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ORIGINAL ARTICLE

A multi-criteria decision-making methodology on the selection of facility location: fuzzy ANP

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Abstract Analytical ways to reach the best decisions are the most preferable issues in many business platforms. During the decision processes, besides the measurable variables, there exist qualitative variables, especially if the decision is based on a selection problem. Analytic hierarchy process (AHP) and analytic network process (ANP) are two of the best ways to decide among the complex criteria structure in different levels using qualitative variables. When there are interactions between the criteria in different levels of the hierarchy, then AHP cannot be used because of their one-way direction of hierarchy; the ANP has been developed for this kind of need. In this study, a fuzzy ANP method is developed for a multi-criteria facility location selection problem where the criteria set includes interactions with each other on the hierarchy structure. Besides the fuzzy ANP model development and implementation on facility location, sensitivity analysis was also originally performed to indicate the upper and lower bounds for the importance levels of alternative locations.

Keywords Analytic hierarchy process (AHP) · Fuzzy analytic hierarchy process (fuzzy AHP) · Fuzzy analytic network process (fuzzy ANP) · Sensitivity analysis

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1 Introduction

People need a systematic and comprehensive approach for decision making because of the person being a decision maker. Especially for the group decision-making processes concerning multiple criteria, besides the measurable variables, there exist qualitative variables, or people are supposed to prefer the best among the many choices; thus, when an analytical way to make a successful decision is needed, the analytical hierarchy process (AHP) is one of the best ways for deciding among the complex criteria structure in different levels; fuzzy AHP is the extension of AHP used for uncertain situations. When there are interactions between the criteria in different levels of the hierarchy, then AHP and fuzzy AHP do not work because of their one-way direction on hierarchy structure; the analytical network process (ANP) has then been developed for this need. The scope of this paper was to develop a basic fuzzy ANP model for facility location selection problem. In the study, a qualitative decision model is developed based on the fuzzy analytic network process and executed on a facility location problem raised in a company from the food industry.

The uncertainty in the environment generates another uncertainty for the decision makers. Then, it is more appropriate to develop a model including fuzzy sets and numbers. Another issue about the model is its criteria structure; it is a network rather than a one-directional hierarchy because regular AHP approaches cannot be used directly on the study. Therefore, the model is developed aiming at presenting a systematic approach to facility location and evaluation based on the linguistic evaluations with the fuzzy numbers. The network structure is analyzed by the ANP method in these evaluations. As seen in the ANP methodology, it requires the AHP method for its sub-matrices, where

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fuzzy ANP requires fuzzy AHP evaluations for the sub-processes and matrices. Thus, the methodology part introduces AHP, fuzzy AHP, and fuzzy ANP. Fuzzy ANP is a relatively new approach developed from the AHP and fuzzy AHP methods, and a few studies can be found about fuzzy ANP models in the literature. This paper presents a novel application on facility location selection based on fuzzy ANP, which has been relatively new in the literature when compared with AHP and fuzzy AHP applications. The paper is also differentiated from similar studies by adding sensitivity analysis results with the decision obtained from fuzzy ANP.

The continuing parts of the study are structured as follows: Section 2 presents the methodology including AHP, fuzzy AHP, ANP, and its fuzzy extension. In Section 3, the problem is defined and implementation results of the problem are discussed. At the end of the results, evaluations of the alternatives are analyzed through a sensitivity analysis.

2 Theoretical framework and literature review

In this part, the theoretical framework and the literature review are represented about AHP, ANP, Fuzzy AHP, Fuzzy ANP and facility location, respectively. After the explanation about these multi-criteria decision-making methodologies, a model formulation about fuzzy ANP is presented.

2.1 AHP and ANP methodologies

In 1977, Saaty [33] proposed the AHP as a decision aid to help solve unstructured problems in economics and social and management sciences. The AHP has been applied in a variety of contexts: from the simple everyday problem of selecting a school to the complex problems of designing alternative future outcomes of a developing country, evaluating political candidacy, allocating energy resources, and so on.

In evaluating n competing alternatives $A_1,\ldots A_n$ under a given criterion, it is natural to use the framework of pairwise comparisons represented by an $n \times n$ square matrix from which a set of preference values for the alternatives is derived. Many methods for estimating the preference values from the pairwise comparison matrix have been proposed and their effectiveness comparatively evaluated. Some of the proposed estimating methods presume interval-scaled preference values. But most of the estimating methods proposed and studied are within the paradigm of the analytic hierarchy process that presumes ratio-scaled preference values [12, 33].

AHP is a method for ranking decision alternatives and selecting the best one when the decision maker has multiple criteria. It answers the question, "Which one?" The decision maker will select the alternative that best meets his or her decision criteria. AHP is a process for developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria [32]. In AHP, preferences between alternatives are determined by making pairwise comparisons. In a pairwise comparison, the decision maker examines two alternatives based on one criterion and indicates a preference. These comparisons are made using a preference scale, which assigns numerical values to different levels of preference [33]. Ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements [30]. The AHP enables the decision makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under conflicting multi-criteria conditions. [11].

There is an extensive literature that addresses the situation where the comparison ratios are imprecise judgments [23]. In most of the real-world problems, some of the decision data can be precisely assessed while others cannot. Humans are unsuccessful in making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting [20]. Essentially, the uncertainty in the preference judgments gives rise to uncertainty in the ranking of alternatives as well as difficulty in determining the consistency of preferences [23]. These applications are performed with many different perspectives and proposed methods for fuzzy AHP. In this study, Chang's extent analysis on fuzzy AHP is formulated for a selection problem.

The fuzzy AHP technique can be viewed as an advanced analytical method developed from the traditional AHP. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision-making problems based on decision makers' judgments, fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgments of decision makers in conventional AHP approaches [4]. Therefore, many researchers [3, 5, 6, 9, 22, 24, 31] who

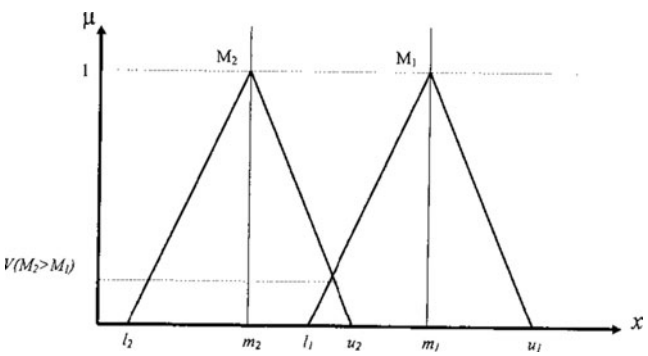


Fig. 1 Intersection between M_1 and M_2. From [47]

have studied fuzzy AHP, which is the extension of Saaty's theory, have provided evidence that fuzzy AHP shows a relatively more sufficient description of these kinds of decision-making processes compared with the traditional AHP methods. Yu [46] employed the property of goal programming to solve group decision-making fuzzy AHP problem. Sheu [38] presented a fuzzy-based approach to identify global logistics strategies. Kulak and Kahraman [20] used fuzzy AHP for multi-criterion selection among transportation companies. Kuo et al. [21] integrated fuzzy

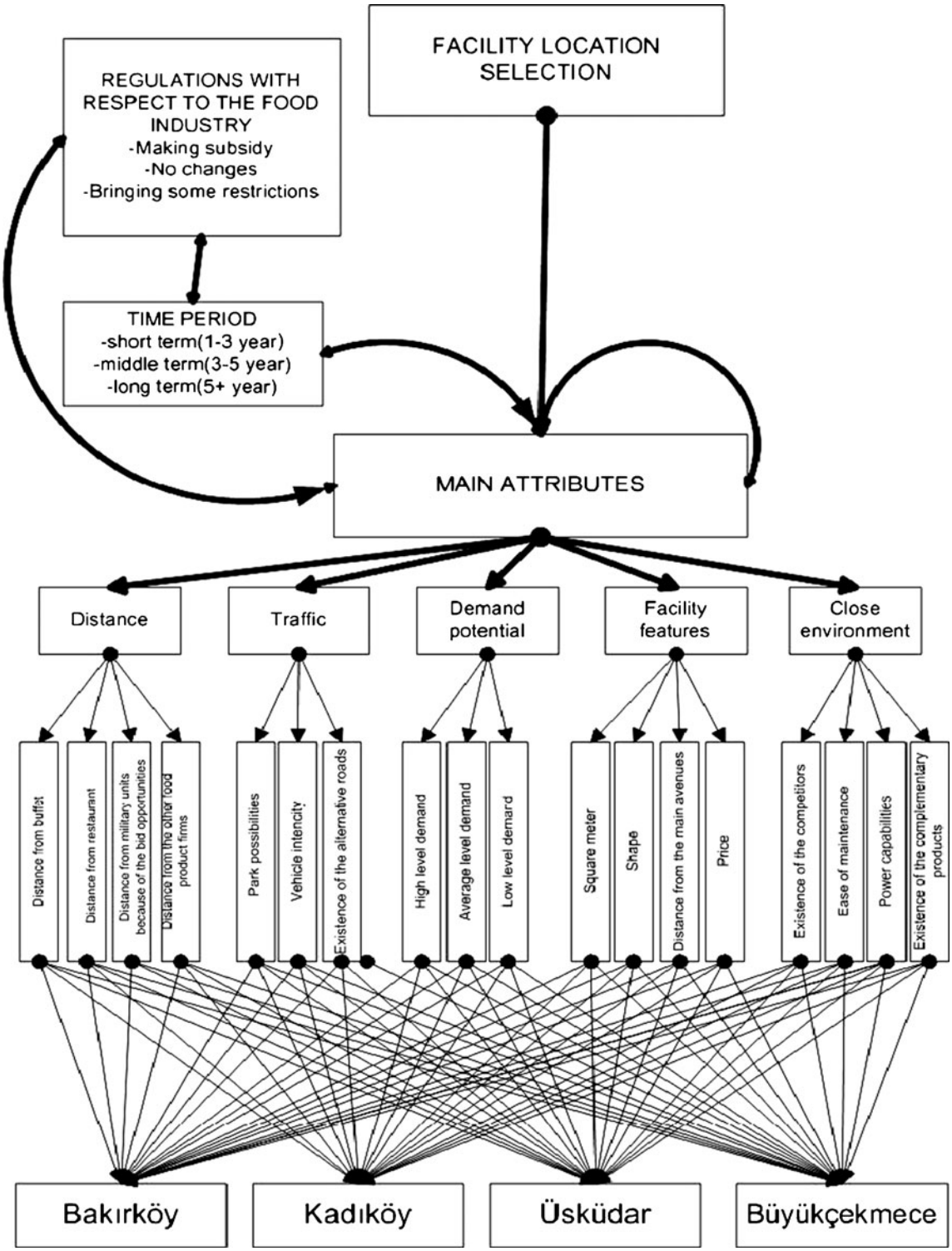


Fig. 2 General representation of the fuzzy ANP for facility location problem

Table 1 TFN values

Statement	TFN
Absolute (the criterion in the row according to the criterion in the column)	(7/2, 4, 9/2)
Very strong (the criterion in the row according to the criterion in the column)	(5/2, 3, 7/2)
Fairly strong (the criterion in the row according to the criterion in the column)	(3/2, 2, 5/2)
Weak (the criterion in the row according to the criterion in the column)	(2/3, 1, 3/2)
Equal (for both two situations)	(1, 1, 1)
Weak (the criterion in the column according to the criterion in the row)	(2/3, 1, 3/2)
Fairly strong (the criterion in the column according to the criterion in the row)	(2/5, 1/2, 2/3)
Very strong (the criterion in the column according to the criterion in the row)	(2/7, 1/3, 2/5)
Absolute (the criterion in the column according to the criterion in the row)	(2/9, 1/4, 2/7)

Developed from [40]

AHP and artificial neural network for selecting convenience store location. Cheng [10] proposed a new algorithm for evaluating naval tactical missile systems by the fuzzy AHP based on grade value of membership function. Zhu et al. [47] present a discussion on the extent analysis method and applications of fuzzy AHP.

ANP is a more general form of AHP. Whereas AHP models a decision-making framework using a unidirectional hierarchical relationship among decision levels, ANP allows for more complex interrelationships among the decision levels and components [34]. Typically, in AHP, the top element of the hierarchy is the overall goal for the decision model. The hierarchy decomposes from a general to a more specific attribute until a level of manageable decision criteria is met. ANP does not require this strictly hierarchical structure. Interdependencies may be graphically represented by two-way arrows (or arcs) among levels or, if within the same level of analysis, a looped arc. The directions of the arcs, in this case, signify dependence; arcs emanate from an attribute to other criteria that may influence it. The relative importance or strength of the impacts on a given element is measured on a ratio scale similar to AHP. A priority (relative importance weighting) vector may be determined by asking the decision maker for their numerical weight directly, but there may be less consistency since part of the process of decomposing the hierarchy is to provide better definitions of higher level criteria [36].

ANP problem formulation starts by modeling the problem that depicts the dependence and influences of the factors involved to the goal or higher level performance objective. These dependence and influences are subjectively judged by pairwise comparisons [39]. The ANP approach is capable of handling interdependences among elements by obtaining the composite weights through the development of a "supermatrix" [36]. A supermatrix is constructed whose columns are the vectors as found in the earlier step. Different ways of manipulating the supermatrix based on the particular type of the problem formulation results in the limiting weights of the criteria [39]. One of the recent studies is that by Yu and Cheng [45] which presents another application for deriving priorities using ANP. In this study, a fuzzy ANP method, one of the multi-criteria decision-making models, is developed for multi-criteria facility location selection problems where the criteria set includes interactions with each other on the hierarchy structure. After the facility location alternatives have been evaluated in many respects, according to the new facility location alternative, the upper and lower limits of the importance levels for each location alternative have been determined through the use of sensitivity analysis.

2.2 Facility location

Facility location selection is a common problem for both the manufacturing and service companies from many industries. Some of these problems are solved heuristically by the experience of the managers, but for optimal and successful decisions, this experience should be supported by analytical approaches. Among the analytical approaches, there exist qualitative techniques to analyze the subjective thoughts of the decision makers such as the analytical hierarchy process and related group decision-making methods, where there are some quantitative methods evaluating numerical data about the facility and location alternative such as optimization models, center of gravity

Table 2 Fuzzy evaluation matrix with respect to the making subsidy

	Short term (k)			Middle term (o)			Long term (u)		
Short term (k)	1	1	1	2/5	1/2	2/3	2/7	1/3	2/5
Middle term (o)	3/2	2	5/2	1	1	1	2/7	1/3	2/5
Long term (u)	5/2	3	7/2	5/2	3	7/2	1	1	1

Table 3 Evaluation of the regulations with respect to the short-term time period

	Making subsidy			No changes			Bring some restrictions		
Making subsidy	1	1	1	2/3	1	3/2	3/2	2	5/2
No changes	2/3	1	3/2	1	1	1	5/2	3	7/2
Bring some restrictions	2/5	1/2	2/3	2/7	1/3	2/5	1	1	1

W = {0.418; 0.582; 0}

technique, and geographic information systems. Empirical selection function [41], multiple regression [28], mathematical network flow model [43], branch-and-bound algorithm [19, 37], solution based on the modern heuristic methods [2, 21], integer programming model [25, 35], dynamic programming model [8], nonlinear model [27], goal programming [1], quadratic programming model [13], center of gravity approaches [14], and geographic information systems [15] are the quantitative models traditionally applied for facility location problems. Among the qualitative models, AHP [1, 42, 44], fuzzy AHP [16], Delphi method [7], quality function deployment, and analytical network process [29] are the common techniques in this field of interest.

3 Methodology

3.1 Model part 1: fuzzy ANP

In complex systems, the experiences and judgments of humans are represented by linguistic and vague patterns. Therefore, a much better representation of this linguistics can be developed as quantitative data; this type of data set is then refined by the evaluation methods of fuzzy set theory. On the other hand, the AHP method is mainly used in nearly crisp (non-fuzzy) decision applications and creates and deals with a very unbalanced scale of judgment. Therefore, the AHP method does not take into account the uncertainty associated with the mapping. The AHP's subjective judgment, selection, and preference of decision makers have great influence on the success of the method. Conventional AHP still cannot reflect the human thinking style. Avoiding these risks on performance, the fuzzy AHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems [11].

Chang's extent analysis on fuzzy AHP depends on the degree of possibilities of each criterion. According to the responses on the question form, the corresponding triangular fuzzy values for the linguistic variables are placed and, for a particular level on the hierarchy, the pairwise comparison matrix is constructed. Subtotals are calculated for each row of the matrix and a new (l,m,u) set is obtained; then, in order to find the overall triangular fuzzy values for each criterion, $l_i/\Sigma l_i$, $m_i/\Sigma m_i$, $u_i/\Sigma u_i$ (i=1, 2,…,n) values are found and used as the latest $M_i(l_i,m_i,u_i)$ set for criterion M_i in the rest of the process. In the next step, membership functions are constructed for each criterion; intersections are determined by comparing each couple. In the fuzzy logic approach, for each comparison, the intersection point is found; the membership values of the point correspond to the weight of that point. This membership value can also be defined as the degree of possibility of the value. For a particular criterion, the minimum degree of possibility of the situations where the value is greater than the others is also the weight of this criterion before normalization. After obtaining the weights for each criterion, they are normalized and called the final importance degrees or weights for the hierarchy level.

According to the method of Chang's extent analysis, each criterion is taken and extent analysis for each criterion, g_i; is performed, respectively. Therefore, m extent analysis values for each criterion can be obtained using following notation [17]:

$$M_{g_i}^1, M_{g_i}^2, M_{g_i}^3, M_{g_i}^4, M_{g_i}^5, \ldots\ldots\ldots\ldots, M_{g_i}^m$$

where g_i is the goal set (i=1, 2, 3, 4, 5,…n) and all the $M_{g_i}^j$ (j=1, 2, 3, 4, 5,…,m) are triangular fuzzy numbers (TFNs).

Table 4 Evaluation of the main criteria with respect to the time period

	Distance			Traffic			Demand potential			Facility features			Close environment		
Distance	1	1	1	2/3	1	3/2	2/3	1	3/2	2/7	1/3	2/5	2/7	1/3	2/5
Traffic	2/3	1	3/2	1	1	1	2/7	1/3	2/5	2/7	1/3	2/5	2/7	1/3	2/5
Demand potential	2/3	1	3/2	5/2	3	7/2	1	1	1	5/2	3	7/2	5/2	3	7/2
Facility features	5/2	3	7/2	5/2	3	7/2	2/7	1/3	2/5	1	1	1	5/2	3	7/2
Close environment	5/2	3	7/2	5/2	3	7/2	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1

W = {0; 0; 0.424; 0.384; 0.192}

Table 5 Evaluation of the main criteria with respect to making subsidy in regulations

	Distance			Traffic			Demand potential			Facility features			Close environment		
Distance	1	1	1	2/3	1	3/2	2/3	1	3/2	2/3	1	3/2	2/3	1	3/2
Traffic	2/3	1	3/2	1	1	1	2/7	1/3	2/5	2/7	1/3	2/5	2/7	1/3	2/5
Demand potential	2/3	1	3/2	5/2	3	7/2	1	1	1	5/2	3	7/2	5/2	3	7/2
Facility features	2/3	1	3/2	5/2	3	7/2	2/7	1/3	2/5	1	1	1	5/2	3	7/2
Close environment	2/3	1	3/2	5/2	3	7/2	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1

W = {0.078; 0; 0.522; 0.331; 0.069}

The steps of Chang's analysis can be given as in the following:

Step 1. The fuzzy synthetic extent value (S_i) with respect to the ith criterion is defined as Eq. 1.

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} \tag{1}$$

To obtain Eq. 2,

$$\sum_{j=i}^{m} M_{g_i}^{j} \tag{2}$$

perform the "fuzzy addition operation" of m extent analysis values for a particular matrix given in Eq. 3 below; at the end step of calculation, a new (l,m,u) set is obtained and used for the next:

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3}$$

where l is the lower limit value, m is the most promising value, and u is the upper limit value.To obtain Eq. 4,

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} \tag{4}$$

perform the "fuzzy addition operation" of $M_{g_i}^{j}$ (j= 1, 2, 3, 4, 5,…m) values give as Eq. 5:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{5}$$

and then compute the inverse of the vector in the Eq. 5. Equation 6 is obtained such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{6}$$

Step 2. The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as Eq. 7:

$$V(M_2) \geq M_1 = \sup_{y \geq x}\left[\min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \tag{7}$$

x and y are the values on the axis of membership function of each criterion. This expression can be equivalently written as given in Eq. 8 below:

$$V(M_2 \geq M_1) = \begin{cases} 1, & \text{if } m_2 \geq m_2, \\ 0, & \text{if } l_1 \geq u_2, \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise,} \end{cases} \tag{8}$$

where d is the highest intersection point μ_{M_1} and μ_{M_2} (see Fig. 1) [47].

Table 6 Evaluation of the main criteria with respect to the distance

	Distance			Traffic			Demand potential			Facility features			Close environment		
Distance	1	1	1	5/2	3	7/2	5/2	3	7/2	2/7	1/3	2/5	2/5	1/2	2/3
Traffic	2/7	1/3	2/5	1	1	1	2/7	1/3	2/5	2/7	1/3	2/5	2/5	1/2	2/3
Demand potential	2/7	1/3	2/5	5/2	3	7/2	1	1	1	5/2	3	7/2	5/2	3	7/2
Facility features	5/2	3	7/2	5/2	3	7/2	2/7	1/3	2/5	1	1	1	5/2	3	7/2
Close environment	3/2	2	5/2	3/2	2	5/2	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1

W = {0.21; 0; 0.378; 0.378; 0.034}

Table 7 Unweighted supermatrix

		Time period			Regulations with respect to the food industry			Main criteria				
		Short term	Middle term	Long term	Making subsidy	No changes	Bring some restrictions	Distance	Traffic	Demand potential	Facility features	Close environment
Time period	Short term	0	0	0	0	0.333	0	0	0	0	0	0
	Middle term	0	0	0	0	0.333	0.17	0	0	0	0	0
	Long term	0	0	0	1	0.333	0.83	0	0	0	0	0
Regulations with respect to the food industry	Making subsidy	0.418	1	1	0	0	0	0	0	0	0	0
	No changes	0.582	0	0	0	0	0	0	0	0	0	0
	Bring some restrictions	0	0	0	0	0	0	0	0	0	0	0
Main criteria	Distance	0	0	0	0.078	0	0.577	0.21	0	0	0	0
	Traffic	0	0	0	0	0.711	0.357	0	0	0	0	0
	Demand potential	0.424	0.424	0.424	0.522	0.289	0.066	0.378	0.577	0.577	0.577	0.577
	Facility features	0.384	0.384	0.384	0.331	0	0	0.378	0.358	0.358	0.358	0.358
	Close environment	0.192	0.192	0.192	0.069	0	0	0.034	0.065	0.065	0.065	0.065

Table 8 Weighted supermatrix

		Time period			Regulations with respect to the food industry			Main criteria				
		Short term	Middle term	Long term	Making subsidy	No changes	Bring some restrictions	Distance	Traffic	Demand potential	Facility features	Close environment
Time period	Short term	0.000	0.000	0.000	0.000	0.167	0.000	0.000	0.000	0.000	0.000	0.000
	Middle term	0.000	0.000	0.000	0.000	0.167	0.085	0.000	0.000	0.000	0.000	0.000
	Long term	0.000	0.000	0.000	0.500	0.167	0.415	0.000	0.000	0.000	0.000	0.000
Regulations with respect to the food industry	Making subsidy	0.209	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	No changes	0.291	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Bring some restrictions	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Main criteria	Distance	0.000	0.000	0.000	0.039	0.000	0.289	0.210	0.000	0.000	0.000	0.000
	Traffic	0.000	0.000	0.000	0.000	0.356	0.179	0.000	0.000	0.000	0.000	0.000
	Demand potential	0.212	0.212	0.212	0.261	0.145	0.033	0.378	0.577	0.577	0.577	0.577
	Facility features	0.192	0.192	0.192	0.166	0.000	0.000	0.378	0.358	0.358	0.358	0.358
	Close environment	0.096	0.096	0.096	0.035	0.000	0.000	0.034	0.065	0.065	0.065	0.065

Table 9 Converged supermatrix

		Time period			Regulations with respect to the food industry			Main criteria				
		Short term	Middle term	Long term	Making subsidy	No changes	Bring some restrictions	Distance	Traffic	Demand potential	Facility features	Close environment
Time period	Short term	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Middle term	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Long term	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Regulations with respect to the food industry	Making subsidy	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	No changes	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Bring some restrictions	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Main criteria	Distance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Traffic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Demand potential	0.577	0.577	0.577	0.577	0.577	0.577	0.577	0.577	0.577	0.577	0.577
	Facility features	0.358	0.358	0.358	0.358	0.358	0.358	0.358	0.358	0.358	0.358	0.358
	Close environment	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065

To compare M_1 and M_2, we need both the values of $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$:

Step 3. The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers

M_i (i=1, 2, 3, 4, 5,…k) can be defined by
$V(M \geq M_1, M_2, M_3, M_4, M_5, M_6,\ldots M_k) =$
$V[(M \geq M_1)$ and $(M \geq M_2)$ and $(M \geq M_3)$ and $(M \geq M_4)$ and… and $(M \geq M_k)] =$
$\min V(M \geq M_i)$, i=1, 2, 3, 4, 5,…k.

Assume that Eq. 9 is

$$d^l(A_i) = \min V(S_i \geq S_k) \tag{9}$$

For k=1, 2, 3, 4, 5,…n, $k \neq i$. Then, the weight vector is given by Eq. 10:

$$W^s = (d^n(A_1), d^n(A_2), d^n(A_3), d^n(A_4), d^n(A_5), \ldots\ldots\ldots, d^n(A_n))^T \tag{10}$$

where A_i (i=1, 2, 3, 4, 5, 6,…n) are n elements.

Step 4. Via normalization, the normalized weight vectors are given in Eq. 11:

$$W = (d(A_1), d(A_2), d(A_3), d(A_4), d(A_5), d(A_6), \ldots\ldots\ldots, d(A_n))^T \tag{11}$$

where W is a non-fuzzy number.

After the criteria have been determined as given in Fig. 2, a question form has been prepared to determine the importance levels of these criteria. To evaluate the questions, people only select the related linguistic variable; for calculations, they are converted to the following scale including the triangular fuzzy numbers developed by [9] and generalized for such analysis, as given in Table 1 below.

3.2 Model part 2: ANP

The ANP analysis will be reviewed through a series of six steps including the analysis of the selection of the main criteria for the facility location model, which is represented as follows.

Step 1. *Model construction and problem structuring*. The first step is to construct a model to be evaluated. The model development will require the delineation of criteria at each level and a definition of their relationships.

Step 2. *Pairwise comparisons matrices of interdependent component levels*. Eliciting preferences of various components and criteria will require a series of pairwise comparisons where the decision maker

Table 10 Evaluation of the sub-criteria with respect to the distance

	Distance from the buffets			Distance from the restaurants			Distance from the military units			Distance from the other food product firms		
Distance from the buffets	1	1	1	7/2	4	9/2	5/2	3	7/2	5/2	3	7/2
Distance from the restaurants	2/9	1/4	2/7	1	1	1	2/7	1/3	2/5	3/2	2	5/2
Distance from the military units	2/7	1/3	2/5	5/2	3	7/2	1	1	1	5/2	3	7/2
Distance from the other food product firms	2/7	1/3	2/5	2/5	1/2	2/3	2/7	1/3	2/5	1	1	1

$W = \{0.78; 0; 0.22; 0\}$

will compare two components at a time with respect to an upper level "control" criterion. These comparisons are collected in a pairwise comparison matrix. In ANP, like AHP, pairwise comparisons of the elements in each level are conducted with respect to their relative importance toward their control criterion [36].

Step 3. *Super matrix formation*. The supermatrix allows for a resolution of the effects of interdependence that exists between the elements of the ANP network. The supermatrix is a partitioned matrix where each sub-matrix is composed of the pairwise comparison matrices formed in step 2 or is zero sub-matrices (all the elements in a zero sub-matrix are zero).

Step 4. *Analyze sub-components*. A similar pairwise comparison made in step 2 is made for the criteria level for relative importance weight calculation (or eigenvector determination).

Step 5. *Alternative program, project, or technology evaluations*. Each alternative will need to be evaluated on each of the sub-criteria. This evaluation is completed by making a pairwise comparison of the performance or impact of each alternative on each sub-criteria.

Step 6. *Selection of best alternative*. The selection of the best alternative depends on the calculation of the "desirability index" for an alternative *i*.

As seen in the ANP methodology, ANP requires the AHP method for its sub-matrices, where fuzzy ANP requires fuzzy AHP evaluations for the sub-processes and matrices following the steps given above. Fuzzy ANP is a relatively new approach developed from the AHP and fuzzy AHP methods. A few studies can be found about fuzzy ANP models in the literature. Yu [46] made a short communication in fuzzy ANP. Kahraman et al. [18] employed an integrated fuzzy ANP approach to formulate and solve a quality function deployment problem. The ANP method deals only with crisp comparison ratios. However, uncertain human judgments with internal inconsistency obstructing the direct application of the ANP are frequently found. To cope with this problem, Mikhailov and Singh [26] proposed the fuzzy ANP (FANP) method.

4 Case study and implementation results

Then, the selection criteria are discussed with the firm according to their experiences and the location choices for the new facility in mind. During the interviews, a concept map is used to construct the criteria set and their network structure. The results of these interviews are converted into interdependencies that are constructed in Fig. 2, which also shows the main and the sub-criteria for the facility location selection problem. In the next step, in harmony with the interdependencies in Fig. 2, the pairwise comparison matrices are prepared. Then, the unweighted supermatrix is constructed in conformity with the matrix results. The supermatrix is used for determining the importance levels of the main criteria in accordance with all interdependencies. The next step consists of calculating the importance levels of the sub-criteria according to main criteria and then

Table 11 Evaluation of the sub-criteria with respect to the traffic

	Park capabilities			Vehicle intensity			Existence of the alternative roads		
Park possibilities	1	1	1	2/7	1/3	2/5	2/7	1/3	2/5
Vehicle intensity	5/2	3	7/2	1	1	1	5/2	3	7/2
Existence of the alternative roads	5/2	3	7/2	2/7	1/3	2/5	1	1	1

$W = \{0; 0.907; 0.093\}$

Table 12 Evaluation of the sub-criteria with respect to the facility features

	Square meter			Shape			Distance from the main avenues			Price		
Square meter	1	1	1	5/2	3	7/2	1	1	1	2/7	1/3	2/5
Shape	2/7	1/3	2/5	1	1	1	2/7	1/3	2/5	2/7	1/3	2/5
Distance from the main avenues	1	1	1	5/2	3	7/2	1	1	1	2/7	1/3	2/5
Price	5/2	3	7/2	5/2	3	7/2	5/2	3	7/2	1	1	1

$W = \{0; 0; 0; 1\}$

calculating the importance levels of the alternatives according to the sub-criteria. By utilizing these data, facility location alternatives are compared. Then, a sensitivity analysis is performed for the alternatives in the event that a new facility location alternative is added to the finding of the performed study.

After the criteria were determined, a questionnaire is prepared to compare the goal, the main criteria, the sub-criteria, and the alternatives. In this questionnaire form, the importance of criteria and alternatives are evaluated linguistically which are analyzed by converting them into the TFNs given in Table 1. The next stage is to construct a fuzzy evaluation matrix with respect to the goal, the main criteria, the sub-criteria, and the alternatives. According to the mutual relationships between "regulations with respect to the food industry" and "time period," which are shown in Fig. 2, the time periods (short term, middle term, and long term) are compared with regard to the regulations with respect to the food industry (making subsidy, no changes, and bringing some restrictions). Table 2 shows the comparisons among the short term, middle term, and long term with regard to making a subsidy, which is one of the regulations with respect to the food industry.

In Table 2, the importance of the main criteria is determined with respect to the decision "making subsidy." From Table 2, S_k = (1.686; 1.833; 2.067) $\otimes$ (1/10.471; 1/12.166; 1/13.966) = (0.121; 0.151; 0.197); S_o = (2.786; 3.333; 3.9) $\otimes$ (1/10.471; 1/12.166; 1/13.966) = (0.199; 0.274; 0.372); S_u = (6; 7; 8) $\otimes$ (1/10.471; 1/12.166; 1/13.966) = (0.43; 0.575; 0.764) are obtained. Using these vectors, $V(M_k \geq M_o) = 0$, $V(M_k \geq M_u) = 0$, $V(M_o \geq M_k) = 0$, $V(M_o \geq M_u) = 0$, $V(M_u \geq M_k) = 1$ and $V(M_u \geq M_o) = 1$ are obtained. Thus, the weight vector from Table 2 is calculated as $W = \{0; 0; 1\}^T$.

The importance levels of the short-term, middle-term, and long-term time periods with regard to no changes and bringing some restrictions, which are the rest of the regulations with respect to the food industry, are found as {0.333; 0.333; 0.333} and {0; 0.17; 0.83}, respectively. According to the interactions or interdependencies, major decisions about making subsidy or not are evaluated with respect to the short time period, as given in Table 3.

The importance levels of making subsidy, no changes in regulations, and bringing some restrictions regarding the middle-term and long-term time periods are found as {1; 0; 0} and {1; 0; 0}, respectively. As in the structure given in Fig. 2, the next phase is to evaluate the main criteria about the characteristics of the alternative places with respect to the other criteria in interaction with the main criteria given in the network structure. Table 4 shows the comparisons among the main criteria—distance, traffic, demand potential, facility features, and close environment—with respect to the short-term time period.

Using the same mathematical operations, the importance levels of the main criteria—distance, traffic, demand potential, facility features, close environment—with respect to the middle and long-term time periods, which are the rest of the time periods, are found as {0; 0; 0.424; 0.384; 0.192} and {0; 0; 0.424; 0.384; 0.192}, respectively. Table 5 shows the comparisons among the main criteria—distance, traffic, demand potential, facility features, and close environment—with respect to the making subsidy in regulations.

Using the same procedure given in Table 5, the importance levels of the main criteria—distance, traffic, demand potential, facility features, close environment—with respect to the no changes and bringing some restrictions, which are the rest of the regulations concerning

Table 13 Evaluation of the sub-criteria with respect to the demand potential

	High-level demand			Average-level demand			Low-level demand		
High level demand	1	1	1	7/2	4	9/2	7/2	4	9/2
Average level demand	2/9	1/4	2/7	1	1	1	5/2	3	7/2
Low level demand	2/9	1/4	2/7	2/7	1/3	2/5	1	1	1

$W = \{1; 0; 0\}$

Table 14 Evaluation of the sub-criteria with respect to the close environment

	Existence of the competitors			Ease of maintenance			Power capabilities			Existence of the complement products		
Existence of the competitors	1	1	1	5/2	3	7/2	3/2	2	5/2	3/2	2	5/2
Ease of maintenance	2/7	1/3	2/5	1	1	1	2/7	1/3	2/5	3/2	2	5/2
Power capabilities	2/5	1/2	2/3	5/2	3	7/2	1	1	1	5/2	3	7/2
Existence of the complement products	2/5	1/2	2/3	2/5	1/2	2/3	2/7	1/3	2/5	1	1	1

W = {0.525; 0; 0.475; 0}

the food industry, are found as {0; 0.711; 0.289; 0; 0} and {0.577; 0.357; 0.066; 0; 0}, respectively. If Fig. 2 is examined, it can be seen that there are mutual relationships among the main criteria. Table 6 exhibits the comparisons among the main criteria—distance, traffic, demand potential, facility features, close environment—corresponding to the distance.

The importance levels of the main criteria—distance, traffic, demand potential, facility features, close environment—belonging to traffic, demand potential, facility features, close environment, which are the rest of the main criteria, are found as {0; 0; 0.577; 0.358; 0.065}, {0; 0; 0.577; 0.358; 0.065}, {0; 0; 0.577; 0.358; 0.065}, and {0; 0; 0.577; 0.358; 0.065}, respectively. The fuzzy evaluation matrix calculations give the parts of the unweighted supermatrix. Therefore, the supermatrix is constructed taking the table given so far as the components, and then the supermatrix is developed as given in Table 7, which is the unweighted one. Using the evaluations and reflecting the weights obtained from these evaluations generates the weighted supermatrix given in Table 8. As the last step of the ANP, calculating the convergent matrix, the general results are obtained by raising the supermatrix to the power 20, which allows convergence of the interdependent relationships and provides the long-term impacts of the components on each other. The converged supermatrix is shown in Table 9. The numbers of powers are not constant like 20; it is dependent on the number of steps when the values do not change within the matrix. This process is well known in the concept of Markov chain and Markov processes and used to obtain long-term transition probabilities.

After this stage, the evaluation of the sub-criteria with respect to the main criteria is carried out with the same phases given in Tables 10, 11, 12, 13, and 14 according to the network structure presented in Fig. 2.

The next step is to evaluate the alternatives with respect to the sub-criteria. Table 15 exhibits an example of the comparisons of the facility location alternatives pertaining to the sub-criterion. The other comparison results of the facility location alternatives as to the other sub-criteria can be seen in Table 18.

Final calculations of the importance levels of the main criteria and sub-criteria have been shown in Tables 16 and 17, respectively.

Then, the importance levels are calculated for the alternative locations with respect to the sub-criteria shown in Table 18, and the final general importance levels calculated are given in Table 19 and represented as follows.

As far as Table 16 is concerned, demand potential, facility features, and close environment are the important criteria for facility location selection. Demand potential is the most important feature for this problem, with 0.577 importance level. For the sub-criteria, high-level demand and the price of the facility are the most important factors. In order to select the most appropriate location, four alternative locations were compared. When the results are analyzed in Table 19, Bakirkoy obtained 0.684 global importance level according to the all sub-criteria. The second appropriate location is Kadikoy, which obtained 0.316 global importance level according to all the sub-criteria. According to these results, the company should eliminate Uskudar and Buyukcekmece options. If the tables are looked through from beginning to end, some of the

Table 15 Evaluation of the sub-criteria with respect to the distance from the buffets

	Bakırköy			Kadıköy			Üsküdar			Büyükçekmece		
Bakırköy	1	1	1	5/2	3	7/2	5/2	3	7/2	5/2	3	7/2
Kadıköy	2/7	1/3	2/5	1	1	1	5/2	3	7/2	5/2	3	7/2
Üsküdar	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1	5/2	3	7/2
Büyükçekmece	2/7	1/3	2/5	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1

W = {0.684; 0.316; 0; 0}

Table 16 Importance levels of the main criteria

Main attribute	Importance level
Distance	0
Traffic	0
Demand potential	0.577
Facility features	0.358
Close environment	0.065

criteria have zero importance values, which are a natural result in fuzzy evaluations. However, these zero importance values explain that the related criterion is considered at the beginning of the evaluations, but in fact, they are not important when compared with the other criteria. If the evaluations are carried out with traditional crisp values, these criteria would not be calculated as zero, but will be very close to zero.

5 Sensitivity analysis in fuzzy AHP methodology

Fuzzy AHP methodology is studied in the criteria hierarchy which is constructed for the problem that is described in the outset. Therefore, alternatives are evaluated according to these criteria in the problem solving. When a new alternative is added on the same problem set, sensitivity analysis can be done for finding out how it can affect the other alternatives. Sensitivity analysis for fuzzy AHP evaluations can be modeled as follows:

A Goal, main criterion or sub-criterion
C_i ith main criterion, sub-criterion, or alternative i=1, 2, …n and j=1, 2,…n
C_y New main criterion, sub-criterion, or alternative
l_{ij} Lower limit value in the fuzzy pairwise comparison of the main criterion, sub-criterion, or alternative in the ith row according to the main criterion sub-criterion or alternative in the jth column
m_{ij} The most likely value in the fuzzy pairwise comparison of the main criterion, sub-criterion, or alternative in the ith row according to the main criterion, sub-criterion, or alternative in the jth column
u_{ij} Upper limit value in the fuzzy pairwise comparison of the main criterion, sub-criterion, or alternative in the ith row according to the main criterion, sub-criterion, or alternative in the jth column
n Number of main criterion, sub-criterion, or alternative

The general structure of the fuzzy evaluation matrix according to the symbols that are explained above is shown in Table 20.

In the proposed approach, the limits of the alternatives have been constructed according to the assigned weights to the new alternative. Preparation of the fuzzy evaluation

Table 17 Importance levels of the sub-criteria

	Importance level	Sub-attribute	Importance level (local)	Importance level (global)
Distance	0	Distance from the buffets	0.78	0
		Distance from the restaurants	0	0
		Distance from the military units	0.22	0
		Distance from the other food product firms	0	0
Traffic	0	Park possibilities	0	0
		Vehicle intensity	0.907	0
		Existence of the alternative roads	0.093	0
Facility features	0.358	Square meter	0	0
		Shape	0	0
		Distance from the main avenues	0	0
		Price	1	0.358
Demand potential	0.577	High level demand	1	0.577
		Average level demand	0	0
		Low level demand	0	0
Close environment	0.065	Existence of the competitors	0.525	0.034
		Ease of maintenance	0	0
		Power capabilities	0.475	0.031
		Existence of the complement products	0	0

Table 18 Importance levels of the alternatives

Sub-attribute	Bakırköy	Kadıköy	Üsküdar	Büyükçekmece
Distance from the buffets	0.684	0.316	0	0
Distance from the restaurants	0.586	0.414	0	0
Distance from the military units	0.684	0.316	0	0
Distance from the other food product firms	0.468	0.422	0.11	0
Park possibilities	0.25	0.25	0.25	0.25
Vehicle intensity	0.062	0.244	0.347	0.347
Existence of the alternative roads	0.684	0.316	0	0
Square meter	0.684	0.316	0	0
Shape	0.468	0.422	0.11	0
Distance from the main avenues	0.684	0.316	0	0
Price	0.684	0.316	0	0
High-level demand	0.684	0.316	0	0
Average-level demand	0.684	0.316	0	0
Low-level demand	0	0.178	0.411	0.411
Existence of the competitors	0.684	0.316	0	0
Ease of maintenance	0.684	0.316	0	0
Power capabilities	0.684	0.316	0	0
Existence of the complement products	0.684	0.316	0	0

matrix aiming at finding the changing interval of the importance values is given below.

W_{ia} Importance level lower limit value of the ith main criterion, sub-criterion, or alternative

W_{iu} Importance level upper limit value of the ith main criterion, sub-criterion, or alternative

Fuzzy evaluation matrix in the assumption that a new main criterion, sub-criterion, or alternative is absolutely important according to the existing main criterion, sub-criterion, or alternative gives the lower limit value of the existing main criterion, sub-criterion, or alternative. Fuzzy evaluation matrix with respect to this condition is shown in Table 21.

Table 19 General importance levels of the sub-criteria

Sub-attribute	Global importance level	Bakırköy	Kadıköy	Üsküdar	Büyükçekmece
Distance from the buffets	0	0	0	0	0
Distance from the restaurants	0	0	0	0	0
Distance from the military units	0	0	0	0	0
Distance from the other food product firms	0	0	0	0	0
Park possibilities	0	0	0	0	0
Vehicle intensity	0	0	0	0	0
Existence of the alternative roads	0	0	0	0	0
Square meter	0	0	0	0	0
Shape	0	0	0	0	0
Distance from the main avenues	0	0	0	0	0
Price	0.577	0.395	0.182	0	0
High-level demand	0.358	0.245	0.113	0	0
Average-level demand	0	0	0	0	0
Low-level demand	0	0	0	0	0
Existence of the competitors	0.034	0.023	0.011	0	0
Ease of maintenance	0	0	0	0	0
Power capabilities	0.031	0.021	0.010	0	0
Existence of the complement products	0	0	0	0	0
General importance level		0.684	0.316	0	0

Table 20 Mathematical exhibition of fuzzy evaluation matrix

In terms of A	C_1			C_2			–			C_n		
C_1	1	1	1	l_{12}	m_{12}	u_{12}	…	…	…	l_{1n}	m_{1n}	u_{1n}
C_2	$1/u_{12}$	$1/m_{12}$	$1/l_{12}$	1	1	1	…	…	…	l_{2n}	m_{2n}	u_{2n}
…	…	…	…	…	…	…	1	1	1	…	…	…
C_n	$1/u_{1n}$	$1/m_{1n}$	$1/l_{1n}$	$1/u_{2n}$	$1/m_{2n}$	$1/l_{2n}$	…	…	…	1	1	1

Table 21 Fuzzy evaluation matrix for "new is the best"

In terms of A	C_1			C_2			....			C_n			C_y		
C_1	1	1	1	l_{12}	m_{12}	u_{12}	…	…	…	l_{1n}	m_{1n}	u_{1n}	2/9	1/4	2/7
C_2	$1/u_{12}$	$1/m_{12}$	$1/l_{12}$	1	1	1	…	…	…	l_{2n}	m_{2n}	u_{2n}	2/9	1/4	2/7
…	…	…	…	…	…	…	1	1	1	…	…	…	2/9	1/4	2/7
C_n	$1/u_{1n}$	$1/m_{1n}$	$1/l_{1n}$	$1/u_{2n}$	$1/m_{2n}$	$1/l_{2n}$	…	…	…	1	1	1	2/9	1/4	2/7
C_y	7/2	4	9/2	7/2	4	9/2	7/2	4	9/2	7/2	4	9/2	1	1	1

W_{ia} is obtained in the fuzzy calculations by utilizing this fuzzy evaluation matrix

Table 22 Fuzzy evaluation matrix for "new is the worst"

In terms of A	C_1			C_2			....			C_n			C_y		
C_1	1	1	1	l_{12}	m_{12}	u_{12}	…	…	…	l_{1n}	m_{1n}	u_{1n}	7/2	4	9/2
C_2	$1/u_{12}$	$1/m_{12}$	$1/l_{12}$	1	1	1	…	…	…	l_{2n}	m_{2n}	u_{2n}	7/2	4	9/2
…	…	…	…	…	…	…	1	1	1	…	…	…	7/2	4	9/2
C_n	$1/u_{1n}$	$1/m_{1n}$	$1/l_{1n}$	$1/u_{2n}$	$1/m_{2n}$	$1/l_{2n}$	…	…	…	1	1	1	7/2	4	9/2
C_y	2/9	1/4	2/7	2/9	1/4	2/7	2/9	1/4	2/7	2/9	1/4	2/7	1	1	1

W_{ia} is obtained in the fuzzy calculations by utilizing this fuzzy evaluation matrix

Table 23 Fuzzy evaluation matrix for "new is the best"

In terms of the distance from the buffets	Bakırköy			Kadıköy			Üsküdar			Büyükçekmece			New		
Bakırköy	1	1	1	5/2	3	7/2	5/2	3	7/2	5/2	3	7/2	2/9	1/4	2/7
Kadıköy	2/7	1/3	2/5	1	1	1	5/2	3	7/2	5/2	3	7/2	2/9	1/4	2/7
Üsküdar	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1	5/2	3	7/2	2/9	1/4	2/7
Büyükçekmece	2/7	1/3	2/5	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1	2/9	1/4	2/7
New	7/2	4	9/2	7/2	4	9/2	7/2	4	9/2	7/2	4	9/2	1	1	1

Table 24 Fuzzy evaluation matrix for "new is the worst"

In terms of the distance from the buffets	Bakırköy			Kadıköy			Üsküdar			Büyükçekmece			New		
Bakırköy	1	1	1	5/2	3	7/2	5/2	3	7/2	5/2	3	7/2	7/2	4	9/2
Kadıköy	2/7	1/3	2/5	1	1	1	5/2	3	7/2	5/2	3	7/2	7/2	4	9/2
Üsküdar	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1	5/2	3	7/2	7/2	4	9/2
Büyükçekmece	2/7	1/3	2/5	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1	7/2	4	9/2
New	2/9	1/4	2/7	2/9	1/4	2/7	2/9	1/4	2/7	2/9	1/4	2/7	1	1	1

Fuzzy evaluation matrix in the assumption that all existing main criteria, sub-criteria, or alternatives are absolutely important according to the new main criterion, sub-criterion, or alternative gives the upper limit value of the existing main criterion, sub-criterion, or alternative. Fuzzy evaluation matrix with respect to this condition is shown in Table 22.

An example for the sensitivity procedure is shown in Tables 23 and 24. Table 23 shows the fuzzy evaluation matrix according to the condition that a new location alternative is absolutely important according to the existing alternatives in terms of the distance from the buffets. Table 24 shows the fuzzy evaluation matrix according to the condition that the existing alternatives are absolutely important according to the new location alternative in terms of the distance from the buffets

After the implementation of this procedure for all sub-criteria, the importance level lower and upper limit values are shown in Table 25.

Because of the fact that the importance levels are shared among the five alternatives instead of four, the upper interval levels are lower than the original facility location alternatives. This is the natural result of the ratio scale and AHP–ANP–fuzzy AHP–fuzzy ANP methodologies. The most frequent upper importance levels for the original alternatives are 0.582; 0.356; 0.063; 0, respectively.

6 Conclusion

Various methods are developed for decision-making processes when an analytical way to make a successful decision is needed; AHP is one of the best ways for deciding among the complex criteria structure in different levels. In the time being, AHP method is extended for different conditions of the decision environment. Classical AHP requires deterministic evaluations; the fuzzy AHP method was developed concerning fuzzy linguistic variables where the decisions are made in uncertain conditions. AHP and its extensions work on a one-way hierarchical structure of criteria grouped in many levels and do not allow any interactions with the other criteria from different hierarchy levels. ANP was arisen on this constraint of AHP and is a methodology for criteria set in interaction with each other such as a network to any direction including sub-matrices and sub-processes based on classical AHP pairwise comparison method. When

Table 25 Intervals for the alternatives

Sub-attribute	Bakırköy		Kadıköy		Üsküdar		Büyükçekmece		New location alternative	
	Lower interval value	Upper interval value	Lower interval value	Upper interval value	Lower interval value	Upper interval value	Lower interval value	Upper interval value	Lower interval value	Upper interval value
Distance from the buffets	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Distance from the restaurants	0.000	0.486	0.000	0.382	0.000	0.132	0.000	0.000	0.000	1.000
Distance from the military units	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Distance from the other food product firms	0.000	0.415	0.000	0.386	0.000	0.199	0.000	0.000	0.000	1.000
Park possibilities	0.000	0.250	0.000	0.250	0.000	0.250	0.000	0.250	0.000	1.000
Vehicle intensity	0.000	0.162	0.000	0.242	0.000	0.298	0.000	0.298	0.000	1.000
Existence of the alternative roads	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Square meter	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Shape	0.000	0.415	0.000	0.386	0.000	0.199	0.000	0.000	0.000	1.000
Distance from the main avenues	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Price	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
High level demand	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Average level demand	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Low level demand	0.000	0.094	0.000	0.218	0.000	0.344	0.000	0.344	0.000	1.000
Existence of the competitors	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Ease of maintenance	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Power capabilities	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963
Existence of the complement products	0.037	0.582	0.000	0.356	0.000	0.063	0.000	0.000	0.000	0.963

decisions will be made in uncertain environments including interactions among the criteria, ANP with fuzzy evaluations is necessary for solution. The major distinction between ANP and fuzzy ANP is its pairwise comparisons, where it is performed based on fuzzy AHP in fuzzy ANP rather than classical AHP.

As a case study to show the applicability of the proposed method, a fuzzy ANP method was successfully implemented for the facility location selection problem raised in the food industry. The managers of which decide whether to establish a new facility in Istanbul, Turkey, or not. Finally, among the choices, a decision was to establish a new location and Bakırköy was selected for this new facility, which was also approved as a right decision according to this experience.

Consequently, one of the main contributions of this study is its fuzziness of ANP, which is not applied in this field of interest; furthermore, there were not many papers presenting ANP applications including fuzzy evaluations. This study could also be evaluated as a successful application example for qualitative problems including multiple criteria interacting with each other. The second major contribution is that the paper included a sensitivity analysis.

After the fuzzy logic is integrated with the ANP methodology, a sensitivity analysis was introduced for determining the changing intervals for the importance levels of the facility location alternatives in the event that a new facility location alternative was added to the problem.

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