Turkish Journal of Forest Science
Available online at dergipark.gov.tr/turkjforsci

A COMBINATION OF AHP AND GRA FOR FURNITURE MANUFACTURING FACILITY LOCATION SELECTION IN A HYBRID FUZZY ENVIRONMENT

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Please cite this article as: Ilce, A. C., Ciritcioglu, H. H. & Yildiz, T. (2024) A combination of AHP and GRA for furniture manufacturing facility location selection in a hybrid fuzzy environment, *Turkish Journal of Forest Science*, 8(2), 146-161.

ESER BİLGİSİ / ARTICLE INFO
Araştırma Makalesi / Research Article
Geliş 24 Temmuz 2024 / Received 24 July 2024
Düzeltmelerin gelişi 31 Temmuz 2024 / Received in revised form 31 July 2024
Kabul 8 Ağustos 2024 / Accepted 8 August 2024
Yayımlanma 31 Ekim 2024 / Published online 31 October 2024

ABSTRACT: This paper aims to solve the location selection problem for a newly established furniture facility. The choice of location is directly related to the costs businesses should bear to continue their operations throughout their life cycle. Therefore, the location of the establishment is very critical for enterprises. For this problem, we propose a combined method with fuzzy analytic hierarchy process (F AHP) and fuzzy grey relation analysis (F-GRA). F-GRA is used to rank the alternatives, while the priority weights of the criteria are estimated via F-AHP. The use of multi-criteria decision-making methods is not only for cost optimization but also optimization of many parameters (technical, social, economic, demographic, etc.) simultaneously to ensure the sustainability of enterprises. In this problem, the main factors considered are closeness, environment, infrastructure, and economy, and the candidate locations are selected as Antalya, Duzce, Gaziantep, Kayseri, Kocaeli, cities in Turkey. The application steps of the combined method are defined, and the result of the case problem is represented.

Keywords: B-AHP, B-GRA, facility location selection, multi-criteria decision making methods, sustainability

HİBRİT BULANIK BİR ORTAMDA MOBİLYA ÜRETİM TESİSİ KURULUŞ YERİ SEÇİMİNDE AHP VE GRA KOMBİNASYONU

ÖZET: Bu çalışma yeni kurulan bir mobilya tesisinin yer seçimi problemini çözmeyi amaçlamaktadır. Yer seçimi, işletmelerin yaşam döngüleri boyunca faaliyetlerini sürdürmek için katlanmaları gereken maliyetlerle doğrudan ilgilidir. Bu nedenle işletmelerin kuruluş yeri oldukça kritik öneme sahiptir. Çalışmada bulanık analitik hiyerarşi süreci (B-AHS) ve bulanık gri ilişki analizi (B-GRA) ile bütünleşik bir yöntem önerilmektedir. B-GRA alternatifleri sıralamak için kullanılırken, kriterlerin öncelik ağırlıkları B-AHP ile tahmin edilmektedir. Çok kriterli karar verme yöntemlerinin kullanımı sadece maliyet optimizasyonu için değil, aynı zamanda işletmelerin sürdürülebilirliğini sağlamak için birçok parametrenin (teknik, sosyal, ekonomik, demografik vb.) eş zamanlı olarak optimizasyonuna yöneliktir. Bu problemde göz önünde bulundurulan ana faktörler yakınlık, çevre, altyapı ve ekonomi olup Türkiye'deki şehirlerden Antalya, Düzce, Gaziantep, Kayseri ve Kocaeli aday lokasyonlar olarak seçilmiştir. Birleştirilmiş yöntemin uygulama adımları tanımlanmış ve örnek problemin sonucu sunulmuştur.

Anahtar kelimeler: B-AHP, B-GRA, tesis kuruluş yeri seçimi, çok kriterli karar verme yöntemi, sürdürülebilirlik

INTRODUCTION

Today, furniture is seen as both stuff and decoration objects because of the dynamic structure of society and economics. Furniture factories should provide flexible solutions to keep up with this viewpoint. The variance of fashion elements causes raw materials, colors, and patterns to constantly change. It sometimes requires labor-intensive production, which requires a particular craft. The ability to overcome these continually changing factors during the production period is directly related to the right pre-planned choice of facility location. For this reason, designating the location of furniture facilities is a complex decision-making problem that considers many factors (Burdurlu and Ejder, 2003). On the other hand, the selection of facility location may efficiently result in carrying out fully some conditions such as the optimal transportation cost, the availability of qualified labor, the sufficient raw material, or the competitive advantage of a company. Therefore, decision-makers should choose a location that will show a good performance for a short period and a site that will ensure good performance throughout the company's life (Athawale and Chakraborty, 2010).

There are a lot of methods to select the location by evaluating criteria. In recent studies, fuzzy sets-based and multi-criteria decision-making methods (MCDM) have been used. Some studies compared the results of the two different MCDM methods, while two or more methods were used together in some studies. Some researchers used these methods individually. Singh (2016) selected factory location using extended fuzzy analytic hierarchy process (F-AHP), although Şen and Demiral (2016) used grey system theory. Gupta et al. (2016) used a newly extended Vikor Method for the location of a hospital. Electre I was used to be determined distribution center by Agrebi et al. (2017).

Burdurlu and Ejder (2003) used a multi-criteria decision-making method to locate a factory in the furniture industry. This study suggested Ankara province as the best factory location after Denizli, Kayseri, Istanbul, and Ankara alternatives were evaluated with the AHP method. In a similar study, Imren (2011) recommended Karabuk as the most convenient location by considering Amasya, Bayburt, Çorum, and Karabuk via the AHP method. In addition to these studies, Giresunlu et al. (1998) chose the location for the factory manufacturing MDF (Medium Density Fiberboard) in the forestry products industry. Ankara, Duzce, Inegol, Kastamonu, Tekirdağ and Gaziantep cities were evaluated by AHP method. Özel et al. (2014) selected a site for afforestation works in Bartın Basin using the AHP method.

Several studies in the literature are presented in Table 1.

Tablo 1. Several Studies on Multi-Criteria Decision-Making Methods and Facility Location

Researcher	Methods	Main Criteria	Sector	Comparison/Combined
Popovic et al. (2019)	adapted step-wise weight assessment ratio analysis – Weighted Sum method, based on the decision-maker's preferred levels of performances	the infrastructure, access, surrounding environment, investment, rest resources, human resources	Hotel (Facility Location)	Combined and Comparison (VIKOR and TOPSIS)
Sahin et al. (2019)	AHP	competitors demand factors: environmental conditions: accessibility-related industry, government	Hospital (Facility Location)	None
Wichapa and Khokhajaikiat (2017)	Fuzzy AHP Goal Programming	infrastructure, geological and social & ecological	Waste Disposal Center (Facility Location)	Comparison
Hanine et al. (2016)	Fuzzy AHP Fuzzy TODIM	land cost, available transportation, distance from residential and historical areas, groundwater quality, soil type, infrastructure cost, and distance from wells	Landfill Site (Facility Location)	Comparison
Kharat et al. (2016)	Fuzzy AHP Fuzzy TOPSIS	public acceptance, hydrology, climate, soil and topography, fracture and faults, adjacent land use, sensitive areas, habitat-flora-fauna, inter-municipality, site capacity, cost, and road network/capacity	Landfill Site (Facility Location)	Combined
Erdogan and Kaya (2016)	Fuzzy AHP Fuzzy TOPSIS	technical factors, economic factors, reliability and safety factors, natural conditions,welfare-related conditions	Nuclear Power Plant (Facility Location)	Combined
Yaslioglu and Onder (2016)	AHP TOPSIS	physical facilities, infrastructure for production, logistic facilities, cost, strategic facilities, and proximity to production factors	Plastic Good Company (Facility Location)	Combined
Beskese et al. (2015)	Fuzzy AHP Fuzzy TOPSIS	available land area, soil condition, and topography, climatologic and hydrologic conditions, economic consideration	Landfill Site (Facility Location)	Combined
Al-Hawari et al. (2014)	AHP ANP	closeness, gap value, expansion flexibility, routing flexibility, volume flexibility, productive area utilization, human issues	wood furniture factory (Facility Location)	Comparison
Safari et al. (2012)	Fuzzy TOPSIS	favorable labor climate, proximity to markets, community considerations, quality of life, proximity to suppliers and resources	Integrated Electerofan Company (Facility Location)	None
Ozdağoğlu (2012)	Fuzzy AHP Fuzzy ANP	distance, traffic, demand potential, facility features, close environment	Food Industry (Facility Location)	Combined
Ertuğrul (2011)	Extended fuzzy TOPSIS	favorable labor climate, proximity to markets, community considerations, quality of life, proximity to suppliers and resources	Textile (Facility Location)	None
Boran (2011)	Intuitionistic fuzzy TOPSIS method	expansion possibility, availability of acquirement material, community consideration, distance to market, and labour cost	General (Facility Location)	None
Athawale and Chakraborty (2010)	PROMETHEE II	the closeness of market, closeness to raw material, land transportation, air transportation, cost of labor, availability of labor, community education, and business climate	General (Facility Location)	None
Ertuğrul and Karakaşoğlu (2008)	Fuzzy AHP Fuzzy TOPSIS	labor climate, proximity to markets, community considerations, quality of life, proximity to suppliers and resources	Textile (Facility Location)	Comparison
Chou et al. (2008)	A fuzzy simple additive weighing	transportation availability, availability of skilled workers, climatic conditions, investment cost	High-tech company (Facility Location)	None
Yong (2006)	Fuzzy TOPSIS	skilled workers, expansion possibility, availability of acquirement material, and investment cost	General (Facility Location)	None
Kahraman et al. (2003)	Fuzzy model of group decision, fuzzy synthetic evaluation, fuzzy AHP	environmental regulation, host community, competitive advantage, and political risk	Motor Company (Facility Location)	Comparison

Based on the extant works in the literature, there is no study with fuzzy sets and multi-criteria decision-making methods, particularly for the location selection problems in the furniture industry. So, this study aims to select the most suitable location for furniture factories by using Fuzzy AHP and Fuzzy GRA methods.

METHODS

This section provides a detailed explanation of the methods used in the MCDM methodology.

Fuzzy Analytic Hierarchy Process

AHP, first introduced by Saaty (1990), is an approach that accomplishes by comparing alternatives. The main advantage of AHP is a being easy to understand and does not involve complex mathematical processes (Mahmoodzadeh et al., 2007).

AHP has often been used in decision-making problems (Dağdeviren & Eren, 2001). In the first step of this method, factors and sub-factors in the evaluation are determined, and the hierarchical structure is modeled. The second step forms the pairwise comparison matrix of factors and sub-factors (Saaty, 1980). The weight vector is calculated using a comparison matrix in the final step (Göksu & Güngör, 2008). The literature has stated that AHP is weak, especially in comparison of qualitative factors, and therefore used with fuzzy numbers (Dağdeviren, 2007). The studies of Van Laarhoven and Pedrycz (1983), and Buckley (1985) were the first examples of using fuzzy numbers in pairwise comparisons. The use of the FAHP method has grown significantly in recent years, proving its effectiveness in tackling various problems.

The most crucial advantage of FAHP facilitates handling multiple criteria. Since defining deterministic preferences is more challenging for decision-makers, perception-based judgment intervals can be used instead. In addition, comparison values in AHP must necessarily be the subjective judgments of decision-makers. In this case, the fuzzy approach can define a more accurate decision-making process (Kuo et al., 1999). Therefore, the FAHP (Fuzzy Analytic Hierarchy Process) methodology is chosen as the best option. A linguistic scale is used for paired comparisons (Table 2). The details of the approach are described in the proposed method section, respectively. During the evaluations of criteria, triangular fuzzy numbers were applied. A triangular fuzzy number ($\tilde{A}$) is a type of fuzzy number that is denoted by three real numbers (l, m, u), and the membership function is defined by these numbers. The fuzzy number $\tilde{A}$ is denoted by (l, m, u), where m represents the most feasible value of the fuzzy number and “l” and “u” represent the upper and lower boundaries, i.e. the extend of fuzziness.

Fuzzy Grey Relational Analysis

GRA is one of the common techniques used in recent years to solve Multi-Criteria Decision Making problems. It is one of the subtitles of Grey System Theory introduced by J. L. Deng in 1982.

In the control theory, people have often used colors to show the clarity of information. In other words, we use white color for completely known information, grey color for partially known information, and black color for unknown information (Liu & Forrest, 2010). GRA is utilized to determine the relational grade between each factor and reference series (compared factor series). Each factor is defined as an array (row or column). The degree of influence between factors is called grey relational grade (Hsu & Wen, 2000).

It's possible that the FGRA like other MCDM techniques will be preferred for comparing the criteria since decision makers will feel more at comfortable utilizing language scales to assess the criterion as compared to crisp numbers.

Furthermore, the FGRA approach is beneficial since it can solve issues effectively even when there is a lack of data or a great deal of uncertainty regarding the relevant parameters. Although F-AHP and F-GRA have a proven track record across diverse scientific fields, their integration for facility site selection represents a completely novel approach.

Our Proposed Method

This study utilized combined F-AHP and F-GRA methods to determine a proper facility location among the candidate cities, and alpha-cut was used for defuzzification (Fig. 1). The steps of this study were as follows;

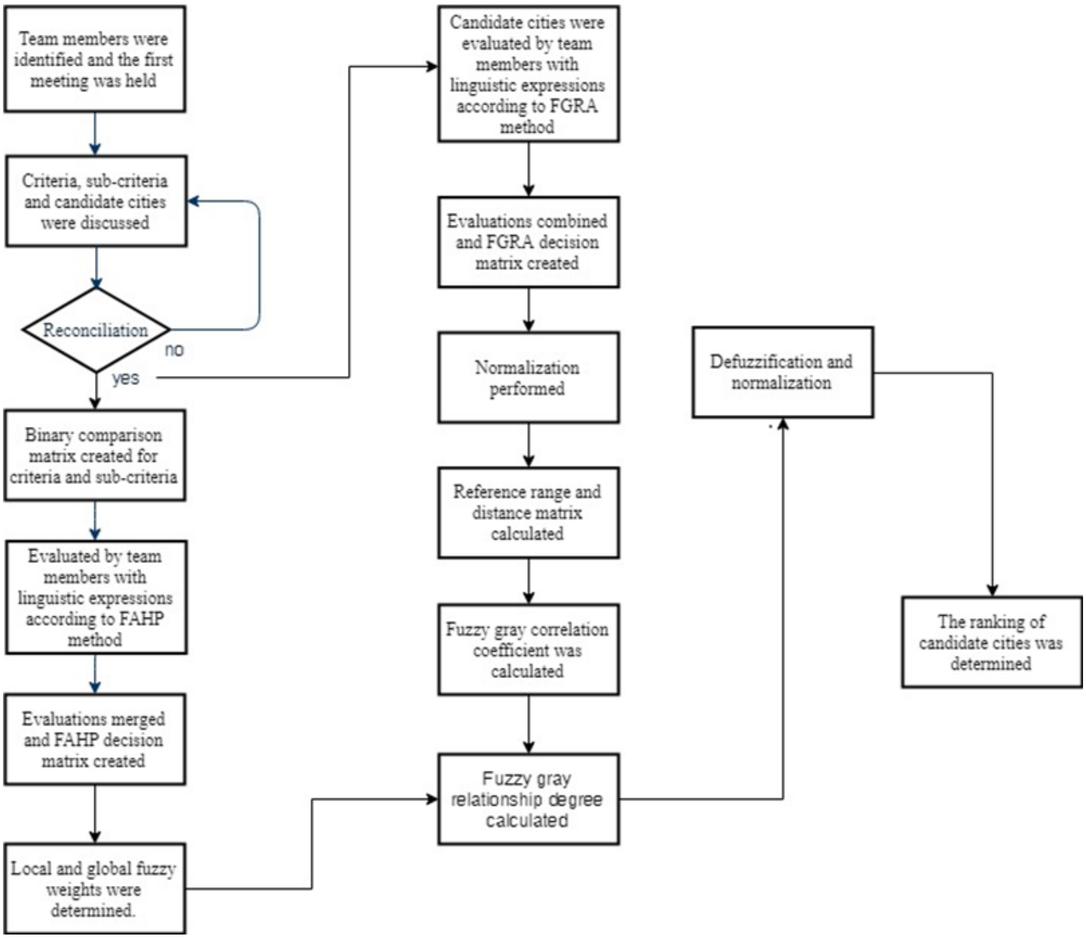

Figure 1. The Steps of Facility Location Selection with F-AHP and F-GRA

Five potential locations for furniture facilities have been identified based on several factors:

- Gaziantep (A1): Features an efficient manufacturing industry, prime location, and well-established supply chains.
- Kocaeli (A2): Benefits from a trained labor force, proximity to ports, and robust industrial infrastructure.

- Kayseri (A3): Known for its manufacturing capabilities, advantageous location, and easy access to raw materials.
- Antalya (A4): Popular for both tourism and eco-friendly initiatives, offering advanced infrastructure and environmental preservation projects.
- Düzce (A5): Strategically located with lower operational costs and access to key transportation networks.

These cities offer favorable conditions for businesses seeking growth, sustainability, and productivity in the furniture industry.

Step 1: Team members are selected to decide the location of the facility. Factors and sub-factors are determined (Fig. 2), and the importance weights of criteria and alternatives were compared with linguistic terms (Table 2). The fuzzy decision matrix is formed by finding the geometric means (gj) of team members' opinions (Eqs. 1).

$$\tilde{g}_j = (\tilde{a}_{j1} \times \tilde{a}_{j2} ...... \times \tilde{a}_{jn})^{1/n} \tag{1}$$

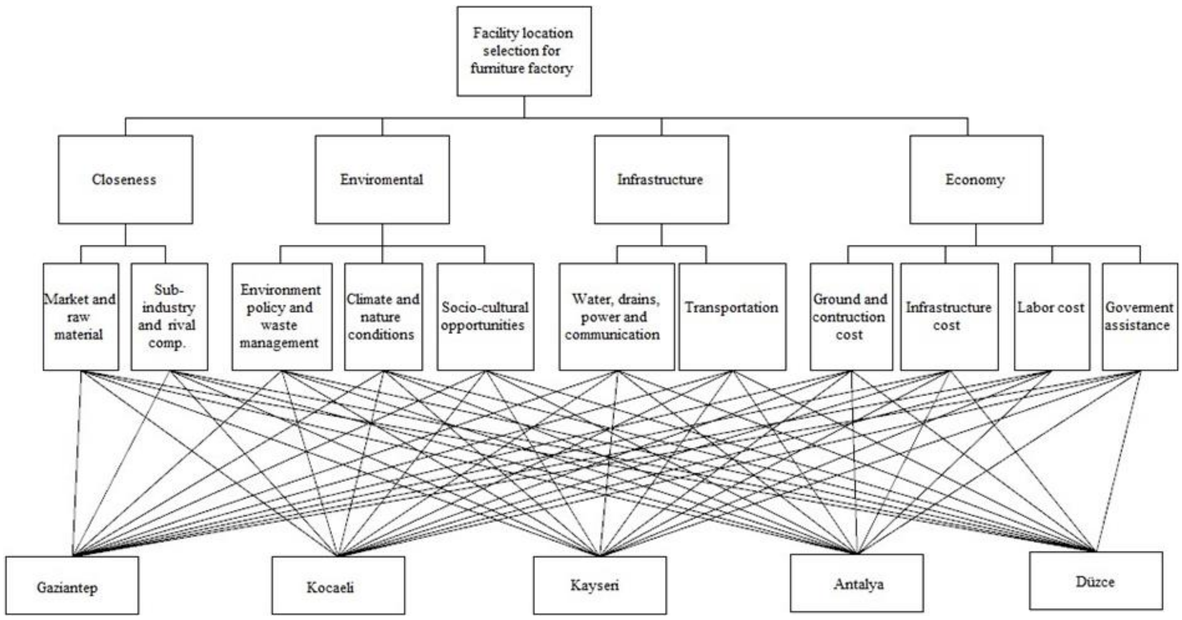

Figure 2. The hierarchy of facility location selection for furniture factory

Tablo 2. Fuzzy numbers and equivalent for factor comparison (Gümüş, 2009)

Fuzzy Number	Linguistic	Scale of Fuzzy Number
9	Perfect	(8, 9, 10)
8	Absolute	(7, 8, 9)
7	Very good	(6, 7, 8)
6	Fairly good	(5, 6, 7)
5	Good	(4, 5, 6)
4	Preferable	(3, 4, 5)
3	Not bad	(2, 3, 4)
2	Weak advantage	(1, 2, 3)
1	Equal	(1, 1, 1)

Step 2: Fuzzy weights of factors and sub-factors are calculated according to Eqs. (2) (Buckley, 1985). Then, global fuzzy weights are figured out. $\tilde{w}_j$ and F-GRA are transmitted evaluation matrix.

$$\tilde{w}_j = \tilde{g}_j \times (\tilde{g}_1 + \tilde{g}_2 + ... + \tilde{g}_n)^{-1} \quad (2)$$

Step 3: Centre of Area (COA) techniques were used for the FAHP defuzzification process, where "l" represents the lower bound, "m" the moderate, and "u" the upper bound of the fuzzy number.

Step 4: The evaluation is made using the fuzzy GRA method for cities selected as facility location. When cities are assessed, linguistic variables and fuzzy numbers responses are used (Table 2). The fuzzy decision matrix is generated by taking the geometric means to reflect the common opinion of the team members.

Step 5: The decision matrix is normalized by Eqs. (3), and the normalized matrix ($\tilde{R}$) is generated. Thus, [0, 1] normalized triangle fuzzy number range property is preserved with this method. B is the beneficial criterion in this equation, while C is the cost criterion.

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m\times n}, \quad \tilde{r}_{ij} = \left(\frac{l_{ij}}{r_j^*}, \frac{m_{ij}}{r_j^*}, \frac{r_{ij}}{r_j^*}\right) j \in B, \quad \tilde{r}_{ij} = \left(\frac{l^-}{r_{ij}^*}, \frac{l^-}{m_{ij}^*}, \frac{l^-}{l_{ij}^*}\right) j \in C \quad (3)$$

$$r_j^* = \max_i(r_{ij}) \text{ if } j \in B, \quad l_j^- = \min_i(l_{ij}) \text{ if } j \in C$$

Step 6: Ideal value for each criterion of alternatives is calculated when creating reference series($\tilde{R}_0$). If a factor is a cost criterion in reference series, then an ideal value ($\tilde{r}_{oj}$) takes the minimum value, otherwise takes a maximum value (Eqs. 4). A distance matrix ($\tilde{\delta}_i^j$) indicating closeness to the ideal score is formed by using Eqs. (5).

$$\tilde{R}_0 = \left[\tilde{r}_{01}, \tilde{r}_{02}, \tilde{r}_{03}, ...\tilde{r}_{0n}\right], \text{ where } \tilde{r}_{oj} = \max_i(r_{ij}) \text{ if } j \in B, \quad \tilde{r}_{oj} = \min_i(r_{ij}) \text{ if } j \in C, \quad j = 1,2,3...n. \quad (4)$$

$$\tilde{\delta}_i^j = \left|\tilde{r}_{0j}^* - \tilde{r}_{ii}^-\right| \quad (5)$$

Step 7: The fuzzy grey relational coefficient ($\tilde{\zeta}_i^j$) is calculated using Eqs. (6). ζ represents the distinguishing coefficient and has a value within the range [0, 1]. For this study, ζ was set at 0.5.

$$\tilde{\zeta}_i^j = \frac{\tilde{\delta}_{\min} + \zeta\tilde{\delta}_{\max}}{\tilde{\delta}_{ij} + \zeta\tilde{\delta}_{\max}}, \quad \tilde{\delta}_{\max} = \max(\tilde{\delta}_{ij}), \quad \tilde{\delta}_{\min} = \min(\tilde{\delta}_{ij}) \quad (6)$$

Step 8: The fuzzy grey relational grade ($\tilde{\gamma}_{\hat{\imath}}$) is estimated (Eqs. 7). Here, $\tilde{w}_j$ denotes the global fuzzy weight of j criteria calculated by fuzzy AHP.

$$\tilde{\gamma}_{\hat{\imath}} = \sum_{j=1}^{n} \tilde{w}_j \times \tilde{\zeta}_{ij} \qquad i = 1......m \tag{7}$$

Step 9: In our paper, we used the α-cut method for the defuzzification phase, where the α value was decided as 0.5. For each α value, the lower and upper limits of α are calculated according to the Eqs. (8).

$$\alpha_{lb} = \alpha \times (m-1) + 1, \quad \alpha_{ub} = u - \alpha \times (u - m) \tag{8}$$

Then, defuzzied values are obtained by Eqs. (9), where λ optimistic index is taken as 0.5, which shows a moderate decision-making profile in this study.

$$W_{crisp} = \lambda \times \alpha_{ub} + (1-\lambda) \times \alpha_{lb} \tag{9}$$

Step 10: After the defuzzificated priorities are normalized, these scores of candidates are sorted by descending. The candidate with the highest priority is determined as facility location.

Application

A team of 10 people, each with at least two years of experience as managers in furniture factories in Ankara, Istanbul, Izmir, and Bursa, was assembled to select an appropriate facility location. Team members identified candidate provinces, factors, and sub-factors. We focused on two key points: First, the candidate cities should be located in different geographical regions of Turkey. Second, the selected cities should be known for furniture production. To identify factors and sub-factors (Table 1), we reviewed studies on similar sectors, as there was insufficient literature specifically on furniture factory location selection criteria. The four most frequently cited factors in these studies were chosen as the main criteria. These are: Proximity (C1), Environment (C2), Infrastructure (C3), and Economy (C4).

Proximity: It is important to supply the different raw materials required for production in a furniture factory on time. Also, this procurement should be cost-effective.

Environment: Consumers support the production recently without damaging the environment. So, the environmental policy of enterprises occupies a vital place. In addition, the climatic conditions and socio-cultural opportunities of the area where the factory will be established will bring an advantage in personnel employment.

Infrastructure: Furniture factories need infrastructures such as power, communication, transportation, water, and drains. Lack of one of them could halt all production activity and cause damage to the factory.

Economy: Costs such as labor, ground, and power supply are very significant expenses affecting the short and long-term profitability of the enterprises. When these costs are reduced, their breakeven time of them will decrease. On the other hand, the tax incentive given by the government is also an essential condition.

Experts determined 11 sub-factors to support the main factors. They were the proximity to raw material and market (C11), proximity to sub-industry and rival company (C12), environment policy and waste management (C21), climate and nature conditions (C22), socio-cultural opportunities (C23), the infrastructure of water, drains, power and communication (C31), transportation opportunities (C32), ground and construction cost (C41), infrastructure cost (C42), labor cost (C43), and government assistance (C44). Ground and construction cost, labor cost, infrastructure cost was cost criteria, while the other eight sub-factors were benefit criteria. The combined decision matrix and fuzzy weights are shown in Table 3.

Table 3. Combined Fuzzy Decision Matrix of Factors

Main Criteria	Proximity	Environmental	Infrastructure	Economy
Proximity	1, 1, 1	0.803, 1.116, 1.614	0.836, 1.149, 1.568	0.780, 1, 1.282
Environmental	0.620, 0.896, 1.246	1, 1, 1	0.699, 0.933, 1.282	0.772, 1.103, 1.540
Infrastructure	0.638, 0.871, 1.196	0.780, 1.072, 1.431	1, 1, 1	0.545, 0.749, 1.084
Economy	0.780, 1, 1.282	0.649, 0.907, 1.296	0.922, 1.335, 1.835	1, 1, 1

Fuzzy geometric mean of the row of proximity=

$$\left\{(1\times0.813\times0.836\times0.780)^{1/4},(1\times0.813\times0.836\times0.780)^{1/4}(1\times0.813\times0.836\times0.780)^{1/4}(1\times0.813\times0.836\times0.780)^{1/4}\right\}=(0.851,1.064,1,342)$$

Fuzzy geometric mean of the row of environmental= (0.760, 0.980, 1.252)
Fuzzy geometric mean of the row of substructure= (0.722, 0.914, 0.167)
Fuzzy geometric mean of the row of economy= (0.827, 1.049, 1.321)
Sum of fuzzy geometric means= (3.159, 4.007, 5.083)

Fuzzy weight of the row of proximity = $\left\{(0.851\div5.083),(1.064\div4.007),(1.342\div3.159)\right\}=(0.167,0.266,0.425)$
Fuzzy weight of the row of environmental = (0.150, 0.245, 0.396)
Fuzzy weight of the row of substructure = (0.142, 0.228, 0.369)
Fuzzy weight of the row of economy = (0.163, 0.262, 0.418)

The local and global fuzzy weights of sub-factors are represented in Table 4. Global fuzzy weights were calculated by using mathematical operations.

Table 4. The Fuzzy Weights of Factor and Sub-factors

Main Criteria	Local Fuzzy Weight	Sub-Criteria	Local Fuzzy Weight	Global Fuzzy Weight	Defuzzified Weight
C1	(0.167, 0.266, 0.425)	**C11**	(0.430, 0.585, 0.777)	(0.072, 0.156, 0.330)	0,179
		C12	(0.308, 0.415, 0.577)	(0.051, 0.110, 0.245)	0,129
C2	(0.150, 0.245, 0.396)	**C21**	(0.236, 0.388, 0.622)	(0.035, 0.095, 0.246)	0,118
		C22	(0.205, 0.329, 0.538)	(0.031, 0.081, 0.213)	0,102
		C23	(0.174, 0.282, 0.468)	(0.026, 0.069, 0.185)	0,087
C3	(0.142, 0.228, 0.369)	**C31**	(0.401, 0.527, 0.689)	(0.057, 0.120, 0.254)	0,138
		C32	(0.349, 0.473, 0.643)	(0.050, 0.108, 0.237)	0,126
C4	(0.163, 0.262, 0.418)	**C41**	(0.171, 0.287, 0.467)	(0.028, 0.075, 0.195)	0,093
		C42	(0.125, 0.205, 0.353)	(0.020, 0.054, 0.148)	0,069
		C43	(0.132, 0.226, 0.383)	(0.022, 0.059, 0.160)	0,075
		C44	(0.167, 0.282, 0.477)	(0.027, 0.074, 0.199)	0,094

Global fuzzy weights were transferred to the FGRA matrix to compute fuzzy grey relational grades. Subsequently, the expert team assessed our candidates with linguistic terms based on sub-factors. So, a fuzzy combined decision matrix for FGRA was prepared by aggregating expert opinions via the geometric mean method (Table 5).

Table 5. Fuzzy Combined Decision Matrix for FGRA

	C11*	**C12***	**C21***	**C22***	**C23***	**C31***
A1	(5.555, 6.576, 7.591)	(5.669, 6.688, 7.703)	(6.996, 8.011, 9.022)	(7.236, 8.245, 9.251)	(7.531, 8.541, 9.548)	(6.812, 7.824, 8.834)
A2	(6.034, 7.056, 8.073)	(6.325, 7.348, 8.367)	(7.282, 8.299, 9.311)	(6.325, 7.348, 8.367)	(6.034, 7.056, 8.073)	(5.757, 6.776, 7.791)
A3	(6.812, 7.824, 8.834)	(6.369, 7.387, 8.401)	(6.629, 7.653, 8.670)	(6.541, 7.563, 8.580)	(6.587, 7.602, 8.614)	(6.812, 7.824, 8.834)
A4	(5.057, 6.064, 7.068)	(5.875, 6.892, 7.905)	(7.333, 8.342, 9.349)	(4.472, 5.477, 6.481)	(6.241, 7.262, 8.279)	(5.797, 6.811, 7.822)
A5	(5.555, 6.576, 7.591)	(6.241, 7.262, 8.279)	(6.856, 7.876, 8.891)	(6.675, 7.693, 8.706)	(6.675, 7.693, 8.706)	(6.675, 7.693, 8.706)
	C32*	**C41****	**C42****	**C43****	**C44***	

A1	(7.140, 8.148, 9.154)	(6.722, 7.733, 8.741)	(5.242, 6.266, 7.283)	(6.076, 7.093, 8.106)	(6.076, 7.093, 8.106)
A2	(6.284, 7.300, 8.313)	(7.090, 8.106, 9.117)	(4.676, 5.681, 6.684)	(6.228, 7.253, 8.272)	(6.076, 7.093, 8.106)
A3	(6.454, 7.474, 8.490)	(6.241, 7.262, 8.279)	(5.409, 6.423, 7.433)	(6.284, 7.300, 8.313)	(6.201, 7.215, 8.225)
A4	(7.045, 8.053, 9.058)	(6.996, 8.011, 9.022)	(5.173, 6.193, 7.207)	(5.797, 6.811, 7.822)	(5.797, 6.811, 7.822)
A5	(6.765, 7.784, 8.798)	(6.996, 8.011, 9.022)	(6.842, 7.866, 8.884)	(7.171, 8.192, 9.206)	(6.228, 7.253, 8.272)

*Beneficial Criterion, **Cost criterion

The normalization process was executed to assess alternatives, considering the cost-benefit scenario. The matrix generated using Eqs. (3) is shown in Table 6.

Table 6. Normalized Fuzzy Decision Matrix

	C11*	**C12***	**C21***	**C22***	**C23***	**C31***
A1	(0.629, 0.744, 0.859)	(0.675, 0.796, 0.917)	(0.748, 0.857, 0.965)	(0.782, 0.891, 1.000)	(0.789, 0.895, 1.000)	(0.771, 0.886, 1.000)
A2	(0.683, 0.799, 0.914)	(0.753, 0.875, 0.996)	(0.779, 0.888, 0.996)	(0.684, 0.794, 0.904)	(0.632, 0.739, 0.846)	(0.652, 0.767, 0.882)
A3	(0.771, 0.886, 1.000)	(0.758, 0.879, 1.000)	(0.709, 0.819, 0.927)	(0.707, 0.817, 0.927)	(0.690, 0.796, 0.902)	(0.771, 0.886, 1.000)
A4	(0.572, 0.686, 0.800)	(0.699, 0.820, 0.941)	(0.784, 0.892, 1.000)	(0.483, 0.592, 0.701)	(0.654, 0.761, 0.867)	(0.656, 0.771, 0.886)
A5	(0.629, 0.744, 0.859)	(0.743, 0.865, 0.986)	(0.733, 0.842, 0.951)	(0.722, 0.832, 0.941)	(0.699, 0.806, 0.912)	(0.756, 0.871, 0.986)

	C32*	**C41****	**C42****	**C43****	**C44***
A1	(0.780, 0.890, 1.000)	(0.714, 0.807, 0.928)	(0.642, 0.746, 0.892)	(0.715, 0.817, 0.954)	(0.735, 0.857, 0.980)
A2	(0.686, 0.797, 0.908)	(0.684, 0.770, 0.880)	(0.700, 0.823, 1.000)	(0.701, 0.799, 0.931)	(0.735, 0.857, 0.980)
A3	(0.705, 0.816, 0.927)	(0.754, 0.859, 1.000)	(0.629, 0.728, 0.865)	(0.697, 0.794, 0.923)	(0.750, 0.872, 0.994)
A4	(0.770, 0.880, 0.990)	(0.692, 0.779, 0.892)	(0.649, 0.755, 0.904)	(0.741, 0.851, 1.000)	(0.701, 0.823, 0.946)
A5	(0.739, 0.850, 0.961)	(0.692, 0.779, 0.892)	(0.526, 0.594, 0.683)	(0.630, 0.708, 0.808)	(0.753, 0.877, 1.000)

*Beneficial Criterion, **Cost criterion

The reference series was determined by considering the benefit-cost situation (Eqs. 4), and the distance matrix (Table 7) was formed by calculating the distances from alternatives to reference series (Eqs. 5)

Table 7. Fuzzy Reference Series and Distance Matrix

	C11*	**C12***	**C21***	**C22***	**C23***	**C31***
A1	(0.142, 0.141, 0.141)	(0.083, 0.083, 0.083)	(0.036, 0.035, 0.035)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)
A2	(0.088, 0.087, 0.086)	(0.005, 0.005, 0.004)	(0.005, 0.005, 0.004)	(0.098, 0.097, 0.096)	(0.157, 0.155, 0.154)	(0.119, 0.119, 0.118)
A3	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.075, 0.074, 0.073)	(0.075, 0.074, 0.073)	(0.099, 0.098, 0.098)	(0.000, 0.000, 0.000)
A4	(0.199, 0.199, 0.200)	(0.059, 0.059, 0.059)	(0.000, 0.000, 0.000)	(0.299, 0.299, 0.299)	(0.135, 0.134, 0.133)	(0.115, 0.115, 0.114)
A5	(0.142, 0.141, 0.141)	(0.015, 0.015, 0.014)	(0.051, 0.050, 0.049)	(0.061, 0.060, 0.059)	(0.090, 0.089, 0.088)	(0.015, 0.015, 0.014)

	C32*	**C41****	**C42****	**C43****	**C44***
A1	(0.000, 0.000, 0.000)	(0.029, 0.037, 0.048)	(0.116, 0.152, 0.209)	(0.085, 0.110, 0.146)	(0.018, 0.019, 0.020)
A2	(0.093, 0.093, 0.092)	(0.000, 0.000, 0.000)	(0.173, 0.229, 0.317)	(0.071, 0.092, 0.122)	(0.018, 0.019, 0.020)
A3	(0.075, 0.074, 0.073)	(0.069, 0.089, 0.120)	(0.103, 0.134, 0.181)	(0.068, 0.086, 0.114)	(0.003, 0.005, 0.006)
A4	(0.010, 0.010, 0.010)	(0.007, 0.009, 0.012)	(0.122, 0.161, 0.221)	(0.111, 0.143, 0.192)	(0.052, 0.053, 0.054)
A5	(0.041, 0.040, 0.039)	(0.007, 0.009, 0.012)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)

*Beneficial Criterion, **Cost criterion

Fuzzy Grey Relational Coefficient Matrix (Table 8) and fuzzy grey relational degree matrix (Table 9) were computed with Eqs. (6) and Eqs. (7). Finally, α-cut values were calculated with defuzzification methods (Eqs. 8-9). They were ranked by being α-cut values (Table 10).

Table 8. Fuzzy Grey Relational Coefficient Matrix

	C11*	**C12***	**C21***	**C22***	**C23***	**C31***
A1	(0.413, 0.414, 0.415)	(0.333, 0.334, 0.334)	(0.511, 0.515, 0.518)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
A2	(0.532, 0.535, 0.537)	(0.888, 0.901, 0.911)	(0.874, 0.890, 0.903)	(0.603, 0.607, 0.610)	(0.333, 0.335, 0.337)	(0.333, 0.335, 0.336)
A3	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(0.333, 0.338, 0.341)	(0.666, 0.670, 0.673)	(0.442, 0.444, 0.445)	(1.000, 1.000, 1.000)
A4	(0.335, 0.334, 0.333)	(0.415, 0.414, 0.414)	(1.000, 1.000, 1.000)	(0.334, 0.334, 0.333)	(0.367, 0.369, 0.371)	(0.342, 0.342, 0.343)
A5	(0.413, 0.414, 0.415)	(0.732, 0.738, 0.742)	(0.425, 0.430, 0.434)	(0.712, 0.715, 0.717)	(0.466, 0.469, 0.470)	(0.794, 0.800, 0.805)

z	C32*	C41**	C42**	C43**	C44**
A1	(1.000, 1.000, 1.000)	(0.670, 0.617, 0.554)	(0.578, 0.510, 0.431)	(0.529, 0.466, 0.397)	(0.597, 0.584, 0.576)
A2	(0.333, 0.335, 0.337)	(1.000, 1.000, 1.000)	(0.477, 0.409, 0.333)	(0.574, 0.511, 0.439)	(0.597, 0.584, 0.576)
A3	(0.384, 0.388, 0.392)	(0.464, 0.401, 0.333)	(0.606, 0.542, 0.466)	(0.586, 0.526, 0.456)	(0.892, 0.854, 0.828)
A4	(0.819, 0.818, 0.817)	(0.892, 0.868, 0.835)	(0.564, 0.496, 0.418)	(0.462, 0.401, 0.333)	(0.343, 0.337, 0.333)
A5	(0.533, 0.540, 0.545)	(0.892, 0.868, 0.835)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)

*Beneficial Criterion, **Cost criterion

Table 9. Fuzzy Grey Relational Grade Matrix

	C11*	C12*	C21*	C22*	C23*	C31*
A1	(0.030, 0.065, 0.137)	(0.017, 0.037, 0.082)	(0.018, 0.049, 0.127)	(0.031, 0.081, 0.213)	(0.026, 0.069, 0.185)	(0.057, 0.120, 0.254)
A2	(0.038, 0.083, 0.177)	(0.045, 0.099, 0.223)	(0.031, 0.085, 0.222)	(0.019, 0.049, 0.130)	(0.009, 0.023, 0.062)	(0.019, 0.040, 0.085)
A3	(0.072, 0.156, 0.330)	(0.051, 0.110, 0.245)	(0.012, 0.032, 0.084)	(0.021, 0.054, 0.143)	(0.011, 0.031, 0.082)	(0.057, 0.120, 0.254)
A4	(0.024, 0.052, 0.110)	(0.021, 0.046, 0.101)	(0.035, 0.095, 0.246)	(0.010, 0.027, 0.071)	(0.010, 0.025, 0.069)	(0.019, 0.041, 0.087)
A5	(0.030, 0.065, 0.137)	(0.037, 0.081, 0.182)	(0.015, 0.041, 0.107)	(0.022, 0.058, 0.153)	(0.012, 0.032, 0.087)	(0.045, 0.096, 0.204)
	C32*	**C41****	**C42****	**C43****	**C44****	
A1	(0.050, 0.108, 0.237)	(0.019, 0.046, 0.108)	(0.012, 0.028, 0.064)	(0.012, 0.028, 0.063)	(0.016, 0.043, 0.115)	
A2	(0.017, 0.036, 0.080)	(0.028, 0.075, 0.195)	(0.010, 0.022, 0.049)	(0.013, 0.030, 0.070)	(0.016, 0.043, 0.115)	
A3	(0.019, 0.042, 0.093)	(0.013, 0.030, 0.065)	(0.012, 0.029, 0.069)	(0.013, 0.031, 0.073)	(0.024, 0.063, 0.165)	
A4	(0.041, 0.088, 0.194)	(0.025, 0.065, 0.163)	(0.011, 0.027, 0.062)	(0.010, 0.024, 0.053)	(0.009, 0.025, 0.066)	
A5	(0.027, 0.058, 0.129)	(0.025, 0.065, 0.163)	(0.020, 0.054, 0.148)	(0.022, 0.059, 0.160)	(0.027, 0.074, 0.199)	

*Beneficial Criterion, **Cost criterion

Table 10. Ranking Alternatives With Defuzzification and Normalization

Candidate cities	αlb	αub	α-cut	Rank
A1 (GAZIANTEP)	0.480	1.129	0.804	3
A2 (KOCAELI)	0.415	0.998	0.706	4
A3 (KAYSERI)	0.502	1.151	0.826	2
A4 (ANTALYA)	0.366	0.868	0.617	5
A5 (DUZCE)	0.483	1.176	0.829	**1**

The research indicates that A5 (Duzce) is the best location for the establishment of the furniture production plant based on the alpha-cut values. The options are listed in the following order, from most to least advantageous: Duzce, Kayseri, Gaziantep, Kocaeli, and Antalya. This ranking emphasizes how crucial it is to choose a location that maximizes operational effectiveness while simultaneously adhering to environmental norms. Duzce's standing as the best option reflects its ability to assist ecologically conscious manufacturing methods by taking advantage of its close proximity to raw materials, strong infrastructure, and advantageous socioeconomic circumstances.

Sensitivity Analysis

Sensitivity analysis is a valuable technique in decision-making that assesses how changes in input variables affect the outcomes of a decision problem. It helps decision-makers determine the robustness of their choices and their sensitivity to changes in underlying factors. This analysis examines various scenarios or alterations in input parameters to evaluate their impact on the decision problem's conclusions. It can be conducted by changing one variable at a time while keeping others constant (univariate sensitivity analysis) or by altering multiple variables simultaneously. The results of a sensitivity analysis provide insights into the reliability and stability of decision-making under different scenarios. Overall, sensitivity analysis plays a crucial role in risk assessment and decision-making.

To perform a sensitivity analysis of the facility location selection decision, we will adjust the weight of the 'proximity to market and raw materials' (C11) criterion. Expert reviews have identified this as the most critical parameter. We used proposed formulas in the literature (Eqs. 3-4) to establish the weights of the criteria (Selçuk, 2013; Kabak et al., 2022).

The sensitivity analysis was conducted using percentage weight change values of -0.200, -0.100, 0.000, 0.100, and 0.200. The weight of each criterion in each scenario, calculated using Equations (3 and 4), is presented in Table 11.

Table 11. Calculated Weights for Each Criterion Based on The Weight Change Ratio

	C11*	**C12***	**C21***	**C22***	**C23***	**C31***
-200	(0.058, 0.125, 0.264)	(0.052, 0.114, 0.269)	(0.036, 0.099, 0.270)	(0.031, 0.084, 0.234)	(0.026, 0.072, 0.203)	(0.058, 0.124, 0.279)
-100	(0.065, 0.140, 0.297)	(0.051, 0.112, 0.257)	(0.035, 0.097, 0.258)	(0.031, 0.082, 0.223)	(0.026, 0.070, 0.194)	(0.057, 0.122, 0.267)
0	(0.072, 0.156, 0.330)	(0.051, 0.110, 0.245)	(0.035, 0.095, 0.246)	(0.031, 0.081, 0.213)	(0.026, 0.069, 0.185)	(0.057, 0.120, 0.254)
100	(0.079, 0.172, 0.363)	(0.051, 0.108, 0.233)	(0.035, 0.093, 0.234)	(0.031, 0.080, 0.203)	(0.026, 0.068, 0.176)	(0.057, 0.118, 0.241)
200	(0.086, 0.187, 0.396)	(0.050, 0.106, 0.221)	(0.034, 0.091, 0.222)	(0.031, 0.078, 0.192)	(0.026, 0.066, 0.167)	(0.056, 0.116, 0.229)
	C41**	**C42****	**C43****	**C44***	**C32***	
-200	(0.051, 0.112, 0.260)	(0.028, 0.078, 0.214)	(0.020, 0.056, 0.163)	(0.022, 0.061, 0.176)	(0.027, 0.077, 0.219)	
-100	(0.050, 0.110, 0.249)	(0.028, 0.076, 0.205)	(0.020, 0.055, 0.155)	(0.022, 0.060, 0.168)	(0.027, 0.075, 0.209)	
0	(0.050, 0.108, 0.237)	(0.028, 0.075, 0.195)	(0.020, 0.054, 0.148)	(0.022, 0.059, 0.160)	(0.027, 0.074, 0.199)	
100	(0.050, 0.106, 0.225)	(0.028, 0.074, 0.185)	(0.020, 0.053, 0.141)	(0.022, 0.058, 0.152)	(0.027, 0.073, 0.189)	
200	(0.049, 0.104, 0.214)	(0.028, 0.072, 0.176)	(0.020, 0.052, 0.133)	(0.022, 0.057, 0.144)	(0.027, 0.071, 0.179)	

*Beneficial Criterion, **Cost criterion

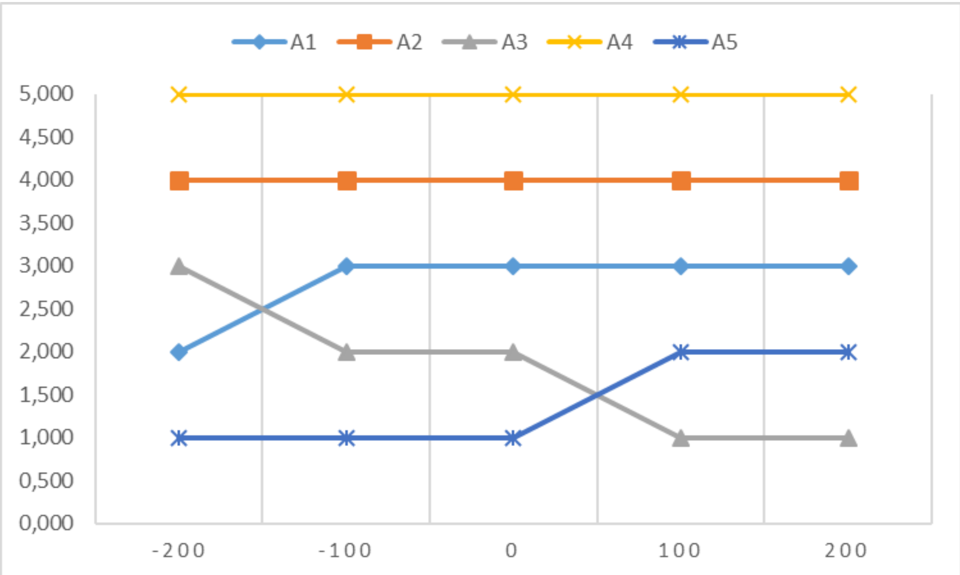

Fig 3. Ranking of Alternatives Based on Weight Change of C11

Our objective was to evaluate how changes in C11's weight affect the ranking of alternatives. Figure 3 illustrates the alternative rankings derived from percentage changes in C11's weight. The GRA analysis decision matrix indicated that the top options were linked to proximity to raw materials and markets. As this criterion's weight increased during the sensitivity analysis, A3 (Kayseri) surpassed A5 (Düzce) as the preferred choice. This is attributed to the Kayseri region's importance as a major furniture production center and its abundance of raw materials.

Regardless of the significance of raw material and market accessibility, A4 (Antalya) consistently ranks as the least favorable option according to this criterion, suggesting that production in this area may be impractical. Decision-makers might have been influenced by the perception that A4 (Antalya), a popular European tourist destination known for its natural beauty, would inherently promote sustainability more effectively than a city primarily recognized for furniture production

CONCLUSION

This study addresses the complex task of selecting a site for the furniture industry, an area that has received limited attention in terms of multi-criteria decision-making methods, especially within the furniture or forestry sectors. Given the global objectives of manufacturing companies, particularly those focused on exporting their products, it is essential to establish widely accepted evaluation standards. Notably, modern furniture companies are increasingly demonstrating environmental awareness alongside effective natural resource management. This trend requires the inclusion of environmental factors in evaluation criteria to meet global market expectations. The factors considered in this study include proximity, infrastructure, economic considerations, and environmental aspects, showcasing a comprehensive approach to decision-making.

In addition to the factors mentioned earlier, it's crucial to emphasize the importance of environmentally friendly practices when choosing a site for furniture companies. Ensuring that furniture manufacturing is established in suitable areas is vital for promoting a sustainable environment. The choice of location directly impacts various environmental aspects, including resource use, waste management, and ecological preservation. By carefully selecting sites with low environmental impact and abundant renewable resources, such as well-managed forests, businesses can support sustainable development goals while reducing their carbon footprint. Moreover, choosing locations with strong environmental regulations and infrastructure encourages the use of eco-friendly methods throughout the production process. Ultimately, including environmental sustainability criteria in the decision-making process for furniture manufacturing site selection is essential to achieve a balance between economic growth and environmental protection.

Building on previous research that has shown the effectiveness of integrated multi-criteria decision-making approaches, this study adopts a combined method, using both fuzzy Analytic Hierarchy Process (AHP) and fuzzy Grey Relational Analysis (GRA) to support effective decision-making. Expert assessments using fuzzy AHP allow for the calculation of criteria weights, which enhances the sensitivity and objectivity of the evaluation process. The inclusion of main and sub-criteria improves the assessment, particularly when examining the socio-cultural impacts of environmental factors, where GRA excels at handling complex and uncertain data.

The application of fuzzy GRA aids in ranking the alternatives (Gaziantep, Kocaeli, Kayseri, Antalya, and Duzce), addressing the challenge of selecting the most suitable option given their varying degrees of alignment with assessment criteria. Ultimately, using the combined fuzzy AHP and fuzzy GRA methods, this study recommends establishing an office furniture factory in Duzce as the optimal choice.

Future studies on location selection in the furniture manufacturing industry could benefit from combining integrated approaches with newer methods. Researchers could develop techniques to assess whether other integrated methodologies surpass the effectiveness of the combined fuzzy AHP and fuzzy GRA methods used in this study. This ongoing research and refinement of decision-making processes will help enhance the efficiency and sustainability of location selection in the furniture sector.

AUTHOR CONTRIBUTIONS

Abdullah Cemil İlçe: Conceptualization, Methodology, Sensitivity analysis, Writing - original draft. **Hasan Hüseyin Ciritcioğlu:** Conceptualization, Literature analysis, Writing-editing. **Tuğba Yıldız:** Conceptualization, Methods development, Writing-original draft

FUNDING STATEMENT

The study received no financial support.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

REFERENCES

Agrebi, M., Abed, M., & Omri, M. N. (2017). ELECTRE I Based Relevance Decision-Makers Feedback to the Location Selection of Distribution Centers. *Journal of Advanced Transportation*, 2017(1), 7131094.

Al-Hawari, T., Mumani, A., & Momani, A. (2014). Application of the Analytic Network Process to facility layout selection. *Journal of manufacturing systems*, 33(4), 488-497.

Beskese, A., Demir, H. H., Ozcan, H. K., & Okten, H. E. (2015). Landfill site selection using fuzzy AHP and fuzzy TOPSIS: a case study for Istanbul. *Environmental Earth Sciences*, 73, 3513-3521.

Boran, F. E. (2011). An integrated intuitionistic fuzzy multi criteria decision making method for facility location selection. *Mathematical and Computational Applications*, 16(2), 487-496.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy sets and systems*, 17(3), 233-247.

Burdurlu, E., & Ejder, E. (2003). Location choice for furniture industry firms by using Analytic Hierarchy Process (AHP) method. *Gazi University Journal of Science*, 16(2), 369-373.

Chou, S. Y., Chang, Y. H., & Shen, C. Y. (2008). A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. *European Journal of Operational Research*, 189(1), 132-145.

Dağdeviren, M., Eren, T.(2001). Using analytical hierarchy process and 0-1 target programming methods in supplier selection (In Turkish). *Journal of the Faculty of Engineering and Architecture of Gazi University*. 16(1), 41-52.

Dağdeviren, M. (2007). Personnel selection with fuzzy analytical hierarchy process and an application. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 22(4), 791-799.

Erdoğan, M., & Kaya, I. (2016). A combined fuzzy approach to determine the best region for a nuclear power plant in Turkey. *Applied Soft Computing*, 39, 84-93.

Ertuğrul, İ. (2011). Fuzzy group decision making for the selection of facility location. *Group Decision and Negotiation*, 20, 725-740.

Ertuğrul, İ., & Karakaşoğlu, N. (2008). Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection. *The International Journal of Advanced Manufacturing Technology*, 39, 783-795.

Giresunlu, M., Tanritanir, E., Öztürk, T.A.(1998) AHP method selection in the MDF industry (In Turkish). In: *75th Anniversary of the Republic of Turkey Symposium on Forestry*. pp. 612–618.

Göksu, A., Güngör, İ. (2008). Fuzzy analytic hierarchical process and implementation of university preference ranking. (In Tukish). *Süleyman Demirel Univ. Journal of Faculty of Economics and Administrative. Science.* 13, 1–26.

Gupta, P., Mehlawat, M. K., & Grover, N. (2016). Intuitionistic fuzzy multi-attribute group decision-making with an application to plant location selection based on a new extended VIKOR method. *Information Sciences*, 370, 184-203.

Gumus, A. T. (2009). Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology. *Expert systems with applications*, 36(2), 4067-4074.

Hanine, M., Boutkhoum, O., Tikniouine, A., & Agouti, T. (2016). Comparison of fuzzy AHP and fuzzy TODIM methods for landfill location selection. *Springer Plus*, 5, 1-30.

Hsu, C. I., & Wen, Y. H. (2000). Application of grey theory and multiobjective programming towards airline network design. *European Journal of Operational Research*, 127(1), 44-68.

İmren, E. (2011) Selection of establishment place using analytical hierarchy method in furniture industry (In Turkish), Msc. Thesis,p.105.

Ju-Long, D. (1982). Control problems of grey systems. *Systems & control letters*, 1(5), 288-294.

Kabak, M., Javadi, H., Aktas, A., & Ecer, B. (2022). GIS-Based Multi-Criteria Decision Making for Site Selection: An Application of GRP Pipe Production Plant. *Journal of Multiple-Valued Logic & Soft Computing*, 39,1-23.

Kahraman, C., Ruan, D., & Doğan, I. (2003). Fuzzy group decision-making for facility location selection. *Information sciences*, 157, 135-153.

Kharat, M. G., Kamble, S. J., Raut, R. D., Kamble, S. S., & Dhume, S. M. (2016). Modeling landfill site selection using an integrated fuzzy MCDM approach. *Modeling Earth Systems and Environment*, 2, 1-16.

Kuo, R. J., Chi, S. C., & Kao, S. S. (1999). A decision support system for locating convenience store through fuzzy AHP. *Computers & Industrial Engineering*, 37(1-2), 323-326.

Liu, S., & Forrest, J. Y. L. (2010). Grey systems: theory and applications. *Springer Science & Business Media.*

Mahmoodzadeh, S., Shahrabi, J., Pariazar, M., & Zaeri, M. S. (2007). Project selection by using fuzzy AHP and TOPSIS technique. *International Journal of Industrial and Manufacturing Engineering*, 1(6), 270-275.

Popovic, G., Stanujkic, D., Brzakovic, M., & Karabasevic, D. (2019). A multiple-criteria decision-making model for the selection of a hotel location. *Land use policy*, 84, 49-58.

Özdağoğlu, A. (2012). A multi-criteria decision-making methodology on the selection of facility location: fuzzy ANP. *The International Journal of Advanced Manufacturing Technology*, 59, 787-803.

Özel, H.B., Karayılmazlar, S., Demirci, A.(2014) Location selection for forestation studies using Mediterranean pine species (Pinus brutia Ten. and Pinus pinea L.) with the analytical hierarchy process (AHP) method in Bartın Basin (In Turkish). *National Mediterr. For. Environ. Symp. Futur. Mediterr. For. Sustain. Soc. Environon*. 22–24

Saaty, T.L. (1980) The Analytic Hierarchy Process. *McGraw-Hill*, New York.

Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. *European journal of operational research*, 48(1), 9-26.

Safari, H., Faghih, A., & Fathi, M. R. (2012). Fuzzy multi-criteria decision making method for facility location selection. *African Journal of Business Management*, 6(1), 206-212.

Selcuk, L. (2013) An avalanche hazard model for Bitlis Province, Turkey, using GIS based multicriteria decision analysis, *Turkish Journal of Earth Sciences*, 22: 523–535

Singh, R. K. (2016). Facility location selection using extent fuzzy AHP. *Int. Advanced Research J. in Science, Engineering and Technology*, 3(2).

Şahin, T., Ocak, S., & Top, M. (2019). Analytic hierarchy process for hospital site selection. *Health Policy and Technology*, 8(1), 42-50.

Şen, H., & Demiral, M. F. (2016). Hospital Location Selection with Grey System Theory. *European Journal of Economics and Business Studies*, Articles, 2(2), 66-79.

Van Laarhoven, P.J.M. & Pedrycz, W.(1983). A fuzzy extension of Saaty's priority theory. *Fuzzy sets Systems*. 11(1-3), 229–241.

Vijay, M. A., & Shankar, C. (2010). Facility Location Selection using PROMETHEE II Method. *In Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management*, Dhaka, Bangladesh (pp. 9-10)

Wichapa, N., & Khokhajaikiat, P. (2017). Solving multi-objective facility location problem using the fuzzy analytical hierarchy process and goal programming: a case study on infectious waste disposal centers. *Operations Research Perspectives*, 4, 39-48.

Yaşlıoğlu, M. M., & Önder, E. (2016). Solving facility location problem for a plastic goods manufacturing company in Turkey using AHP and TOPSIS methods. *Yönetim Bilimleri Dergisi*, 14(28), 223-249.

Yong, D. (2006). Plant location selection based on fuzzy TOPSIS. *The International Journal of Advanced Manufacturing Technology*, 28, 839-844.