A Multi-Attribute Decision-Making Model for Hospital Location Selection

Gül İmamoğlu and Y. Ilker Topcu

Abstract The demand for the healthcare sector is increasing day by day due to the population growth, the prolongation of the average human life, changing eating habits, and the rapid spread of epidemics such as COVID-19 in large areas. New hospitals are being built in Turkey, as in other countries, to meet the increase in demand in the health sector and reach high health standards. Therefore, the selection of hospital location arises as a vital decision problem. In the case of an incorrect hospital location, loss of life can occur, as well as a significant financial burden. For this reason, decision makers should handle hospital location selection with analytical and rational methods. For this purpose, in this study, a hybrid Multi-Attribute Decision-Making model, in which the importance of the attributes is determined using the Analytic Network Process method, and evaluating the alternatives is carried out by the PROMETHEE method was proposed. As a case study, the proposed model was utilized to select a suitable location for a new hospital in Trabzon, Turkey.

Keywords Healthcare · Hospital Location Selection · Multi-Attribute Decision-Making · Analytic Network Process · PROMETHEE

1 Introduction

Due to the environmental factors brought about by modern life, changing eating habits, and the prolongation of average life expectancy, the proportion of the elderly population and diseases is increasing. In addition, pandemics such as the COVID-19 outbreak increase the number of patients dramatically in a short time.

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All these factors lead to an increase in the demand for the health sector. Accordingly, new hospitals have to be built as hospitals are essential components of health systems and critical points of reforms in the health sector. They provide constant nursing care, beds, and meals for their patients who undergo medical therapy at the hands of professional physicians.

Health expenditures are increasing both in Turkey and other countries. For this reason, governments attach great importance to the more effective use of hospitals (Atılgan, 2016). The efficiency of hospitals is affected by many factors. These factors can be grouped under clinical effectiveness and managerial effectiveness (Fragkiadakis et al., 2016).

Hospital location selection is one of the critical elements of managerial effectiveness. An appropriate selection of the location will attract many potential patients and affect the hospital's business success (Soltani and Marandi, 2011). On the other hand, an improper location selection for a hospital can result in the loss of life. Furthermore, it will also create a sizeable monetary load, likewise any wrong location selection for any purpose. For these reasons, the hospital location selection should be focused on analytical and rational methods.

Location selection problems are often addressed under a "set-covering" framework as the goal is to achieve maximum coverage at minimum cost. In addition to coverage and cost, there should be other evaluation factors when choosing a hospital location. Demand, centrality, proximity to major roads, distance to noise centers, and other similar factors need to be considered. Therefore, Multi-Attribute Decision-Making (MADM) methods, which consider many factors and offer an integrated assessment that evaluates alternatives with respect to these factors, can be utilized to treat hospital location decision problems.

This study differs from other hospital location selection studies, which will be discussed in the following section, regarding a careful consideration of the evaluation attributes and usage of actual data not considered in previous studies. Besides, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), an effective outranking MADM method, was utilized for the first time in the hospital location selection.

Another contribution of this study is the analysis of a local hospital location selection problem. A case study was conducted in Trabzon Province. Trabzon is an attractive destination to become a leading international medical tourism center by providing treatment and rehabilitation services to international patients, especially patients from Azerbaijan, Georgia, Iran, and Arab countries. In Trabzon, there is a hospital shortage for both locals and those who come for health tourism.

This chapter aims to identify the factors that should be taken into account when choosing a hospital location. Additionally, it also aims to reveal the importance of these factors and recommend policymakers the appropriate locations for a hospital to be built in Trabzon. For this purpose, we used an integrated decision approach utilizing Analytic Network Process (ANP) and PROMETHEE methods.

The rest of the chapter is organized as follows. In section "Literature Review," a literature review of hospital location selection is presented. The theoretical background of the methods utilized in the proposed approach is provided in section "Methods." Section "Application of the Proposed Approach" presents the application of the proposed approach for the hospital location selection in Trabzon province and the revealed results. Finally, some concluding remarks and further suggestions are specified in section "Conclusions and Further Suggestions."

2 Literature Review

The studies on location selection are prevalent in the literature. When we searched the Web of Science Core Collection with the topic "location selection" and "multi-attribute decision-making," we have found 37 articles published in 2020 and 2021.

Some of them are analyzing the following location selection problems in the energy sector:

- Thermal power plant (Milovanovic et al., 2021)
- Offshore wind power station/farm (Abdel-Basset et al., 2021; Tercan et al., 2020)
- Marine current energy production plant (Yucenur and Ipekci, 2021)
- Artificial recharge site with treated wastewater (Mahmoudi et al., 2021)
- Solar site / photovoltaic plants (Kannan et al., 2021; Furtado and Sola, 2020)
- Distributed photovoltaic power stations for high-speed railway (Li et al., 2020)

There are also some studies addressing location selection problems in logistics and supply chain management:

- Inland terminal for shipping lines (Liang et al., 2021)
- Warehouse location or distribution center (Ehsanifar et al., 2020; Agrebi and Abed 2021; Liu and Li, 2020)
- Emergency shelter in preparation for immediate, short-, and long-term floods (Lee et al., 2020)

On the other hand, in an earlier study, Imamoglu (2015) conducted an extensive literature survey on location selection. She found studies in various areas such as logistics (Yang et al., 2007; Demirel et al., 2010; Kampf et al., 2011; Dey et al., 2013; Wey, 2015), energy (Magaji and Mustafa, 2011; Yunna and Geng, 2014; Kumar and Srikanth, 2015), environment (Meng and Lu, 2011; Kabir and Sumi, 2014; Gang et al., 2015), manufacturing (Guneri et al., 2009; Shen and Yu, 2009; Mokhtarian and Hadi-Vencheh, 2012; Rahmaniani and Ghaderi, 2015), informatics (Lu et al., 2011; Xie et al., 2013), retailing (Cheng et al., 2007), tourism and hospitality (Chou et al., 2008; Ishizaka et al., 2013; Dock et al., 2015), and disaster management (Kılcı et al., 2015).

The field of application of the studies on location selection has recently shifted to the energy sector. This outcome is not surprising as the climate crisis, affordable and clean energy, and environmental sustainability are among the top global challenges the world is facing. However, since 2020, humanity has been paying close attention to the worldwide pandemic that has brought about a health crisis as well as an economic crisis, an inequality crisis, an education crisis, and other crises. So health care management will be again one of the promising fields. For instance, in the recent literature, the following location selection studies address healthcare management in a multi-criteria decision-making environment. Zeferino et al. (2021) proposed an integrated approach for selecting a suitable quarantine facility for COVID-19 patients. Mirzahossein et al. (2020) developed a model to choose the appropriate locations for the construction of the medical emergency centers.

We conducted a literature survey to classify the studies treating hospital location selection problems with respect to the multi-attribute decision-making methods utilized:

- AHP (Sinuany-Stern et al., 1995; Wu et al., 2007a; Chatterjee and Mukherjee, 2013; Chiu and Tsai, 2013; Şahin et al., 2019)
- ANP (Onut et al., 2008)
- Fuzzy AHP (Wu et al., 2007b; Lin et al., 2008; Aydın and Arslan, 2010)
- Fuzzy ANP (Wu et al., 2009)
- AHP and Pareto technique (Zeferino et al., 2021)
- AHP and Geographic Information System integration (Eldemir and Onden, 2016; Mirzahossein et al., 2020)
- AHP and Gray Relational Analysis integration (Şen and Demiral, 2016)
- ANP and TOPSIS integration (Lin and Tsai, 2009)
- Fuzzy AHP and Geographic Information System integration (Vahidnia et al., 2009)
- Fuzzy ANP and Geographic Information System integration (Soltani and Marandi, 2011)
- Hesitant Fuzzy Sets and TOPSIS integration (Şenvar et al., 2016)
- Additive Ratio Assessment method with Gray values (Sen, 2017)
- Data Envelopment Analysis (Lin et al., 2010)

As can be seen, Analytic Hierarchy Process (AHP) and its variants are widely used. Some of these studies offer an appropriate location for a hospital across the country. Sinuany-Stern et al. (1995) developed mathematical models for hospital location selection, which were planned to be established to ensure smooth distribution of the population in the Negev region. They have identified six alternative cities. They utilized AHP to evaluate the alternatives. Wu et al. (2007a) determined which one of the three alternatives would be appropriate to provide a competitive advantage for a hospital to be built in Taiwan by utilizing AHP and made a sensitivity analysis for the importance of the attributes. Chatterjee and Muherjee (2013) used AHP to evaluate three potential rural hospital sites in India based on three attributes and 11 sub-attributes. To build the planned regional teaching hospital in Taiwan's Yunlin County, Chiu and Tsai (2013) have determined which one of the two major regions of the county would be appropriate using AHP.

On the other hand, some studies offer an appropriate location in a city or region. Şahin et al. (2019) have developed a hospital location selection model for the province Muğla of Turkey by utilizing AHP. This model determined counties as alternatives, and evaluation is made based on six attributes and 19 sub-attributes.

There are also studies utilizing the ANP method. For a medium-sized hospital planned to be established in Istanbul, Onut et al. (2008) have decided which one of the three alternative counties would be appropriate by utilizing ANP. Wu et al. (2009) have determined with Fuzzy ANP which of the three alternative cities would be convenient for the planned establishment of the hospital in Taiwan.

Like Wu et al. (2009), some researchers used fuzzy sets and algorithms to treat the problem. Wu et al. (2007b) made the location selection for the planned establishment of a regional hospital in Taiwan by Fuzzy AHP. Lin et al. (2008) evaluated three alternatives according to six attributes and 18 sub-attributes using Fuzzy AHP to establish a competitive regional hospital in Taiwan. Aydın and Arslan (2010) decided which of the five candidate regions would be appropriate to establish a new hospital in Ankara by Fuzzy AHP. According to six attributes with the ARAS-G method, Sen (2017) evaluated three alternative locations for a new public hospital.

Another group of studies treated the location selection problem with the integration of more than one MADM method. Zeferino et al. (2021) proposed integrating the AHP and Pareto technique to assess the factors that can be used to select a suitable quarantine facility for COVID-19 patients based on facility location experts' opinions. Şen and Demiral (2016) presented a model using six attributes to select a new public hospital location. They determined the importance of these attributes utilizing AHP, and they utilized the Gray Relational Analysis to choose one of three alternative locations. To make a hospital investment in the most appropriate location for the investors in the cities of three major particular economic regions of China, Lin and Tsai (2009) have used the TOPSIS method to rank the alternatives after determining attributes importance by ANP method. Şenvar et al. (2016) set a TOPSIS model which uses Hesitant Fuzzy sets for the hospital location selection model.

In some studies, we confronted an integration of a MADM method and an additional method such as Geographic Information System (GIS). Mirzahossein et al. (2020) developed a model to select the appropriate locations for the construction of the medical emergency centers to elevate the new silk road's safety measures utilizing AHP in the ArcGIS platform. Eldemir and Onden (2016) determined attributes' importance by using AHP and then evaluated alternatives based on 13 attributes by using GIS. Vahidnia et al. (2009) have set 5 lands as alternatives with GIS and have evaluated these alternatives with Fuzzy AHP. For the planned establishment of a new hospital in the fifth Region of Iran's Şiran town, Soltani and Marandi (2011) have set three alternatives by Fuzzy AHP and GIS and then determined the area to establish the hospital by fuzzy ANP. In the proposed model, we evaluated alternative locations according to three attributes and ten sub-attributes, and they applied this model to a sample in the city of Dallas.

When studies on hospital location selection problems were examined, we realized that the studies were not using actual data, assessing the subjective judgments of the experts instead. Most of the studies in the literature utilize AHP or ANP to derive performance values of alternatives with respect to attributes from pairwise comparisons (Sinuany-Stern et al., 1995; Lin et al., 2008; Önüt et al., 2008; Lin and Tsai, 2009; Vahidnia et al., 2009; Wu et al., 2009; Wu et al., 2007a; Wu et al., 2007b;

Aydın and Arslan, 2010; Chatterjee and Muherjee, 2013; Chiu and Tsai, 2013; Şen and Demiral, 2016, Şen, 2017; Şahin et al., 2019). In the remaining few studies using subjective data, the inadequacy of the used attributes is noticeable (Soltani and Marandi 2011; Kim et al., 2015). The list of attributes used in these previous studies is presented in Appendix. Based on the literature review results, the most widely used hospital location selection attribute can be stated as land cost, followed by population density.

3 Methods

Multi-attribute value function methods aggregate the performances of alternatives with respect to attributes on a normative basis. These methods are too rich to be reliable in some cases (Brans & Vincke, 1985). On the other hand, outranking methods aggregate decision makers' preferences on alternatives on a descriptive basis. These methods enrich the dominance relation, which is too poor to be useful at multi-attribute decision problems. Therefore, in this study, PROMETHEE, a widely used outranking method, was used to reveal decision makers' preferences on possible hospital locations with respect to conflicting attributes.

Compared to other MADM methods, the difference of the PROMETHEE method is using an evaluation system employing the preference function. Through this preference function, characteristics and preferences of different attributes are transmitted better to the decision model. The threshold values have significant meaning in terms of alternatives. PROMETHEE is a user-friendly method that is easy to use and to interpret the parameters (Al-Shemmeri et al., 1997). In terms of the effect of minor deviations in the values of threshold parameters on final recommendations, the PROMETHEE method can be considered more stable than the ELECTRE method, another widely-used outranking method (Brans et al., 1986). Furthermore, Brans and Mareschal (1994) have developed a decision support system called GAIA to visualize the PROMETHEE results.

PROMETHEE, like most of the MADM methods, cannot reveal the importance of attributes. That is why an additional method can be used to prioritize the attributes (Macharis et al., 2004). As will be discussed in the next section, due to relationships among evaluation attributes, ANP, which takes dependencies and feedback into account, was used.

In the literature, there are various studies that use ANP to assess the importance of attributes and PROMETHEE to evaluate the preferences on alternatives. Kabak and Dağdeviren (2014) proposed a MADM approach that combines ANP and PROMETHEE to present to aid students at their selection among universities. Peng and Xiao (2013) utilized ANP and PROMETHEE methods in their hybrid decision model for material selection. Kilic et al. (2015) used the aggregation of ANP and PROMETHEE methods to select an ERP system for a small-medium enterprise. Govindan et al. (2015) presented an integrated MADM model where Dematel, ANP, and PROMETHEE methods were utilized together to evaluate green production practices.

Similarly, the proposed MADM model in this study is an integrated MADM model utilizing ANP and PROMETHEE. The details of these two methods are given in the following subsections.

3.1 Analytic Network Process

Saaty (1996) has introduced the ANP method for complicated and unstructured problems. ANP uses a network structure to model a complex decision problem with interconnections (dependencies and feedback). A network model with dependence and feedback improves the priorities derived from judgments and makes a prediction, especially prioritizes the attributes much more accurately. This method allows groups or individuals to deal with the interconnections between factors of complex structure in the decision-making process.

ANP assesses decision makers' judgments through pairwise comparisons of the attributes in the network. Possible replies may be the values in Saaty's 1–9 scale (1 = equally important, 3 = moderately important, 5 = strongly important, 7 = very strongly important, 9 = absolutely important, and reciprocals for inverse comparisons).

The ANP consists of six steps:

1. *Identifying elements and clusters*: At this stage, the aim of the problem must be stated clearly. Relate attributes and alternatives are determined. These elements, i.e., attributes and alternatives, are grouped under clusters.
2. *Assessing relations*: The relations among elements are identified, i.e., which element affects which one. If these exist relations, a network structure is created consisting of inner dependencies, outer dependencies, and feedback.
3. *Comparing elements*: For each element, decision makers are asked to compare the influence degrees of the affecting elements in pairs. A pairwise comparison matrix of the elements is created for each affected element by using the responses.
4. *Computing eigenvectors*: Then, the eigenvector of each matrix is calculated:

$$\mathbf{A}\mathbf{w} = \boldsymbol{\lambda}_{\mathbf{max}}\mathbf{w} \tag{1}$$

where **A** represents the pairwise comparison matrix, **w** represents the eigenvector of the matrix, and $\boldsymbol{\lambda}_{\mathbf{max}}$ represents the largest eigenvalues of matrix **A**.

5. *Constructing special matrices*: Eigenvectors are placed as entries into a particular matrix called a supermatrix. Supermatrix represents each element at one row and one respective column. There, an eigenvector is read at a column of an affected element and rows of affecting elements

Then, column totals in supermatrix are normalized to have a column stochastic matrix called a weighted supermatrix.

By raising that matrix to significantly high degrees, the limit matrix with stable and converged values is obtained.

6. *Revealing priorities*: Any column of limit matrix presents the global priority values of the elements. These priorities would be the importance of attributes or preference for the alternatives based on each cluster's type of elements

3.2 PROMETHEE

PROMETHEE, which was brought into literature first in a conference held in Canada in 1982 by Jean Pierre Brans, is a multi-attribute decision aid method that allows building outranking relations among alternatives. It is an acronym representing the phrase Preference Ranking Organization METHod for Enrichment Evaluations (Brans and Vincke, 1985).

PROMETHEE, as an outranking method, includes two phases (Brans and Vincke, 1985), i.e., the construction of an outranking relation and the exploitation of this relation to aid decision maker.

1. *Constructing the outranking relation*

First of all, the preference of decision maker for an alternative a_i compared to another alternative a_j for each attribute k, a preference function $P_k(a_i, a_j)$ is defined:

$$P_k\left(a_i, a_j\right) = \begin{cases} 0 & if\ \ f_k\left(a_i\right) \leq f_k\left(a_j\right) \\ p\left[f_k\left(a_i\right), f\left(a_j\right)\right] & if\ \ f_k\left(a_i\right) > f_k\left(a_j\right) \end{cases} \quad (2)$$

where $f_k(a_i)$ represents the performance value of alternative a_i with respect to attribute k.

Decision maker chooses among six generalized criteria which are used to find the values of preference function. Figure 1 shows the functions used for the generalized criteria, while Fig. 2 shows the representation of these functions.

Here, the difference between the performance values of alternatives a_i and a_j with respect to attribute k is calculated to find the value of d; on the other hand, the decision maker identifies necessary parameters such as indifference threshold (q) and preference threshold (p).

Then, the weighted average of the preference functions is computed to reveal a multi-attribute preference index:

$$\pi\left(a_i, a_j\right) = \sum_k w_k P_k\left(a_i, a_j\right) \quad (3)$$

2. *Exploiting the outranking relation*

- Usual Criterion

$$P_k(a_i,a_j) = \begin{cases} 0 & \forall d \le 0 \\ 1 & \forall d > 0 \end{cases}$$

- Quasi Criterion

$$P_k(a_i,a_j) = \begin{cases} 0 & \forall d \le q_k \\ 1 & \forall d > q_k \end{cases}$$

- Crit. with Linear Pref.

$$P_k(a_i,a_j) = \begin{cases} 0 & d \le 0 \\ d / p_k & 0 \le d \le p_k \\ 1 & d \ge p_k \end{cases}$$

- Level Criterion

$$P_k(a_i,a_j) = \begin{cases} 0 & d \le q_k \\ 0.5 & q_k < d \le p_k \\ 1 & d > p_k \end{cases}$$

- Crit. With Indifference Area.

$$P_k(a_i,a_j) = \begin{cases} 0 & d \le q_k \\ \dfrac{d - q_k}{p_k - q_k} & q_k \le d \le p_k \\ 1 & d \ge p_k \end{cases}$$

- Gaussian Criterion

$$P_k(a_i,a_j) = \begin{cases} 0 & d \le 0 \\ 1 - \exp(-d^2/2\sigma_k^2) & d \ge 0 \end{cases}$$

p: preference threshold, q: indifference threshold

Fig. 1 Generalized criteria functions (Source: Topcu et al. (2020), p. 6)

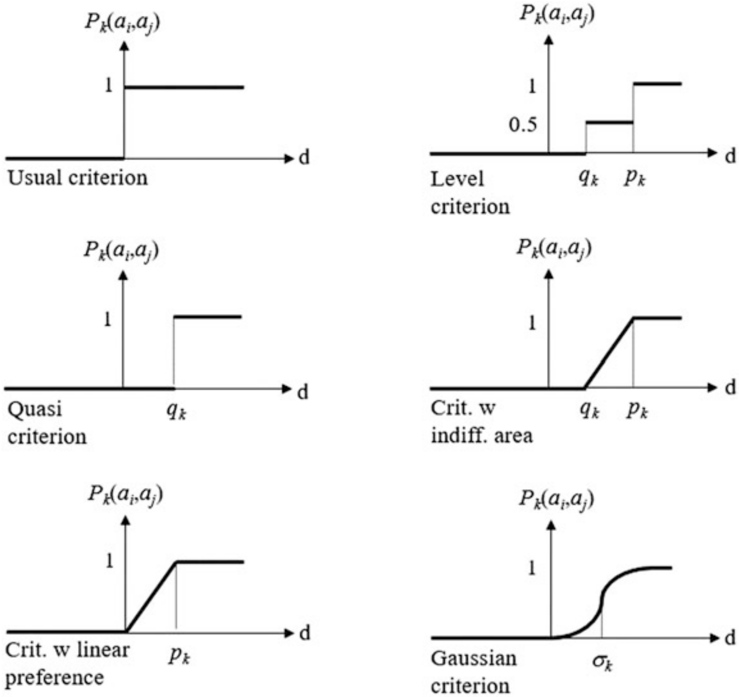

Fig. 2 Representation of generalized criteria functions (Source: Topcu et al. (2020), p. 6)

Based on the preference indices, three types of flows are calculated for an alternative a_i, i.e., the leaving flow ($\Phi^+(a_i)$), the entering flow ($\Phi^-(a_i)$), and the net flow ($\Phi(a_i)$):

$$\Phi^+(a_i) = \sum_{a_j \in A} \pi\left(a_i, a_j\right) \tag{4}$$

$$\Phi^-(a_i) = \sum_{a_j \in A} \pi\left(a_j, a_i\right) \tag{5}$$

$$\Phi(a_i) = \Phi^+(a_i) - \Phi^-(a_i) \tag{6}$$

Based on these flows, three types of ranking are revealed:

- Ranking of alternatives based on the decreasing order of leaving flows.
- Ranking of alternatives based on the increasing order of entering flows.
- Ranking of alternatives based on the decreasing order of net flows.

PROMETHEE I uses the intersection of the first two rankings and yields a partial pre-order of alternatives where preference, indifference, and incomparability among them are allowed.

PROMETHEE II, on the other hand, uses the third ranking and yields a complete pre-order of alternatives where preference and indifference among them are allowed.

4 Application of the Proposed Approach

4.1 Structuring the Problem

Trabzon province, located in the Eastern Black Sea Region of Turkey at the seaside, is a bridge between the Caucasus, Central Asia, and the West on the "Trans Caucasian Corridor" passing through the Caucasus into the Middle East. The population of the city is 811,901 as of 2019 (Turkish Statistical Institute, 2021). The location of Turkey in the world (URL1, n.d.) and Trabzon in Turkey (URL2, n.d.) as well as the layout of the counties of Trabzon (URL3, n.d.) are shown in Fig. 3.

As aforementioned, Trabzon is expected to become a leading international medical tourism center. Hospitals in Trabzon aim to provide treatment and rehabilitation services to international patients, especially from Azerbaijan, Georgia, Iran, and Arab countries. In Trabzon, currently, there are 22 hospitals, including 12 public hospitals, four branch hospitals, one university hospital, four private hospitals, and one training research hospital affiliated to the Ministry of Health. Although three new hospital buildings have been built in Trabzon in the last decade, there is still a hospital shortage for both local people and those who come for health tourism in

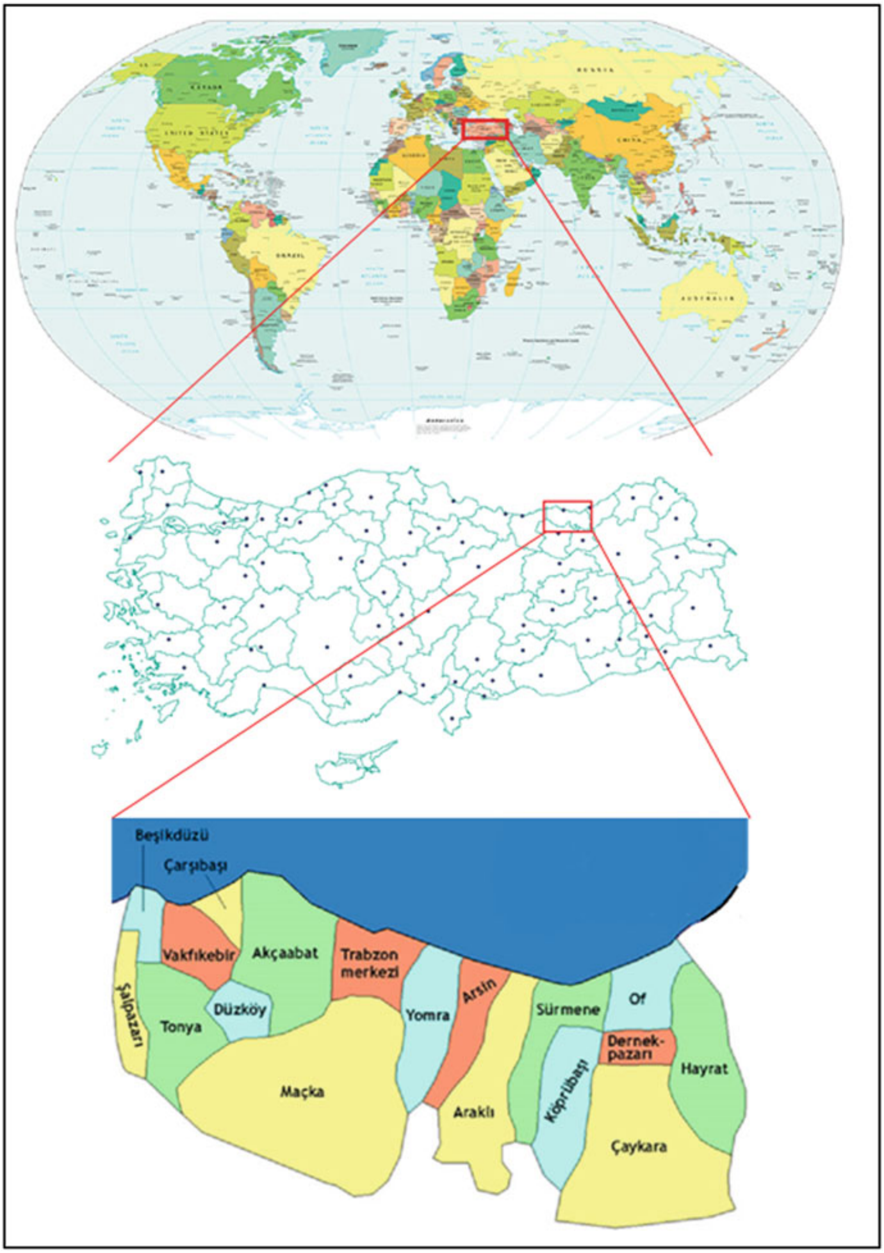

Fig. 3 Location of Trabzon Province and its counties (Sources: URL1, URL2, URL3)

conjunction with increasing demand. For this reason, in this study, we aimed to find an appropriate location for a new hospital building in Trabzon.

It has seemed more appropriate to construct a new building for the hospital instead of converting existing buildings used for other purposes because it is necessary for a hospital building to meet many physical, environmental, infrastructural, and ergonomic attributes. Therefore, the alternatives were not selected as existing buildings. Since the hospital to be established as a non-profit public hospital, we assumed that every land can be accessible and can be determined as alternatives.

Some quantitative information such as population and density is accessible only based on counties in the region. In addition, attributes such as the cost of land and traffic density differ dramatically among counties. Hence, the counties of Trabzon were considered as alternatives to this multi-attribute decision problem. There are 18 counties in this province, namely, Ortahisar (city center), Akçaabat, Araklı, Arsin, Beşikdüzü, Çarşıbaşı, Çaykara, Dernekpazarı, Düzköy, Hayrat, Köprübaşı, Maçka, Of, Sürmene, Şalpazarı, Tonya, Vakfıkebir, and Yomra.

To evaluate these counties on an MADM basis, first, as aforementioned in section "Literature Review," a detailed literature review was conducted. Then, the list of attributes used in the previous studies was revealed as given in Appendix. After that, we interacted with 11 experts to finalize the list. Among the experts, five were medical doctors, another five were authorities working at Trabzon Provincial Health Directorate. The last one was an authority working at Trabzon Regional Directorate of Transport and Infrastructure.

Based on their advice, some attributes used in the previous studies conducted for location selection of private hospitals were disabled because, in this study, the location would be selected for a public hospital. Accordingly, level of income, management objective, the rank of competitors, health sector and activities of competitors, and distance of competing hospitals have been excluded. Some attributes evaluating lands or buildings were discarded as counties were determined as the alternatives. These attributes were lease cost, building rearrangement cost, landscape cost, water and electricity supply, enlargement opportunity, city plan compliance, and parking area. Besides, the attribute of the pharmaceutical sector was not taken into consideration as many pharmacies would be opened around the new hospital in a short period. On the other hand, attributes such as construction cost and labor cost have been eliminated, as they would not vary between counties of a medium-sized city. As a result, after discussing the remaining attributes in the literature with experts, we made a final list of 14 attributes classified under four clusters as can be seen in Table 1.

The population of a county (a1) and all of the attributes of Cluster B (b1, b2, . . . b7) are self-explanatory and need objective evaluation. The sources are given in Table 1. Other objective attributes are population density (a2), centrality (a3), and distance to the main road (c1). Population density is the ratio of the population of a county to its area. Centrality is the sum of ratios of the population of each county to

Table 1 The evaluation attributes

Attribute groups	Attributes	Data source
A. Demographic characteristics	a1. Population	Turkish Statistical Institute
	a2. Population density	By calculation
	a3. Centrality	By calculation
B. The health sector and medical applications	b1. The number of family health centers in the county	Trabzon Provincial Public Health Office
	b2. The number of physicians in the family health centers	Trabzon Provincial Public Health Office
	b3. The number of public hospitals in the county	Turkey Public Hospitals Authority, Trabzon Public Hospitals Association, General Secretary, and Public Health Agency of Turkey
	b4. Total number of beds in the county's public hospitals	Same as the source of b3
	b5. The number of branch hospitals in the county	Same as the source of b3
	b6. Total number of beds in the county's branch hospitals	Same as the source of b3
	b7. The number of private hospitals in the county	General Secretary and Public Health Agency of Turkey
C. Environmental effects	c1. Distance to the main road	Turkey General Directorate of Highways
	c2. Traffic congestion	Experts' opinion
	c3. Noise center	Experts' opinion
D. Cost	d1. Land cost	Experts' opinion

its distance to the county whose centrality is computed. Finally, the distance to the main road is the distance of a county center to the state highway that runs along the coastline.

The last three attributes, namely traffic congestion (c2), noise center (c3), and land cost (d1), need subjective evaluation. Traffic congestion in the county and average land cost of possible areas in that county are self-explanatory. The distance of an alternative land to the nearest noise center is taken into account in the literature. However, in this study, the noise center attribute was used as the average noise level from the noise centers such as factories and garbage collection areas in a given county as counties were considered alternatives.

4.2 *Constructing the Decision Model*

4.2.1 Determination of the Relations among Attributes

The experts were then requested to identify the existence of the effects among attributes. We constructed an adjacency matrix based on experts' judgments as presented in Table 2. In the matrix, if an entry is filled with "X," the attribute in the row of that entry affects the attribute in the column of the same entry.

As can be seen in Table 2, population attribute directly affects 11 attributes. Centrality attribute directly affects nine attributes, and distance to the main road affects six attributes. On the other hand, 11 attributes affect population attribute. Six attributes affect traffic congestion and land cost attributes.

Table 2 The adjacency matrix

	a1	a2	a3	b1	b2	b3	b4	b5	b6	b7	c1	c2	c3	d1
a1 Population		X	X	X	X	X	X			X	X	X	X	X
a2 Population density											X	X		X
a3 Centrality						X	X	X	X	X	X	X	X	X
b1 The number of family health centers (FHC) in the county	X				X									
b2 The number of physicians in the county's FHC	X													
b3 The number of public hospitals in the county	X						X					X		X
b4 Total number of beds in the county's public hospitals	X													
b5 The number of branch hospitals in the county	X								X			X		X
b6 Total number of beds in the county's branch hospitals	X													
b7 The number of private hospitals in the county	X													
c1 Distance to the main road	X		X							X		X	X	X
c2 Traffic congestion	X										X			
c3 Noise center	X													
d1 Land cost	X									X	X			

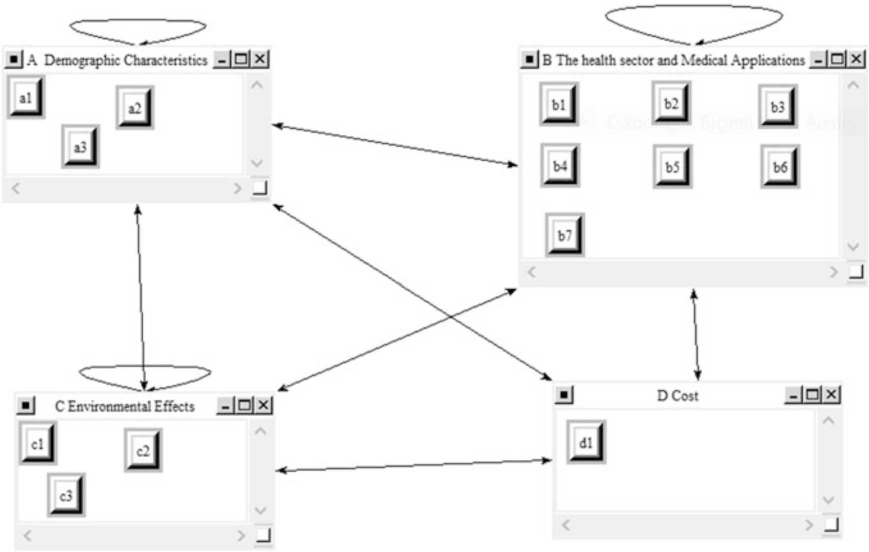

Fig. 4 The Decision Network

After determining the groups of attributes and attributes affecting each other, creating clusters and dependencies, a network structure was formed at Super Decisions software which works based on two multi-attribute decision-making methods, AHP and ANP. The decision network representing the dependencies among clusters is presented in Fig. 4.

4.2.2 Assessing the Importance of the Attributes

In this study, the importance of attributes was calculated using ANP as dependencies exist among the attributes. In accordance with ANP, the experts were asked to reply to a set of pairwise comparison questions as a further step. We computed the geometric means of the replies of the experts for each pairwise comparison question assessed on a 1-9 scale to aggregate their judgments. These judgments were then entered into Super Decisions software which computed the eigenvectors of the pairwise comparison matrices, the supermatrix, the weighted supermatrix, and the limit matrix. The entries of any column of the limit matrix revealed the importance of the attributes. We also aggregated the judgments of the medical doctors and the civil authorities and computed the importance of the attributes accordingly. The overall importance and importance for the two groups of participants are given in Table 3.

Table 3 The importance of attributes

	Attribute	Priorities according to MD	Priorities according to civil authorities	Overall priorities
A	a1. Population	0.2909	0.2898	0.2891
	a3. Centrality	0.1856	0.1700	0.1780
	a2. Population density	0.0208	0.0409	0.0318
B	b3. Number of public hospitals	0.1160	0.1246	0.1198
	b5. Number of branch hospitals	0.0469	0.0505	0.0496
	b4. Total number of beds in the public hospitals	0.0235	0.0346	0.0305
	b1. Number of FHC	0.0316	0.0143	0.0203
	b7. Number of private hospitals	0.0179	0.0172	0.0180
	b6. Number of beds in the branch hospitals	0.0128	0.0137	0.0135
	b2. Number of physicians in FHC	0.0103	0.0085	0.0095
C	c1. Distance to main road	0.1121	0.1101	0.1114
	c2. Traffic congestion	0.05937	0.05985	0.0598
	c3. Noise center	0.01481	0.00904	0.0112
D	d1. Land cost	0.05744	0.05699	0.0572

As shown in Table 3, there is no significant difference between the two groups, and the ranking is the same. According to the overall results as well as the groups' results, the population attribute (a1) is the most important attribute, followed by centrality (a2), the number of public hospitals (b3), and distance to the main road (c1). On the other hand, the number of physicians in the county's family health centers attribute (b2) becomes the least important attribute.

4.2.3 Decision Matrix

As we aimed to evaluate the counties of Trabzon according to the identified attributes in a multi-attribute decision-making basis, a decision matrix representing alternatives (i.e., the counties) at the rows, attributes at the columns, and the performance values of alternatives with respect to the attributes at the entries were generated. Most of the performance values were gathered from databases such as the Turkish Statistical Institute (TUIK), Turkey Public Hospitals Authority, Trabzon's provincial public health office, Trabzon Public Hospitals Association General Secretary, and Public Health Agency of Turkey, official websites of the private hospitals in Trabzon, and the Republic of Turkey General Directorate of Highways.

As aforementioned in section "Structuring the problem," population density (a2) value was computed by dividing the population of a county by its area while the centrality (a3) value of a county was computed as the sum of the ratios of the population of other counties to the distances of them to that county. However, there is no specific data for traffic congestion (c2), noise center (c3), and land cost (d1). For this reason, the values of the counties with respect to these attributes were obtained from experts on a scale of 0-100. The arithmetic averages of these subjective evaluations were computed. At this step, five authorities working at Trabzon Regional Directorate of Highways determined the average traffic congestion of the counties. Five academicians from the City and Regional Planning Department of Karadeniz Technical University determined the values of the noise center attribute. Finally, three land surveyors working in Trabzon determined the average land cost of possible areas in that county. The resulting decision matrix is shown in Table 4.

4.3 Analyzing the Problem

To select the most appropriate county for building a new hospital, we constructed outranking relations among counties utilizing PROMETHEE. The alternatives (i.e., the counties) and the attributes were introduced into Visual PROMETHEE software, and then the performance values of each alternative with respect to each attribute were entered.

In accordance with PROMETHEE, the preference functions were defined to represent the preferences of experts among alternatives with respect to each attribute. The experts were also consulted to determine the corresponding indifference and preference threshold values (Table 5). Each expert specified threshold values individually. Then, their arithmetic means were computed.

Based on this information, necessary computations were made on the decision matrix given in Table 4 utilizing Visual PROMETHEE software, and we came up with the partial and complete pre-orders of the counties.

PROMETHEE I provides the partial pre-order of the counties based on the decreasing order of their leaving flows and the increasing order of their entering flows as given in Fig. 5. As a result, a subset of counties appropriate for a new hospital building location in Trabzon was revealed. Akçaabat, Beşikdüzü, Of, and Araklı counties outranked most of the counties while Ortahisar county was found incomparable with the others.

We need a complete pre-order to propose the most appropriate county for a new hospital location in Trabzon, instead of the subset of the countries found above. PROMETHEE II provides the ranking of the counties based on the decreasing order

Table 4 The decision matrix

	a1	a2	a3	b1	b2	b3	b4	b5	b6	b7	c1	c2	c3	d1
Criteria importance	0.2891	0.03186	0.1780	0.0203	0.0095	0.1198	0.0305	0.0496	0.0135	0.0180	0.1114	0.0598	0.0112	0.0572
Unit	(person)	(centrality)	(person/m^2)	(FHC)	(physician)	(public hospital)	(bed)	(branch hospital)	(bed)	(private hospital)	(km)	(0.100)	(0.100)	(TL)
Akçaabat	115,939	309.1707	141993.8774	13	33	1	221	0	0	2	0	87	0.1333	700,000
Araklı	47,960	103.3621	71817.9022	1	14	1	106	0	0	0	0	44	0.8836	900,000
Arsin	28,208	179.6688	64934.4800	2	10	1	5	0	0	0	0	42	1.4013	550,000
Beşikdüzü	21,870	260.3571	44015.9544	1	6	0	0	0	0	0	0	40	0.7143	800,000
Çarşıbaşı	15,596	236.3030	39632.4214	2	5	0	0	0	0	0	0	41	0.0000	350,000
Çaykara	13,854	24.1359	25351.2921	3	4	1	15	1	88	0	26	28	0.0000	400,000
[p] Dernekpazarı	3803	42.7303	18458.3615	1	1	0	0	0	0	0	18	19	0.0000	500,000
Düzköy	14,527	116.2160	29889.7561	3	5	1	10	0	0	0	28	19	0.0000	500,000
Hayrat	7631	31.2746	21138.9758	2	3	0	0	0	0	0	11	19	0.0000	250,000
Köprübaşı	4940	26.1376	20451.7782	1	2	1	10	0	0	0	14	22	0.0000	1,000,000
Maçka	24,232	26.1968	43320.2633	2	6	0	0	1	110	0	26	38	0.1622	700,000
Of	42,405	164.3605	58101.9159	2	11	1	79	0	0	0	0	47	0.1938	750,000
Ortahisar	314,246	67.9010	332203.9963	66	98	2	999	2	430	2	0	98	0.0983	7,000,000
Sürmene	10,903	65.6807	38769.7518	2	8	1	61	0	0	0	0	42	0.2711	1,000,000
Şalpazarı	26,421	164.1056	37276.0245	1	5	1	10	0	0	0	16	22	0.0000	650,000
Tonya	15,217	86.4602	28489.9815	2	5	1	5	0	0	0	20	23	0.5114	600,000
Vakfıkebir	26,636	188.9078	49459.6786	3	7	1	132	0	0	0	0	46	0.0000	600,000
Yomra	32.394	161.970	77112.6864	4	10	1	616	0	0	0	0	71	0.3750	1,250,000

Table 5 Information on preference functions

Attribute	Preference function type	Indifference threshold value	Preference threshold value
Population	Linear preference	.	140707.03
Population density	Linear preference	.	172.51
Centrality	Indifference area	85107.30	143940.17
The number of FHC in the county	Linear preference	.	28.47
The number of officials as physicians in the county's FHC	Indifference area	5.00	43.26
The number of public hospitals in the county	Level	0.56	1.30
Total number of beds in the county's public hospitals	Indifference area	50.00	250.00
The number of branch hospitals in the county	Level	0.66	1.07
Total number of beds in the county's branch hospitals	Linear preference	.	250.00
The number of private hospitals in the county	Level	0.81	1.230
Distance to the main road	Linear preference	.	14.00
Traffic congestion	Indifference area	21.35	45.93
Noise center	Indifference area	0.25	0.578
Land cost	Indifference area	500,000	1,500,000

of their net flows. As shown in Fig. 6, Akçaabat county, which had a net flow value of 0.1892, outranked all other counties and may be recommended as the most appropriate hospital location. On the other hand, Ortahisar county, which had a net flow value of 0.1503, followed Akçaabat county with a slight difference. Despite Ortahisar, which had the highest leaving flow, was at the best position (0.5082), it took second place in the final ranking because of its very high entering flow where less is better. According to the entering flow, Beşikdüzü, which had the lowest entering flow, was at the best position. However, it took fifth place in the final ranking due to its low leaving flow value.

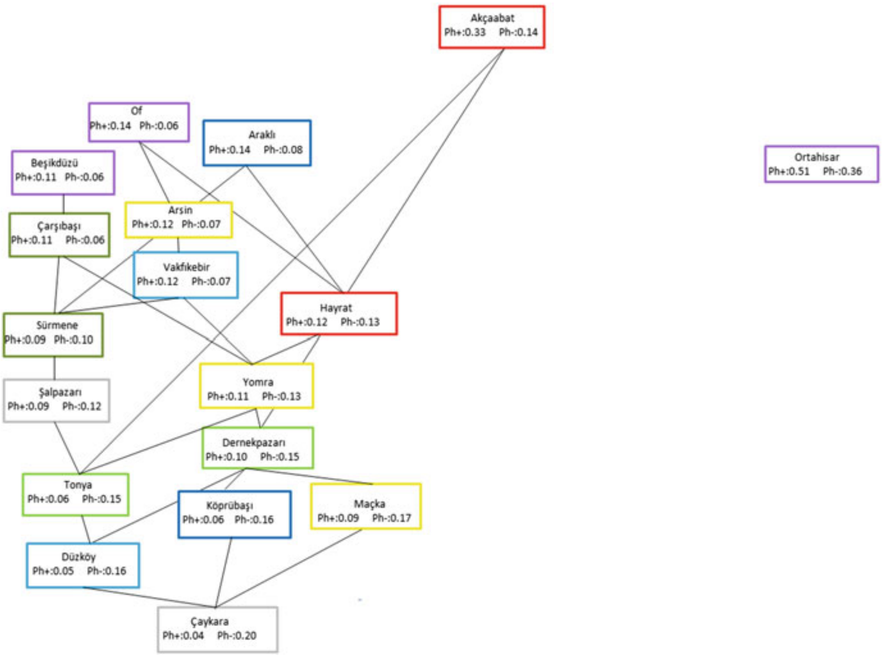

Fig. 5 The partial pre-order of the counties

4.4 Sensitivity Analysis Findings

As a final step, we conducted a sensitivity analysis to assess the robustness of the results of the proposed approach. For this purpose, we observed the ranking changes when importance of attributes changes.

PROMETHEE II results were found to be insensitive to the change in the importance of most of the attributes. When the importance of the attributes such as population density (a2), number of branch hospitals in the county (b5), number of beds in the county's branch hospitals (b6), distance to the main road (c1), and noise center (c3) change, Akçaabat county maintains its first place. Akçaabat also holds its first place even if there is a moderate change in the importance of the remaining attributes except for land cost (d1). Akçaabat loses its first place only when there is a slight change (0.02 points) in the importance of the land cost attribute. Readers may find more detailed information on the conducted sensitivity analysis in İmamoğlu's (2015) study.

PROMETHEE Flow Table

Rank	action	Phi	Phi+	Phi-
1	Akçaabat	0,1892	0,3302	0,1410
2	Ortahisar	0,1503	0,5082	0,3579
3	Of	0,0725	0,1360	0,0636
4	Araklı	0,0636	0,1393	0,0757
5	Beşikdüzü	0,0577	0,1137	0,0560
6	Çarşıbaşı	0,0518	0,1098	0,0580
7	Arsin	0,0473	0,1180	0,0707
8	Vakfıkebir	0,0404	0,1152	0,0748
9	Hayrat	-0,0066	0,1228	0,1294
10	Sürmene	-0,0083	0,0886	0,0969
11	Yomra	-0,0250	0,1100	0,1350
12	Şalpazarı	-0,0353	0,0861	0,1214
13	Dernekpazarı	-0,0510	0,1012	0,1523
14	Maçka	-0,0791	0,0893	0,1683
15	Tonya	-0,0949	0,0564	0,1514
16	Köprübaşı	-0,1018	0,0643	0,1661
17	Düzköy	-0,1117	0,0532	0,1648
18	Çaykara	-0,1588	0,0401	0,1989

Fig. 6 The complete pre-order of the counties

5 Conclusions and Further Suggestions

The health sector is in constant development due to advanced technology and increasing healthcare needs. Within this development, new hospital requirements and the problem of selecting appropriate locations for these hospitals arise. Additionally, the COVID-19 outbreak makes this decision very important and urgent.

In this study, an integrated MADM model was presented for finding an appropriate hospital location in Trabzon province of Turkey at the level of counties. In the proposed model, ANP was utilized to determine the importance of the attributes, and PROMETHEE was used to rank the counties.

Based on an extensive literature review and the point of view of experts, we determined 14 attributes under four clusters to evaluate counties considered as alternatives to hospital locations. Then, we identified the relations among the attributes, and we found that a network model was appropriate for the analysis. Based on the number of relations among attributes, the population attribute can be considered the most central attribute, i.e., had the highest number of attributes affected by itself and it affected the highest number of attributes. We utilized the ANP method to assess the importance of the attributes. The population, the most central attribute, was also found as the most important attribute. As a further step, we used PROMETHEE to evaluate counties with respect to objective and subjective attributes. Akçaabat county was the most appropriate location for building a new hospital, according to PROMETHEE II. Besides, we found that the first place of Akçaabat was not sensitive to the changes in the importance of the attributes. If policymakers want to build more than one hospital, the counties such as Akçaabat, Ortahisar, Beşikdüzü, Of, and Araklı may be recommended according to PROMETHEE I results.

The findings are justified as Akçaabat is a county with one of the highest populations and a central one in Trabzon. Besides, the current state-owned hospital in the county was not meeting the demand even before the COVID-19 outbreak.

The generated MADM model is a generic model that can be applied in other cities and other countries by changing experts as well as updating pairwise comparison questions and attributes importance.

Furthermore, different aspects such as the point of view of the potential patients can be included in the model as decision makers. Finally, to improve this study, a decision model can be developed to select a suitable location for a new hospital in Akçaabat county.

Appendix: The List of Attributes Used in Previous Studies

	Construction/ Lease Cost	Building rearrange-ment cost	Landscape cost	Labour cost /Oppor-tunity	Land cost/ opportu-nity	Water and Elec-tricity supply	Enlargement opportunity	Population	Population density	Population age structure	Level of income	Management objective	Rank of competi-tors	Policymaker's attitude	Puplic support	Hospital man-age-ment sector	Medical practice and phar-maceu-tical sector
Wu et al.(2007a)	X			X	X			X	X	X		X	X	X		X	X
Wu et al.(2007b)	X			X	X			X	X	X		X	X	X		X	X
Lin et al.(2008)				X	X			X	X	X		X	X	X		X	X
Önüt et al.(2008)	X			X	X			X	X		X	X	X	X		X	X
Lin and Tsai (2009)	X			X	X						X			X		X	X
Vahidnia et al. (2009)																	
Wu et al. (2009)	X			X	X			X	X	X		X	X	X		X	X
Aydın and Arslan (2010)	X	X	X						X		X						
Sinuany-Stern et al. (1995)					X				X								

(continued)

	Construction/ Lease Cost	Building rearrange-ment cost	Landscape cost	Labour cost /Oppor-tunity	Land cost/ opportu-nity	Water and Elec-tricity supply	Enlargement opportunity	Population	Population density	Population age structure	Level of income	Management objective	Rank of competi-tors	Policymaker's attitude	Puplic support	Hospital man-age-ment sector	Medical practice and pharma-ceutical sector
Soltani and Marandi (2011)					X				X								
Chatterjee and Muherjee (2013)			X		X		X		X		X						
Chiu and Tsai (2013)	X				X			X	X				X			X	X
Kim et al.(2015)						X		X		X	X			X	X		X
Sen and Demi-ral(2016)	X		X		X		X										
Şen (2017)	X		X		X		X										
Şahin et al.(2019)				X		X		X		X	X						X

	Health sector and activities of competitors	Distance of competing hospitals	Regulation and standards of establishment of hospitals	Efforts to promote medical network	Centrality	Distance from main road	Transport time to the hospital / traffic density	Proximity to settlements	City plan compliance	Proximity to noise centers	Public Transportation	Parking area	Significant change in market demand	Significant fluctuations in production costs	Significant changes in the financial market	Reduction local unemployment rate	Providing population distribution
Wu et al.(2007a)	X		X	X										X	X		
Wu et al.(2007b)	X		X	X										X	X		
Lin et al.(2008)	X		X	X									X	X	X		
Önüt et al.(2008)	X												X		X		
Lin and Tsai (2009)	X		X														
Vahidnia et al. (2009)						X	X			X							
Wu et al. (2009)			X	X										X	X		
Aydın and Arslan (2010)	X	X			X			X	X	X		X					
Sinuany-Stern et al. (1995)																X	X
Soltani and Marandi (2011)		X				**X**	X										

(continued)

	Health sector and activities of competitors	Distance of competing hospitals	Regulation and standards of establishment of hospitals	Efforts to promote medical network	Centrality	Distance from main road	Transport time to the hospital / traffic density	Proximity to settlements	City plan compliance	Proximity to noise centers	Public Transportation	Parking area	Significant change in market demand	Significant fluctuations in production costs	Significant changes in the financial market	Reduction local unemployment rate	Providing population distribution
Chatterjee and Muherjee (2013)						X	X	X			X						
Chiu and Tsai (2013)	X					X			X		X	X					
Kim et al.(2015)	X					X					X						
Sen and Demiral(2016)										X	X	X					
Şen (2017)										X	X	X					
Şahin et al.(2019)	X	X				**X**				X	X		X				

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