Supplier Selection for Construction Projects Through 'TOPSIS' and 'VIKOR' Multi-Criteria Decision Making Methods

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Abstract- Materials constitute 60% in total cost of the project. Cement contributes for 10 to 15% of the total materials cost. Selecting a best supplier for supply of cement is very crucial for profit making and further achieving success of any construction project. In recent times, there has been a trend not to select a supplier who is having lowest bid offer. Multi-criteria approach is quite effective to select a best supplier. In this paper, seven criteria such as quality, cost, delivery time, technical capability, financial capability, commercial and managerial capability and trust are considered. Relative weights of criteria in the form of criteria weights are generated through Analytic Hierarchy Process (AHP). Then, Technique for order preference by similarity to ideal solution (TOPSIS) and Vlsekriterijumska Optimimizacija I Kompromisno Resenje (VIKOR) methods are applied for best supplier selection. The results show that one of the suppliers is ranked first by both the methods. Being the highest ranked supplier by the TOPSIS method, it shows that this supplier is the best in terms of the ranking index. As the same supplier is highest ranked by VIKOR method, it shows that it is the closest to the ideal solution. Such innovative approach can bring profit maximization and quality enhancement of construction projects.

Keywords--Supplier selection; Multi criteria methods; Analytic Hierarchy Process; TOPSIS; VIKOR

I. INTRODUCTION

Material component is more than 60% of the total cost in any construction project. Construction companies have to follow strategies to get better quality material at most economical rate with shortest lead time. Hence, supplier plays a key role in achieving success of the project. Supplier selection is a crucial strategic decision which brings long term impact on company's efficiency and profitability. The main objective of supplier selection process is to reduce purchase risk, maximize overall value to the purchaser and develop closeness and long-term relationships between buyers and suppliers [15]. Supplier selection depends upon several conflicting factors such as: Quality, cost, delivery time, technical capability, financial capability etc. Hence, it is a multi criteria decision making problem. More research is needed to suggest best supplier due to increasing complexity of projects, increasing expectations of owners, more competition and higher performance expectations. Several methods, such as Analytic Hierarchy Process [1], Analytic Network Process (ANP) [14], linear weighting methods [18] and total cost approach [12] have helped decision makers to deal with supplier selection problem. While selecting the supplier, his information is not always precisely studied and hence decision making could prove to be wrong. Most of the construction companies are selecting the supplier based on few criteria and that too without use of any scientific technique. Cement is one of the most important of all construction materials. It contributes for 10 to 15% of total material cost in any construction project [3]. Quality of the structure largely depends on quality of cement. Hence, best supplier selection for purchase of cement is the most crucial decision in any construction project. This paper uses three multi criteria decision making techniques such as: Analytic Hierarchy Process (AHP), Technique for order preference by similarity to ideal solution (TOPSIS) and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method for best supplier selection for purchase of cement in construction project.

II. LITERATURE REVIEW

Research on supplier selection has passed through three different phases: qualitative research, quantitative research and combination of qualitative and quantitative research [20]. Weber et al. [19] proposed analytic hierarchy process to evaluate suppliers. Ghodsypour & O'brien [6] combined AHP and linear programming method to select best suppliers and allocate the optimal order quantity. Kumar et al. [11] proposed fuzzy multi-objective programming model for supplier selection problem. Jadidi et al. [8] proposed a new approach based on 'TOPSIS' concept to deal with problem of supplier selection. Kasirian & Hong [9] integrated AHP and ANP techniques to select the best supplier. At present, many techniques like AHP, ANP, ELECTRE III, multi attribute utility theory (MAUT), goal programming, fuzzy set theory, TOPSIS, VIKOR etc. are available for supplier selection. Bhutia & Phipon used integrated approach of AHP and TOPSIS for supplier selection and found is quite effective for optimized decision making [2]. Singh et. al. used TOPSIS technique for supplier selection in Auto Industry [17]. Wu & Liu [20] used fuzzy vague sets incorporating TOPSIS along with VIKOR for supplier selection. Cristobal [4] used TOPSIS and VIKOR for best contractor selection along with AHP technique for weight generation of criteria. Kilic, H.S. [10] used integrated approach of fuzzy technique for TOPSIS and linear programming for supplier selection. Shemshadi et al. [16] used fuzzy logic approach along with VIKOR method for supplier selection.

In this paper AHP technique is integrated with 'TOPSIS' and 'VIKOR' methods for supplier selection in construction project for purchase of cement. In next section of "Methodology", the TOPSIS and VIKOR methods are elaborately explained.

III. METHODOLOGY

In recent past, many researchers have used 'TOPSIS' and 'VIKOR' methods for decision making of supplier selection problem [21]. Use of these two methods can help for best supplier selection on the basis of different criteria while considering their relative importance. The TOPSIS method determines the solution by giving the shortest distance from the ideal solution and with the greatest distance from the negative-ideal solution, while not considering the relative importance of these distances. The VIKOR method determines ranking of the criteria based on the particular measure of "closeness" to the ideal solution [13]. The compromise solution is a feasible solution that is the "closest" to the ideal solution, and compromise means an agreement established by mutual concessions.

A. TOPSIS Method

Technique for order preference by similarity to ideal solution (TOPSIS) was first introduced by Hwang and Yoon [7] with an idea to offer an alternative for elimination and choice expressing reality III (ELECTRE III) method. It is on the basis of principle that the optimal point should have the shortest distance from the positive ideal solution and the farthest from the negative-ideal solution. So, it is most suitable for decision makers who want to achieve maximum profit at minimum risk. The TOPSIS method consists of following steps:

Step 1: Prepare a decision matrix as given below:

$$D = \begin{array}{c} \\ \end{array}\begin{array}{cccccc} & X_1 & X_2 & X_j \ldots & X_n \\ A_1 & x_{11} & x_{12} & x_{1j} \ldots & x_{1n} \\ A_2 & x_{21} & x_{22} & x_{2j} \ldots & x_{2n} \\ A_i & x_{i1} & x_{i2} & x_{ij} \ldots & x_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A_m & x_{m1} & x_{m2} & x_{mj} \ldots & x_{mn} \end{array}$$

Here,
A_i = i^{th} alternative supplier
X_{ij} = Numerical evaluation outcome for i^{th} supplier with respect to j^{th} criterion

Step 2: Calculate the normalized decision matrix with following formula:

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{j=1}^{j} x_{ij}^2} \quad j = 1,2\ldots\ldots j \text{ and } i = 1,2\ldots n \qquad (1)$$

where j = number of alternatives ; i = number of criteria; and x_{ij} = value of the j^{th} alternative for the i^{th} criterion.

Step 3: Construct the weighted normalized decision matrix by multiplying the normalized decision matrix with its associated weights which are derived by Analytic Hierarchy Process. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_{ij}\, r_{ij} \qquad (2)$$

where w_{ij} = weight of the i^{th} criterion

Step 4: Determine the positive ideal solution and negative ideal solution.

$$A^* = \{v_1^*, \ldots, v_n^*\} = \{(\max_j v_{ij} \mid i \in I'), (\min_j v_{ij} \mid i \in I'')\} \qquad (3)$$

$$A^- = \{v_1^-, \ldots, v_n^-\} = \{(\min_j v_{ij} \mid i \in I'), (\max_j v_{ij} \mid i \in I'')\} \qquad (4)$$

where I' is associated with benefit criterion and I'' is associated with cost criterion.

Step 5: Calculate the separation measure. The separation of each alternative from the positive ideal one is given by:

$$S_j^* = \sqrt{\sum_{i=1}^{n} (vij - v_i^*)^2} \qquad (5)$$

where i = 1,2,3…….m

Similarly, the separation of each alternative from the negative ideal one is given by:

$$S_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2} \qquad (6)$$

where i = 1,2,3…….m

Step 6: Calculate the relative closeness with the ideal solution. The relative closeness of A_i with respect to A^* is defined as:

$$C_i^* = S_j^- / (S_j^* + S_j^-),\ 0 \le C_i^* \le 1 \qquad (7)$$

where i = 1,2,3…….m

Larger the C_i^* value better is the performance of the alternatives. Rank the alternatives by the value of C_i^* in decreasing order. Propose the alternative that is the best ranked by the measure.

B. VIKOR Method

Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method works on the basis of the particular measure of closeness to the positive ideal solution. It gives a compromise solution that is the 'closest' to the ideal solution, where compromise means an agreement established by mutual concessions [5]. VIKOR method has following four steps as given by Opricovic and Tzeng [13]:

Step 1: Determine the best and worst values, which are known as positive ideal and negative ideal solutions:

$f_j^* = \max_j f_{ij}$ and $f_j^- = \min_j f_{ij}$

and if i^{th} function represents cost, then, $f_j^* = \min_j f_{ij}$ and $f_j^- = \max_j f_{ij}$

where f_{ij} = value of the j^{th} alternative for the i criteria.

Step 2: Calculate the values of S_j and R_j by following equations:

$$S_j = \sum_{i=1}^{n} w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \quad (8)$$

$$R_j = \max_i \left[w_i (f_i^* - f_{ij}) / (f_i^* - f_{ij}) \right] \quad (9)$$

Here, S_j is the maximum group of utility of the majority of alternative j; R_j is a minimum of individual regret of the opponent of alternative j and w_i is the weight of the criteria, which expresses the expert's opinion regarding relative importance of the criteria.

Step 3: Calculate the following values:
$S^* = \min_j S_j$; $S^- = \max_j S_j$; $R^* = \min_j R_j$; $R^- = \max_j R_j$
$Q_i = v(S_j - S^*)/(S^- - S^*) + (1-v)(R_j - R^*)/(R^- - R^*)$ (10)
v is introduced as a weight for the strategy of maximum group utility, whereas (1 - v) is weight of the individual regret. The solution obtained by $\min_j S_j$ is with a maximum group utility and the solution obtained by $\min_j R_j$ is with a minimum individual regret of the opponent. The value of v is taken as 0.5 however it can be taken from 0 to 1.

Step 4: Rank the alternatives, sorting by the values of S, R and Q in decreasing order. The results are three ranking lists. Propose as a compromise solution the alternative $A^{(1)}$ which is the best ranked by the measure Q (minimum), if the following two conditions are satisfied:

1. Acceptable advantage: $Q[A^{(2)}] - Q[A^{(1)}] \geq DQ$, where $DQ = 1/(J-1)$ and $A^{(2)}$ is the alternative with second position in the ranking list by Q.
2. Acceptable stability in decision making: The alternative $A^{(1)}$ must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or "by consensus" (v is approximately 0.5) or with veto ($v < 0.5$).

If one of the above conditions is not satisfied, then a set of compromise solutions is proposed which is given as below:

3. Alternative $A^{(1)}$ and $A^{(2)}$ if only condition 2 is not satisfied, or

Alternatives $A^{(1)}, A^{(2)}, \ldots .. A^{(M)}$ if the condition 1 is not satisfied. $A^{(M)}$ is determined by the relation $Q[A^{(M)}] - Q[A^{(1)}] < DQ$ for maximum n; the positions of these alternatives are "in closeness".

IV. CASE STUDY

Cement is the major building material which is required for every construction project. It consists almost 20% of total material cost of the project. There are various companies in the market which manufactures good quality cement. In this study, cement supplier selection problem is solved through 'TOPSIS' and 'VIKOR' method. 'TOPSIS' and 'VIKOR' methods were used along with Analytic Hierarchy Process (AHP) technique. AHP helps the evaluator to decide how well each supplier satisfies or scores for each criterion, while assigning weights on the basis of expert's opinion.

This study has decided 7 different criteria for best supplier evaluation: Quality (CR 1), Cost (CR 2), Delivery time (CR 3), Technical capability (CR 4), Financial capability (CR 5), Managerial & Commercial capability (CR 6) and Trust (CR 7). Various alternative suppliers for selection as the best one were: 'Kamal' brand, Digvijay Cement Co. Ltd. (S1), 'Ambuja' brand, Ambuja Cements Ltd. (S2), 'Ultratech' brand, Ultratech Cement Ltd. Aditya Birla Group (S3), 'J K Laxmi' brand, J K Laxmi Cement Ltd, J K Group (S4) and 'Hi-Bond' brand, Hi Bond Cement (India) Pvt. Ltd., Kishan Group of Companies (S5). To determine relative importance of criteria, AHP technique was used. Steps of AHP are explained below:

1. Construct a pair wise comparison matrix for each criterion using a scale of 1 to 9 for their relative importance.
2. Use Eigenvector approach of AHP: For each of the column, divide each entry in column i of A by the sum of the entries in column i. This will give new matrix called as normalized matrix in which the sum of the entries in each column is 1. Estimate W_i as the average of the entries in row i of the matrix.
3. Consistency check: Following steps are used to check the consistency of the decision maker's opinion:
4. Calculate AW^T where A is the pair wise comparison matrix and superscript T denotes transpose.
5. Workout Eigen value $\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} i_{th}$ entry in AW^T / i_{th} entry in W^T.
6. Calculate Consistency index (CI): CI = $\frac{\lambda_{max} - n}{n-1}$. The smaller the CI, lesser is the deviation from the consistency.
7. Compare CI with Random Consistency Index (RI). RI is taken as per value given following Table. If (CI/RI) < 0.10, the degree of consistency is acceptable. If (CI/RI) > 0.10, expert is inconsistent and results may not be correct. Table 1 shows Random Consistency Index (RI) for different values of n.

Table 1: Values of Random Index (RI)

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

In this study responses of 12 purchase managers were taken. They were actively involved in purchase of construction materials in various construction organizations. Their responses were handled through AHP technique and weights were generated for each respondent. Weights of all respondents were aggregated through Geometric Mean Method (GMM) to get final aggregated weight for each criterion. Table 2 gives weights of each respondent and final aggregated weight with their Consistency Ratio (CR). It is to be noted that each respondent's CR value is below 0.10.

After deriving criteria weights with AHP process, next step is to evaluate different suppliers based on above criteria. An experienced purchase manager was asked to evaluate them on 1 to 9 scales. 9 point scale for various criterions is as given below:

- For Quality (CR 1), Technical capability (CR 4), Financial capability (CR 5), Managerial & Commercial capability (CR 6) and Trust (CR 7): Very poor – 1, Between very poor and poor – 2, Poor – 3, Between poor & good – 4, Good – 5, Between good and very good – 6, Very good – 7, Between very good & extremely good – 8 and Extremely good – 9.
- For Cost (CR 2): Very low – 1, Between very low and low – 2, Low – 3, Between low & high – 4, High – 5, Between high

and very high – 6, Very high – 7, Between very high & extremely high – 8 and Extremely high – 9.

- For Delivery Time (CR 3): Very Slow – 1, Between very slow and slow – 2, Slow – 3, Between slow & fast – 4, Fast – 5, Between fast and very fast – 6, Very fast – 7, Between very fast & extremely fast – 8 and Extremely fast – 9.

Based on feedbacks of an experienced purchase manager of a construction firm, each supplier was evaluated on 1 to 9 scales for performance under seven different criteria. Table 3 gives evaluation attributes for various suppliers of cement.

Next, the 'TOPSIS' and the 'VIKOR' methods are applied. From available criteria, Quality, Delivery time, Technical capability, Financial capability, Managerial & Commercial capability and Trust are beneficial attributes, so, higher values are desirable. Cost is non beneficial attribute and so lower value is desirable. Applying TOPSIS method, the normalized matrix and weighted normalized matrix as per Eqs. (1) and (2) are calculated.

The ideal (A^*) and negative-ideal (A^-) solutions are calculated using Eqs. (3) and (4) and they are shown in Table 5. Table 6 shows the values of the separation measures (S_j^* and S_j^-) and the relative closeness to the ideal solution (C_i^*) with reference to the five suppliers calculated using Eqs. (5) to (7).

As Supplier 3 is having maximum value of Ci* (0.5498), he is the best supplier out of the available ones. With reference to VIKOR method, Table 7 shows the best f_j^* and the worst f_j^- values of all criterion functions. The values of S_j, R_j and Q_i are obtained using Eqs. (8) to (10) respectively. Sample calculations of them are as given below.

The results obtained by 'TOPSIS' and 'VIKOR' methods are given in Table 8. Ranking of Suppliers by the TOPSIS method gives Supplier 3 as the best one. VIKOR method finds that Supplier 3 is closest to the ideal solution. By VIKOR method, Supplier 3 is found as best one as a compromise solution as its Q is the minimum (0). In addition to this, conditions given in step 4(1) and 4(2) are satisfied as $Q[A^{(2)}] - Q[A^{(1)}] > DQ$ ($0.3135 \geq 0.25$), and Supplier 3 is also best ranked by *S* and *R* value (*S* = 0.0584 and *R* = 0.0585 both are minimum). There is a difference in ranking for lowest ranked supplier. TOPSIS has ranked 2nd supplier as the lowest one, whereas VIKOR has ranked 5th supplier as the lowest one.

V. CONCLUSION

Cement plays very crucial role in success of construction projects. It contributes around 15% of total material cost. Hence, proper supplier selection for Cement is vital for performance of projects. Most of the construction companies select the supplier which offers lowest rates of materials. This may affect the project performance in longer run. In this paper, multi-criteria decision making methods like AHP, TOPSIS and VIKOR are used for the selection of best supplier for supply of cement to construction companies. The novel approach adopted in this paper considers multi-criteria in supplier selection along with their relative importance. Results show that one of the suppliers is best by TOPSIS as well as VIKOR method. TOPSIS suggests best supplier according to ranking index and VIKOR method suggests best supplier who is closest to the ideal solution. Such innovative approach can bring profit maximization and quality enhancement of construction projects.

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Table 2: Weights of different criteria by Respondents with Consistency Ratio (CR)

	Res 1	*Res 2*	*Res 3*	*Res 4*	*Res 5*	*Res 6*	*Res 7*	*Res 8*	*Res 9*	*Res 10*	*Res 11*	*Res 12*	*Aggregated Weight*
Quality (CR 1)	0.1995	0.2466	0.2917	0.2169	0.2768	0.1786	0.2869	0.2684	0.3233	0.3166	0.2495	0.3185	0.2623
Cost (CR 2)	0.1971	0.2134	0.2183	0.1948	0.1666	0.2306	0.2048	0.2222	0.2216	0.1944	0.2177	0.2021	0.2083
Delivery Time (CR 3)	0.0692	0.0633	0.0559	0.0540	0.0879	0.0836	0.0542	0.0832	0.0379	0.0471	0.0322	0.0407	0.0585
Technical Capability (CR 4)	0.1618	0.1259	0.1247	0.1121	0.1206	0.1344	0.0976	0.0818	0.1170	0.1025	0.1176	0.1019	0.1170
Financial Capability (CR 5)	0.1307	0.1073	0.0809	0.0877	0.1059	0.0940	0.0852	0.0715	0.0641	0.0692	0.0924	0.0906	0.0904
Managerial & Commercial Capability (CR 6)	0.0578	0.0870	0.0696	0.0877	0.0792	0.0614	0.0469	0.0468	0.0564	0.0513	0.0562	0.0643	0.0644
Trust (CR 7)	0.1839	0.1566	0.1590	0.2470	0.1630	0.2174	0.2244	0.2260	0.1796	0.2189	0.2344	0.1820	0.1991
Consistency Ratio (CR)	0.1000	0.0685	0.0612	0.0268	0.0819	0.0883	0.0827	0.0364	0.1000	0.0751	0.1000	0.1000	Total = 1

Table 3: Structure of decision matrix – Supplier with evaluation attributes

	Quality (CR 1)	Cost (CR 2)	Delivery Time (CR 3)	Technical Capability (CR 4)	Financial Capability (CR 5)	Managerial & Commercial Capability (CR 6)	Trust (CR 7)
Criteria Weights	0.2623	0.2083	0.0585	0.1170	0.0904	0.0644	0.1990
Supplier 1	7	6	9	9	7	8	7
Supplier 2	7	7	7	9	7	8	7
Supplier 3	9	8	7	9	7	8	8
Supplier 4	5	4	9	7	6	7	6
Supplier 5	5	3	7	7	5	7	6

Table 4: Weighted normalized matrix by TOPSIS method

	CR 1	CR 2	CR 3	CR 4	CR 5	CR 6	CR 7
S 1	0.8494	0.5686	0.2694	0.5132	0.3071	0.2420	0.6375
S 2	0.8494	0.7739	0.1630	0.5132	0.3071	0.2420	0.6375
S 3	1.4041	1.0109	0.1630	0.5132	0.3071	0.2420	0.8327
S 4	0.4334	0.2527	0.2694	0.3105	0.2256	0.1853	0.4684
S 5	0.4334	0.1422	0.1630	0.3105	0.1567	0.1853	0.4684

Table 5: Ideal (A^*) and Negative-ideal (A^-) solutions – TOPSIS method

	Quality	Cost	Delivery Time	Technical Capability	Finance Capability	Managerial & Commercial Capability	Trust
	Max	Min	Max	Max	Max	Max	Max
A*	1.4041	0.1422	0.2694	0.5132	0.3071	0.2420	0.8327
A^-	0.4334	1.0109	0.1630	0.3105	0.1567	0.1853	0.4684

Table 6: Separation measures (S_j^* and S_j^-) and Relative closeness to Ideal Solution (C_i^*)

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Si*	0.7264	0.8696	0.8752	1.0669	1.0739
Si^-	0.6896	0.5699	1.0686	0.7687	0.8687
Ci*	0.4870	0.3959	0.5498	0.4188	0.4472

$$S_1 = 0.2623\left(\frac{9-7}{9-5}\right) + 0.2083\left(\frac{8-6}{8-3}\right) + 0.085\left(\frac{9-9}{9-7}\right) + 0.1170\left(\frac{9-9}{9-7}\right) + 0.0904\left(\frac{7-7}{7-5}\right) + 0.0644\left(\frac{8-8}{8-7}\right) + 0.1990\left(\frac{8-7}{8-6}\right) = 0.3136$$

$$R_1 = Max\left\{0.2623\left(\frac{9-7}{9-5}\right), 0.2083\left(\frac{8-6}{8-3}\right), 0.0585\left(\frac{9-9}{9-7}\right), 0.1170\left(\frac{9-9}{9-7}\right), 0.0904\left(\frac{7-7}{7-5}\right), 0.0644\left(\frac{8-8}{8-7}\right), 0.1990\left(\frac{8-7}{8-6}\right)\right\} = 0.1312$$

$$Q_1 = 0.50\left[\frac{0.3136-0.0585}{0.9999-0.0585}\right] + (1-0.5)\left[\frac{0.13115-0.0585}{0.2623-0.0585}\right] = 0.3135$$ (v is assumed as 0.50)

The values of S_i, R_i and Q_i are given in Table 7.

Table 7: Values of S_i, R_i and Q_i by VIKOR method

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
S_i	0.3136	0.3306	0.0584	0.8538	0.9999
R_i	0.1312	0.1312	0.0584	0.2623	0.2640
Q_i	0.3135	0.3230	0.0000	0.9226	1.0000

Table 8: Results of TOPSIS and VIKOR methods

Rank	TOPSIS METHOD		VIKOR METHOD			
		*Ci**		*Q*	*S*	*R*
1	Supplier 3	0.549	Supplier 3	0.000	0.058	0.058
2	Supplier 1	0.487	Supplier 1	0.313	0.314	0.131
3	Supplier 5	0.447	Supplier 2	0.323	0.331	0.131
4	Supplier 4	0.419	Supplier 4	0.923	0.854	0.262
5	Supplier 2	0.396	Supplier 5	1.000	0.999	0.264

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