Nigerian Journal of Technology (NIJOTECH)
Vol. 41, No. 4 July, 2022, pp.797 –804
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v41i4.17

A Fuzzy TOPSIS Model for Selecting Raw Material Suppliers in a Manufacturing Company

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Article history: Received 24 March 2022; Revised form 23 June 2022; Accepted 5 July 2022; Available online 10 September 2022

Abstract
Multi-criteria decision model (MCDM) is used to describe a family of techniques which considers multiple criteria in order to make a choice (among several alternatives). Sometimes, both alternatives and criteria involve qualitative definitions which have to be accounted for. Accordingly, fuzzy TOPSIS is one of several MCDM methods and it serves as a scientific way to solve selection problems that involve uncertainty in criteria definition. This work considers a beverage manufacturing company where selection problem has caused a downturn in production. Inconsistency and unreliability of previous suppliers have caused the company to loose their competitive edge. Fuzzy TOPSIS is proposed to solve the challenge in selecting suppliers of a key raw material. Three decision makers evaluated three suppliers of sugar considering eight criteria for subjective weights based on a 5-point scale. Decision matrices were constructed and normalized for the three submissions. Result obtained showed that supplier 2 had the lowest fuzzy positive ideal solution and the highest fuzzy negative ideal solution. The same supplier had the highest closeness coefficient (0.782) which implies that supplier 2 is the best option.

Keywords: Fuzzy TOPSIS, Multi criterion decision making, Supplier selection

1.0 INTRODUCTION

Decision-making is a key process in the day-to-day activities of organizations. Decisions including selection, ranking and evaluation of alternatives play key roles in the growth of any system. Particularly, selection of suppliers has been identified as a major decision in the supply chain of any company [1] and of huge significance in achieving strategic objectives. Several factors (criteria) such as reliability, timeliness, consistency, capability, risk etc., are usually considered in choosing these suppliers (alternatives). Decision-making processes as those involving multiple criteria are referred to as multi-criteria decision making (MCDM).

Multi criteria decision model are used for describing techniques which consider multiple criteria in order to determine the choice (alternative) to be made. Their general structure supports complex decision-making situations with several objectives, that the stakeholders or decision-makers, value differently. Authors in [2] refer to MCDM as a technique for structuring and solving planning problems with multiple criteria. It is a branch of operation research that deals with decision making under numerous criteria [3] and are considered as complex and dynamic processes involving engineering and managerial levels of problem-solving [4].

These methods abound and have been used implicitly or explicitly in numerous life problems as demonstrated by [5-10] and many more. These approaches include Technique for order preference by similarity to ideal solution (TOPSIS) [10]; Analytical Hierarchical Process (AHP) [11], Analytical Network Process (ANP) [12]; VIKOR meaning Multicriteria Optimization and Compromise Solution [13], Preference ranking organization method for enrichment evaluation (PROMETHEE) [14]; Decision-making trial and evaluation laboratory (DEMATEL) [15] as well as hybrid methods- [16], [3], [4] etc. These techniques are usually developed based on the suitability of the method and complexity of the problem to be solved.

Multi-criteria decision-making techniques have also been utilized in solving problems in different areas and sectors such as mining [17]; energy [18]; construction [4], and [19]; automobile [20], and [5]**;** business management

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and manufacturing [21]-[24] etc., aviation [25], amongst others. In contrast to existing results, this work considers the use of fuzzy TOPSIS as a multi-variate decision-making tool to solve the challenge of selecting suppliers of a key raw material in a beverage manufacturing company where selection problem has caused a downturn in production.

2.0 FUZZY TOPSIS

Fuzzy TOPSIS is one of the most common techniques for solving MCDM problems [26]. It combines the fuzzy set theory and TOPSIS. The TOPSIS method is based on the concept that the chosen alternative should have the shortest distance to positive ideal solution (PIS) which is the solution that minimizes the cost criteria and maximizes the benefit criteria, and the farthest distance to negative ideal solution (NIS). In most decision-making processes, several uncertainties arise as a result of unquantifiable and indescribable characteristics that define the problem. Typical examples of these characteristics are the importance of alternatives available, and relevance of criterion to be considered. While the uncertainty is addressed by the fuzzy set theory, TOPSIS provides a veritable way to solve problems in these scenarios.

In assessing fuzzy TOPSIS, [26] outlined several applications of fuzzy TOPSIS including solution to location and supplier problems, renewable energy challenges, raw materials selection, etc. [27]- strategy selection for SWOT analysis; [28]- green supplier selection; [29] – machine-breakdown factor selection; [5] - car selection in a market; [30]– supplier selection for propeller shaft parts in commercial vehicles; [31] - smart phone selection using intuitionistic fuzzy set; [29] - six sigma project selection in an automotive industry are examples of selection problems addressed by fuzzy TOPSIS. Others include [32] - selection of a middle level consulting manager in a consulting company; [33] - project selection by contractors; [34] - plant species selection in rangeland improvement; [35] - investment selection using hybrid intuitionistic fuzzy TOPSIS etc.

In manufacturing, fuzzy TOPSIS has been used in solving selection problems of various sorts. [17], used fuzzy TOPSIS to select an equipment in a coal mine from two alternatives and seven criteria. The transparency of the method makes it easy for the selection of the option with the most optimal benefit criteria and cost saving. [28] selected a green supplier of a light prism producer using fuzzy TOPSIS. Similarly, [30] and [21] addressed the use of fuzzy TOPSIS in production.

3.0 MATERIALS AND METHOD

Authors in [26] outlined the algorithm of fuzzy TOPSIS and identified the following steps to describe its methodology.

Step 1: Decision maker/expert.

$$D = \{1,2, \dots \dots . . k\}$$

Table 1 shows the decision matrix to determine the weight of any criteria.

Table 1: Decision matrix to determine the weight of criteria

Criterion / Alternative	C_1	C_2	C_m
A_1	X_{11}	X_{12}	X_{1m}
A_2	X_{21}	X_{22}	X_{2m}
A_n	X_{n1}	X_{n2}	X_{nm}

Where A_1, A_2...A_n are alternatives the decision maker has to choose from, and C_1, C_2,…C_m are possible criterion the decision maker has to consider for proper decision making. For each decision maker, X_{nm} is the decision maker rating of alternative n with respect to criteria m.

The decision rating of each alternative is a fuzzy set which can be triangular, gaussian, or trapezoidal. For ease and convenience, this work uses a triangular fuzzy set $A = (a, b, c)$ as shown in Fig. 1 below. The combined decision matrix is given by

$$X_{nm} = [a_{ij}, b_{ij}, c_{ij}]$$

$where\ i = 1,2, \dots n;$ and $j = 1,2, \dots m,$
where

$$a_{ij} = \min_j a_i \ \ for\ decision\ maker\ k$$

$$b_{ij} = \frac{1}{D} \sum_j b_i \ \ for\ decision\ maker\ k$$

$$c_{ij} = \max_j a_i \ \ for\ decision\ maker\ k$$

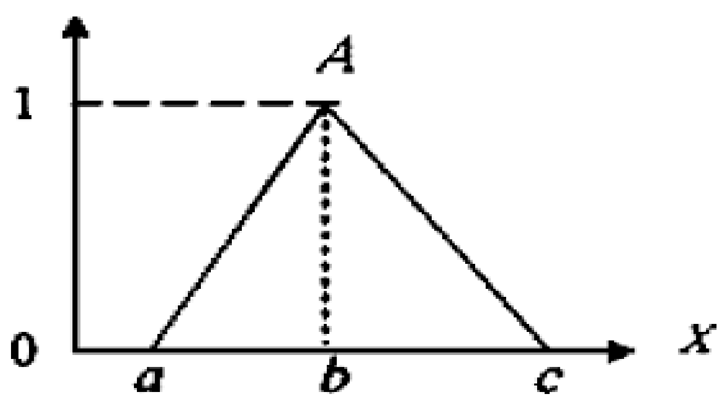

Figure 1: A Triangular Fuzzy set

Now

Step 2: Determine relative importance of criterion:
Now, $w^k = [w_1^k, w_2^k, w_3^k, \dots \dots \dots . w_n^k]$

w = weight vector for k = decision maker

$$\sum w_j^k = 1 \dots \qquad \dots \qquad \dots \dots . (1)$$

Step 3: Calculate the normalized decision matrix:
To standardize the ratings from each decision maker, the responses are normalized using equation (2a) and/or (2b).
For a maximization problem:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \dots \dots \dots \qquad \dots \qquad \dots . . (2a)$$

For a minimization problem:

$$n_{ij} = \frac{\frac{1}{x_{ij}}}{\sqrt{\sum_{i=1}^{n} \frac{1}{x_{ij}}}} \dots \dots \dots \qquad \dots \qquad \dots (2b)$$

Step 4: Calculate the weighed normalized decision matrix:
To ascertain the impact of each criterion, the weights are factored in with each criterion in the decision matrix.

$$V_{ij} = w_i n_{ij} \dots \qquad \dots \qquad (3)$$

Step 5: Determine the positive ideal and negative ideal solutions:

The Positive Ideal Solution (PIS) is the alternative that has the best scores in all the criteria considered. The negative ideal solution (NIS) represents the option with the worst scores among all the attributes considered. Here, alternatives with lower cost criteria are preferred while benefit attributes with higher scores are preferred.
Positive solution:

$$A^+ = (V_1^+, V_2^+, \dots \dots, V_n^+) = \left[\left(max_i \times V_{ij} \middle| j \in 1 \right) \left(min_i \times V_{ij} \middle| j \in J \right) \right] \dots \qquad . . (4a)$$

Negative solution:

$$A^- = (V_1^-, V_2^-, \dots \dots, V_n^-) = \left[\left(min_i \times V_{ij} \middle| j \in 1 \right) \left(max_i \times V_{ij} \middle| j \in J \right) \right] \dots . \qquad . (4b)$$

where I is associated with the benefit criteria and J is associated with the cost criteria

Step 6: Calculate fuzzy distance from PIS & NIS

$$PIS(d_i^+) = \left(\sum_{j=1}^{n} \left(V_{ij} - V_j^+ \right)^p \right)^{\frac{1}{p}}, i = 1, \dots, m \qquad (4a)$$

$$\text{NIS:} d_i^- = \left(\sum_{j=1}^{n} \left(V_{ij} - V_j^- \right)^p \right)^{\frac{1}{p}}, i = 1,2, \dots, m \ \dots \qquad (4b)$$

$$d_j^- = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^- \right)^2} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \qquad (4c)$$

Step 7: Calculate the closeness coefficient to PIS
The closeness coefficient is based on the multidistance. It considers the level of similarity between the criteria assessed.

$$R_i = \frac{d_i^-}{d_i^- + d^+} (0 \le R \le 1) \ \ i = 1,2, \dots ., m \dots \dots \ \ \dots \dots . (5)$$

Step 8: Rank the preference order and select the best alternative:
The closeness coefficients are ranked in the order of their size and the highest (best) alternative is selected.

3.1 Case Study

The case study organization is a beverage manufacturing company where the selection of the suppliers of a raw material is pivotal to the overall performance and efficiency of the company. As a result of decisions emanating from wrong supplier selection, the company recorded a 20% downturn in production volume, and 10% reduction in size of market in the previous production year. Criteria such as capability and consistency of supplier, cost of goods, timeliness and reliability, risk factor (see Table 3) were identified as crucial to the decision-making process. To achieve optimal results, the author and key procurement executives of the company narrowed down the list of suppliers for a key raw material (sugar) to three. Steps 1-8 (above) were carried out to select the preferred supplier of sugar.

Data was collected from questionnaires distributed among three decision makers of the organization. The alternative suppliers to be selected (three) were denoted as Supplier 1, Supplier 2, and Supplier 3.

The three decision makers of the case study organization to whom the questionnaires were distributed were required to rate the suppliers on a 5-point scale as shown in Table 2.

Based on Table 2, the opinions of the decision makers (DM) were collected, and their decision matrix collated are shown in the Tables 4-6 as shown below.

Table 2: Linguistic Variable for Weight of Criteria

Linguistic Variables	**Fuzzy number**
Very Low, VL	1,1,3
Low, L	1,3,5
Average, A	3,5,7
High, H	5,7,9
Very High, VH	7,9,9

Table 3: Allocated Weight for each Criteria (where B = Beneficial variable and C = Cost variable). With respect to eight (8) criteria as shown below.

Symbol	**Criteria**	**Allocated Weight**	**Benefit factor**
C1	Cost of purchase	A	C
C2	Product value	H	B
C3	Supplier capability	VH	B
C4	Supplier Consistency	VH	B
C5	Risk factor	A	C
C6	Time of delivery	A	C
C7	Supplier communication ability	VH	C
C8	Reliability in emergency	VH	B

Table 4: Decision Matrix for DM 1

Alternatives	**Criteria**							
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
S1	A	VH	H	L	VH	VL	L	H
S2	H	VH	A	A	H	L	VL	A
S3	VH	A	L	VL	A	A	VL	VH

Table 5: Decision Matrix for DM 2

Alternatives	Criteria							
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
S1	H	VH	H	L	VL	L	L	H
S2	H	H	A	A	A	VL	H	VH
S3	VH	A	VL	VL	L	A	VH	H

Table 6: Decision Matrix for DM 3

Alternatives	Criteria							
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
S1	A	H	H	VL	A	VH	H	VL
S2	H	A	A	L	A	A	A	L
S3	H	A	L	VL	H	H	A	L

3.2 Determination of combined Decision Matrix

The combined decision matrix is derived from the formula

$$x_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$$

where $a_{ij} = Min\left(a_{ij}\right)\ b_{ij} = Mean\left(b_{ij}\right), c_{ij} = Max\left(c_{ij}\right)$ i=number of row, j=number of column.

3.3 Normalization of Combined Decision Matrix

In other to normalize the combined decision matrix, the Beneficial (B) and Cost (C) values are taken into consideration.

Table 7: Combined Decision Matrix

	Criteria							
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
S1	3,5.667,9	5,8.333,9	5,7,9	1,2.333,5	1,5,9	1,4.333,9	1,4.333,9	1,5,9
S2	5,7,9	3,7,9	3,5,7	1,4.333,7	3,5.667,9	1,3,7	1,4.333,9	1,5.667,9
S3	5,8.333,9	3,5,7	1,2.333,5	1,1,3	1,5,9	3,5.667,9	1,5,9	1,6.333,9

Table 8: Normalized Decision Matrix

	Criteria							
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
S1	0.333, 0.529, 1	0.556, 0.921, 1	0.556, 0.778, 1	0.111, 0.259, 0.556	1, 0.2, 0.111	0.111, 0.231, 1	0.111, 0.231, 1	0.111, 0.556, 1
S2	0.333, 0.429, 0.6	0.333, 0.778, 1	0.333, 0.556, 0.778	0.111, 0.63, 1	0.111, 0.176, 0.333	0.143, 0.333, 1	0.111, 0.231, 1	0.111, 0.63, 1
S3	0.333, 0.36, 0.6	0.333, 0.556, 0.778	0.111, 0.259, 0.556	0.111, 0.556, 1	0.111, 0.2, 1	0.111, 0.176, 0.333	0.111, 0.2, 0.333	0.111, 0.704, 1
Weightage	3,5,7	5,7,9	7,9,9	7,9,9	3,5,7	3,5,7	7,9,9	7,9,9

Table 9: Weighted Normalized Decision Matrix

Alternatives	Criteria							
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
S1	0.999, 2.645, 7	2.78, 6.446, 9	3.892, 7.002, 9	0.777, 2.331, 5.004	0.333, 1, 7	0.333, 1.155, 7	0.777, 2.099, 9	0.777, 5.004, 9
S2	0.999, 2.145, 4.2	1.665, 5.446, 9	2.331, 5.004, 7.002	0.777, 5.62, 9	0.333, 0.88, 2.331	0.429, 1.665, 7	0.777, 2.099, 9	0.777, 5.67, 9
S3	0.999, 1.8, 4.2	1.665, 3.892, 7.002	0.777, 2.331, 7.002	0.777, 5.004, 9	0.333, 1, 7	0.332, 0.85, 2.331	0.777, 1.8, 2.997	0.777, 6.336, 9

Table 10: Fuzzy Positive Ideal Solution

Alt	**Criteria**								
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**d+**
S1	0	0	0	5.175	4.671	0.513	0	1.332	11.691
S2	2.844	1.208	2.966	0	0	0	0	0.666	7.684
S3	2.925	3.334	6.405	0.616	4.671	4.74	6.009	0	28.7

Table 11: Fuzzy Negative Ideal Solution

Alternatives	Criteria								
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**d-**
S1	2.925	3.323	6.405	0	0	4.679	6.009	0	23.422
S2	0.345	2.517	3.456	5.175	4.671	4.79	6.009	0.666	27.629
S3	0	0	0	4.808	0	0	0	1.332	6.14

Table 12: Determination of Closeness Coefficient, CCi

	d+	d-	CCi	Rank
S1	11.691	23.422	0.667	2
S2	7.684	27.629	0.782	1
S3	28.7	6.14	0.172	3

4.0 RESULTS AND DISCUSSION

In Table 9, the weighted normalized decision matrix was computed while the FPIS and FNIS was determined in Tables 10 and 11, respectively. FPIS was computed as

A^+ =[(0, 2.844, 2.925), (0, 1.208, 3.334), (0, 2.966, 6.405), (5.175, 0, 0.616), (4.671, 0, 4.671), (0.513, 0, 4.74), (0, 0, 6.009), (1.332, 0.666, 0)]

While FNIS, A^- =[(2.925, 0.345, 0), (3.323, 2.517, 0), (6.405, 3.456, 0), (0, 5.175, 4.808), (0, 4.671, 0), (4.679, 4.79, 0), (6.009, 6.009, 0), (0, 0.666, 1.332)]

By applying step 8 of the methodology, the closeness coefficient for each supplier is obtained. From Table 12, Supplier 2 has the highest closeness coefficient (0.782) which implies that Supplier 2 is the best option. Considering the various criteria, Supplier 1 can also be considered whenever Supplier 2 is unavailable.

In order to ascertain this result, the company chose Supplier 2 for specific production runs and it was observed to produce a better turnaround time of six hours than usual.

From the questionnaire circulated among three decision makers of the case study organization, it can be deduced that the alternatives from which the best choice of supplier was selected from, putting into considerations the respective criteria, were represented as supplier 1, 2, and 3. After the application of fuzzy TOPSIS selection process to the supplier selection, it was observed that supplier 2 has the highest ranking and also the highest CCi. This implies that analyzing all three alternatives with respect to the given criteria, it is safer and more convenient to work with supplier 2.

5.0 CONCLUSION

This research uses Fuzzy TOPSIS as an analytical tool to determine the weight of each criterion for selecting suppliers of a raw material in a beverage producing company.

The scientific nature of Fuzzy TOPSIS promotes the integrity and objectivity of the selection process. The model is transparent and easy to comprehend by the decision maker. This is an advantage of the methodology. Further studies can take into consideration a larger number of suppliers and criteria for selection. While this study adopts three decision-makers in the same company, effort can be made to increase the number of decision makers.

Though this will lead to more complexity in the calculation, the use of a computational tool is strongly advised. Also, the use of other multi-criterion making models can also be explored. It can be combined with several methods such as AHP, VIKOR, ELECTREE, PROMETHEE.

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