b. Calculating weights for each rank using the appropriate rank order weighting methods

Two functions, rank reciprocal and rank sum (Stillwell, Seaver & Edwards, 1981) were initially developed followed by rank centroid method for the purpose of weight determination method (Solymosi & Dompi, 1985; Barron, 1992). We have used all the three approaches in the study owing to their simplicity and effectiveness. The weight calculation procedures are presented below.

The rank sum (RS) method calculates weights (Stillwell *et al.*, 1981) as:

$$W_j\ (RS) = \frac{n - r_j + 1}{\sum_{k=1}^{n}(n - r_k + 1)} = \frac{2(n + 1 - r_j)}{n(n+1)}$$ where r_j: rank of jth criterion, j=1,2,...,n & r_k: kth rank

The rank reciprocal or inverse (RR) method calculates criteria weights (Stillwell *et al.*, 1981) as:

$$W_j\ (RR) = \frac{\frac{1}{r_j}}{\sum_{k=1}^{n}\left(\frac{1}{r_k}\right)}$$ where r_j: rank of jth criterion, j=1,2,...,n & r_k: kth rank

The rank-order centroid (ROC) method estimates criteria weights that are based on minimizing the maximum error of each weight through centroid identification for all possible weights. Weights obtained by this approach were found to be very stable (Barron & Barrett, 1996a). This method was generalized for n > 2 and with more criteria the error for rank criteria is even lesser (Barron & Barret, 1996). Rank order centroid weight is calculated as:

$$W_j\ (ROC) = \frac{1}{n}\sum_{k=1}^{n}\frac{1}{r_k}$$ where r_k is the kth rank

5. Constructing the fuzzy decision matrix where each $\tilde{x}_{ij}$ is triangular fuzzy number i.e. $\tilde{x}_{ij}^k = \left(a_{ij}^k, b_{ij}^k, c_{ij}^k\right)$. Transformation of triangular fuzzy numbers, which is the aggregate fuzzy ratings, to fuzzy decision matrix and it is obtained as (Nadaban *et al.*, 2016):

$$a_{ij} = \min_k \left\{a_{ij}^k\right\}, b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^k, c_{ij} = \max_k \left\{c_{ij}^k\right\}$$

6. Constructing the normalized fuzzy decision matrix using the concept of α-cut (Definition 2) as per Jahanshahloo *et al.* (2006). The subsequent section details the steps involved in construction of normalized decision matrix with triangular fuzzy numbers.

a. In the first step, a set of α-cut is calculated and each of the fuzzy numbers are transformed to an interval fuzzy number as $\tilde{x}_{ij} = \left[\left[\tilde{x}_{ij}\right]_\alpha^L, \left[\tilde{x}_{ij}\right]_\alpha^U\right]$ (Jahanshahloo *et al.*, 2006).

b. In this step, the fuzzy interval number is transformed to its normalized interval as:

$$\left[\tilde{n}_{ij}\right]_\alpha^L = \left[\tilde{x}_{ij}\right]_\alpha^L \Big/ \sqrt{\sum_{i=1}^{m}\left(\left[\tilde{x}_{ij}\right]_\alpha^L\right)^2 + \left(\left[\tilde{x}_{ij}\right]_\alpha^U\right)^2},$$

i = 1, 2, …, m and j = 1, 2,…., n

$$\left[\tilde{n}_{ij}\right]_\alpha^U = \left[\tilde{x}_{ij}\right]_\alpha^U \Big/ \sqrt{\sum_{i=1}^{m}\left(\left[\tilde{x}_{ij}\right]_\alpha^L\right)^2 + \left(\left[\tilde{x}_{ij}\right]_\alpha^U\right)^2},$$

i = 1, 2, …, m and j = 1, 2,…., n

where $\left[\left[\tilde{n}_{ij}\right]_\alpha^L, \left[\tilde{n}_{ij}\right]_\alpha^U\right]$ is the normalized fuzzy interval of the fuzzy interval $\left[\left[\tilde{x}_{ij}\right]_\alpha^L, \left[\tilde{x}_{ij}\right]_\alpha^U\right]$.

c. In the final step of constructing a fuzzy decision matrix, the normalized interval is transformed into normalized triangular fuzzy number $\widetilde{N}_{ij} = \left(n_{ij}, p_{ij}, q_{ij}\right)$. By setting α = 1, we get the left span of the triangular fuzzy number as $\tilde{n}_{ij} = \left[\tilde{n}_{ij}\right]_{\alpha=1}^L = \left[\tilde{n}_{ij}\right]_{\alpha=1}^U$ and by setting α = 0, we get the mid value and the right span. The mid value is obtained from $\left[\tilde{n}_{ij}\right]_{\alpha=0}^L = n_{ij} - p_{ij}$ and the right span from $\left[\tilde{n}_{ij}\right]_{\alpha=0}^U = n_{ij} + q_{ij}$. Thus, the mid value $p_{ij} = n_{ij} - \left[\tilde{n}_{ij}\right]_{\alpha=0}^L$ and the right span $q_{ij} = \left[\tilde{n}_{ij}\right]_{\alpha=0}^U - n_{ij}$. The normalized fuzzy decision matrix is created from $\widetilde{N}_{ij}$.

7. Constructing weighted normalized fuzzy decision matrix $\tilde{v}_{ij}$ from the criteria weights and fuzzy decision matrix as per *Definition 7*. Thus, $\tilde{v}_{ij} = \widetilde{N}_{ij}\,.\widetilde{w}_j$, from each $\tilde{v}_{ij} \in [0,1]$.

8. Identifying fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) as (Jahanshahloo *et al.*, 2006; Wang & Lee, 2009):

$$A^+ = \{\tilde{v}_1^+, \ldots\ldots, \tilde{v}_n^+\} = \left\{\left(\max_j \tilde{v}_{ij} \middle| i \in I\right), \left(\min_j \tilde{v}_{ij} \middle| i \in J\right)\right\}$$

$$A^- = \{\tilde{v}_1^-, \ldots\ldots, \tilde{v}_n^-\} = \left\{\left(\min_j \tilde{v}_{ij} \middle| i \in I\right), \left(\max_j \tilde{v}_{ij} \middle| i \in J\right)\right\}$$

where *I* and *J* are associated with the benefit and cost criteria respectively.

9. Calculating closeness or separation measure of each alternative from its FPIS (d_i^+) and FNIS (d_i^-) using vertex method *(Definition 10)*.

10. Finding the closeness coefficient or the relative closeness whose values are used to rank the alternatives. The relative closeness of alternative A_i with respect to A^+ is defined as (Jahanshahloo *et al.*, 2006): $R_i = d_i^- \Big/ (d_i^+ + d_i^-)$, $R_i \in [0,1]$ *and i = 1, 2, …, m*. Since $d_i^- \geq 0$ and $d_i^+ \geq 0$, $R_i \in [0, 1]$. Alternatives with higher value of R_i have better rank or more preferred compared to those with lower values.

III. RESEARCH FRAMEWORK

This paper is descriptive in nature and relies on cross sectional study design. Primary survey forms the basis of the study. Before conducting the survey, the MCDM problem is first defined from a real life industry situation of supplier selection. A mid-sized adhesive manufacturing company was approached and on explaining the pure research motive behind the study, they introduced to the decision makers in supplier selection. Three members, one each from sales (D1), technical (D2) and marketing (D3) business verticals forms the decision making group. The members participated in criteria identification, alternative selection, evaluated performance of the alternatives against each criteria and assigned ranks to each criteria. The decision making group emerged with three suppliers; Kent (A1), Loctite (A2) and 3M (A3); as alternatives. They also identified six criteria that includes (1) price offered by the suppliers, (2) supplier's capability of delivering products on time, (3) supplier's technical knowhow, (4) supplier's service support level, (5) supplier's track history with the company & (6) supplier's product quality. To arrive at a solution to the decision problem, fuzzy TOPSIS method is chosen due to paucity of crisp data. Alternative prioritization is done on the basis of the extended TOPSIS method as detailed in the previous section. To capture the judgement of the decision makers, a linguistic scale is developed. The scale consists of linguistic terms, each of which correspond to a rating and each rating further correspond to a triangular fuzzy number (TFN) (Table 1). The decision makers rated the criteria and the alternatives with respect to each criteria independently using the linguistic scale.

IV. PROBLEM SOLVING APPROACH AND FINDINGS

The problem solving approach using extended fuzzy TOPSIS method is executed in a step wise manner. The findings of each operation performed are also presented and the overall prioritization of alternatives arrived at. Three sets of ranks are obtained, each with ROC, RS & RR weights.

1. The linguistic judgement of the decision makers is converted to the corresponding fuzzy triangular numbers (Table II).
2. The TFNs that correspond to the performance of suppliers against each criteria is then transformed to fuzzy decision matrix (FDM) (as per *5* and is shown in Table III.
3. The normalized FDM is made from the FDM using the concept of α-cut (as per *6* and is represented in Table IV.

TABLE I LINGUISTIC TERMS FOR ALTERNATIVES RATING

Linguistic Scale	Rating	Triangular Fuzzy Number
Extremely Poor	1	(0.5,0.5,1)
Very Poor	2	(1,1.5,2)
Poor	3	(2,2.5,3)
Medium Poor	4	(3,3.5,4)
Fair	5	(4,4.5,5)
Medium Good	6	(5,5.5,6)
Good	7	(6,6.5,7)
Very Good	8	(7,7.5,8)
Excellent	9	(8,8.5,9)

Source: Author's own scale development based on Zadeh (1970)

TABLE II SUPPLIER RATING WITH RESPECT TO CRITERIA BY DECISION MAKERS (TFN)

Alternatives	Decision Makers	C1	C2	C3	C4	C5	C6
A1	D1	(5,5.5,6)	(1,1.5,2)	(7,7.5,8)	(1,1.5,2)	(7,7.5,8)	(8,8.5,9)
	D2	(5,5.5,6)	(3,3.5,4)	(7,7.5,8)	(0.5,0.5,1)	(7,7.5,8)	(6,6.5,7)
	D3	(4,4.5,5)	(1,1.5,2)	(7,7.5,8)	(1,1.5,2)	(6,6.5,7)	(8,8.5,9)
A2	D1	(8,8.5,9)	(8,8.5,9)	(8,8.5,9)	(6,6.5,7)	(8,8.5,9)	(5,5.5,6)
	D2	(8,8.5,9)	(8,8.5,9)	(7,7.5,8)	(7,7.5,8)	(7,7.5,8)	(6,6.5,7)
	D3	(7,7.5,8)	(8,8.5,9)	(8,8.5,9)	(7,7.5,8)	(8,8.5,9)	(5,5.5,6)
A3	D1	(6,6.5,7)	(4,4.5,5)	(7,7.5,8)	(6,6.5,7)	(7,7.5,8)	(4,4.5,5)
	D2	(7,7.5,8)	(8,8.5,9)	(7,7.5,8)	(5,5.5,6)	(7,7.5,8)	(6,6.5,7)
	D3	(7,7.5,8)	(5,5.5,6)	(8,8.5,9)	(7,7.5,8)	(7,7.5,8)	(3,3.5,4)

Source: Author's calculation

TABLE III FUZZY DECISION MATRIX (FDM)

Alternatives	C1	C2	C3	C4	C5	C6
A1	(4,5.2,6)	(1,2.2,4)	(7,7.5,8)	(0.5,1.2,2)	(6,7.2,8)	(6,7.8,9)
A2	(7,8.2,9)	(8,8.5,9)	(7,8.2,9)	(6,7.2,8)	(7,8.2,9)	(5,5.8,7)
A3	(6,7.2,8)	(4,6.2,9)	(7,7.8,9)	(5,6.5,8)	(7,7.5,8)	(3,4.8,7)

Source: Author's calculation

TABLE IV NORMALIZED FUZZY DECISION MATRIX (NFDM)

Alternatives	C1	C2	C3	C4	C5	C6
A1	(0.13,0.03,0.02)	(0.05,0.03,0.04)	(0.18,0.01,0.01)	(0.03,0.02,0.02)	(0.18,0.03,0.02)	(0.19,0.05,0.03)
A2	(0.21,0.04,0.03)	(0.21,0.01,0.01)	(0.2,0.03,0.02)	(0.18,0.03,0.02)	(0.2,0.03,0.02)	(0.14,0.02,0.03)
A3	(0.18,0.03,0.02)	(0.15,0.05,0.07)	(0.19,0.02,0.03)	(0.16,0.04,0.03)	(0.18,0.01,0.01)	(0.12,0.04,0.05)

Source: Author's calculation

4. The decision makers ranked the criteria individually and the same is shown in Table V. Each of the ranks is converted to ranked weights. The ranked weights of criteria vary depending on the weighting method chosen. Table VI shows varying criteria weights based on ROC, RS and RR weight determination methods.
5. The normalized fuzzy decision matrix (NFDM) thus obtained in step 3 is then transformed to the weighted normalized fuzzy decision matrix (WNFDM) using *7*. It involves multiplication of a triangular fuzzy number with a non-fuzzy number. Since three different rank order weight determination methods are considered in the study, we have three different WNFDMs, one based on ROC, the other based on RS and the third one based on RR method, which are shown in Table VII to IX.

TABLE V RANKING OF CRITERIA BY DECISION MAKERS

Decision Makers	C1	C2	C3	C4	C5	C6
D1	1	3	4	5	6	2
D2	3	2	4	5	6	1
D3	1	3	5	4	6	2

Source: Author's calculation

TABLE VI CRITERIA WEIGHTS BASED ON ROC, RS & RR METHODS

Type of Weights	C1	C2	C3	C4	C5	C6
ROC Weight	0.408	0.242	0.158	0.103	0.061	0.028
RS Weight	0.286	0.238	0.190	0.143	0.095	0.048
RR Weight	0.408	0.204	0.136	0.102	0.082	0.068

Source: Author's calculation

Table VII WEIGHTED NORMALIZED FUZZY DECISION MATRIX BASED ON ROC METHOD

Alternatives	C1	C2	C3	C4	C5	C6
A1	(0.042,0.01,0.007)	(0.009,0.006,0.007)	(0.016,0.001,0.001)	(0.002,0.002,0.002)	(0.005,0.001,0.001)	(0.056,0.015,0.009)
A2	(0.068,0.013,0.01)	(0.039,0.002,0.002)	(0.018,0.003,0.002)	(0.014,0.002,0.002)	(0.006,0.001,0.001)	(0.042,0.006,0.009)
A3	(0.059,0.01,0.007)	(0.028,0.009,0.013)	(0.017,0.002,0.003)	(0.012,0.003,0.003)	(0.005,0,0)	(0.036,0.012,0.015)

Source: Author's calculation

TABLE VIII WEIGHTED NORMALIZED FUZZY DECISION MATRIX BASED ON RS METHOD

Alternatives	C1	C2	C3	C4	C5	C6
A1	(0.033,0.008,0.005)	(0.01,0.006,0.008)	(0.023,0.001,0.001)	(0.003,0.002,0.002)	(0.009,0.001,0.001)	(0.048,0.013,0.008)
A2	(0.053,0.01,0.008)	(0.043,0.002,0.002)	(0.025,0.004,0.003)	(0.02,0.003,0.002)	(0.01,0.001,0.001)	(0.036,0.005,0.008)
A3	(0.046,0.008,0.005)	(0.031,0.01,0.014)	(0.024,0.003,0.004)	(0.018,0.004,0.003)	(0.009,0,0)	(0.03,0.01,0.013)

Source: Author's calculation

TABLE IX WEIGHTED NORMALIZED FUZZY DECISION MATRIX BASED ON RR METHOD

Alternatives	C1	C2	C3	C4	C5	C6
A1	(0.041,0.01,0.006)	(0.008,0.005,0.006)	(0.017,0.001,0.001)	(0.003,0.002,0.002)	(0.012,0.002,0.001)	(0.052,0.014,0.008)
A2	(0.067,0.013,0.01)	(0.033,0.002,0.002)	(0.019,0.003,0.002)	(0.016,0.003,0.002)	(0.014,0.002,0.001)	(0.038,0.005,0.008)
A3	(0.057,0.01,0.006)	(0.024,0.008,0.011)	(0.018,0.002,0.003)	(0.014,0.004,0.003)	(0.012,0.001,0.001)	(0.033,0.011,0.04)

Source: Author's calculation

6. The fuzzy positive ideal solution and fuzzy negative ideal solution are calculated from the weighted normalized fuzzy decision matrix (shown in Tables VII to IX) as per *8*.
7. The three WNFDMs are used to calculate the distance or separation measure of each alternative from its FPIS (d_i^+) & FNIS (d_i^-) as per *9*.
8. Using the separation measures, the relative closeness or closeness coefficient is determined (as per *9*. from which the rank of suppliers is arrived at. Table X shows the FPIS, FNIS, closeness coefficient (relative closeness) and supplier ranking using ROC method of criteria weight determination while Table XI and Table XII shows the same parameters using RS method and RR methods criteria weight assessment respectively.

TABLE X ROC METHOD BASED SEPARATION MEASURES, RELATIVE CLOSENESS & RANK

Alternatives	d_i^+	d_i^-	R_i	Rank
A1	0.0739	0.0675	0.4775	2
A2	0.1185	0.1074	0.4756	3
A3	0.0857	0.0832	0.4925	1

Source: Author's calculation

TABLE XI RS METHOD BASED SEPARATION MEASURES, RELATIVE CLOSENESS & RANK

Alternatives	d_i^+	d_i^-	R_i	Rank
A1	0.0748	0.0654	0.4664	2
A2	0.1228	0.1059	0.4631	3
A3	0.0904	0.0823	0.4765	1

Source: Author's calculation

TABLE XII RR METHOD BASED SEPARATION MEASURES, RELATIVE CLOSENESS & RANK

Alternatives	d_i^+	d_i^-	R_i	Rank
A1	0.0762	0.0759	0.4992	2
A2	0.1170	0.1100	0.4845	3
A3	0.0827	0.1026	0.5536	1

Source: Author's calculation

It is found that the order of prioritization i.e. the rank of suppliers derived with ROC, RS and RR weights are same. This is indeed a good indication to anticipate consistency in results among the three separate measures of weights which remains our prime objective. Thus, the choice of rank order weight appears to have low significance in determining the relative preference in fuzzy decision making environment. Results reveal A3 to be more preferred. Finally, Table XIII summarizes the supplier ranks that have obtained by deploying fuzzy TOPSIS integrated with ROC, RS and RR weights, all of which are based on rank order.

TABLE XIII FUZZY TOPSIS RANKS BASED ON ROC, RS & RR WEIGHTS

Alternatives	Rank *(ROC Wt.)*	Rank *(RS Wt.)*	Rank *(RR Wt.)*
A1	2	2	2
A2	3	3	3
A3	1	1	1

Source: Author's calculation

V. CONCLUSION

Real life business decision making process gets more complex with the non-availability of crisp data and crucial decisions have to be taken based on imprecise i.e. vague data. The domain of fuzzy mathematics offers solution to business practitioners and researchers worldwide in such situations. The present paper has its inspiration rooted in finding an alternative solution to multi criteria business decision problems dealing with imprecise data. The output of the extended fuzzy TOPSIS method is represented by the relative closeness values and ranks derived from it. The value of relative closeness of an alternative is found to be different if one compares three outputs, each based on a different criteria weight determination method. The relative closeness value of supplier A1 is 0.4775, 0.4664 and 0.4992 with ROC, RS and RR methods respectively. Similar behaviour is seen for supplier A2 and A3; however, the order of supplier preference, represented by their ranks have been found to be exactly the same i.e. a very high level of consistency in supplier rank is observed. Thus, in multi criteria group decision making situations where criteria weights have to be determined by subjective methods, rank order weights prove to generate fairly consistent and uniform results. It is also seen that alternative A3 i.e. 3M is the most preferred supplier followed by A1 i.e. Kent and Loctite (A2) in order of decreasing preference. Though fuzzy TOPSIS with different rank order weights have yielded same overall rank of the suppliers, it may be of academic and business interest to find out if other subjective methods yield similar results.

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