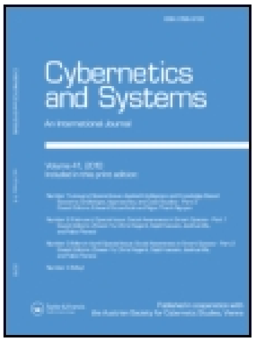

Taylor & Francis
Taylor & Francis Group

Cybernetics and Systems
An International Journal

ISSN: 0196-9722 (Print) 1087-6553 (Online) Journal homepage: https://www.tandfonline.com/loi/ucbs20

PERFORMANCE EVALUATION OF SUGAR PLANTS BY FUZZY TECHNIQUE FOR ORDER PERFORMANCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS)

Muhammed Arslan & Mehmet Çunkaş

To cite this article: Muhammed Arslan & Mehmet Çunkaş (2012) PERFORMANCE EVALUATION OF SUGAR PLANTS BY FUZZY TECHNIQUE FOR ORDER PERFORMANCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS), Cybernetics and Systems, 43:7, 529-548, DOI: 10.1080/01969722.2012.717851

To link to this article: https://doi.org/10.1080/01969722.2012.717851

Published online: 08 Oct 2012.

Submit your article to this journal

Article views: 245

View related articles

Citing articles: 1 View citing articles

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=ucbs20

Cybernetics and Systems: An International Journal, 43:529–548
Copyright © 2012 Taylor & Francis Group, LLC
ISSN: 0196-9722 print/1087-6553 online
DOI: 10.1080/01969722.2012.717851

Performance Evaluation of Sugar Plants by Fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS)

MUHAMMED ARSLAN[1] and MEHMET ÇUNKAŞ[2]

[1]*Computer Department, Ahi Evran University, Vocational School, Kırşehir, Turkey*
[2]*Selcuk University, Faculty of Technology, Electric & Electronics Engineering, Konya, Turkey*

This study presents the performance evaluation of sugar plants using the technique for order performance by similarity to ideal solution (TOPSIS) under a fuzzy environment. First, the decision criteria used to evaluate the performances are determined, and then the data from financial statements are collected from sugar plants. Accordingly, the ratings of various alternatives under various criteria and the importance weights of various criteria are assessed by evaluators using linguistic terms. The data obtained are converted into a fuzzy triangular number system and then the fuzzy TOPSIS method is applied to make a final decision. According to the closeness coefficients, the sugar plants are ranked from strong to weak. A real case study involving eight evaluation criteria and nine sugar plants assessed by nine evaluators is provided to illustrate the proposed method. The results show that this method is an effective tool for evaluating investment risks based on the heuristic knowledge acquired from experts.

KEYWORDS *decision-making, fuzzy sets, performance evalution, sugar plants, TOPSIS*

INTRODUCTION

Sugar is an unnatural substance manufactured mostly from sugarcane or sugar beets through industrial processes. In Turkey, state-owned companies

Address correspondence to Mehmet Çunkaş, Selcuk University, Faculty of Technology, Electric & Electronics Engineering, 42003, Selcuklu, Konya, Turkey. E-mail: mcunkas@selcuk.edu.tr

have a 70% market share in sugar production, comprising 25 of the 29 sugar plants. State dominance continues to be prevalent in sugar production. There is no significant difference in the pure sugar produced from either cane or beet. Sugar production from sugar beet is more costly than that from sugar cane. The Turkish sugar industry continues to produce sugar from sugar beet. However, the sugar law restricts sugar beet and in the near future there will be reduction in sugar beet per acreage (Erdal et al. 2007).

Decision making is very complex and requires the decision maker, decision environment, criteria, and alternatives. Decision makers need to find the most appropriate options among different and sometimes conflicting objectives when choosing among the alternatives. Effective and efficient decision making is one of the basic elements of good governance. The decisions are indicators of how groups solve problems, use sources, and reach objectives. Because decision making is related to the process of data collection and information, the complexity of the process has increased over time. Therefore, when faced with such a problem, multiple-criteria decision-making (MCDM) methods are used to make a final decision. Multiple-criteria decision making determines the best solution from among many alternatives and includes evaluation, sorting, and selection (Hwang and Yoon 1981; Daft 1991). The fuzzy technique for order performance by similarity to ideal solution (TOPSIS) is rational and understandable, permitting research on the best alternatives for each criterion depicted in a simple mathematical form and incorporating the importance weights into comparison procedures (T. C. Wang and Chang 2007). MCDM methods, in particular, fuzzy TOPSIS, have been applied to many different areas as follows.

Byun and Lee (2005) dealt with the selection of an optimal rapid prototyping system by using multiple-attribute decision making and the test part designed with conjoint analysis to reflect users' preferences. Yong and Qi (2005) proposed a new centroid-index ranking method of fuzzy numbers using TOPSIS. They presented some numerical examples in which the new method can overcome the drawbacks of existing methods. Smitt (2006) showed an application of flexible aggregation in multiple-attribute decision making for the Kuranda Range Road Upgrade. Büyüközkan et al. (2007) investigated 10 worldwide and 11 locally successful web sites using MCDM techniques. They showed that their methods could be useful to e-learning service providers and system developers, as well as to researchers related to web research. Rahimi et al. (2007) modified the TOPSIS method for the implementation of a web-based medical diagnostic system. Sun and Lin (2009) investigated the performance of shopping web sites using fuzzy TOPSIS, taking into consideration technology acceptance factors, web site service quality, and specific holdup cost factors. Ertuğrul and Karakaşoğlu (2009) developed a fuzzy model based on fuzzy analytic hierarchy process (FAHP) and TOPSIS methods to evaluate the performance of cement firms using financial ratios while taking subjective judgments of decision makers into consideration. Aiello et al. (2009) developed a fuzzy TOPSIS method to support the decision maker in the selection of the most suitable extinguisher substance for a specific application. They properly regrouped the criteria into clusters to determine their relative importance using an analytical hierarchy process (AHP) and then used the criteria to score the alternatives. Mahdavi et al. (2009) proposed a fuzzy distance formula to calculate a crisp value for the standard deviation of fuzzy data. They used TOPSIS to determine the ranking order of the alternatives. Y. J. Wang and Kao (2010) utilized a fuzzy TOPSIS method to solve the site selection in order to encompass uncertainty and vagueness of messages. Torlak et al. (2011) used the fuzzy TOPSIS approach in the Turkish domestic airline industry to rank air carriers according to their relative closeness coefficient on the basis of certain criteria. They also aimed to evaluate empirical findings from a managerial perspective. Krohling and Campanharo (2011) developed a tool to aid decision makers involved in oil spill contingency planning. The tool helps decision makers to take decision on both operational and tactical levels. Amiri and Golozari (2011) introduced an algorithm based on fuzzy TOPSIS that considers not only time but cost, risk, and quality criteria to determine the critical path under the four criteria.

In the literature, the fuzzy TOPSIS method has not been used to evaluate the performance of sugar plants. The significant contribution of this article is the suggestion of the use of fuzzy TOPSIS in sugar plant evaluation. Another purpose for this study is to provide some operational and tactical perspectives in order to enhance management performance for the Turkish sugar industry. For this purpose, the performance of sugar plants is evaluated using the fuzzy TOPSIS method and financial ratios. First, the decision criteria used to evaluate the performance were determined and data on financial ratios were collected from sugar plants. Accordingly, the ratings of various alternatives under various criteria and the importance weights of various criteria were assessed by evaluators using linguistic terms. The data obtained were converted into a fuzzy triangular number system. The fuzzy TOPSIS method was applied to make a final decision and to help decision makers involved in sugar plants. The firms were objectively ranked by evaluating their achievements. An MCDM method was used for the correct and effective evaluation of performance of Turkish sugar plants.

MULTICRITERIA DECISION MAKING AND FUZZY TOPSIS METHOD

Fuzzy Sets Theory

Fuzzy set theory, which provides a mathematical way to represent vagueness and fuzziness in humanistic systems, originally proposed by Zadeh, was inspired by man's ability to understand and analyze knowledge uncertainty (1965). Zadeh's work had quite an important effect on the thinking regarding decision processes that contain nonrandom uncertainty, such as the uncertainty in natural language. The suggested set membership is the key to decision making when faced with uncertainty, which represents similarities of objects to nondistinct properties, and probabilities, which provides knowledge about relative frequencies. The set membership is central to the representation of many real-world application problems by fuzzy sets. The classical sets contain objects that satisfy precise properties of membership; it is not allowed that an object is in different sets at the same time. Fuzzy set theory accepts partial memberships that contain objects satisfying imprecise properties of membership. A fuzzy set can have an infinite number of membership functions, whereas a classical set has a unique membership function. A fuzzy set $\tilde{A}$ in a universe of information (discourse) X can be represented by a membership function, $\mu_{\tilde{A}}(x)$. This membership can be defined mathematically with the indicator function (Ross 2004).

$$\mu_{\tilde{A}}(x) = \begin{cases} 1, & x \in \tilde{A} \\ 0, & x \notin \tilde{A} \end{cases} \tag{1}$$

Fuzzy TOPSIS Method

A technique for order preference by similarity to ideal solution (TOPSIS) was proposed by Hwang and Yoon (1981). Chen (2000) extended this method to fuzzy group decision making using triangular fuzzy numbers and describing Euclidean distance between two fuzzy numbers. The method uses the concepts of a positive ideal solution and a negative ideal solution to solve MCDM problems. The best alternative should have the shortest distance from the positive-ideal solution point and the longest distance from the negative-ideal solution point. An index called similarity to the positive-ideal solution is defined to choose an alternative with the maximum similarity to the positive-ideal solution (Sun and Lin 2009). This study evaluates the performance of Turkish sugar plants and ranks them from best to worst performance results. The overall performance of each alternative is computed using linguistic variables represented by triangular fuzzy numbers. The conceptual schema and mathematical form of triangular fuzzy numbers are described by Kaufmann and Gupta (1985). The membership function can be defined by a triplet (a_1, a_2, a_3) as follows: (see Figure 1; T. C. Wang and Chang 2007; Krohling and Campanharo 2011; Torfi and Rashidi 2011).

$$\mu_{\tilde{A}}(x) = \left\{ \begin{array}{ll} 0, & x \langle a_1, \\ (x - a_1)/(a_2 - a_1), & a_1 \le x \le a_2, \\ (a_3 - x)/(a_3 - a_2), & a_2 \le x \le a_3, \\ 0, & x \rangle a_3. \end{array} \right\} \tag{2}$$

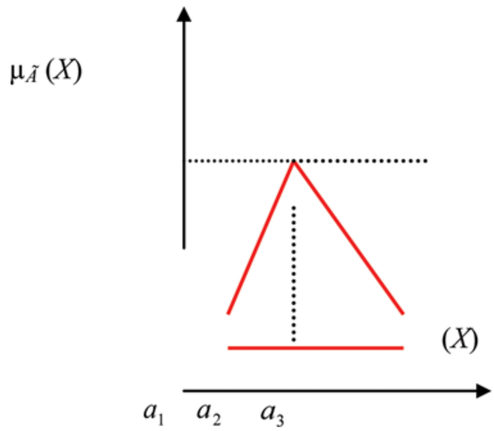

FIGURE 1 Membership function of triangular fuzzy number (color figure available online).

The linear representation is given in Eq. (2) according to the left and right extreme values on the fuzzy number.

Let $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ be two triangular fuzzy numbers; then basic operations are defined as:

$$\begin{aligned}
&\tilde{A}(+)\tilde{B} = (a_1, a_2, a_3)(+)(b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3)\\
&\tilde{A}(-)\tilde{B} = (a_1, a_2, a_3)(-)(b_1, b_2, b_3) = (a_1 - b_1, a_2 - b_2, a_3 + b_3)\\
&\tilde{A}(\times)\tilde{B} = (a_1, a_2, a_3)(\times)(b_1, b_2, b_3) = (a_1 \cdot b_1, a_2 \cdot b_2, a_3 \cdot b_3)\\
&\tilde{A}(/)\tilde{B} = (a_1, a_2, a_3)(/)(b_1, b_2, b_3) = (a_1/b_1, a_2/b_2, a_3/b_3)\\
&k\tilde{A} = k(a_1, a_2, a_3) = (ka_1, ka_2, ka_3) \qquad (3)
\end{aligned}$$

The distance between $\tilde{A}$ and $\tilde{B}$ is calculated using a vertex method as follows:

$$d(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{3}(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2} \qquad (4)$$

The decision matrix covering alternatives and criteria can be expressed as:

$$\tilde{D} = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{matrix}, \; i = 1, 2, \ldots\ldots, m; j = 1, 2, \ldots, n \qquad (5)$$

where $A_1, A_2, \ldots, A_m$ are the alternatives and $C_1, C_2, \ldots, C_n$ show the criteria, and x_{ij} are fuzzy numbers that represent the performance rating of alternative

A_i with respect to criterion C_j. Fuzzy TOPSIS is an efficient tool for solving the group decision-maker problem in environments of uncertainty. Fuzzy TOPSIS is defined as follows:

Step 1. Evaluators and criteria for group decision making are determined. Evaluators are selected according to evaluation criteria.

Step 2. According to importance weight, the linguistic variables for each criterion are specified. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language instead of numerical values (Ross 2004). Decision makers use linguistic variables to calculate the degree of importance of alternatives considering different criteria.

Step 3. As seen in Table 1, the importance weight of the criteria is determined by using linguistic variables. Table 2 shows linguistic values for rating of each alternative. The evaluators utilize these linguistic terms to express their opinions about the alternatives.

Step 4. The evaluations of evaluators regarding to the same alternatives and criteria are integrated by using the average method.

$$x_{ij} = \frac{1}{k}(x_{ij}^1 + x_{ij}^2 + \ldots + x_{ij}^k) \tag{6}$$

where k is the number of evaluators, w_j is the weight of the jth criterion, and x_{ij} is the value of the ith alternative with respect to the jth criterion evaluated by the kth evaluator (Wang and Chang 2007; Krohling and Campanharo 2011).

Normalization of raw data is necessary to avoid anomalies associated with different measurement units and scales. The normalized fuzzy decision matrix is defined as:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \tag{7}$$

TABLE 1 Linguistic Variables for the Importance Weight of Each Criterion

Linguistic variables	Triangular fuzzy number		
Very low	0.0	0.1	0.1
Low	0.0	0.1	0.3
Medium low	0.1	0.3	0.5
Medium	0.3	0.5	0.7
Medium high	0.5	0.7	0.9
High	0.7	0.9	1.0
Very high	0.9	0.9	1.0

TABLE 2 Linguistic Values for Rating of Each Alternative

Linguistic variables	Triangular fuzzy number		
Very poor	0	0	1
Poor	0	1	3
Fair poor	1	3	5
Fair	3	5	7
Fair good	5	7	9
Good	7	9	10
Very good	9	10	10

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right), \quad c_j^+ = \max_i c_{ij} \tag{8}$$

Step 5. The weighted normalized fuzzy decision matrix is constructed using weighted normalized values as follows:

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j = \begin{bmatrix} \tilde{w}_1\tilde{r}_{11} & \tilde{w}_2\tilde{r}_{12} & \cdots & \tilde{w}_n\tilde{r}_{1n} \\ \tilde{w}_1\tilde{r}_{21} & \tilde{w}_1\tilde{r}_{22} & \cdots & \tilde{w}_n\tilde{r}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{w}_1\tilde{r}_{m1} & \tilde{w}_1\tilde{r}_{m2} & \cdots & \tilde{w}_n\tilde{r}_{mn} \end{bmatrix}, \qquad \tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n] \tag{9}$$

where w_j represents the importance weight of criteria.

Step 6. The positive-ideal (A^+) and negative-ideal (A^-) solutions are identified as follows:

$$A^+ = \left(v_1^+, v_2^+, \ldots v_n^+\right)\ A^- = \left(v_1^-, v_2^-, \ldots v_n^-\right) \\ v_j^+ = (1,1,1)\ v_j^- = (0,0,0)\ j = 1, 2 \ldots\ldots n. \tag{10}$$

Step 7. The distance of each alternative from the positive-ideal (A^+) and negative-ideal (A^-) solutions can be calculated by:

$$d_i^+ = \sum_{j=1}^{n} d\left(v_{ij}, v_j^+\right), \quad i = 1, 2, 3 \ldots m; \quad j = 1, 2 \ldots n \\ d_i^- = \sum_{j=1}^{n} d\left(v_{ij}, v_j^-\right), \quad i = 1, 2, 3 \ldots m; \quad j = 1, 2 \ldots n \tag{11}$$

Step 8. The closeness coefficient of each alternative is computed by:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1, 2, 3 \ldots m \tag{12}$$

In this way, the alternatives can be ordered in descending order. The alternative with maximum CC_i among alternatives can be selected as the best one.

DETERMINING CRITERIA FOR SUGAR PLANTS

Financial statements are useful for making and evaluating decisions about firms. In this study, the following financial statements were used as criteria.

Current Ratio (C_1)

The current ratio is calculated by dividing the gross operating capital needed to keep the companies' activities (current assets) by current liabilities. This ratio shows whether a certain business entity can meet its short-term debts. Current assets comprise the cash on hand in the bank and any assets that can be converted into cash within 12 months, such as marketable securities held as short-term investments, accounts receivables, inventories, and prepayments. Current liabilities comprise financial obligations expected to fall due within next year, such as accounts payables, and accrued expenses such as taxes and notes payable (Moyer et al. 1992).

$$\text{Current ratio} = \frac{\text{Current assets}}{\text{Current liabilities}}$$

Debt Structure Ratio (C_2)

The debt structure ratio provides information about the weight of foreign sources in short-term debts. The height of this ratio is a negative indicator in terms of firms because the height of short-term debts is inadequate to produce funds from the company's own activities and sources. The debt structure ratio is calculated by dividing short-term liabilities by total liabilities as follows:

$$\text{Debt structure ratio} = \left(\frac{\text{Short term debts}}{\text{Total debts}}\right) \times 100$$

Profitability Ratio (C_3)

The profitability ratio is very important to assess the performance of firms. There are different expenditure items among expenses, which cause an important impact on the incomes of firms. Therefore gross profit of sales to net sales ratio, operating profit margin, and net profit margin make it necessary to analyze together. If a firm cannot provide adequate returns in the form of dividends and share price appreciation to investors, it will not be able to maintain its asset base. Therefore, the economic interests will be interested in profitability ratios (Moyer et al. 1992). Although there are different formulas to calculate the profitability ratios, in this study the following formulation is used:

$$\text{Profitability ratio} = \frac{\text{Net profit}}{\text{Gross sale rate}}$$

Operating Profit Margin (C_4)

The operating profit margin is calculated by subtracting the operating expenses; R&D expenses; marketing, sales, and distribution expenses; and general administrative expenses from the gross profit, which is an indicator of the company's sales ability. It is important in terms of comparison of the competitive capabilities of firms in the same category. In addition, it is the ability to reduce the costs of profit reduction resulting from the firm's activities. So, in a sense, the height of the operating profit margin indicates how a company reduces their expenses.

$$\text{Operating profit margin} = \left(\frac{\text{Operating profits sales}}{\text{Net sales}}\right) \times 100$$

Net Profit Margin (C_5)

The net profit margin is a value that reflects the consequences of all of a company's activities. This ratio can be calculated by proportioning the earnings after taxes to sales.

$$\text{Net profit margin} = \left(\frac{\text{Earnings after taxes}}{\text{Sales}}\right) \times 100$$

Productivity Per Worker (C_6)

Changes in employment by year show the status of the economy. The deterioration of a firm's economic situation causes the dismissal of workers. In the case of an increase in production, firms should employ new workers.

However, another reason for employment losses is the transition from labor-intensive production to technology-intensive production. *Total employees* is defined as the sum of temporary workers, permanent workers, and officers. The employment term of temporary workers in factories is 3 months but they comprise 50% of all employees. This rate is valid in all plants researched. Therefore, in this study, the only permanent employees were considered for the number of employees.

$$\text{Productivity per Worker} = \frac{\text{Net Profit}}{\text{Number of employees}}$$

Per Capita Sales (C_7)

Per capita sales are calculated by dividing the number of employees by the net sales for that year. The number of employees is considered as in the calculation of productivity per worker.

$$\text{Per Capita Sale} = \frac{\text{Net Sales}}{\text{Number of employees}}$$

Liabilities Maturity Rate (C_8)

The liabilities maturity rate is the ratio of short-term foreign funds to total foreign funds. A rate of two thirds is considered acceptable.

$$\text{Liabilities maturity rate} = \frac{\text{Short-term foreign funds}}{\text{Total foreign funds}}$$

CASE STUDY: PERFORMANCE EVALUATION OF SUGAR PLANTS

The evaluation method needs economic data that show the performance of the plants. The financial statements and their indicators are used as the criteria. Because sugar plants were not traded on the Istanbul Stock Exchange, it was hard to obtain the entire data from plants. This study includes eight evaluation criteria (see previous section) and nine alternatives as illustrated in Figure 2. After determining the alternatives and the criteria for the evaluation, the decision hierarchy is formed. In this context, nine experts were invited to evaluate nine alternatives for group decision making. The weights of each criteria and rank of alternatives were calculated using the fuzzy TOPSIS method. The application of this method for determining the performance of the sugar plants is discussed in the following.

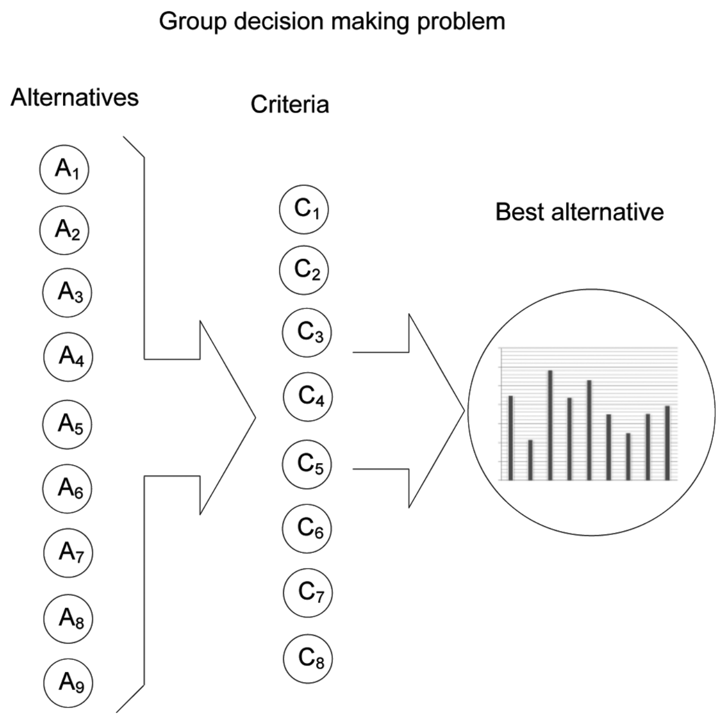

FIGURE 2 Group decision-making problem.

Step 1. *Determination of the weighting of each criterion*: First, the evaluators are requested to rank the importance of each criterion. Table 3 shows the importance weight of each criterion as obtained by fuzzy TOPSIS method. The center of area (COA) method (Zhao and Govind 1991) was used to convert the triangular fuzzy numbers into the best nonfuzzy performance (BNP) values in order to compare the criteria. For example, the BNP value of the weight of C_1 is calculated as follows:

$$\begin{aligned} BNP_1 &= [(U_1 - L_1) + (M_1 - L_1)]/3 + L_1 \\ &= [(0.989 - 0.789) + (0.933 - 0.789)]/3 + 0.789 \end{aligned}$$

TABLE 3 Importance Weight of Each Criterion

		BNP	Rank
C_1	(0.789, 0.933, 0.989)	0.9036	1
C_2	(0.467, 0.656, 0.811)	0.6466	6
C_3	(0.522, 0.722, 0.789)	0.6776	5
C_4	(0.722, 0.878, 0.956)	0.8520	2
C_5	(0.678, 0.867, 0.978)	0.8410	3
C_6	(0.389, 0.578, 0.744)	0.5703	7
C_7	(0.289, 0.478, 0.677)	0.4813	8
C_8	(0.522, 0.722, 0.878)	0.7073	4

As can be seen from Table 3, the first criterion C_1 is more important than the other criteria; therefore, its order is one.

Step 2. *Construction of the fuzzy decision matrix*: The evaluators express their opinions about the rating of every sugar plant regarding each performance criteria using the linguistic terms in Table 2 and the financial ratios. Evaluators sometimes have different opinions on the financial ratios. The various personnel judgments are combined by averaging the fuzzy performance ratings of each plant considering the evaluation criteria. The fuzzy decision matrix can be calculated using Eq. (6) as in Table 4.

Step 3. *Normalization of the fuzzy decision matrix*: The normalized fuzzy decision matrix is calculated using Eqs. (7) and (8) as seen in Table 5. For instance, because the maximum value of the first row of Table 5 is 9.889, the normalized values are computed by dividing by 9.889. The other rows are normalized using a similar method.

Step 4. *Construction of the weighted normalized fuzzy decision matrix*: The weighted fuzzy decision matrix is found using Eq. (9), based on the normalized decision matrix. Let us take into consideration the fuzzy numbers (0.303, 0.506, 0.708) of alternative A_1 regarding C_1.

$$0.303 \times 0.789 = 0.239;\ \ 0.506 \times 0.933 = 0.472;\ \ 0.708 \times 0.989 = 0.700$$

This operation is applied to the normalized decision matrix in Table 5 and so the weighted normalized fuzzy decision matrix is obtained as in Table 6.

Step 5. *Determination of the fuzzy positive-ideal and fuzzy negative-ideal solutions*: The fuzzy positive-ideal solution (A^+) and the fuzzy negative-ideal solution (A^-) are defined as follows:

$$A^+ = [(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),\\ (1,1,1),(1,1,1)]$$

$$A^- = [(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0),\\ (0,0,0),(0,0,0)]$$

Step 6. *Performance evaluation and ranking the alternatives*: In order to identify the closeness coefficients of each alternative, the distances from the fuzzy positive-ideal solution and the fuzzy negative-ideal solution for each sugar plant are computed using Eqs. (4) and (11). The calculation of negative distance for alternative A_1 is shown below:

TABLE 4 Fuzzy Decision Matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9
C1	(3.00, 5.00, 7.00)	(1.333, 3.000, 5.00)	(7.222, 9.000, 9.889)	(3.00, 5.00, 7.00)	(8.333, 9.444, 9.667)	(0.778, 2.111, 4.111)	(1.111, 2.778, 4.778)	(2.222, 3.889, 5.889)	(0.778, 2.111, 4.111)
C2	(2.667, 4.00, 5.444)	(2.444, 3.778, 5.222)	(4.111, 6.111, 7.778)	(2.667, 4.00, 5.444)	(2.667, 4.111, 5.667)	(2.444, 3.778, 5.222)	(3.00, 4.778, 6.556)	(2.667, 4.00, 5.444)	(2.444, 3.889, 5.444)
C3	(5.544, 6.889, 8.00)	(0.00, 0.00, 1.00)	(2.333, 3.444, 5.000)	(0.667, 2.333, 4.333)	(1.333, 3.00, 5.00)	(0.667, 3.778, 4.333)	(0.00, 0.00, 1.00)	(0.00, 0.889, 2.778)	(0.667, 2.333, 4.333)
C4	(2.556, 4.556, 6.556)	(0.00, 0.00, 1.00)	(7.00, 9.00, 10.00)	(5.222, 7.222, 9.111)	(9.00, 10.00, 10.00)	(2.333, 4.333, 6.222)	(0.00, 0.222, 1.444)	(3.00, 5.00, 7.00)	(3.444, 5.444, 7.444)
C5	(3.111, 5.00, 7.00)	(0.00, 0.00, 1.00)	(8.333, 9.667, 10.00)	(4.222, 6.111, 8.111)	(9.00, 10.00, 10.00)	(2.667, 4.556, 6.556)	(0.111, 0.667, 2.111)	(2.111, 3.889, 5.889)	(2.667, 4.556, 6.556)
C6	(4.778, 6.778, 8.33)	(0.00, 0.111, 1222)	(9.00, 10.00, 10.00)	(4.778, 6.778, 8.333)	(7.667, 9.222, 9.889)	(3.000, 5.00, 6.889)	(0.00, 0.333, 1.667)	(3.00, 5.00, 6.889)	(6.111, 7.778, 9.00)
C7	(7.00, 8.556, 9.444)	(4.556, 6.556, 8.333)	(9.00, 10.00, 10.00)	(4.556, 6.556, 8.333)	(0.556, 2.111, 4.111)	(3.667, 5.667, 7.444)	(4.333, 6.333, 8.222)	(2.667, 4.556, 6.556)	(7.667, 9.222, 9.889)
C8	(3.333, 4.667, 6.00)	(3.333, 4.667, 6.00)	(4.556, 6.00, 7.222)	(3.444, 5.00, 6.444)	(3.444, 5.111, 6.667)	(3.444, 5.000, 6.444)	(4.00, 5.889, 7.556)	(3.444, 5.00, 6.444)	(3.222, 4.889, 6, 444)

TABLE 5 The Normalized Fuzzy Decision Matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9
C1	(0.303, 0.506, 0.708)	(0.135, 0.303, 0.506)	(0.730, 0.910, 1.000)	(0.303, 0.506, 0.708)	(0.843, 0.955, 0.978)	(0.079, 0.213, 0.416)	(0.112, 0.281, 0.483)	(0.225, 0.393, 0.596)	(0.079, 0.213, 0.416)
C2	(0.343, 0.514, 0.700)	(0.314, 0.486, 0.671)	(0.529, 0.786, 1.000)	(0.343, 0.514, 0.700)	(0.343, 0.529, 0.729)	(0.314, 0.486, 0.671)	(0.386, 0.614, 0.843)	(0.343, 0.514, 0.700)	(0.314, 0.500, 0.700)
C3	(0.681, 0.861, 1.000)	(0.000, 0.000, 0.125)	(0.292, 0.431, 0.625)	(0.083, 0.292, 0.542)	(0.167, 0.375, 0.625)	(0.083, 0.292, 0.542)	(0.000, 0.000, 0.125)	(0.000, 0.111, 0.347)	(0.083, 0.292, 0.542)
C4	(0.256, 0.456, 0.656)	(0.000, 0.000, 0.100)	(0.700, 0.900, 1.000)	(0.522, 0.722, 0.911)	(0.900, 1.000, 1.000)	(0.233, 0.433, 0.622)	(0.000, 0.022, 0.144)	(0.300, 0.500, 0.700)	(0.344, 0.544, 0.744)
C5	(0.311, 0.500, 0.700)	(0.000, 0.000, 0.100)	(0.833, 0.967, 1.000)	(0.422, 0.611, 0.811)	(0.900, 1.000, 1.000)	(0.267, 0.456, 0.656)	(0.011, 0.067, 0.211)	(0.211, 0.389, 0.589)	(0.267, 0.456, 0.656)
C6	(0.478, 0.6780.833)	(0.000, 0.011, 0.122)	(0.900, 1.000, 1.000)	(0.478, 0.678, 0.833)	(0.767, 0.922, 0.989)	(0.300, 0.500, 0.689)	(0.000, 0.033, 0.167)	(0.300, 0.500, 0.689)	(0.611, 0.778, 0.900)
C7	(0.700, 0.856, 0.944)	(0.456, 0.656, 0.883)	(0.900, 1.000, 1.000)	(0.456, 0.656, 0.833)	(0.056, 0.211, 0.411)	(0.367, 0.567, 0.744)	(0.433, 0.633, 0.822)	(0.267, 0.456, 0.656)	(0.676, 0.922, 0.989)
C8	(0.441, 0.618, 0.794)	(0.441, 0.618, 0.794)	(0.603, 0.794, 0.956)	(0.456, 0.662, 0.853)	(0.456, 0.676, 0.882)	(0.456, 0.662, 0.853)	(0.529, 0.779, 1.000)	(0.456, 0.662, 0.853)	(0.426, 0.647, 0.853)

TABLE 6 Weighted Normalized Fuzzy Decision Matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9
C1	(0.239, 0.472, 0.700)	(0.107, 0.283, 0.500)	(0.576, 0.849, 0.989)	(0.239, 0.472, 0.700)	(0.665, 0.891, 0.967)	(0.062, 0.199, 0.411)	(0.411, 0.088, 0.262)	(0.478, 0.178, 0.367)	(0.062, 0.199, 0.411)
C2	(0.160, 0.337, 0.568)	(0.147, 0.319, 0.544)	(0.247, 0.516, 0.811)	(0.160, 0.337, 0.568)	(0.160, 0.347, 0.591)	(0.147, 0.319, 0.544)	(0.544, 0.180, 0.403)	(0.684, 0.160, 0.337)	(0.147, 0.328, 0.568)
C3	(0.355, 0.622, 0.789)	(0.000, 0.000, 0.099)	(0.152, 0.311, 0.493)	(0.043, 0.211, 0.428)	(0.087, 0.271, 0.493)	(0.043, 0.211, 0.428)	(0.428, 0.000, 0.000)	(0.099, 0.000, 0.080)	(0.043, 0.211, 0.428)
C4	(0.185, 0.400, 0.627)	(0.000, 0.000, 0.096)	(0.505, 0.790, 0.956)	(0.377, 0.634, 0.871)	(0.650, 0.878, 0.956)	(0.168, 0.380, 0.595)	(0.595, 0.000, 0.019)	(0.138, 0.217, 0.439)	(0.248, 0.478, 0.711)
C5	(0.211, 0.434, 0.685)	(0.000, 0.000, 0.098)	(0.565, 0.838, 0.978)	(0.286, 0.530, 0.793)	(0.610, 0.867, 0.978)	(0.181, 0.395, 0.642)	(0.642, 0.007, 0.058)	(0.206, 0.143, 0.337)	(0.181, 0.395, 0.642)
C6	(0.186, 0.392, 0.620)	(0.000, 0.006, 0.091)	(0.350, 0.578, 0.744)	(0.186, 0.392, 0.620)	(0.298, 0.533, 0.736)	(0.117, 0.289, 0.513)	(0.513, 0.000, 0.019)	(0.124, 0.117, 0.289)	(0.238, 0.450, 0.670)
C7	(0.202, 0.409, 0.630)	(0.132, 0.314, 0.556)	(0.260, 0.478, 0.667)	(0.132, 0.314, 0.556)	(0.016, 0.101, 0.274)	(0.106, 0.271, 0.496)	(0.496, 0.125, 0.303)	(0.548, 0.077, 0.218)	(0.222, 0.441, 0.660)
C8	(0.230, 0.446, 0.697)	(0.230, 0.446, 0.697)	(0.315, 0.573, 0.839)	(0.238, 0.478, 0.749)	(0.238, 0.488, 0.774)	(0.238, 0.478, 0.749)	(0.749, 0.276, 0.562)	(0.878, 0.238, 0.487)	(0.222, 0.467, 0.749)

$$0.392 = \sqrt{\frac{1}{3}\left[(0-0.160)^2 + (0-0.337)^2 + (0-0.568)^2\right]}$$

$$0.614 = \sqrt{\frac{1}{3}[(0-0.355)^2 + (0-0.622)^2 + (0-0.789)^2]}$$

$$0.442 = \sqrt{\frac{1}{3}\left[(0-0.185)^2 + (0-0.400)^2 + (0-0.627)^2\right]}$$

$$0.483 = \sqrt{\frac{1}{3}[(0-0.211)^2 + (0-0.434)^2 + (0-0.685)^2]}$$

$$0.436 = \sqrt{\frac{1}{3}[(0-0.186)^2 + (0-0.392)^2 + (0-0.620)^2]}$$

$$0.448 = \sqrt{\frac{1}{3}[(0-0.202)^2 + (0-0.409)^2 + (0-0.630)^2]}$$

$$0.495 = \sqrt{\frac{1}{3}[(0-0.230)^2 + (0-0.446)^2 + (0-0.697)^2]}$$

Thus, d_i^- is computed by summation of the negative distance of eight criteria as follows:

$$d_i^- = 0.506 + 0.392 + 0.614 + 0.442 + 0.483 + 0.436 + 0.448 + 0.495 = 3.822$$

The calculation of positive distance for alternative A_1 is shown below:

$$0.562 = \sqrt{\frac{1}{3}[(1-0.239)^2 + (1-0.472)^2 + (1-0.700)^2]}$$

$$0.666 = \sqrt{\frac{1}{3}[(1-0.160)^2 + (1-0.337)^2 + (1-0.568)^2]}$$

$$0.448 = \sqrt{\frac{1}{3}[(1-0.355)^2 + (1-0.622)^2 + (1-0.789)^2]}$$

$$0.622 = \sqrt{\frac{1}{3}[(1-0.185)^2 + (1-0.400)^2 + (1-0.627)^2]}$$

$$0.589 = \sqrt{\frac{1}{3}[(1-0.211)^2 + (1-0.434)^2 + (1-0.685)^2]}$$

$$0.626 = \sqrt{\frac{1}{3}[(1 - 0.186)^2 + (1 - 0.392)^2 + (1 - 0.620)^2]}$$

$$0.611 = \sqrt{\frac{1}{3}[(1 - 0.202)^2 + (1 - 0.409)^2 + (1 - 0.630)^2]}$$

$$0.574 = \sqrt{\frac{1}{3}[(1 - 0.230)^2 + (1 - 0.446)^2 + (1 - 0.697)^2]}$$

Thus, d_i^+ is computed by summation of the positive distance of eight criteria as follows:

$$d_i^+ = 0.562 + 0.666 + 0.448 + 0.622 + 0.589 + 0.626 + 0.611 + 0.574 = 4.702$$

After obtaining the positive and negative distances, the closeness coefficient can be determined by Eq. (12). This value is the score of alternative A_1,

$$CC_0 = \frac{3.822}{3.822 + 4.702} = 0.448$$

The positive and negative distances and the closeness coefficient for each alternative are given in Table 7.

According to the closeness coefficient, the sugar plant with the highest value had the best performance, and the one with the lowest value has the worst performance. Therefore, their rank is as follows:

$$CC_3 \rangle CC_5 \rangle CC_1 \rangle CC_4 \rangle CC_9 \rangle CC_8 \rangle CC_6 \rangle CC_7 \rangle CC_2$$

The rankings were different but the best performance found was alternative A_3, as shown in Figure 3. Sugar plant A_3 is operated by the private sector, and the rest are state-owned enterprises. As can be seen from Figure 3, compared to the private sector, the performance of the state is not good

TABLE 7 The Closeness Coefficient and Ranking of Sugar Plants

	d_i^+	d_i^-	CC_i	Rank
A_1	4.702	3.822	0.448	3
A_2	6.541	1.805	0.216	9
A_3	3.566	5.019	0.584	1
A_4	4.815	3.753	0.438	4
A_5	3.983	4.523	0.531	2
A_6	5.518	2.992	0.351	7
A_7	6.330	2.113	0.250	8
A_8	5.494	3.007	0.353	6
A_9	5.155	3.380	0.396	5

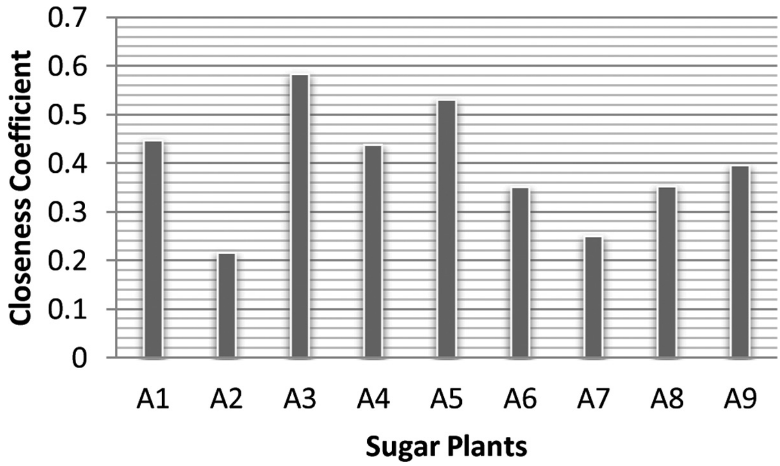

FIGURE 3 Ranking the alternatives.

enough; thus, the structure of the state sector should be considered for analyzing the efficacy of the sugar plants in strategic planning processes. The names of the sugar factories were not mentioned due to the privacy policy.

CONCLUSION

Multicriteria decision making enables the decision maker to determine criteria and evaluate their relative importance in order to make a final decision. In this study, the performance of sugar plants considering eight criteria was evaluated using a fuzzy TOPSIS method based on an MCDM process. The performance rankings were determined according to the plants' financial statements. Evaluations of the performance of nine sugar plants were performed in an effective and reliable way. Based on the findings within the described study, the proposed evaluation method could be very useful tool for assessing suitable investments and choosing the best alternative in decision-making. In addition, it can be said that fuzzy TOPSIS is an appropriate method for evaluating the performance of other industrial sectors.

REFERENCES

Aiello, G., Enea, M., Galante, G., and Scalia, G. L. "Clean Agent Selection Approached by Fuzzy TOPSIS Decision-Making Method." *Fire Technology* 45, (2009): 405–18.

Amiri, M. and Golozari, F. "Application of Fuzzy Multi-Attribute Decision Making in Determining the Critical Path by Using Time, Cost, Risk, and Quality Criteria." *International Journal of Advanced Manufacturing Technology* 54, (2011): 393–401.

Büyüközkan, G., Ruan, D., and Feyzioglu, O. "Evaluating E-Learning Web Site Quality in a Fuzzy Environment." *International Journal of Intelligent Systems* 22, (2007): 567–86.

Byun, H. S. and Lee, K. H. "A Decision Support System for the Selection of a Rapid Prototyping Process Using the Modified TOPSIS Method." *International Journal of Advanced Manufacturing Technology* 26, (2005): 1338–47.

Chen, C. T. "Extensions of the TOPSIS for Group Decision-Making under Fuzzy Environment." *Fuzzy Sets and Systems* 114, (2000): 1–9.

Daft, R. L. *Management*, 2nd ed. Chicago, USA: The Dryden Press, 1991.

Erdal, G., Esengun, K., Erdal, H., and Gunduz, O. "Energy Use and Economical Analysis of Sugar Beet Production in Tokat Province of Turkey." *Energy* 32, (2007): 35–41.

Ertuğrul, I. and Karakaşoğlu, N. "Performance Evaluation of Turkish Cement Firms with Fuzzy Analytic Hierarchy Process and TOPSIS Methods." *Expert Systems with Applications* 36, (2009): 702–15.

Hwang, C. L. and Yoon, K. *Multiple Attributes Decision Making Methods and Applications*. Berlin: Springer, 1981.

Kaufmann, A. and Gupta, M. M. *Introduction to Fuzzy Arithmetic: Theory and Applications*. New York: Van Nostrand Reinhold, 1985.

Krohling, R. A. and Campanharo, V. C. "Fuzzy TOPSIS for Group Decision Making: A Case Study for Accidents with Oil Spill in the Sea." *Expert Systems with Applications* 38, (2011): 4190–7.

Mahdavi, I., Heidarzade, A., Sadeghpour-Gildeh, B., and Mahdavi-Amiri, N. "A General Fuzzy TOPSIS Model in Multiple Criteria Decision Making." *International Journal of Advanced Manufacturing Technology* 45, (2009): 406–20.

Moyer, R. C., McGuigan, J. R., and Kretlow, W. J. *Contemporary Financial Management*. West Publishing Company, 1992.

Rahimi, S., Gandy, L., and Mogharreban, N. "A Web-Based High-Performance Multicriteria Decision Support System for Medical Diagnosis." *International Journal of Intelligent Systems* 22, no. 10 (2007): 1083–99.

Ross, T. J. *Fuzzy Logic with Engineering Applications*. West Sussex, England: Wiley, 2004.

Smitt, P. N. "Flexible Aggregation in Multiple Attribute Decision Making: Application to the Kuranda Range Road Upgrade." *Cybernetics and Systems* 37, (2006): 1–22.

Sun, C. C. and Lin, G. T. R. "Using Fuzzy TOPSIS Method for Evaluating the Competitive Advantages of Shopping Websites." *Expert Systems with Applications* 36, (2009): 11764–71.

Torfi, F. and Rashidi, A. "Selection of Project Managers in Construction Firms Using AHP and Fuzzy TOPSIS: A Case Study." *Journal of Construction in Developing Countries* 16, no. 1 (2011): 69–89.

Torlak, G., Sevkli, M., Sanal, M., and Zaim, S. "Analyzing Business Competition by Using Fuzzy TOPSIS Method: An Example of Turkish Domestic Airline Industry." *Expert Systems with Applications* 38, (2011): 3396–3406.

Wang, T. C. and Chang, T. H. "Application of TOPSIS in Evaluating Initial Training Aircraft under a Fuzzy Environment." *Expert Systems with Applications* 33, (2007): 870–80.

Wang, Y. J. and Kao, C. S. "Fuzzy TOPSIS for the Site Selection of Nodes in Supply Chain System." Paper presented at the Seventh International Conference on Fuzzy Systems and Knowledge Discovery, (2010): 103–130.

Yong, D. and Qi, L. "A TOPSIS-Based Centroid–Index Ranking Method of Fuzzy Numbers and Its Application in Decision-Making." *Cybernetics and Systems* 36, (2005): 581–95.

Zadeh, L. A. "Fuzzy Sets." *Information and Control* 8, no. 3 (1965): 338–353.

Zhao, R. and Govind, R. "Algebraic Characteristics of Extended Fuzzy Numbers." *Information Science* 54, (1991): 103–30.