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Research Article

Integrated Fuzzy FUCOM and Fuzzy MARCOS Approaches for Housing Location Problem

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Abstract

When choosing a housing, the region in which it is located is as important as the quality of the housing. Depending on a number of factors such as the socio-cultural structure of that region, the services offered, and the opportunities in the surrounding area, the choice of housing location may change. In this context, the aim is to investigate which district is the most suitable when buying a house by evaluating customers' preferences for housing location in Erzurum province. In the case study, 3 alternative regions (Palandoken, Yakutiye ve Aziziye) and 6 criteria (transportation accessibility, housing price, population density, noise and air pollution, infrastructure safety, social and cultural activity areas) were defined and the criteria weights were calculated using the Fuzzy Full Consistency Method (F-FUCOM). Then, the Fuzzy Measurement Alternatives and Ranking According to Compromise Solution (F- MARCOS) method was used to evaluate the alternatives. The results of the research have shown that the most important criterion is the price of the house, while the least important criterion is noise and air pollution for customers to buy a house. In addition, the results have shown that Yakutiye district is the best alternative for choosing housing districts in Erzurum province. The other alternatives are Palandoken and Aziziye respectively.

1. Introduction

Housing is a product with an environment and a physical size that should meet the basic needs of people such as food, clothing, and shelter in a safe and healthy way. Housing has an important socio-cultural as well as a physical meaning [1]. Housing and living environment is a fundamental living space to meet people's basic needs fulfil their expectations, and improve the overall health of the individual/community.

It is important to recognise the needs and preferences of customers who buy housing. However, it is also an important and difficult process to research the regions where the housing is located and decide on the most suitable area to buy a housing. The difficulty of this process is due to the socio-demographic characteristics, cultural and economic structures and lifestyles of the people who buy housing. For this reason, the problem of housing location selection is an important decision-making problem. For decision making problems, researchers in the literature use multi-criteria decision making (MCDM) methods. In this context, the housing location problem of the customers in Erzurum was addressed using a multi-criteria decision-making approach. Erzurum is the 4th largest province of Turkey with an area of 25.066 km^2. In 2021, the number of households in Erzurum is 197.862 and population is 756.893 [2]. The province of Erzurum consists of 20 districts (Figure 1). Among these districts, Palandoken, Aziziye and Yakutiye are the central districts. Palandoken is one of the large districts in the center of Erzurum. The area of Palandoken is 700 km^2 and the population is 175.920. The district, conspicuous for its high proportion of young population, has a constantly developing momentum of its own [3]. Aziziye district is located in the west of Erzurum and has the largest area of Erzurum with an area of about 1702 km^2 [4]. The population of Aziziye is 65.133. The area of Yakutiye is 883.7 km^2 and the population is 187.249 [5]. Within the framework of the study, the central districts of Palandoken, Aziziye and Yakutiye from the districts of Erzurum were considered as alternative regions in the selection of housing location.

The criteria by which customers make their choice of housing area is a notable topic among researchers. The studies conducted in the literature to determine the criteria in question are as follows; Tosun and Fırat [6] investigated the criteria that people living in Bursa take into account when choosing their housing through a face-to-face survey of 1328 people. The study found that the most important criteria for choosing housing are the price of the house (29.8%), the safety measures in the house (14.9%) and the earthquake resistance of the house (13.7%). Yi and Lee [7] concluded in their study of the Korean housing market that the factors influencing the choice of location differ depending on the length of residence. Akturk and Tekman [8] studied the factors influencing the housing decisions of consumers living in the city center of Erzurum. The survey of 650 people showed that the price of the house, the reliability of the builder, the safety of the house, the size of the house, the quality of the materials used, the proximity of the house to the center, the strength and spaciousness of the house, etc are important factors. Wang et al. [9] investigated the factor influencing housing choice, urban services, and commute time tolerance based on a survey and comparative analysis of 241 individuals in the Qiaobei district of the urban periphery in Nanjing. The results show that there are reciprocal links of incentives and constraints between life, employment, and services. Mazicioglu [10] conducted a survey to determine the variables that affect the preferences of high-income housing users in the city of Gaziantep in relation to urban living space. The analyzes conducted have shown that satisfaction with the quality of the environment increases people's quality of life and thus influences their life satisfaction. Memis [11] studied the criteria that influence the choice of housing by conducting a survey among real estate companies and experts in Giresun. The criteria identified were weighted using the Analytical Hierarchical Process method. According to the results obtained, it was

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found that the most important criterion in choosing a housing in Giresun province is the location of the house. As a result of Jackson and Archer [12] survey of 430 people selected from 14 neighborhoods in Jamaica, they concluded that the most important factors influencing household housing preferences were housing and its surroundings, accessibility, and neighborhood characteristics.

The aim of this study is to evaluate three central districts in Erzurum in terms of customer preferences using the proposed integrated F-FUCOM and F- MARCOS method. The other aim of the study is to fill this gap in the literature since there is no study on housing district selection in the light of literature review. At the same time, it is believed that this study will be an alternative lens to show the preferences of customers who buy houses. In addition, to the author's knowledge, there is no study in the literature on housing district selection using F-FUCOM and F- MARCOS methods. In this regard, it is believed that this study will contribute to the literature and real life.

The remainder of this paper is organized as follows. Chapter 2 explains the F-FUCOM and F-MARCOS methods used to solve the site selection problem. In the third chapter, the case study on the central districts of Erzurum is mentioned. In Chapter 4, the results of the study are presented and discussed. Finally, in Chapter 5, the results of the study and future studies are mentioned.

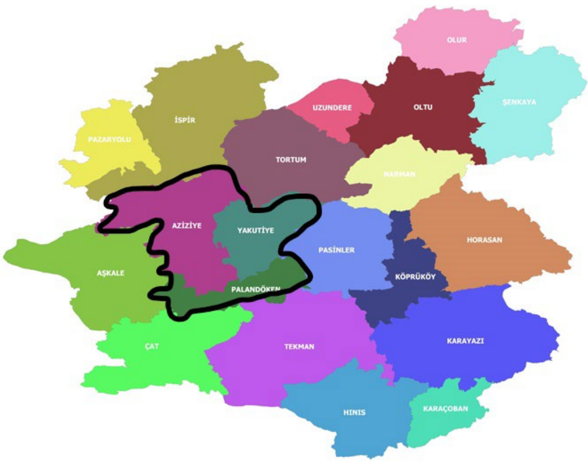

Figure 1. Map of the central districts of Erzurum

2. Material and Method

Multi-criteria decision making approaches are often used in solving important real-life decision problems. Some of these studies are: the problem of industrial engineering sector choosing [13], location selection of solar power plants [14], smart wristband selection [15], the problem of software selection [16], location selection of data center [17], the problem of warehouse location selection 18], selection problem for underground waste containers [19], the problem of lean and sustainable supplier selection [20], determination of priority investment sectors [21].

In this study, integrated F-FUCOM and F-MARCOS methods for the housing district selection were discussed. The steps of the F-FUCOM and F-MARCOS methods are as follows.

2.1. F-FUCOM Method

FUCOM is one of the subjective weighting methods recently developed by Pamucar et al. As a method based on linear programming, FUCOM checks whether two important consistency conditions are met. The first is that the ratios between the weights of the criteria are equal to the priorities in the pairwise comparison matrix. Another condition is based on the test of the mathematical transitivity property. In this way, the degree of deviation from consistency is calculated together with the obtained weights, and more reliable criterion weights are obtained [22, 23].

The F-FUCOM method is a fuzzy extension of the FUCOM method. For a decision problem where the number of criteria is n, the steps of the F-FUCOM method are given below:

Step 1: First, the decision criteria are established; C = {C1, C2, ..., Cn} where the number of criteria j ranges from 1 to n (j={1,2,3,...,n}).

Step 2: Established decision criteria are listed. Sorting is done according to the importance of the criteria; that is, it is made according to the criterion with the lowest weighting coefficient, starting from the criterion that is expected to have the highest weighting coefficient. Thus, the criteria ordered according to the expected values of the weighting coefficients are obtained:

$$C_{j(1)} > C_{j(2)} > \ldots. > C_{j(k)} \quad (1)$$

Where k stands for the ranking of the criteria. When two or more criteria have the same importance, the equal sign " = " is placed between the criteria instead of " > ".

Step 3: The criteria are compared using triangular fuzzy numbers (TFN). Comparative priorities are determined for the criteria that are ranked using the linguistic scale. The vectors $\tilde{\varphi}_{k\,/\,(k+1)}$ of the comparative priorities are created.

$$\phi = (\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}) \quad (2)$$

Here, the expression $\varphi_{k\,/\,(k+1)}$ indicates how advantageous the ranking of criterion $C_{j(k)}$ is compared to criterion $C_{j(k+1)}$.

Step 4: The final weights are determined by creating a mathematical model. At this point, two important conditions must be met. These conditions are as follows.

Condition 1: The ratio of the weighting coefficients should be equal to the comparative priorities. This condition is shown in Equation (3).

$$\frac{\tilde{w}_k}{\tilde{w}_{k+1}} = \tilde{\varphi}_{k/(k+1)} \quad (3)$$

Condition 2: The criterion weights must satisfy the property of mathematical transitivity. The necessary criterion for the second condition is given in Equation (4).

$$\frac{\tilde{w}_k}{\tilde{w}_{k+2}} = \tilde{\varphi}_{k/k+1} \oplus \tilde{\varphi}_{(k+1)/(k+2)} \quad (4)$$

To achieve complete consistency, the equations given should be created at the highest level. If equality cannot be achieved, it is desirable to minimize the extent of deviation. By solving the mathematical model in Equation (5), the final weights and deviation from the maximum consistency (DMC) value and x are determined and the criterion weights are assigned.

$$\begin{aligned}
& min\ x \\
& s.t. \\
& \left|\tilde{w}_k - \tilde{w}_{k+1} \otimes \tilde{\varphi}_{k/(k+1)}\right| \le x, \forall j \\
& \left|\tilde{w}_k - \tilde{w}_{k+2} \otimes \tilde{\varphi}_{k/(k+1)} \otimes \tilde{\varphi}_{(k+1)/(k+2)}\right| \le x, \forall j \\
& \textstyle\sum_{j=1}^{n} \tilde{w}_j = 1, \quad \forall j \qquad (5) \\
& w_j^l \le w_j^m \le w_j^u \\
& w_j^l \ge 0, \forall j \\
& j = 1,2, \ldots, n
\end{aligned}$$

Where $\widetilde{w}_j = (w_j^l, w_j^m, w_j^u)$j. is the fuzzy weighting of the criteria and $\widetilde{\varphi}_{k/(k+1)} = \varphi_{k/(k+1)}^l, \varphi_{k/(k+1)}^m, \varphi_{k/(k+1)}^u)$.

2.2. Fuzzy MARCOS Method

The method MARCOS, one of the most recent MCDM techniques, was developed by Stević et al. The basis of the method MARCOS is based on the definition of the relationship between decision alternatives and reference values, in other words, ideal and anti-ideal decision alternatives [24-26]

Step 1. Creating the decision matrix

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (6)$$

Step 2. In this step, the anti-ideal (AAI) and the ideal solution (AI) are determined and the extended initial decision matrix is created.

$$\tilde{X} = \begin{matrix} \widetilde{AAI} \\ \tilde{A}_1 \\ \tilde{A}_2 \\ \dots \\ \tilde{A}_m \\ \tilde{A}I \end{matrix} \begin{bmatrix} \tilde{x}_{aa1} & \tilde{x}_{aa2} & \dots & \tilde{x}_{aam} \\ \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \\ \tilde{x}_{ai1} & \tilde{x}_{ai2} & \dots & \tilde{x}_{ain} \end{bmatrix} \quad (7)$$

The anti-ideal solution (AAI) is an alternative with the worst properties, depending on the type of criterion. The ideal solution (AI) is the alternative with the best characteristics.

With the help of Equation (8) and Equation (9), anti-ideal solution (AAI) and ideal solution (AI) are calculated. Here, B represents the benefit maximizing criteria, while C represents the cost criteria.

$$\widetilde{AAI} = \min_i \tilde{x}_{ij} \;\; if \;\; j \in B \;\; and \;\; \max_i \tilde{x}_{ij} \;\; if \;\; j \in C \quad (8)$$

$$\widetilde{AI} = \max_i \tilde{x}_{ij} \;\; if \;\; j \in B \;\; and \;\; \min_i \tilde{x}_{ij} \;\; if \;\; j \in C \quad (9)$$

Step 3. The extended fuzzy decision matrix is normalized.

Normalization is performed using Equations (10)-(11), $\tilde{n}_{ij}$ represents the normalized fuzzy performance value:

$$\tilde{n}_{ij} = (n_{ij}^l, n_{ij}^m, n_{ij}^u) = \left(\frac{x_{AAI}^l}{x_{ij}^u}, \frac{x_{AAI}^l}{x_{ij}^m}, \frac{x_{AAI}^l}{x_{ij}^l}\right) \; if \; j \in C \quad (10)$$

$$\tilde{n}_{ij} = (n_{ij}^l, n_{ij}^m, n_{ij}^u) = \left(\frac{x_{ij}^l}{x_{AAI}^u}, \frac{x_{ij}^m}{x_{AAI}^u}, \frac{x_{ij}^u}{x_{AAI}^u}\right) \; if \; j \in B \quad (11)$$

Step 4. Generating a weighted normalized fuzzy decision matrix

The weighting is made using Equation (12), it shows the $\tilde{v}_{ij}$ weighted normalized fuzzy performance values. $\widetilde{\omega}_j (0 < \widetilde{\omega}_j < 1)$ j. represents the weight of the criterion.

$$\tilde{v}_{ij} = (v_{ij}^l, v_{ij}^m, v_{ij}^u) = \tilde{n}_{ij} \otimes \widetilde{\omega}_j = (n_{ij}^l \times w_j^l, n_{ij}^m \times w_j^m, n_{ij}^u \times w_j^u) \quad (12)$$

Step 5. Calculation of utility degree K_i for each alternative

The calculation of the utility degree of K_i according to the anti-ideal and ideal solution is given in Equation (13)-(14):

$$\widetilde{K_i^-} = \frac{\tilde{S}_i}{\tilde{S}_{AAI}} \quad (13)$$

$$\widetilde{K_i^+} = \frac{\tilde{S}_i}{\tilde{S}_{AI}} \quad (14)$$

Where $\widetilde{S_i} = \sum_{i=1}^{n} \tilde{v}_{ij}$

Step 6. The total utility degree $\tilde{T}_i$ for both ideal and anti-ideal solutions of each alternative is calculated by Equation (15) below.

$$\tilde{T}_i = \widetilde{K_i^-} \oplus \widetilde{K_i^+} \quad (15)$$

Step 7. Calculation of the total degree of utility

A new fuzzy representation of the total degree of utility is found by Equation (16).

$$\widetilde{D} = \max_i \tilde{T}_i \quad (16)$$

Step 8. Clarification of $\widetilde{D}$

Equation (17) is used to clarify fuzzy numbers.

$$Df_{crisp} = \frac{l + 4m + u}{6} \quad (17)$$

Step 9. Determination of utility functions associated with ideal and anti-ideal solutions

$f(\widetilde{K}_i^-)$ shows the useful function with respect to the ideal solution, and $f(\widetilde{K}_i^+)$with respect to the anti-ideal solution. Equation (18)–(19) is used to calculate $f(\widetilde{K}_i^-)$ and $f(\widetilde{K}_i^+)$.

$$f(\widetilde{K_i^+}) = \frac{\widetilde{K}_i^-}{Df_{crisp}} \quad (18)$$

$$f(\widetilde{K_i^-}) = \frac{\widetilde{K}_i^+}{Df_{crisp}} \quad (19)$$

Step 10. Calculating the total utility $f(K_i)$ for each alternative

The final utility function $f(K_i)$ is calculated using Equation (20.

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} \quad (20)$$

Step 11. Ranking of the alternatives

3. Case Study

The aim of this study is to analyze the preferences of customers by creating a set of criteria for housing district selection using expert opinions on the importance of the criteria and the evaluation of alternatives. In this context, the F-FUCOM method was applied to calculate the coefficients for weighting the criteria in order to determine the preferences of customers living in Erzurum in choosing housing according to the central districts. After calculating the weighting coefficients of the criteria, the method F-MARCOS was used to prioritize the alternatives. In order to evaluate the criteria and alternatives, a decision-making team of three Erzurum residents was formed. Attention was taken to ensure that the members of the decision-making team were people who had bought a house in Erzurum within the last year. One of the decision makers (DMs) works in the private sector and two of them in the public.

As a result of the literature review, 6 criteria for the selection of housing for the central districts of Erzurum were established. These criteria are: transportation accessibility (C1), housing price (C2), infrastructure safety (C3), social and cultural activity areas (C4), population density (C5), noise and air pollution (C6). Alternatives are the central districts of Erzurum Yakutiye, Palandoken and Aziziye. In Figure 2, the hierarchy of the housing location problem in Erzurum is shown.

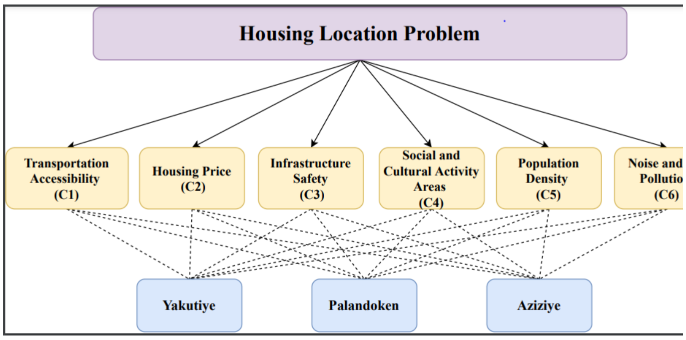

Figure 2. Hierarchy of the problem of housing location problem

3.1. Calculation of Criterion Weights by F-FUCOM Method

The first step in determining which criterion is important according to the application steps of the F-FUCOM method is to determine the order of importance of the criteria according to the decision-makers' own assessments. The steps of the method were then followed. The fuzzy linguistic expressions listed in Table 1 were used as fuzzy scales [27]. For example, the order of importance of the criteria of DM1 is as follows: transportation accessibility (C1) > housing price (C2) > population density (C5) > noise and air pollution (C6) > infrastructure safety (C3) > social and cultural activity areas (C4). In the next step, based on the preferences of the DMs, the language expressions of the comparative importance of the criteria were determined in order of importance. Using the fuzzy language scale, the linguistic expressions were transformed into TFN according to Table 1. Table 2 shows the ranking of criteria and the table of linguistic expressions for DM1.

Table 1. Scale for fuzzy language

Linguistic terms	Membership function
Equally important (EI)	(1,1,1)
Weakly important (WI)	(2/3,1,3/2)
Fairly Important (FI)	(3/2,2,5/2)
Very important (VI)	(5/2,3,7/2)
Absolutely important (AI)	(7/2,4,9/2)

Table 2. Ranking of criteria and table of linguistic expressions for DM1

Criteria	Order of importance	Linguistic Expressions	TFN	Ranking
C1	1	EI	(1 1 1)	
C2	2	WI	(0.67 1 1.5)	
C3	5	VI	(2.5 3 3.5)	C1> C2 > C5 > C6 > C3 > C4
C4	6	AI	(3.5 4 4.5)	
C5	3	FI	(1.5 2 2.5)	EI, WI, FI, VI, VI, AI
C6	4	VI	(2.5 3 3.5)	

The first group of the fuzzy significance vector φ=((0.67,1.00,1.50), (1, 2, 3.74), (1, 1.5, 2.33), (0.71, 1, 1.4), (1, 1.33, 1.8)) which contains the comparative significance of the criteria, is determined. The constraints arising from the transitivity conditions of the second group relation transitivity conditions calculated using Equation (4), are as follows:

$$\varpi_{c2}/\varpi_{c3} = (0.67, 2, 5.69)$$

$$\varpi_{c1}/\varpi_{c6} = (1, 3, 8.83)$$

$$\varpi_{c3}/\varpi_{c4} = (0.71, 1.5, 3.26)$$

$$\varpi_{c6}/\varpi_{c5} = (0.71, 1.33, 2.52)$$

In order to determine the optimal values of the criteria weighting coefficients, the nine obtained constraints were transformed into a fuzzy linear mathematical model using Equation (5). The fuzzy linear model created for DM1 is given below. In the model, l, m, and u represent the lower, middle, and upper values of the TFN.

$$min\ x$$
$$s.t.$$

$$(w_2^l - 0.67w_1^u) \le X\ ;\ (w_2^l - 0.67w_1^u) \le -X$$

$$(w_2^m - w_1^m) \le X\ ;\ (w_2^m - w_1^m) \le -X$$

$$(w_2^u - 1.5w_1^l) \le X\ ;\ (w_2^u - 1.5w_1^l) \le -X$$

$$(w_1^l - w_3^u) \le X\ ;\ (w_1^l - w_3^u) \le -X$$

$$(w_1^m - 2w_3^m) \le X\ ;\ (w_1^m - 2w_3^m) \le -X$$

$$(w_1^u - 3.74w_3^l) \le X\ ;\ (w_1^u - 3.74w_3^l) \le -X$$

$$(w_3^l - w_6^u) \le X\ ;\ (w_3^l - w_6^u) \le -X$$

$$(w_3^m - 1.5w_6^m) \le X\ ;\ (w_3^m - 1.5w_6^m) \le -X$$

$$(w_3^u - 2.33w_6^l) \le X\ ;\ (w_3^u - 2.33w_6^l) \le -X$$

$$(w_6^l - 0.71w_4^u) \le X\ ;\ (w_6^l - 0.71w_4^u) \le -X$$

$$(w_6^m - w_4^m) \le X\ ;\ (w_6^m - w_6^m) \le -X$$

$$(w_6^u - 1.4w_4^l) \le X\ ;\ (w_6^u - 1.4w_4^l) \le -X$$

$$(w_4^l - w_5^u) \le X\ ;\ (w_4^l - w_5^u) \le -X$$

$$(w_4^m - 1.33w_5^m) \le X\ ;\ (w_4^m - 1.33w_5^m) \le -X$$

$$(w_4^u - 1.8w_5^l) \le X\ ;\ (w_4^u - 1.8w_5^l) \le -X$$

$$(w_1^l - 0.67w_6^u) \le X\ ;\ (w_1^l - 0.67w_6^u) \le -X$$

$$(w_2^m - 2w_3^m) \le X\ ;\ (w_2^m - 2w_3^m) \le -X$$

$$(w_2^u - 5.69w_3^l) \le X\ ;\ (w_2^u - 5.69w_3^l) \le -X$$

$$(w_1^l - w_6^u) \le X\ ;\ (w_1^l - w_6^u) \le -X$$

$$(w_1^m - 3w_6^m) \le X\ ;\ (w_1^m - 3w_6^m) \le -X$$

$$(w_1^u - 8.83w_6^l) \le X\ ;\ (w_1^u - 8.83w_6^l) \le -X$$

$$(w_3^l - 0.71w_4^u) \le X\ ;\ (w_3^l - 0.71w_4^u) \le -X$$

$$(w_3^m - 1.5w_4^m) \le X\ ;\ (w_3^m - 1.5w_4^m) \le -X$$

$$(w_3^u - 3.26w_4^l) \le X\ ;\ (w_3^u - 3.26w_4^l) \le -X$$

$$(w_6^l - 0.71w_5^u) \le X\ ;\ (w_6^l - 0,71w_5^u) \le -X$$

$$(w_6^m - 1.33w_5^m) \le X\ ;\ (w_6^m - 1.33w_5^m) \le -X$$

$$(w_6^u - 2.52w_5^l) \le X\ ;\ (w_6^u - 2.52w_5^l) \le -X$$

$$(w_1^l + 4w_1^m + w_1^u)/6 + (w_2^l + 4w_2^m + w_2^u)/6 + (w_3^l + 4w_3^m + w_3^u)/6 + (w_4^l + 4w_4^m + w_4^u)/6 + (w_5^l + 4w_5^m + w_5^u)/6 + (w_6^l + 4w_6^m + w_6^u)/6 = 1$$

$$w_1^l \leq w_1^m \leq w_1^u;\ w_2^l \leq w_2^m \leq w_2^u; w_3^l \leq w_3^m \leq w_3^u; w_4^l \leq w_4^m \leq w_4^u; w_5^l \leq w_5^m \leq w_5^u; w_6^l \leq w_6^m \leq w_6^u$$

$$w_1^l, w_2^l, w_3^l, w_4^l, w_5^l \geq 0$$

The fuzzy linear models are solved for each DM separately using the program Lingo 16.0 and the optimal values of the criteria are determined. The maximum consistency of the criteria weighting coefficients was found to be X=0.052 for DM1, X=0.054 for DM2, and X= 0.052 for DM3. X values close to 0 (X≈0) were found when solving the models. Results near zero indicate high consistency of criterion weights. The weighting coefficients of the criteria were calculated for three DMs using the F-FUCOM method. By forming the geometric mean of DMs' criterion weights, a common matrix of fuzzy criterion weights was obtained as follows.

$$\widetilde{w}_j(C) = \begin{bmatrix} 0.157 & 0.292 & 0.292 \\ 0.155 & 0.294 & 0.294 \\ 0.059 & 0.145 & 0.147 \\ 0.062 & 0.127 & 0.127 \\ 0.061 & 0.119 & 0.119 \\ 0.043 & 0.112 & 0.112 \end{bmatrix}$$

The final fuzzy criteria weighting matrix is clarified by the formula $\widetilde{w} = (w^l + 4w^m + w^u)/6$. According to the results of the clarification process, the Crips values (net value) were calculated as follows: w1= 0.2695, w2=0.2708, w3=0.1310, w4= 0.1162, w5= 0.1093, w6= 0.1005. The results show that the degree of importance of transportation accessibility is 26.95%, housing price is 27.08%, infrastructure safety is 13.10%, social and cultural activity areas are 11.62%, population density is 10.93%, and noise and air pollution is 10.05%. For DMs, house price (27.08%) was the most important criterion compared to other criteria, while noise and air pollution (10.93%) were ranked as less important criteria.

3.2. Ranking of the Alternatives According to the F- MARCOS Method

According to the criteria identified in this part of the study, the steps of the F- MARCOS method were applied to find out which districts customers prefer when buying a house. The central districts of Erzurum (Yakutiye, Palandoken, Aziziye) are used as alternatives for customers to choose their district. Decision makers evaluated six criteria for three alternatives using fuzzy linguistic expressions as in Table 3.

The linguistic expressions resulting from the DMs' evaluation were converted into TFN using Table 1 (Language Scale). The fuzzy decision matrices of the DMs were combined using the geometric mean (Table 4).

In Table 4, the fuzzy decision matrix is extended by calculating the ideal and anti-ideal solution using Equations (8) and (9). The process of matrix normalization was performed according to Equations (10)-(11). It is given in Table 5.

The normalized fuzzy decision matrix is multiplied by the criteria weights determined by the F-Fucom method and a weighted normalized fuzzy decision matrix is obtained (Table 6).

The F-MARCOS method differs from other methods by calculating the utility and the utility function. The degree of utility was calculated using the Equations (13)-(14) (Table 7). The fuzzy matrix $\tilde{T}_i$ was calculated with the help of equation (15). Then, using Equation (16), $\widetilde{D}$=(0.891 2.628 7.7109) is obtained.

It was determined as Df_{crisp}=3.186 (0.891+4×2.628+7.711)/6) using equation (17). This value is used to calculate the utility function corresponding to the anti-ideal and ideal solutions. The utility function was calculated using Equations (18) and (19), and the final utility function $f(K_i)$ was calculated using Equation (20). The utility function of the alternatives is shown in Table 8.

According to the results obtained by applying the integrated model F-FUCOM and F- MARCOS, it was found that the best district for the housing location selection problem was Yakutiye, followed by Palandoken and finally Aziziye.

Table 3. Decision makers evaluate six criteria for three alternatives

	Yakutiye			Palandoken			Aziziye		
Criteria	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1	AI	AI	VI	FI	WI	VI	FI	WI	FI
C2	AI	FI	FI	FI	FI	FI	WI	WI	FI
C3	FI	FI	VI	VI	FI	VI	WI	FI	WI
C4	AI	AI	VI	FI	WI	VI	FI	WI	WI
C5	FI	FI	AI	WI	WI	FI	WI	WI	WI
C6	AI	VI	FI	WI	WI	FI	WI	FI	WI

Table 4. Combined fuzzy decision matrix

	Transportation accessibility (C1)			**Housing price (C2)**			**Infrastructure safety (C3)**			**Social and cultural activity areas (C4)**			**Population density (C5)**			**Noise and air pollution (C6)**		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
Yakutiye	3.129	3.634	4.138	1.990	2.520	3.041	1.778	2.289	2.797	3.129	3.634	4.138	1.990	2.520	3.041	2.359	2.884	3.402
Palandoken	1.359	1.817	2.359	1.500	2.000	2.500	2.109	2.621	3.129	1.359	1.817	2.359	0.876	1.260	1.778	0.876	1.260	1.778
Aziziye	1.147	1.587	2.109	0.876	1.260	1.778	0.876	1.260	1.778	0.876	1.260	1.778	0.670	1.000	1.500	0.876	1.260	1.778
AI	1.147	1.587	2.109	1.990	2.520	3.041	0.876	1.260	1.778	0.876	1.260	1.778	1.990	2.520	3.041	2.359	2.884	3.402

AAI	3.129	3.634	4.138	0.876	1.260	1.778	2.109	2.621	3.129	3.129	3.634	4.138	0.670	1.000	1.500	0.876	1.260	1.778

Table 5. Normalized fuzzy decision matrix

	Transportation accessibility (C1)			**Housing price (C2)**			**Infrastructure safety (C3)**			**Social and cultural activity areas (C4)**			**Population density (C5)**			**Noise and air pollution (C6)**		
	l	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**
Yakutiye	0.756	0.878	1.000	0.288	0.348	0.441	0.568	0.732	0.894	0.756	0.878	1.000	0.220	3.761	2.969	3.881	3.291	2.691
Palandoken	0.329	0.439	0.570	0.351	0.438	0.584	0.674	0.838	1.000	0.329	0.439	0.570	0.377	1.880	1.308	2.029	1.437	1.000
Aziziye	0.277	0.384	0.510	0.493	0.696	1.000	0.280	0.403	0.568	0.212	0.304	0.430	0.447	1.493	1.000	2.029	1.437	1.000
AI	0.277	0.384	0.510	0.493	0.696	1.000	0.280	0.403	0.568	0.212	0.304	0.430	0.447	3.761	2.969	3.881	3.291	2.691
AAI	0.756	0.878	1.000	0.288	0.348	0.441	0.674	0.838	1.000	0.756	0.878	1.000	0.220	1.493	1.000	2.029	1.437	1.000

Table 6. Weighted normalized fuzzy decision matrix

	Transportation accessibility (C1)			**Housing price (C2)**			**Infrastructure safety (C3)**			**Social and cultural activity areas (C4)**			**Population density (C5)**			**Noise and air pollution (C6)**		
	l	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**
Yakutiye	0.119	0.256	0.292	0.045	0.102	0.130	0.033	0.106	0.131	0.047	0.112	0.127	0.013	0.446	0.352	0.166	0.367	0.302
Palandoken	0.052	0.128	0.166	0.054	0.129	0.172	0.039	0.122	0.147	0.020	0.056	0.073	0.023	0.223	0.155	0.087	0.160	0.112
Aziziye	0.044	0.112	0.149	0.076	0.205	0.294	0.016	0.059	0.083	0.013	0.039	0.055	0.027	0.177	0.119	0.087	0.160	0.112
AI	0.044	0.112	0.149	0.076	0.205	0.294	0.016	0.059	0.083	0.013	0.039	0.055	0.027	0.446	0.352	0.166	0.367	0.040
AAI	0.119	0.256	0.292	0.045	0.102	0.130	0.039	0.122	0.147	0.047	0.112	0.127	0.013	0.177	0.119	0.087	0.160	0.112

Table 7. The utility degrees of alternatives in relation to the anti-ideal and ideal solution

	Si			**Ki-**			**Ki+**			**Ti**		
	l	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**
AI	0.342	1.227	0.973									
Yakutiye	0.423	1.390	1.334	0.435	1.133	3.898	0.456	1.495	3.813	0.891	2.628	7.711
Palandoken	0.275	0.818	0.825	0.283	0.669	2.410	0.297	0.880	2.357	0.580	1.547	4.768
Aziziye	0.263	0.751	0.812	0.271	0.6123	2.372	0.284	0.808	2.320	0.555	1.420	4.693
AAI	0.350	0.930	0.926									

Table 8. Utility function of alternatives

	$f(K_i^-)$			$f(K_i^+)$			K-	K+	fK-	fK+	Ki	Rank
	l	m	u	l	m	u						
Yakutiye	0.143	0.469	1.197	0.136	0.356	1.224	1.477	1.708	0.536	0.464	1.054	1
Palandoken	0.093	0.276	0.740	0.089	0.209	0.757	0.893	1.029	0.323	0.280	0.340	2
Aziziye	0.089	0.254	0.728	0.085	0.192	0.745	0.849	0.973	0.305	0.266	0.302	3

4. Results and Discussion

The study examined the problem of region selection in the purchase of housing based on the criteria established for customers. It is noteworthy that the most important criterion for customers in the selection of a housing district is the price of the house. According to the study of Tosun and Fırat, the fact that the most important criterion that influences the choice of housing is the price of the house, which shows the similarity of the results with the study [6]. Housing prices are influenced by the quantity and quality of materials used, the size of the house, its location, infrastructure facilities, labor, construction costs, and the price of land [28]. For this reason, customers determine the most suitable housing for them that fits their budget. The other important criterion is the ease of transportation of the house. Transportation accessibility includes the ability to getting around the city, taking into account the proximity of the housing to public transportation and traffic density. With increasing urbanization and population growth, transportation has recently become a major problem. It is very important to choose the most comfortable housing in terms of transportation. Reasons for this are the overcrowding of public transport, the density of traffic and the increase in time spent by individuals in traffic. Another important criterion was found to be infrastructure safety. It is likely that customers will have access to services such as roads, water, electricity, sewerage, natural gas and internet without any problems, which will increase the attractiveness of housing. Customers do not want to live in regions where there are problems with infrastructure and where there are regular interruptions or disruptions due to infrastructure. The fourth important criterion was the presence of social and cultural activity areas (shopping centers, gymnasiums, swimming pools, parks and gardens, cinemas and theaters, etc). For customers, the criteria of price, transportation, and infrastructure security were more important than social and cultural activity opportunities. Because these criteria are the most important factors that affect the quality of life and welfare of people. Although the availability of social and cultural activity areas affects the quality of life, this is a less important criterion because it corresponds to the socialization needs of the individual. Population density emerged as the fifth important criterion for people's housing preferences. It can be concluded that people do not consider the population density in the people. Figure 3 shows the order of importance of the criteria.

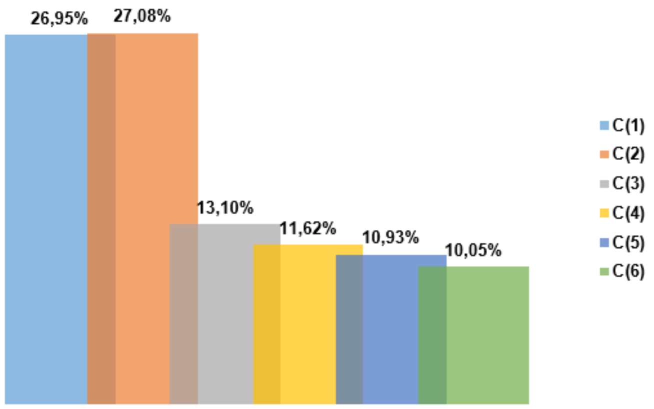

Figure 3. The order of importance of the criteria according to the results of the F-FUCOM method

According to the central districts of Erzurum, the preferences of customers in the selection of housing were found to be Yakutiye, Palandoken and Aziziye were determined. Yakutiye district is located in the most central location of Erzurum province. This district, which includes the city center, is the region where the settlement is the oldest. For this reason, the old houses in the city center are cheaper in price, because they have insufficient structural characteristics compared to the new buildings. It is the most advantageous region in terms of transportation, infrastructure and social and cultural areas. Yakutiye district is more disadvantaged than other regions in terms of population density, noise and air pollution.

Palandoken district is a region with a high price level, as there are many new house here. The district is quite advanced in terms of transportation and infrastructure security. The social and cultural offer in Palandoken district is well developed The fact that the region has shopping centers, swimming pools, gyms, and parks and gardens in almost every neighborhood is an important factor in the preference of customers. The noise pollution is less because it is far from the crowds of the city and the distances between the houses are large. In addition, due to the higher altitude of the region, the air quality is better than in other regions. Considering the region in terms of population density, it has almost the same population ratio as Yakutiye district.

Aziziye district is partly far from the city center and has a horizontal architectural layout. Due to its horizontal architectural structure, it negatively affects the price of housing. The fact that the region is far from the city center negatively affects the preference of customers in terms of transportation. Infrastructure safety in the region has improved. The fact that the region is far from social and cultural activity areas is a negative feature. Aziziye district is the region with the lowest population density among the central districts of Erzurum. The region, which performs very well in terms of noise pollution, has a disadvantage in terms of air pollution because it is located in a low area.

Housing sales statistics broken down by district for the years 2015-2021 from the Turkish Statistical Institute (TSI) were examined [2]. According to the data from TSI, the central district with the most housing sales in 2015-2021 is Yakutiye, and the second district is Palandoken. The central district with the lowest housing sales is Aziziye (Figure 4). The fact that the ranking resulting from our study region in their housing preferences. Noise and air pollution are the least important criteria in housing preference. It is thought that especially the last three criteria vary according to the socio-demographic characteristics of the individuals. While the presence of social and cultural spheres is less important for individuals in the elderly group, this criterion might be more important for young and middle-aged individuals. Also in terms of population density, quiet areas and areas with low noise and air pollution are more important for older people, while this may be less important for young and middle-aged

and the statistics from TSI are in the same direction shows the consistency of the study.

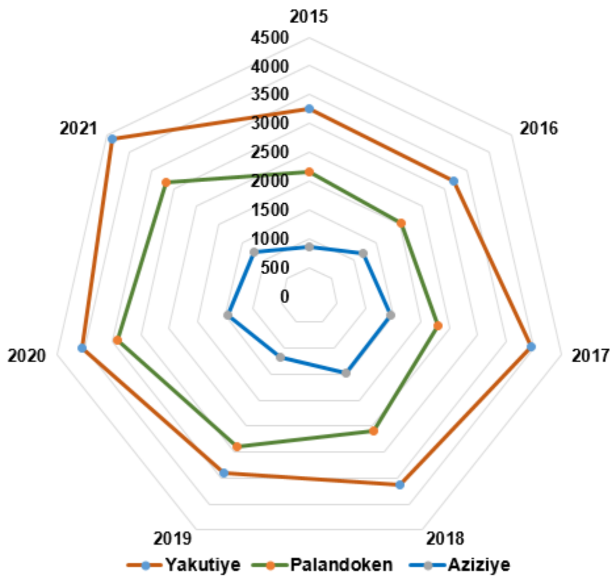

Figure 4. TSI housing sales statistics for 2015-2021

5. Conclusion

For those who want to own a housing, whether for investment or residence, the most important consideration when choosing a home is the district in which it is located. Each customer has individual priorities for housing district. While some customers pay attention to transportation accessibility, other customers pay attention to the fact that there are more social and cultural activity areas. In this study, the problem of customers' housing location choice according to the central districts of Erzurum is discussed. The methods F-FUCOM and F- MARCOS, which are MCDM methods, are integrated to solve this problem. Six criteria were identified that are important for customers in the selection of housing were determined as transportation accessibility, housing price, population density, noise and air pollution, infrastructure safety, social and cultural activity areas. The optimal weighting of the criteria was calculated using the F-FUCOM method. Using the F-FUCOM method, it was found that the most important criterion in customers' housing preferences is the housing price. Three alternatives (Yakutiye, Palandoken, Aziziye) identified by F-MARCOS method were evaluated. According to the evaluation results, it was found that the most preferred central district was Yakutiye and the least preferred district was Aziziye. The results of the study were compared with the housing sales statistics of the Turkish Statistical Institute. The similarity of the obtained results with the TSI shows that the results of the study are logical and consistent.

In addition to its contributions, this study also has some limitations. The limitations of this study are that the analyzes depend on the opinions of the DMs and the number of DMs participating in the study. In future studies, the number of DMs can be separated by socio-demographic characteristics, cultural and economic structures, and a wider audience can be reached. The housing district selection problem is quite complex and involves many different criteria. In future studies, the number of criteria can be increased by extending the existing framework and applying empirical research techniques to the group of DMs. It can be evaluated by using other MCDM methods such as COCOSO, MOORA for customers' housing selection for different provinces or the country in general.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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