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# Locating Emergency Stations Using Multi-Criteria Decision-Making (MCDM) Methods: Application of Ankara Province

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**Abstract**: An earthquake ranks first among natural disasters in Turkey, with a rate of 70%. Minimizing the effects of a disaster after it occurs is possible by establishing effective disaster management. Especially the earthquakes that occurred on February 6, 2023, showed how important it is to deliver aid to the disaster area. In this study, the problem of determining the location of emergency stations to be established in order to deliver aid to the disaster area in case of a disaster was examined. There are studies in the literature to determine the locations of emergency stations to be established in provincial centers. In this study, the locations of emergency stations to be established in the non-central districts of Ankara were tried to be determined using multi-criteria decision-making (MCDM) methods. In the study, firstly, the criteria that would be effective in the location selection of emergency stations were determined, and the weights of these criteria were calculated with the Pythagorean Fuzzy Analytical Hierarchy Process (PFAHP) method. In the second stage of the study, 16 districts outside the center of Ankara were compared with the Pythagorean Fuzzy Technique for Order Preference by Similarity To An Ideal Solution (PFTOPSIS) method, and the districts where emergency stations should be opened first were evaluated.

**Keywords:** Emergency station, Site selection, Fuzzy logic

## Introduction

Disasters can be defined as events that occur largely beyond human control, can cause loss of property and life, and pose a risk to the environment and human life. Natural disasters are events that cause great losses, seriously affect both the whole world and natural life, and cannot be avoided (Hoyois et al., 2006). Natural disasters occur all over the world from time to time. Earthquakes are among the most common natural disasters in the world. Large and devastating earthquakes occur from time to time in Turkey. It is of great importance to make the necessary preparations before the emergency in order to quickly deliver aid to disaster victims affected by large and devastating earthquakes. In order to deal effectively with disasters, effective implementation of disaster management becomes important (Sen & Esmer, 2017). Providing relief materials and delivering the necessary aid after a disaster is of vital importance for people experiencing disasters. In order to deliver aid quickly and effectively, emergency stations are established before the disaster and emergency supplies are stored there. In order to quickly deliver emergency supplies to people experiencing disasters, the locations of Emergency Stations (ES) must be determined correctly.

Since Türkiye is located on active faults, major earthquakes occur from time to time. In particular, the Kahramanmaraş earthquakes that occurred on February 6, 2023 caused great loss of life and property in 10 provinces. Many highways were destroyed in these earthquakes, and this prevented aid from reaching the earthquake areas. Therefore, it is of great importance to determine the locations of ESs where aid will be stored before the disaster. This situation showed how important the aid that can be provided to the earthquake region from nearby provinces is. It is important to determine the locations of ESs so that they will serve neighboring provinces as well, instead of determining their locations so that they will serve only that province.

The concept of disaster logistics has emerged in order to minimize the impact of disasters that occur from time to time all over the world. Sending relief materials to people living in that region after a disaster, storing these materials in a certain area, and making the necessary plans before the disaster are defined as disaster logistics (Thomas & Kopczak, 2005). Disaster logistics consists of three stages: pre-disaster planning, disaster response activities and post-disaster aid activities. One of the most important elements of disaster logistics is the ESs where aid materials are stored.

The locations of ESs must be determined accurately so that aid can be delivered quickly. In the studies in the literature, it is seen that the assumption that ESs are installed in city centers and only that city is served is taken into account (Tezcan et al., 2023; Durdag et al., 2021). However, the Kahramanmaraş earthquakes that occurred on February 6, 2023 affected 10 provinces and revealed that the aid from surrounding provinces is of vital importance. Therefore, this study aimed to determine the locations of ESs to be opened in districts outside the center of Ankara, taking into account the assumption of providing service to neighboring provinces. Considering that a possible Istanbul earthquake will also affect the surrounding provinces, it is aimed to provide service to these provinces with the ESs established.

The problem of selecting the most appropriate alternative by evaluating alternatives under different criteria is defined as the multi-criteria decision making (MCDM) problem in the literature (Desticioglu & Ayan, 2023). MCDM approaches are extensively utilized in problem-solving. The most commonly used MCDM methods include AHP, TOPSIS, COPRAS, ELECTRE, PROMETHEE, etc. In decision-making problems with unclear situations, methods such as fuzzy AHP and fuzzy TOPSIS are used (Bayram & Eren, 2023). It is seen that triangular fuzzy numbers, quadrilateral fuzzy numbers, and Pythagorean fuzzy numbers (PFNs) are mostly used in fuzzy MCDM problems. Since more reliable and realistic results are obtained with PFNs (Torul Yürek et al., 2023), Pythagorean Fuzzy AHP (PFAHP) and Pythagorean Fuzzy TOPSIS (PFTOPSIS) methods were used in this study. As far as is known, this is the first study in which the establishment of ESs outside the city center was taken into account in order to serve the surrounding provinces and districts, and the locations of the ESs were determined using PFAHP and PFTOPSIS methods. The study initially established the criteria for determining the sites of ESs by consulting relevant literature. The weights of the criteria were derived using the PFAHP approach. Using the calculated criterion weights, the locations of the ESs planned to be established in 16 districts outside the center of Ankara were listed with the PFTOPSIS method. In the last stage, ES locations were listed by calculation using MCDM methods that include similar steps. In the sensitivity analysis, the effect of the criterion weights on the ranking was tried to be determined by taking the binary changes of the criterion weights.

The study consists of the following sections: First, the study includes a literature review on determining the locations of ESs. In the method section, information is given about the PFAHP and PFTOPSIS methods used in the study. Subsequently, attempts were made to estimate the positions of the ESs to be formed using calculations conducted with PFAHP and PFTOPSIS. There is no text provided. The previous section involved doing sensitivity analysis by making binary adjustments to criterion weights. This analysis was performed using the FCOPRAS and FTOPSIS methods, both of which follow similar procedures. The resulting rankings obtained from these methods were then compared. The conclusion phase of the study involved an assessment of the collected results and the formulation of recommendations for future research.

## Literature Review

In this section, a literature review about studies carried out with MCDM methods within the scope of disaster logistics is included. Roh et al. (2013) determined the locations of warehouses to be used in humanitarian aid logistics using the AHP method. Peker et al. (2016) used integrated AHP and VIKOR methods to determine the locations of emergency facilities to be opened in Erzincan province. In the study, first the weights of the criteria were determined with AHP, and then the alternatives were ranked with the VIKOR method (Peker et al., 2016). Ofluoglu et al. (2017) tried to determine the locations of ESs to be established in Trabzon province using the entropy weight method-based VIKOR, SAW and TOPSIS methods. Trivedi (2018) determined the locations of temporary settlement areas within the scope of disaster logistics using the DEMATEL method. Şekkeli (2019) used the AHP method in the selection of the emergency assembly center in the Oniki February district of Kahramanmaraş province. Hazırcı and Sahin (2019) used the AHP-based p-median model in the selection of temporary housing areas that will serve after the disaster. In the study, the locations of temporary settlement areas in Burdur province were determined (Hazırcı & Şahin, 2019). In their study, Öztürk and Kaya (2020) used the PROMETHEE method to compare 43 alternative emergency assembly points in Istanbul within the scope of disaster logistics. Ergun et al. (2020) used MAUT and SAW

methods, which are among the MCDM methods, to determine the locations of ESs to be established in Giresun within the scope of sustainable disaster logistics. Cetinkaya et al. (2021) tried to determine the locations of emergency warehouses on the Turkey-Syria border with the Geographical Information System (GIS)-based AHP method. Derse (2022) used the cluster coverage model with DEMATEL and TOPSIS methods to determine the locations of ESs to be established in the Aegean Region. Gocmen Polat (2022) determined the locations of distribution centers to be established within the scope of disaster logistics in Tunceli province by using the goal programming model integrated with the AHP-based TOPSIS method. Tezcan et al. (2023) used MCDM methods to determine the locations of temporary disaster warehouses to be opened in Kırıkkale province. The study employed the AHP approach to initially identify the weights of the criteria. In the subsequent stage, the VIKOR, TOPSIS, and PROMETHEE methods were utilized to rank the possibilities for the establishment of a temporary warehouse (Tezcan et al., 2023). Bayram and Eren (2023) used AHP-based PROMETHEE, ELECTRE and TOPSIS methods to determine the locations of ESs to be opened in Sultanbeyli, one of the districts that will be most affected by the earthquake in an earthquake that may occur in Istanbul. Studies on site selection within the scope of disaster logistics were examined in the literature and Table 1 was created using these studies.

Table 1. Studies on disaster logistics

| Study | Year | Problem Examined | Method |
|---|---|---|---|
| Roh et al. | 2013 | Humanitarian aid warehouse location selection | AHP |
| Peker et al. | 2016 | Emergency warehouse location selection | AHP - VIKOR |
| Ofluoglu et al. | 2017 | Emergency warehouse location selection | Entropi, VIKOR, SAW and TOPSIS |
| Trivedi | 2018 | Location selection of temporary residence areas | DEMATEL |
| Şekkeli | 2019 | Emergency assembly area location selection | AHP |
| Hazıcı & Şahin | 2019 | Location selection of temporary residence areas | AHP and P-Medyan |
| Ozturk & Kaya | 2020 | Emergency assembly point location selection | PROMETHEE |
| Ergun et al. | 2020 | Emergency warehouse location selection | MAUT - SAW |
| Cetinkaya et al. | 2021 | Emergency warehouse location selection | GIS - AHP |
| Derse | 2022 | Emergency warehouse location selection | DEMATEL - TOPSIS |
| Gocmen Polat | 2022 | Distribution center location selection | AHP - TOPSIS |
| Tezcan et al. | 2022 | Temporary distribution warehouse location selection | AHP – VIKOR, TOPSIS, PROMETHEE |
| Bayram & Eren | 2023 | Emergency warehouse location selection | AHP – PROMETHEE, ELECTRE, TOPSIS |

When the studies in the literature within the scope of disaster logistics are examined, it is seen that researchers mostly work on ES location selection. When Table 1 is examined, it is seen that AHP and TOPSIS methods are mostly used in these studies. Studies in the literature generally assume that service is provided to the location of the opened station and that no aid is sent to the surrounding provinces and districts from these depots. In addition, in the studies in the literature, it was determined that ESs were established only in city centers, and that no studies were conducted on the establishment of ESs in non-central districts. The Kahramanmaraş earthquakes that occurred on February 6, 2023 affected 10 provinces and revealed how important the aid from surrounding provinces is. It is thought that a possible Istanbul earthquake may also affect the surrounding provinces. Therefore, in this study, the locations of emergency stations planned to be opened in 16 districts outside the center of Ankara were tried to be determined. The assumption that the ESs to be opened will provide service to neighboring provinces and districts has been taken into account. Studies in the literature were used to determine the criteria to be taken into account in comparing the alternatives of 16 districts located outside the center of Ankara. Expert opinion was used to determine the criterion weights. These data may vary from person to person. In order to eliminate this change, fuzzy logic is used in the literature (Desticioglu et al., 2023). Since more reliable and realistic results are obtained with Pythagorean fuzzy numbers (PFNs) (Bulut & Ozcan, 2023), PFAHP and PFTOPSIS methods were used in this study. In the study, 16 district alternatives were compared and the districts where emergency stations could be established were listed. In the next section, PFAHP and PFTOPSIS method are discussed.

## Method

The importance of the criteria used in evaluating alternatives in MCDM problems varies from person to person and from region to region. To eliminate this change, fuzzy numbers are used in the literature. Since more realistic data is obtained with PFNs compared to other fuzzy numbers (Bulut and Özcan, 2023), PFNs was used in this study. In the study, PFAHP was first used to determine the criterion weights and the PFTOPSIS method was used to compare the district alternatives where emergency facilities will be established.

### Pythagorean Fuzzy Sets (PFSs)

Intuitive fuzzy numbers were first introduced by Atanassov (1986), and fuzzy numbers with different properties have been introduced to the literature by many researchers. Yager (2013) developed Pythagorean fuzzy sets (PFSs). These sets provide better results in cases where intuitive fuzzy sets are insufficient to eliminate uncertainty. PFSs provides flexibility in solving models containing uncertainty and obtains stronger results (Ilbahar et al., 2018; Gul & Ak, 2018). As in other intuitive fuzzy sets, it is assumed that PFSs values will not exceed 1. PFS definitions are presented below.

Definition 1: Let X denote a set of constants. P, PFS can be defined as an object that satisfies the following condition:

$$P = \{< x, P(\mu_p(x), v_p(x)) > x \in X\} \quad (1)$$

Here, $\mu_p(x): X \rightarrow [0,1]$ and $v_p(x): X \rightarrow [0,1]$, define the degree of membership and non-ownership of objects xϵX and p respectively.

$$0 \leq \mu_p(x)^2 + v_p(x)^2 \leq 1 \quad (2)$$

The degree of hesitation is given in equation number 3.

$$\pi_p(x) = \sqrt{1 - \mu^2{}_p(x) - v^2{}_p(x)} \quad (3)$$

Definition 2: Let $\beta_1 = P(\mu_{\beta_1}, v_{\beta_1})$ and $\beta_2 = P(\mu_{\beta_2}, v_{\beta_2})$, be two Pythagorean fuzzy numbers, γ>0. These PFNs can be defined by the following operators (Zeng et al., 2016):

$$\beta_1 \oplus \beta_2 = P\left(\sqrt{\mu_{\beta_1}^2 + \mu_{\beta_2}^2 - \mu_{\beta_1}^2 \mu_{\beta_2}^2}, v_{\beta_1} v_{\beta_2}\right) \quad (4)$$

$$\beta_1 \otimes \beta_2 = P\left(\mu_{\beta_1} \mu_{\beta_2}, \sqrt{v_{\beta_1}^2 + v_{\beta_2}^2 - v_{\beta_1}^2 v_{\beta_2}^2}\right) \quad (5)$$

$$\gamma\beta_1 = P\left(\sqrt{1 - (1 - \mu_{\beta_1}^2)^{\gamma}}, (v_{\beta_1})^{\gamma}\right) \quad (6)$$

$$\beta_1^{\gamma} = P\left((\mu_{\beta_1})^{\gamma}, \sqrt{1 - (1 - v_{\beta_1}^2)^{\gamma}}\right) \quad (7)$$

Definition 3: Let $\beta_1 = P(\mu_{\beta_1}, v_{\beta_1})$ and $\beta_2 = P(\mu_{\beta_2}, v_{\beta_2})$, be two PFNs. The order of these two PFNs is shown as follows.

If $\beta_1 > \beta_2$ then $\mu_{\beta_1} \geq \mu_{\beta_2}$ and $v_{\beta_1} \leq v_{\beta_2}$.

The score function of the two PFNs is given in Equation 8.

$$s(\beta_1) = (\mu_{\beta_1})^2 - (v_{\beta_1})^2 \quad (8)$$

Definition 4: According to the score function given in Equation 8, the comparison of 2 PFNs is as follows (Zhang and Xu, 2014):

i. If s($\beta_1$)< s($\beta_2$) it is $\beta_1 \prec \beta_2$
ii. If s($\beta_1$) > s($\beta_2$) it is $\beta_1 \succ \beta_2$
iii. If s($\beta_1$) = s($\beta_2$) it is $\beta_1 \sim \beta_2$

**Pythagorean Fuzzy AHP (PFAHP) Method**

The algorithm steps of the PFAHP method are listed below (Bulut & Ozcan, 2021):

Step 1: Pairwise comparison matrices are created with the 1-9 scale developed by Saaty for the criteria used in comparison. Afterwards, these numbers are converted into the weight measure for PFAHP developed by Ilbahar et al. (2018).

Step 2: Using Equations 9 and 10, the lower and upper limits of the membership and non-membership functions and the difference matrices $D=(d_{ik})_{mxm}$ are calculated.

$$d_{ikL} = \mu_{ikL}^2 - v_{iku}^2 \quad (9)$$

$$d_{ikU} = \mu_{ikU}^2 - v_{ikL}^2 \quad (10)$$

Step 3: Using Equations 11 and 12, the range multiplication matrix $S = (s_{ik})_{mxm}$ is calculated.

$$s_{ikL} = \sqrt{1000^{d_L}} \quad (11)$$

$$s_{ikU} = \sqrt{1000^{d_U}} \quad (12)$$

Step 4: Using the equation given in Equation 13, the determination value $\tau = (\tau_{ik})_{mxm}$ is calculated.

$$\tau_{ik} = 1 - (\mu_{ikU}^2 - \mu_{ikL}^2) - (v_{ikU}^2 - v_{ikL}^2) \quad (13)$$

Step 5: Multiply $S = (s_{ik})_{mxm}$ ile $\tau = (\tau_{ik})_{mxm}$ using Equation 14 to create the weight matrix before normalization.

$$t_{ik} = \left(\frac{s_{ikL} + s_{ikU}}{2}\right)\tau_{ik} \quad (14)$$

Step 6: The weighted normalized matrix is obtained by Equation 15:

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{k=1}^{m} t_{ik}} \quad (15)$$

The AHP method can be a guide for the decision maker by taking into account both subjective and objective criteria. In addition, the AHP method enables evaluation of which criterion is more important by comparing each criterion in pairs (Desticioglu & Ayan, 2023). The AHP method is an MCDM method that allows the application of qualitative and nical criteria together, taking into account the opinions of individuals and groups (Omurbek & Simsek, 2014). In this study, since both quantitative and qualitative criteria are taken into account in comparing alternatives in the ES location selection problem, the AHP method was preferred in determining the criterion weights. Pairwise comparison of the determined criteria involves uncertainty as it will vary from person to person or from region to region. Fuzzy logic is used to eliminate this uncertainty (Desticioglu et al., 2023). More realistic and reliable results are obtained with PFNs compared to other fuzzy numbers (Bulut & Özcan, 2023). Therefore, in this study, it was preferred to compare the alternatives with PFAHP and PFTOPSIS methods.

**Pythagorean Fuzzy TOPSIS (PFTOPSIS) Method**

The TOPSIS approach, devised by Hwang and Yoon in 1979, is used to prioritize options. In the TOPSIS method, the closest and furthest alternatives to the ideal solution can be determined (Hwang & Yoon, 1979).

The TOPSIS method is an MCDM method that allows the evaluation of alternatives by taking into account both benefit criteria and cost criteria (Yıldırım et al., 2019). That's why it is one of the most preferred methods by researchers. In cases where the criteria to be used in comparing alternatives are uncertain, the TOPSIS method can be used with fuzzy numbers. In this study, fuzzy PFNs were used to reduce the uncertainty inherent in the criteria used. Due to the presence of uncertainty in the criteria used for evaluating alternatives in the study, and the fact that different individuals may have different evaluations of the options, the PFTOPSIS approach was employed to compare the alternatives. The application steps of the PFTOPSIS method are explained below (Oz et al., 2019):

Step 1: A decision matrix is created for the alternatives, taking into account PFSs (Bulut and Özcan, 2021). A decision matrix is created as shown in Equation 16 to show $C_j$ (j=1, 2, …, n) alternatives and $x_i$ (i= 1, 2, …, m) criteria.

$$R = \left(C_j(x_i)\right)_{mxm} = \begin{pmatrix} P(u_{11},v_{11}) & P(u_{12},v_{12}) & \cdots & P(u_{1n},v_{1n}) \\ P(u_{21},v_{21}) & P(u_{22},v_{22}) & \cdots & P(u_{2n},v_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ P(u_{m1},v_{m1}) & P(u_{m2},v_{m2}) & \cdots & P(u_{mn},v_{mn}) \end{pmatrix} \quad (16)$$

Step 2: Pythagorean fuzzy positive ideal and negative ideal solutions are calculated with Equations 17 and 18.

$$x^+ = \left\{C_j \max_i s\left(C_j(x_i)\right) \middle| j = 1,2,\dots,n\right\}$$
$$= \{\langle C_1, P(u_1^+, v_1^+)\rangle, \langle C_2, P(u_2^+, v_2^+)\rangle, \dots, \langle C_n, P(u_n^+, v_n^+)\rangle\} \quad (17)$$
$$x^- = \left\{C_j \min_i \langle s\left(C_j(x_i)\right)\rangle | j = 1,2,\dots,n\right\}$$
$$= \{\langle C_1, P(u_1^-, v_1^-)\rangle, \langle C_2, P(u_2^-, v_2^-)\rangle, \dots, \langle C_n, P(u_n^-, v_n^-)\rangle\} \quad (18)$$

Step 3: The distances to the positive and negative ideal solution are calculated with equations 19 and 20, respectively:

$$D(x_i, x^+) = \sum_{j=1}^{n} w_j\, d\left(C_j(x_i), C_j(x^+)\right)$$

$$= \frac{1}{2}\sum_{j=1}^{n} w_j \left(\left|(u_{ij})^2 - (u_j^+)^2\right| + \left|(v_{ij})^2 - (v_j^+)^2\right| + \left|(\pi_{ij})^2 - (\pi_j^+)^2\right|\right) \quad (19)$$

$$D(x_i, x^-) = \sum_{j=1}^{n} w_j\, d\left(C_j(x_i), C_j(x^-)\right)$$

$$= \frac{1}{2}\sum_{j=1}^{n} w_j \left(\left|(u_{ij})^2 - (u_j^-)^2\right| + \left|(v_{ij})^2 - (v_j^-)^2\right| + \left|(\pi_{ij})^2 - (\pi_j^-)^2\right|\right) \quad (20)$$

Step 4: Closeness values for each alternative are calculated according to Equation 21:

$$\xi(x_i) = \frac{D(x_i, x^-)}{D_{max}(x_i, x^-)} - \frac{D(x_i, x^+)}{D_{min}(x_i, x^+)} \quad (21)$$

Step 5: Alternatives are ranked from the one with the greatest closeness value to the alternative with the worst closeness value. The alternative with the highest Closeness value is the optimal choice.

## Case Study

Disasters are events that destroy a certain region or a country. In order to reduce the negative effects caused by disasters, necessary planning must be made before the disaster. In order to reduce the negative effects of disasters, the locations of ESs that will serve after the disaster must be determined correctly. In the literature,

it is seen that researchers are working on determining the locations of ESs to be established in city centers to serve only that province. However, the Kahramanmaraş earthquakes that occurred on February 6, 2023 affected 10 provinces and revealed how important the aid from surrounding provinces is. Therefore, in this study, it is aimed to provide service to the surrounding provinces with the ESs to be opened. It is thought that the possible Istanbul earthquake may also affect the surrounding provinces. In this study, in order to reduce the effects of earthquakes, the locations of ESs that will be established in districts outside the center of Ankara and will serve neighboring provinces have been tried to be determined. In the studies in the literature, it is seen that MCDM methods are used in location selection problems based on many criteria among different alternatives. Therefore, in this study, PFAHP and PFTOPSIS methods, which are among the MCDM methods, were used in the location selection problem of ESs to be opened in the non-central districts of Ankara.

In the study, firstly, the criteria to be used in ES location selection were used by using studies in the literature. It is aimed to provide service to neighboring provinces and districts with the ESs to be opened in the study. Therefore, unlike the studies in the literature, the "Number of Provinces within Coverage Distance" and "Number of Districts within Coverage Distance" criteria were also taken into account in the evaluation of the alternatives. Once the criteria were established, views were sought from 10 AFAD employees who were experts in the field. They were then instructed to evaluate and compare the established criteria in pairs. Given the subjective nature of these opinions, fuzzy logic has been employed to mitigate this variability. Since more realistic solutions are obtained with PFNs compared to other fuzzy numbers (Bulut and Özcan, 2021), PFNs were also used in this study. First, criterion weights were calculated using pairwise comparison matrices received from experts with the PFAHP method. Afterwards, 16 districts located outside the center of Ankara were compared in terms of places where ESs would be opened according to the determined criteria, and the alternatives were listed using the PFTOPSIS method. In the last part of the study, calculations were made with FTOPSIS and FCOPRAS methods, which contain similar steps to PFTOPSIS, and the results were compared. The sensitivity analysis involved doing computations using binary changes in the criterion weights that were derived for the selection of ES locations. The resulting outcomes were then compared. The stages of this study regarding the location selection of ESs are shown in Figure 1.


Figure 1. ES location selection flow chart

**Determination of Criteria**

It is seen in the literature that there are studies on determining the locations of ESs using MCDM methods. In the studies on ES location selection in the literature, the most common criteria for comparing alternatives are "Population", "Earthquake / Disaster Risk", "Distance to the Center", "Transportation", "Land Cost", "Proximity to the Port / Airport / Highway", "Infrastructure", “Security” etc. criteria are used. Since the most preferred criteria in the studies in the literature are "Population", "Earthquake Risk" and "Distance to the Center", these criteria were used to compare the alternatives in this study. Unlike the studies in the literature, the aim of this study is to provide service to neighboring provinces and districts with the ESs opened.

Therefore, in this study, unlike the literature, the "Number of Provinces within the Coverage Distance" and "Number of Districts within the Coverage Distance" criteria, which are within the specified coverage distance to the ES to be opened, were also used among the evaluation criteria to compare the alternatives. The criteria used and explanations of these criteria are given in Table 2.

Table 2 Criteria used in ES location selection and explanations

| Criteria. | Explanation |
|---|---|
| Population ($ESC_1$) (Roh et al., 2013) | Population of the district where the Emergency Station is planned to be established |
| Earthquake Risk ($ESC_2$) (Peker et al., 2016, Hazırcı & Sahin, 2019) | Earthquake risk of the district where the Emergency Station is planned to be established |
| Distance to the Center ($ESC_3$) (Roh et al., 2013; Peker et al., 2016, Ergun et al., 2020)) | Distance of the district where the Emergency Station is planned to be established to the city center |
| Number of Provinces within the Coverage Distance ($ESC_4$) | Number of neighboring provinces within the 300 km coverage area of the district where the Emergency Station will be established |
| Number of Districts within the Coverage Distance ($ESC_5$) | Number of neighboring districts within the 100 km coverage area of the district where the Emergency Station will be established |

It is aimed to deliver aid to the disaster area within approximately 1 - 1.5 hours from the ES planned to be opened. Therefore, the coverage area for the ES planned to be opened was determined as 100 km according to the "Number of Districts in Coverage Distance" criterion. It is aimed to deliver aid to neighboring provinces within approximately 4 hours from the ES planned to be opened. Therefore, in the "Number of Provinces in Coverage Distance" criterion, the coverage distance was taken as 300 km, taking into account factors such as traffic and speed limits that may be encountered on the way from the ES planned to be opened to the disaster area. As a result, the number of districts 100 km away from that district was taken into account from the "Number of Districts in Coverage Distance" criterion. In the "Number of Provinces within Coverage Distance" criterion, the number of provinces within 300 km coverage distance from the district where the ES is planned to be established is taken into account. In calculating the distances between provinces and districts, the Distance from District to District tab of the General Directorate of Highways was used (KGM, 2024).

**Calculation of Criterion Weights with PFAHP**

The PFAHP approach was employed to determine the weights of the criteria for the purpose of selecting locations for ESs. In the previous section, the criteria to be used for ES location selection were determined as "Population", "Earthquake Risk", "Distance to the Center", "Number of Provinces within Coverage Distance" and "Number of Districts within Coverage Distance".

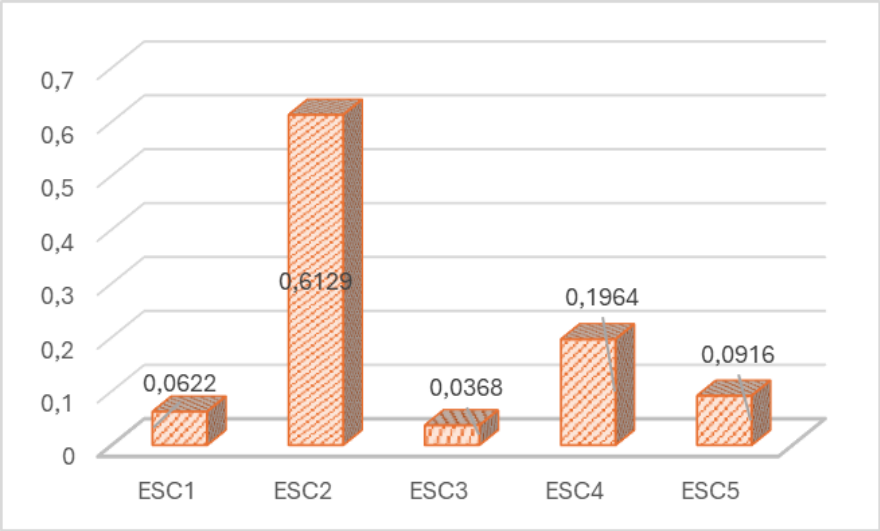


Figure 2. Criteria weights calculated with PFAHP

To establish the criterion weights in the study, 10 individuals employed at Ministry of Interior Disaster and Emergency Management Presidency (AFAD) were questioned. These individuals were requested to assess and compare the criteria using the 1-9 scale devised by Saaty. Afterwards, these comparison scores were converted into fuzzy Pythagorean numbers and calculations were made by following the steps of the PFAHP method. The criterion weights obtained as a result of the calculations are given in Figure 2.

When Figure 2 is examined, it can be seen that the most important criterion for ES location selection is earthquake risk with a weight of 0.6129. This shows that when choosing the location of ESs, the earthquake risk in the selected region is taken into account first. The second most important criterion for location selection was the "Number of Provinces within Coverage Distance" Criteria, which takes into account the aim of delivering aid to surrounding provinces from the station to be opened. The weights of other criteria are also given in Figure 2.

**Ranking of Alternatives with the PFTOPSIS Method**

In the study, the problem of determining the locations of ESs to be established in 16 districts outside the center of Ankara was examined. In addition, it is aimed to determine the locations of these ESs in a way that will serve neighboring provinces and districts. In the study, the PFTOPSIS method was used to evaluate 16 alternative districts where ESs were planned to be opened. First of all, data corresponding to the criteria were obtained for each district. Population, earthquake risk and distance to the center data of the districts are given in the Appendix. In the study, first the data corresponding to these criteria were scored according to the 1-9 scale, and then these scores were converted into PFNs. The PFTOPSIS method was used to do calculations, resulting in the determination of proximity values for each choice. In the calculations, "Population", "Number of Provinces within Coverage Distance" and "Number of Districts within Coverage Distance" were taken as benefit criteria, "Earthquake Risk" and "Distance to the Center" were taken as cost criteria and the calculations were made accordingly. Figure 3 was created with the calculated closeness values.

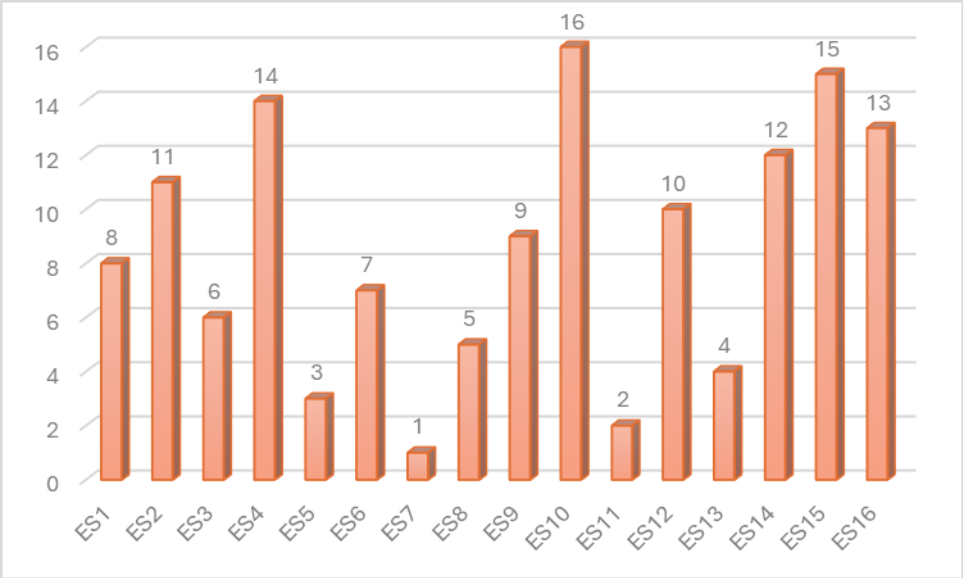


Figure 3. Ranking of alternative districts calculated with PFTOPSIS

When Figure 3 is examined, it is seen that ESs should first be established in Elmadağ, Kahramankazan and Çamlıdere districts, respectively. The most effective criterion in creating the ranking is the "Earthquake Risk" criterion, which has the highest weight. When the districts are compared according to the determined criteria, the order of the alternatives where ESs will be opened is ES7 – ES11 – ES5 – ES13 – ES8 – ES3 – ES6 – ES1 – ES9 – ES12 – ES2 – ES14 – ES16 – ES4 – ES15 – ES10. In this case, if ESs will be opened in more than one district, the districts where the stations will be opened can be determined by following this order.

**Comparative Analysis**

In this section, the results obtained with the PFAHP - PFTOPSIS method developed for ES location selection are compared with the results obtained with the PFAHP - FTOPSIS and PFAHP - FCOPRAS methods, which include similar algorithm steps. In the calculations made with all three methods, criterion weights calculated with PFAHP were used. During the comparison of alternatives, calculations were made using PFTOPSIS, FTOPSIS and FCOPRAS methods. First, the data of alternative ESs were converted into triangular fuzzy numbers. Afterwards, calculations were made by following the steps of the FTOPSIS and FCOPRAS methods. In the calculations made, it is seen that there are differences from the ranking obtained with the PFTOPSIS method, but a similar ranking is obtained in the calculations made with the FTOPSIS and FCOPRAS methods. Figure 4 was created using calculations made with the PFAHP – PFTOPSIS, PFAHP – FTOPSIS and PFAHP – FCOPRAS methods.

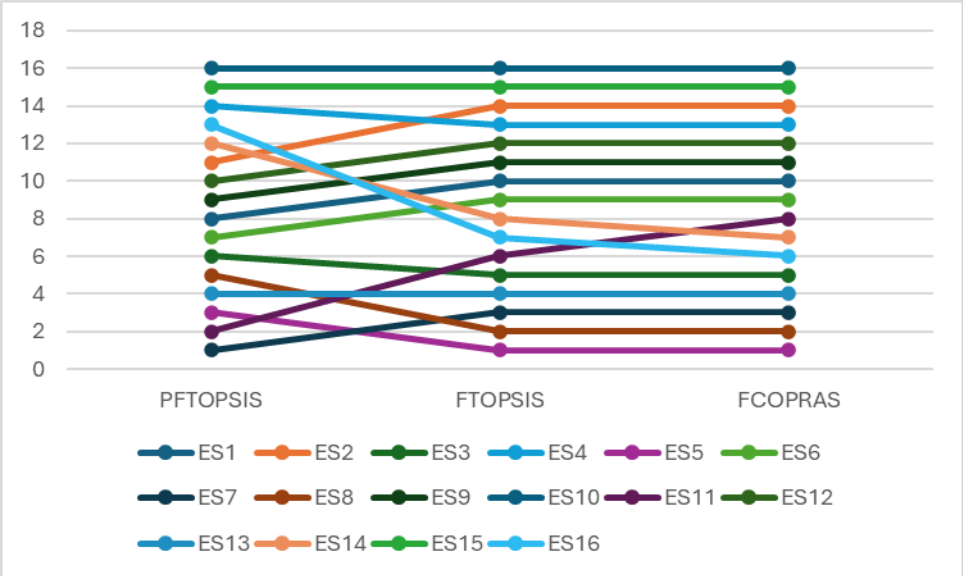


Figure 4. Comparison of calculations made with PFTOPSIS, FTOPSIS and FCOPRAS

When Figure 4 is examined, it is noted that the ranking obtained from the calculations made with PFTOPSIS is slightly different from the rankings obtained with the FTOPSIS and FCOPRAS methods, but the ranking does not change significantly. This is due to the use of different fuzzy numbers in these methods. It can be seen that the rankings obtained by calculations made with FTOPSIS and FCOPRAS methods are the same, except for a few alternatives. This is due to the fact that these methods involve similar steps and use the same fuzzy numbers. However, studies indicate that more realistic results are achieved with PFNs (Yager, 2014; Bulut & Ozcan, 2021). Therefore, it would be a more accurate approach to determine the locations of the ESs to be opened in the non-central districts of Ankara according to the order made by the PFAHP - PFTOPSIS method.

**Sensitivity Analysis**

The Kahramanmaraş earthquakes that occurred on February 6, 2023 affected a wide region and airports and highways suffered great damage in this earthquake. These earthquakes affected a large area and showed how important the aid to be delivered from surrounding provinces is. It is assumed that a possible Istanbul earthquake may also affect a wide area. Therefore, planning accordingly before the earthquake will be effective in reducing the negative effects of the earthquake on the region. Therefore, in this study, the problem of determining the locations of ESs to be established in the non-central districts of Ankara in order to deliver aid to the surrounding provinces that will be affected by a possible Istanbul earthquake was examined. Since more than one criterion will be effective in location selection, the integrated PFAHP – PFTOPSIS method of MCDM techniques was used to solve the problem. It is thought that there may be changes in the future periods, such as changes in the characteristics of the region and the opening of new ESs in the surrounding provinces, and it is assumed that this situation may also cause changes in the criterion weights. Therefore, in this section, sensitivity analysis of binary changes in criterion weights was conducted and the effect of the change in criterion weights on the alternative ranking was tried to be determined. The weights of the 5 criteria used in comparing the alternatives were changed in pairs and calculations were made for the 10 scenarios created. The rankings obtained in solving 10 different scenarios created within the scope

of sensitivity analysis are given in Figure 5. In Figure 5, the ranking obtained with the current criterion weights is shown as "S1", and in other scenarios, it is shown which criteria weights were obtained by changing.

| | ES1 | ES2 | ES3 | ES4 | ES5 | ES6 | ES7 | ES8 | ES9 | ES10 | ES11 | ES12 | ES13 | ES14 | ES15 | ES16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 8 | 11 | 6 | 14 | 3 | 7 | 1 | 5 | 9 | 16 | 2 | 10 | 4 | 12 | 15 | 13 |
| C1-C2 | 5 | 7 | 11 | 6 | 13 | 2 | 4 | 16 | 9 | 14 | 3 | 10 | 8 | 15 | 1 | 12 |
| C1-C3 | 8 | 11 | 6 | 14 | 3 | 7 | 1 | 5 | 9 | 16 | 2 | 10 | 4 | 12 | 15 | 13 |
| C1-C4 | 9 | 15 | 6 | 12 | 2 | 4 | 1 | 3 | 14 | 16 | 5 | 13 | 7 | 11 | 8 | 10 |
| C1-C5 | 8 | 13 | 7 | 14 | 2 | 6 | 1 | 4 | 9 | 16 | 3 | 12 | 5 | 10 | 15 | 11 |
| C2-C3 | 4 | 5 | 7 | 12 | 13 | 3 | 2 | 16 | 10 | 11 | 1 | 6 | 8 | 15 | 9 | 14 |
| C2-C4 | 6 | 2 | 11 | 9 | 10 | 5 | 3 | 13 | 4 | 16 | 1 | 8 | 7 | 14 | 12 | 15 |
| C2-C5 | 4 | 3 | 6 | 12 | 13 | 7 | 2 | 14 | 8 | 10 | 1 | 5 | 9 | 15 | 11 | 16 |
| C3-C4 | 6 | 11 | 4 | 12 | 3 | 5 | 1 | 8 | 13 | 16 | 6 | 9 | 7 | 14 | 15 | 10 |
| C3-C5 | 6 | 11 | 4 | 12 | 3 | 5 | 1 | 8 | 13 | 16 | 2 | 9 | 7 | 14 | 15 | 10 |
| C4-C5 | 7 | 12 | 4 | 13 | 3 | 8 | 1 | 5 | 10 | 16 | 2 | 9 | 6 | 11 | 15 | 14 |

Figure 5. Alternative rankings obtained by sensitivity analysis

In the calculations made with PFAHP, it was determined that the ESC2 criterion had the greatest criterion weight. This shows that the most effective criterion in creating the ranking is the ESC2 criterion. The criterion with the second highest weight in the calculations is the ESC4 criterion. When Table 3 is examined, it is noted that the rankings change significantly, especially when the ESC2 criterion weight is replaced with other criterion weights. This is due to the fact that the ESC2 criterion has a weight of 0.6129 and has a great impact on the creation of the ranking. It is seen that there is a change in the ranking when the weights of the ESC4 criterion, which ranks second with a weight of 0.1964, and the other criteria are changed. It is noteworthy that since the weight values of the other criteria are close to each other, there is no major change in the ranking when the weights of these criteria are changed.

## Conclusion

Disasters can be defined as technology, nature or human-induced events that occur at unexpected times and negatively affect a part or all of the society physically, economically and socially. Although it is impossible to predict when disasters will occur, it is possible to minimize the negative effects of disasters with precautions and planning. In taking these precautions, it is necessary to know in advance how many people in that region may be affected by the disaster and which disasters are most likely to occur in that region. Studies carried out before disasters to reduce the negative effects that disasters may cause are defined as disaster logistics. Disaster logistics includes many activities such as planning, location selection, distribution, transportation and storage. One of the most important elements of disaster logistics is ESs. Determining the location of ESs correctly is of great importance as it will be effective in quickly delivering aid to the region after the disaster. Therefore, in this study, the problem of location selection of ESs was examined. More than one criterion is effective in the location selection of ESs. Therefore, AHP and TOPSIS methods, which are the most preferred MCDM methods, were used in determining the locations of ESs in the study. In determining the criterion weights, AFAD personnel were interviewed and asked to compare the criteria. This information contains uncertainty as it may vary from person to person. In order to eliminate this uncertainty, PFNs were used in the study and integrated PFAHP – PFTOPSIS methods were used to make the calculations.

In order to eliminate this uncertainty, PFNs were used in the study and integrated PFAHP – PFTOPSIS methods were used to make the calculations. However, the Kahramanmaras earthquakes that occurred on February 6, 2023 affected a wide geography and showed that the aid sent from surrounding provinces is of great importance. Therefore, it is aimed to provide service to the surrounding provinces with the ESs opened in this study. It is thought that the possible Istanbul earthquake will also affect a wide geography. Therefore, in this study, it is aimed to provide service to the neighboring provinces with a coverage distance of 300 km and the neighboring districts with a coverage distance of 100 km with the ESs that will be opened outside the center of Ankara. As far as is known, this is the first study in which the aim is to provide service to neighboring provinces and districts with ESs to be opened in out-of-center districts, and the integrated PFAHP - PFTOPSIS methods are used in the location selection of the ES. Since more than one criterion is taken into account when comparing alternative districts, MCDM methods were used to solve the location selection problem of ESs.

In the study, firstly, studies in the literature on ES location selection were examined and the criteria effective in location selection were determined. However, in this study, unlike the literature, it is planned to provide service to the neighboring provinces and neighboring districts from stations that will be opened. In comparing the alternative districts determined for ESs, the "Population", "Earthquake Risk" and "Distance to the Center" criteria, which are the most used in the literature, as well as the "Number of Provinces within the Coverage Distance" and "Number of Districts within the Coverage Distance" criteria were taken into account. Pairwise comparison matrices of the criteria were created through interviews with experts and the scores were converted into PFNs. Afterwards, the criterion weights were calculated with the PFAHP method and it was determined that the most effective criterion in location selection was Earthquake Risk with a weight of 0.6129. In this case, it seems that the earthquake risk is primarily effective in determining the locations of emergency stations. In this case, it seems that the earthquake risk is primarily effective in determining the locations of emergency stations. Accordingly, ESs should first be opened in Elmadağ, Kahramankazan, Camlıdere, Kızılcahamam and Evren districts.

In order to determine the effectiveness of the PHAHP – PFTOPSIS methods used for ES location selection, calculations were made with the FTOPSIS and FCOPRAS methods, which have similar application steps with the same criterion weights. When the rankings obtained as a result of the calculations were compared, it was determined that a ranking close to the ranking obtained with the PFTOPSIS method was obtained, and the rankings of some alternatives were changed. In the last part of the study, recalculations were made by taking the binary changes of the criterion weights and the resulting rankings were compared. In the calculations made, it was determined that the rankings changed greatly when the weights of the ESC2 and ESC4 criteria, which have the largest criterion weights, were changed in pairs. This shows that these criteria are primarily effective in determining the places where emergency facilities will be established. The weights of the other criteria vary between 0-0.1, and since these criteria have weights close to each other, it is noteworthy that the bilateral changes in the criterion weights do not affect the alternative rankings much.

## Recommendations

In this study, the integrated PFAHP – PFTOPSIS method was used to determine the locations of ESs that will also serve the surrounding provinces. In future studies, the location selection problem of ESs can be examined by adding different criteria. The study examined the location selection problem of ESs planned to be opened outside the center of Ankara. In future studies, the problem can be expanded to include different provinces and regions. In addition, in future studies, the results obtained by solving this problem using spherical, neutrosophic and hesitant fuzzy numbers and different MCDM methods can be compared.

## Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

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## References

Atanassov, K. T., (1999). *Intuitionistic fuzzy sets* (pp. 1-137). Physica-Verlag HD.

Bayram, B., & Eren, T. (2023). Cok kriterli karar verme yontemleriyle afet sonrası gecici depo yeri seçimi. *Acil Yardım ve Afet Bilimi Dergisi*, *3*(2), 22-30.

Bulut, M., & Ozcan, E. (2021). Integration of battery energy storage systems into natural gas combined cycle power plants in fuzzy environment. *Journal of Energy Storage*, *36*, 102376.

Bulut, M., & Ozcan, E. (2023). Ranking of advertising goals on social network sites by Pythagorean fuzzy hierarchical decision making: Facebook. *Engineering Applications of Artificial Intelligence*, *117*, 105542.

Cetinkaya, C., Ozceylan, E., & Isleyen, S. K. (2021). Emergency shelter site selection in maar shurin community of Idlib (Syria). *Transportation Journal*, *60*(1), 70-92.

Derse, O. (2022). Dematel tabanlı TOPSIS yontemi ve kume kapsama modeli ile afet lojistigi icin depo yeri secimi: Ege bolgesi ornegi. *Kahramanmaras Sutcu Imam Universitesi Muhendislik Bilimleri Dergisi*, *25*(4), 702-713.

Desticioglu- Tasdemir, B., & Asilogullari Ayan, M. (2023). Sustainable supplier selection in the defense industry with multi-criteria decision-making methods. *International Symposium on Intelligent Manufacturing and Service Systems* (pp. 95-106). Singapore: Springer Nature Singapore.

Desticioglu - Taşdemir, B., Kumcu, S., & Ozyoruk, B., (2023). Comparison of e-commerce sites with pythagorean fuzzy AHP and TOPSIS methods. *Intelligent and Fuzzy Systems. INFUS 2023. Lecture Notes in Networks and Systems* (pp.327-335), Zurich: Springer Nature.

Durdag, C., Ergenecoşar, S., Kınık, Z., & Yılmaz, K. K. (2021). Afet bakış acısıyla lojistik depo yeri seçimi: İstanbul Beykoz ilçesi üzerine bir uygulama. *Beykoz Akademi Dergisi*, *9*(1), 98-107.

Ergun, M., Korucuk, S., & Memiş, S. (2020). Surdurulebilir afet lojistiğine yönelik ideal afet depo yeri seçimi: Giresun ili ornegi. *Canakkale On Sekiz Mart Universitesi Fen Bilimleri Enstitusu Dergisi*, *6*(1), 144-165.

Gul, M., & Ak, M. F. (2018). A comparative outline for quantifying risk ratings in occupational health and safety risk assessment. *Journal of Cleaner Production*, *196*, 653-664.

Hoyois, P., Scheuren, J. M., Below, R., & Guha-Sapir, D. (2007). *Annual disaster statistical review: Numbers and trends*. Retrieved from https://theisrm.org/.pdf

Hwang, C. L.& Yoon, K. (1981). Methods for multiple attribute decision making. In *Multiple attribute decision making: methods and applications a state-of-the-art survey* (pp.58-191). Springer.

Ilbahar, E., Karas, A., Cebi, S., & Kahraman, C. (2018). A novel approach to risk assessment for occupational health and safety using Pythagorean fuzzy AHP & fuzzy inference system. *Saf Sci., 103*, 124–136

KGM (2024). Karayolları Genel Mudurlugu Retrieved from https://www.kgm.gov.tr/sayfalar/Kgm/sitetr/uzakliklar/ilcedenilceyemesafe.aspx

Ofluoglu, A., Birdogan, B., & Ar, I. M. (2017). Multi-criteria decision analysis model for warehouse location in disaster logistics. *Journal of Management Marketing and Logistics*, *4*(2), 89-106.

Oz, N. E., Mete, S., Serin, F., & Gul, M. (2018). Risk assessment for clearing and grading process of a natural gas pipeline project: An extended TOPSIS model with Pythagorean fuzzy sets for prioritizing hazards. *Human and Ecological Risk Assessment: An International Journal*.

Omurbek, N., & Simsek, A. (2014). Analitik hiyerarşi süreci ve analitik ağ süreci yöntemleri ile online alişveriş site secimi. *Journal of Management and Economics Research*, *12*(22), 306-327.

Ozturk, F., & Kaya, G. K. (2020). Afet sonrası toplanma alanlarının promethee metodu ile değerlendirilmesi. *Uludag Universitesi Muhendislik Fakultesi Dergisi*, *25*(3), 1239-1252.

Peker, I., Korucuk, S., Ulutas, S., Okatan, B. S., & Yasar, F. (2016). Afet lojistigi kapsaminda en uygun dağitim merkez yerinin ahs-vıkor butunlesik yontemi ile belirlenmesi: Erzincan ili örneği. *Journal of Management and Economics Research*, *14*(1), 82-103.

Polat, E. G. (2022). Distribution centre location selection for disaster logistics with integrated goal programming-AHP based TOPSIS method at the city level. *Afet ve Risk Dergisi*, *5*(1), 282-296.

Roh, S. Y., Jang, H. M., & Han, C. H. (2013). Warehouse location decision factors in humanitarian relief logistics. *The Asian Journal of Shipping and Logistics*, *29*(1), 103-120.

Saaty, T. L. (1980). The analytic hierarchy process (AHP). *The Journal of the Operational Research Society*, *41*(11), 1073-1076.

Sahin, Y., & Hazırcı, M. (2019). Gecici iskân alanlarının seçimi için ahp temelli p-medyan modeli: Burdur ornegi. *Muhendislik Bilimleri ve Tasarım Dergisi*, *7*(2), 403-417.

Sekkeli, Z. H. (2020). Afet ve acil durum lojistigi kapsamında acil durum toplanma merkezi seçiminde AHP yontemi: Kahramanmaraş on iki subat belediyesinde bir uygulama. *Insan ve Toplum Bilimleri Arastırmaları Dergisi*, *9*(2), 903-930.

Sen, G., & Esmer, S. (2017). Afet lojistigi: Bir literatür taraması. *The International New Issues in Social Sciences*, *5*(5), 231-250.

Tezcan, B., Alakaş, H. M., Özcan, E., & Tamer, E. R. E. N. (2021). Afet sonrası geçici depo yeri seçimi ve çok araçlı araç rotalama uygulaması: Kırıkkale ilinde bir uygulama. *Politeknik Dergisi*, *26*(1), 13-27.

Thomas, A. S., & Kopczak, L. R. (2005). From logistics to supply chain management: the path forward in the humanitarian sector. *Fritz Institute*, *15*(1), 1-15.

Trivedi, A. (2018). A multi-criteria decision approach based on DEMATEL to assess determinants of shelter site selection in disaster response. *International Journal of Disaster Risk Reduction*, *31*, 722-728.

Yager, R. R. (2013). Pythagorean membership grades in multicriteria decision making. *IEEE Transactions on fuzzy systems*, *22*(4), 958-965.

Yıldırım, M., Karakaya, O., & Altan, İ. M. (2019). TOPSIS yöoteminde maliyet ve karlılık oranlarının kullanılmasıyla finansal performansın olcumu: Ana metal sanayi sektöründen bir şirket ornegi. *Gazi Iktisat ve Isletme Dergisi*, *5*(3), 170-181.

Yurek, Y. T., Ozyoruk, B., Ozcan, E., & Bulut, M. (2023). Socio-political evaluation of renewable energy resources under uncertain environment. *Engineering Applications of Artificial Intelligence*, *126*, 106881.

Zeng, S., Chen, J., & Li, X. (2016). A hybrid method for Pythagorean fuzzy multiple-criteria decision making. *International Journal of Information Technology & Decision Making*, *15*(02), 403-422.

Zhang, X., & Xu, Z. (2014). Extension of TOPSIS to multiple criteria decision making with Pythagorean fuzzy sets. *International Journal of Intelligent Systems*, *29*(12), 1061-1078.

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## Appendix

| Alternative | Population | Earthquake Risk | Distance from Center | Number of province within coverage distance | Number of districts within coverage distance |
|---|---|---|---|---|---|
| Akyurt | 40625 | 3 | 35 | 12 | 5 |
| Ayaş | 12998 | 4 | 57 | 12 | 7 |
| Bala | 20521 | 2 | 67 | 12 | 2 |
| Beypazarı | 48357 | 3 | 99 | 10 | 4 |
| Çamlıdere | 8100 | 1 | 103 | 8 | 3 |
| Çubuk | 95449 | 3 | 39 | 11 | 5 |
| Elmadağ | 44379 | 2 | 41 | 13 | 5 |
| Evren | 2952 | 1 | 175 | 8 | 1 |
| Güdül | 8079 | 3 | 91 | 10 | 6 |
| Haymana | 26016 | 4 | 76 | 11 | 1 |
| Kahramankazan | 59123 | 3 | 46 | 13 | 7 |
| Kalecik | 12794 | 3 | 68 | 12 | 4 |
| Kızılcahamam | 26872 | 2 | 78 | 10 | 5 |
| Nallıhan | 26553 | 2 | 158 | 8 | 2 |
| Polatlı | 128378 | 4 | 78 | 10 | 2 |
| Şereflikoçhisar | 33140 | 2 | 147 | 7 | 1 |