix (n × n) for criteria with respect to objective by using Saaty's 1-9 scale of pair wise comparisons shown in Table 1. In other words, it is used to compare each criterion with each other criterion, one-by-one.

Table 1: Saaty's 1-9 scale of pair wise comparisons

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgment slightly favour one activity over another
4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favour one activity over another
6	Strong Plus	
7	Very Strong	An activity is favoured very strongly over another
8	Very, very Strong	
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation

2) For each comparison, we will decide which of the two criteria is most important, and then assign a score to show how much more important it is.

3) Compute each element of the comparison matrix by its column total and calculate the priority vector by finding the row averages.

4) Weighted sum matrix is found by multiplying the pair-wise comparison matrix and priority vector.

5) Dividing all the elements of the weighted sum matrix by their respective priority vector element.

6) Compute the average of this value to obtain max λ_{max} .

7) Find the Consistency Index, CI, as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (1)$$

Where n is the matrix size.

8) Calculate the consistency ratio, CR, as follows:

9) $$CR = \frac{CI}{RI} \quad (2)$$

10) Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value of RI in Table2. The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved.

Table 2: Average Random Consistency (RI)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Step 2:

Construct a decision matrix (m × n) that includes m supplier and n criteria. Calculate the normalized decision matrix for positive criteria:

$$n_{ij} = \frac{r_{ij}}{r_j^*} \qquad i = 1, \dots, m, \qquad j = 1, \dots, n \quad (3)$$

And for negative criteria:

$$n_{ij} = \frac{r_j^{min}}{r_{ij}} \qquad i = 1, \dots, m, \qquad j = 1, \dots, n \quad (4)$$

r_j^* is a maximum number of r in the column of j.

Step 3:

Evaluate each alternative, A_i by the following formula:

$$A_j = \sum w_j * x_{ij} \quad (5)$$

Where x_{ij} is the score of the i^{th} alternative with respect to the j^{th} criteria, w_j is the weighted criteria.

This methodology is designed in order to select and consider suitable criteria and supplier in spring manufacturer unit. The way of data collection that is applied for this phase is questionnaire. By using Comparison Matrix the weights of criteria will be computed. After computing weights of criteria, specifying of Consistency Rate will be executed. If Consistency of data is more than 0.1, revision of pair-wise comparison must be done. So we will continue it until consistency Rate reach to less than 0.1. After CR is less than 0.1, it indicates sufficient consistency. In that time, we use SAW method for ranking supplier. The procedure of methodology has been shown in Fig. 1.

Supplier selection in the lean manufacturing system is a group multiple criteria decision making problem. This is illustrated by the following sets.

1. A set of decision makers called D = {D1, D2, D3}

2. A set of possible supplier called S= {S1, S2, S3, S4, S5}

3. A set of criteria, C = {C1, C2, C3, C4, C5}

As the company desires to select a good lean supplier, five candidate suppliers (S1, S2, S3, S4, and S5) remain for further evaluation after preliminary screening.

A committee of three decision makers (DM), D1; D2 and D3, has been formed to select the most suitable supplier. The following criteria have been defined: C_1 – Delivery Commitments, C_2 – Product and Service Quality, C_3 – Reliability and Responsiveness, C_4 – Flexibility, C_5 – Customer Service.

The weights of criteria have been computed by using comparison matrix. Meanwhile, data was gathered from five expert's opinion with questionnaire in spring manufacturer unit by using scale values of 1-5 as shown in Table 3.

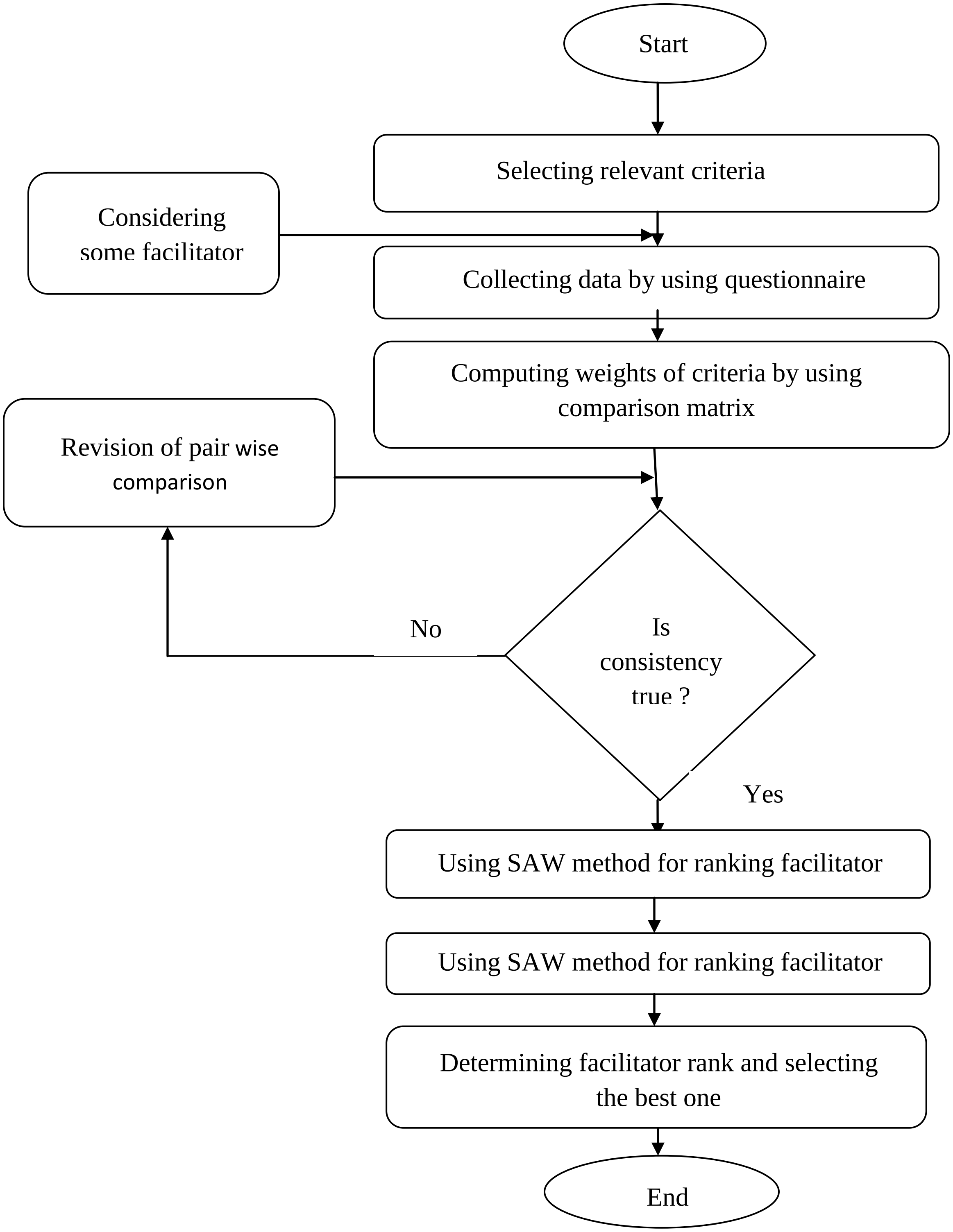

Fig. 1 Research Framework

Table 3: Specifying the scale values of 1-5

Intensity of importance	Definition
1	Equal importance
2	Moderate importance
3	Strong importance
4	Very strong
5	Extreme importance

The comparison matrix is shown in Table 4, indicating the relative importance of the criterion in the columns compared to the criterion in the rows.

Table 4: Weights of criteria by Comparison matrix

	C_1	C_2	C_3	C_4	C_5	Weights
C_1	1	1	1	2	1	0.22
C_2	1	1	2	2	1	0.25
C_3	1	0.5	1	2	1	0.19
C_4	0.5	0.5	0.5	1	1	0.13
C_5	1	1	1	1	1	0.19
Total	4.5	4	5.5	8	5	1

TEST OF CONSISTENCY FOR SELECTED SET OF CRITERIA

The consistency Rate calculated was 0.024 that is less than 0.1, indicating sufficient consistency. The following steps will show how the test of consistency will be done.

Step 1:

In order to calculate computing Weighted Sum Vector (WSM):

$$\begin{bmatrix} 1 & 1 & 1 & 2 & 1 \\ 1 & 1 & 2 & 2 & 1 \\ 1 & 0.5 & 1 & 2 & 1 \\ 0.5 & 0.5 & 0.5 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} 0.22 \\ 0.25 \\ 0.19 \\ 0.13 \\ 0.19 \end{bmatrix} = \begin{bmatrix} 1.11 \\ 1.3 \\ 0.985 \\ 0.65 \\ 0.98 \end{bmatrix}$$

By rounding off the number to three decimal places, we will get Consistency vector (CV). In following division, each corresponding cell must be divided each other.

$$\begin{bmatrix} 1.11 \\ 1.3 \\ 0.985 \\ 0.65 \\ 0.98 \end{bmatrix} / \begin{bmatrix} 0.22 \\ 0.25 \\ 0.19 \\ 0.13 \\ 0.19 \end{bmatrix} = \begin{bmatrix} 5.045 \\ 5.20 \\ 5.15 \\ 5.00 \\ 5.15 \end{bmatrix}$$

$$\lambda_{max} = \frac{5.045 + 5.20 + 5.15 + 5.00 + 5.15}{5} = 5.109$$

Consistency Index (CI) and consistency ratio are calculated using equations 1 and 2.

$$CI = \frac{5.109 - 5}{5 - 1} = 0.02725$$

Consistency rate will be computed as follows as the amount of Random Index (RI) could be got by looking at Table 2, according to the value of n (n is size of matrix).

$$CR = \frac{CI}{RI} = \frac{0.02725}{1.12} = 0.024$$

So the Consistency Index is indicating that the opinion of experts is sufficient. After preparing collected data from experts, based on scale values 1-9 in Table 2 and computing weights of criteria in Table 4, following steps shows the procedure of SAW method:

Table 5: Collected data based on scale values (1-9)

	C_1	C_2	C_3	C_4	C_5
S_1	5	5	5	6	5
S_2	7	7	7	6	7
S_3	6	6	7	7	6
S_4	7	6	7	7	6
S_5	6	6	5	5	6

C means Criteria and S means Supplier

Step 2:

Calculate the normalized decision matrix (m × n) that includes m supplier and n criteria.

$$n_{ij} = \frac{r_{ij}}{r_j^*} \qquad i = 1, \dots, m, \qquad j = 1, \dots, n \tag{6}$$

And for negative criteria:

$$n_{ij} = \frac{r_j^{min}}{r_{ij}} \qquad i = 1, \dots, m, \qquad j = 1, \dots, n \tag{7}$$

r_j^* is a maximum number of r in the column of j.

In this case study, criteria has been taken as positive and normalized decision matrix for positive criteria are calculated using equation 6. The results are as shown in Table 6.

Table 6 Normalized decision matrix

	C_1	C_2	C_3	C_4	C_5
S_1	0.71	0.71	0.71	0.85	0.71
S_2	1.00	1.00	1.00	0.85	1.00
S_3	0.85	0.85	1.00	1.00	0.85
S_4	1.00	0.85	1.00	1.00	0.85
S_5	0.85	0.85	0.71	0.71	0.85

Table 7: Weighted Criteria

C_1	C_2	C_3	C_4	C_5
0.22	0.25	0.19	0.13	0.19

Step 3:

Evaluate each alternative, A_i by the following formula as shown below and results are tabulated in Table 8 and final ranked supplier are presented Table 9 and Fig. 2.

$$A_j = \sum w_j * x_{ij} \quad (8)$$

Where x_{ij} is the score of the i^{th} alternative with respect to the j^{th} criteria, w_j is the weighted criteria.

Table 8: Weighted normalized decision matrix

	C_1	C_2	C_3	C_4	C_5
S_1	0.1562	0.1775	0.134	0.110	0.134
S_2	0.220	0.250	0.190	0.110	0.190
S_3	0.187	0.2125	0.190	0.130	0.160
S_4	0.220	0.2125	0.190	0.130	0.160
S_5	0.187	0.2125	0.134	0.0923	0.160

Table 9: Ranked Personnel

S_1	S_2	S_3	S_4	S_5
0.71	0.96	0.89	0.91	0.78

Finally in SAW method, the best supplier is S_2 and then S_4, S_3, S_5 and S_1 will be respectively.

Fig. 2: Rating of suppliers (Method: SAW)

3. VIKOR method

Opricovic and Tzeng developed VIKOR, the Serbian name: VlseKriterijumska Optimizacija I KompromisnoResenje, means multi-criteria optimization and compromise solution (Chu, et al. 2007). The VIKOR method was developed for multi-criteria optimization of complex systems (Opricovic & Tzeng, 2004). This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision makers to reach a final decision. Here, the compromise solution is a feasible solution which is the closest to the ideal, and a compromise means an agreement established by mutual concessions. It introduces the multi-criteria ranking index based on the particular measure of ‘‘closeness” to the ‘‘ideal” solution (Opricovic, 1998).According to (Opricovic & Tzeng, 2007) the multi-criteria measure for compromise ranking is developed from the PLp-metric used as an aggregating function in a compromise programming method. The various J alternatives are denoted as a_1; a_2; . . . ; a_J. For alternative a_j, the rating of the i^{th} aspect is denoted by f_{ij} , i.e. f_{ij} is the value of i^{th} criterion function for the alternative a_j ; n is the number of criteria. Development of the VIKOR method started with the following form of Lp-metric:

$$L_p;j = \left\{ \sum_{i=1}^{n} \left[w_i \left(f_1^* - f_{ij} \right) / (f^* - f_1^-)^p \right]^{1/p} \right\}$$

1≤p≤ infinity; j = 1, 2, 3,…, j.

Within the VIKOR method L1;j and L1;j is used to formulate ranking measure. L1;j is interpreted as 'concordance' and can provide decision makers with information about the 'maximum group utility' or 'majority'. Similarly, L1;j is interpreted as 'discordance' and provides decision makers with information about the minimum individual regret of the 'opponent'. The VIKOR method uses linear normalization, and the normalized value in the VIKOR method does not depend on the evaluation unit of criterion function.

3.1. Fuzzy Approach

In the decision making process, the decision maker is frequently faced with doubts, problems and doubts. In other words usual language to express observation or judgment is always subjective, uncertain or unclear. To determine the vagueness, ambiguity and subjectivity of human judgment, fuzzy set theory (Zadeh, 1965) was introduced to express the linguistic terms in decision making (DM) process. Bellman and Zadeh (1970) developed fuzzy multi criteria decision making (FMCDM) methodology to resolve the lack of precision in assigning importance weights of criteria and the ratings of alternatives regarding evaluation criteria. This logical tools that people can depend on are generally measured the outcome of a bivalent logic (yes/no, true/false), but the problems posed by real-life situations and human thought processes and approaches to problem-solving are by no means bivalent. Just as conventional, bivalent logic is based on classic sets, fuzzy logic is based on fuzzy sets. A fuzzy set is a set of objects in which there is no clear-cut or predefined the boundary between the objects that are or are not members of the set. The key concept behind this definition is that of ''membership": any object may be a member of a set ''to some degree"; and a logical proposition may hold true "to some degree". Each element in a set is associated with a value indicating to what degree the element is a member of the set. This value comes within the range [0, 1], where 0 and 1, respectively, indicate the minimum and maximum degree of membership, while all the intermediate values indicate degrees of ''partial" membership (Bevilacqua, Ciarapica, & Giacchetta, 2006). This approach helps decision makers solve complex decision making problems in a systematic, consistent and productive way (Carlsson & Fuller, 1996) and has been widely applied to tackle DM problems with multiple criteria and alternatives. In short, fuzzy set theory offers a mathematically precise way of modelling vague preferences for example when it comes to setting the weights of performance scores on criteria.

3.2. Chen and Hwang 5 Point Method

The method proposed by Chen and Hwang (1992) first converts linguistic terms into fuzzy numbers and then the fuzzy numbers into crisp scores. The method is described below:

This method systematically converts linguistic terms into their corresponding fuzzy numbers. It contains eight conversion scales. To demonstrate the method, a 5-point scale having the linguistic terms low, fairly low, medium, fairly high, and high (Chen and Hwang 1992), is considered. These linguistic terms can be equated to other terms like low, below average, average, above average and high.

The method uses a fuzzy scoring approach that is a modification of the fuzzy ranking approaches proposed by Jain (1976), and Chen (1985). The crisp score of fuzzy number 'M' is obtained as follows:

Linguistic term	**Fuzzy number**	**Crisp score**
Very poor	M_1	0.115
Poor	M_2	0.295
Fair	M_3	0.495
Good	M_4	0.695
Very good	M_5	0.895

In this section a methodical approach of the VIKOR being applied to solve the supplier selection problem under a fuzzy environment. The magnitude weights of various criteria and the ratings of qualitative criteria measured as linguistic variables. Because linguistic assessments merely about the slanted judgment of decision makers.

Same criteria chosen for supplier selection using SAW method, have considered for the supplier selection using VIKOR method.

Three decision makers use the linguistic weighting variables to assess the importance of the criteria. The importance weights of the criteria determined by these three decision makers are shown in Table 10. Also the decision makers use the linguistic rating variables to evaluate the ratings of candidates with respect to each criterion. The ratings of the five suppliers by the decision makers under the various criteria are shown in Table 11.

Table 10: Importance weight of criteria

Criteria	**DM_1**	**DM_2**	**DM_3**
C_1	H	H	H
C_2	H	H	AA
C_3	A	A	BA
C_4	A	AA	A
C_5	AA	A	AA

Table 11: Rating of suppliers of five suppliers under each criterion in terms of linguistic variables determined by DMs

Criteria	**C_1**			**C_2**			**C_3**			**C_4**			**C_5**		
Supplier	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**
S_1	F	F	G	F	F	G	F	G	G	G	G	G	G	G	VG
S_2	F	G	G	G	VG	VG	F	G	VG	F	F	G	F	G	G
S_3	G	VG	VG	F	G	G	G	G	VG	G	G	VG	F	F	G
S_4	F	VG	VG	G	G	G	G	VG	VG	G	VG	VG	F	G	G
S_5	P	F	F	G	G	VG	F	F	G	F	G	G	G	G	VG

Step 4:

The linguistic evaluations shown in Tables 10 and 11 are converted into fuzzy numbers. Then the aggregated weight of criteria and aggregated fuzzy rating of alternatives is calculated to construct the fuzzy decision matrix and determine the fuzzy weight of each criterion, as in Tables 12.

Table 12: Decision Matrix in Crisp score for suppliers

	C_1	C_2	C_3	C_4	C_5
Weights	**0.267**	**0.248**	**0.128**	**0.168**	**0.189**
S_1	0.56	0.56	0.63	0.70	0.76
S_2	0.63	0.83	0.70	0.56	0.63
S_3	0.83	0.63	0.76	0.76	0.56
S_4	0.76	0.70	0.83	0.83	0.63
S_5	0.43	0.76	0.56	0.63	0.76

Step 5:

The values of S, R and Q are calculated by using the equations, for all the suppliers.

$$S_i = \sum_n^m \frac{w_j[((m_{ij})\max - (m_{ij})]}{[((m_{ij})\max - (m_{ij})min]} \quad (9)$$

$$R_i = \text{Max of } \sum_n^m \frac{w_j[((m_{ij})\max - (m_{ij})]}{[((m_{ij})\max - (m_{ij})\min]} \quad (10)$$

$$Q_i = v\,((S_i - S_{imin}) / (S_{imax} - S_{imin})) + (1 - v)\,((R_i - R_{imin}) / (R_{imax} - R_{imin})) \quad (11)$$

Table 13: Values of S, R and Q for all suppliers

	S_1	S_2	S_3	S_4	S_5
S	0.60	0.4851	0.4481	0.287	0.583
R	0.248	0.168	0.189	0.122	0.267
Q	0.93	0.474	0.488	0	0.972

Step 6:

The ranking of the Lean supplier by S, R and Q in decreasing order is shown in Table 14, in decreasing order.

Table 14: Ranking of the suppliers by S, R and Q in order

Ranking of Lean Facilitators					
By S	S_4	S_3	S_2	S_5	S_1
By R	S_4	S_2	S_3	S_1	S_5
By Q	S_4	S_2	S_3	S_1	S_5

From Table 14 and Figs. 3 to 5, it can be concluded that, the Supplier S4 is the best ranked.

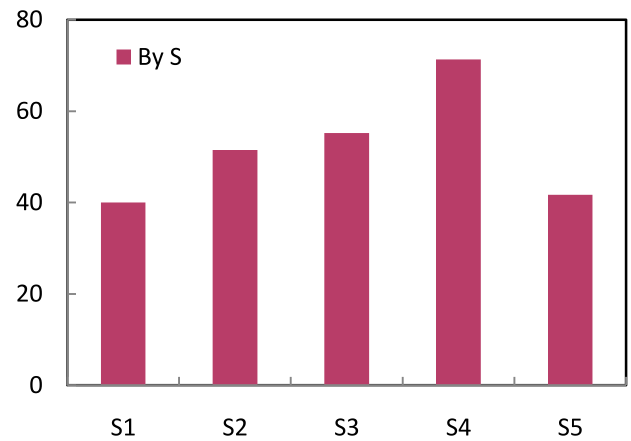

Fig. 3: Advantage rate of suppliers by Utility Measure

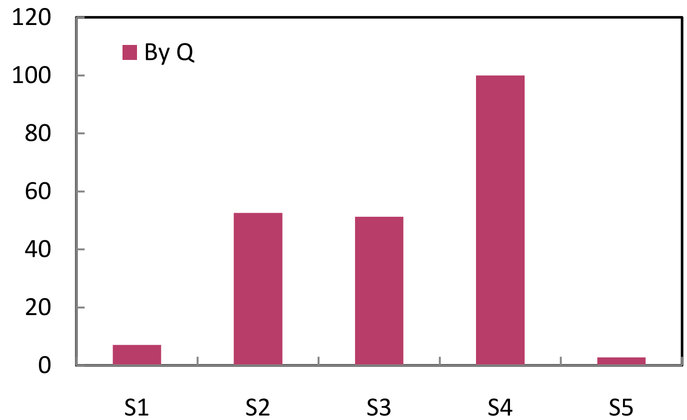

Fig. 4 Advantage rate of suppliers by Regret Measure

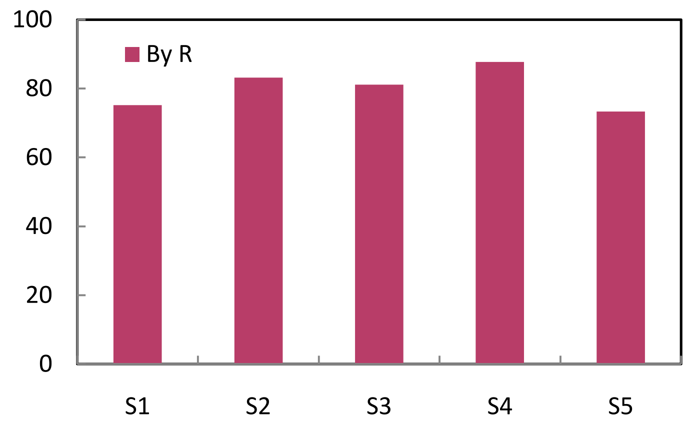

Fig. 5 Advantage rate of suppliers by VIKOR Index

4. CONCLUSIONS

The present study explores the use of SAW method and fuzzy based VIKOR methods in solving a supplier selection problem and the results obtained can be valuable to the decision maker in framing the supplier selection strategies. The methods were applied using data from a real case in the spring manufacturer unit in Ananthapur, India. For the selected criteria, S2, S4, S3, S5, S1 and S4, S2, S3, S1, S5 are the ranking sequence according to SAW and VIKOR method respectively. Thus, these popular MAGDM methods can be successfully employed by the decision makers for the process of supplier selection in the spring manufacturing domain.

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