TÜRKİYE CUMHURİYETİ
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL
INDUSTRIAL ENGINEERING DEPARTMENT

LOCATION SELECTION OF FIELD HOSPITAL FOR FUTURE PANDEMICS USING FUZZY COMBINED MCDM METHODS

EMİNE SERAY GÜN

M.Sc.

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ADANA, 2024

DECLARATION OF CONFORMITY

In this thesis study, which was prepared following the thesis writing rules of Adana Alparslan Türkeş Science and Technology University Institute of Graduate School, I declare that I provide all the information, documents, evaluations and results in accordance with scientific ethics and moral codes without resorting to any means or assistance that would be contrary to scientific ethics and traditions. I also declare that I refer to all of the articles I used in this study with appropriate references and accept all moral and legal consequences if a situation is found contrary to my statement regarding my work.

18/01/2024

[Signature]

Emine Seray GÜN

ABSTRACT

LOCATION SELECTION OF FIELD HOSPITAL FOR FUTURE PANDEMICS USING FUZZY COMBINED MCDM METHODS

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For thousands of years, human beings have struggled with many natural disasters such as earthquakes, floods, epidemics, and volcanic eruptions. Among these natural disasters, epidemics have caused the death of hundreds of people. Many epidemics, from the plague epidemic, also known as the Black Death to the Swine flu and today to the COVID-19 pandemic, have affected societies deeply by affecting a wide range of areas. Due to the rapid spread of the COVID-19 pandemic, which arised from Wuhan, China in December 2019, many hospitals around the world have exceeded their capacity and insufficient. Authorities of some countries have built field hospitals during the pandemic to find a solution to this problem.

In this thesis study, field hospital location selection problem for pandemics that are predicted to increase in the future in the globalizing world was discussed and a real case study was conducted in Adana. Since the location selection problem, which is one of the topics of operations research, involves multiple conflicting criteria and a limited number of alternatives, Multi-Criteria Decision Making (MCDM) is one of the most effective classical methods known to solve such problems. Since these classical methods are insufficient to handle uncertain and imprecise situations in real life, it may be more realistic to make decisions based on fuzzy versions of these methods that take into account human judgments. Thus, in this study, a fuzzy FUCOM & fuzzy MARCOS model was suggested to solve the field hospital location selection problem. The weights of the criteria were calculated with the fuzzy FUCOM method. The alternative locations were then ranked with the fuzzy MARCOS method. According to the analysis results, it was determined that the best alternative location was TUYAP Adana Fair and Congress Center Surrounding. Lastly, a sensitivity analysis was conducted to test the accuracy and validity of the proposed model.

Keywords: Hospital Location Selection, Fuzzy FUCOM, Fuzzy MARCOS, Fuzzy MCDM, Pandemic.

ÖZET

BULANIK BÜTÜNLEŞİK ÇKKV YÖNTEMLERİ KULLANILARAK GELECEKTEKİ PANDEMİLER İÇİN SAHRA HASTANESİ YER SEÇİMİ

Emine Seray GÜN
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İnsanoğlu binlerce yıldır deprem, sel, salgın hastalıklar, volkanik patlamalar gibi pek çok doğal afetle mücadele etmiştir. Bu doğal afetler arasında salgın hastalıklar yüzlerce insanın ölümüne neden olmuştur. Kara Ölüm olarak da bilinen Veba salgınından domuz gribine ve günümüzde COVID-19 pandemisine kadar pek çok salgın hastalık çok geniş bir alanda etkisini göstererek toplumları derinden etkilemiştir. Aralık 2019'da Çin'in Wuhan kentinde ortaya çıkan COVID-19 pandemisinin hızla yayılmasından dolayı dünya çapında birçok hastane kapasitelerini aşarak yetersiz kalmıştır. Bazı ülke yetkilileri bu soruna çözüm üretmek için salgın sırasında sahra hastaneleri inşa etmiştir.

Bu tez çalışmasında, küreselleşen dünyada gelecekte artması öngörülen pandemiler için sahra hastanesi yer seçimi problemi ele alınmış ve Adana'da gerçek bir vaka çalışması yapılmıştır. Yöneylem araştırmasının konularından biri olan yer seçimi problemi, birden fazla birbiriyle çelişen kriter ve sınırlı sayıda alternatif içerdiğinden, bu tür problemleri çözmek için Çok Kriterli Karar Verme (ÇKKV) bilinen en etkili klasik yöntemlerden biridir. Bu klasik yöntemler gerçek yaşamdaki belirsiz ve kesin olmama durumlarını ele almada yetersiz kaldığından, bu yöntemlerin insan yargılarını dikkate alan bulanık versiyonlarına göre karar almak daha gerçekçi olacaktır. Bu nedenle bu tez çalışmasında sahra hastanesi yer seçimi probleminin çözümü için bulanık FUCOM & bulanık MARCOS modeli önerilmiştir. Kriter ağırlıkları bulanık FUCOM yöntemi ile belirlenmiştir. Ardından alternatif lokasyonlar bulanık MARCOS yöntemi ile sıralanmıştır. Analiz sonuçlarına göre en iyi alternatif lokasyonun TÜYAP Adana Fuar ve Kongre Merkezi Çevresi olduğu belirlenmiştir. Çalışmanın sonunda önerilen modelin doğruluğunu ve geçerliliğini test etmek amacıyla duyarlılık analizi yapılmıştır.

Anahtar Kelimeler: Bulanık ÇKKV, Bulanık FUCOM, Bulanık MARCOS, Hastane Yer Seçimi, Pandemi.

To my soulmate

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I would like to thank my mother and father who supported me throughout my life.

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LIST OF ABBREVIATIONS

AFAD	: Disaster and Emergency Management Authority
AGV	: Automatically Guided Vehicles
AHP	: Analytical Hierarchy Process
ANP	: Analytical Network Process
ARAS	: Additive Ratio Assessment
ARAS-G	: Additive Ratio Assessment with Gray values
BPM	: Business Process Management
BWM	: Best-Worst Method
CCSD	: Correlation Coefficient and the Standard Deviation
CoCoSo	: Combined Compromise Solution
CODAS	: COmbinative Distance-based ASsessment
COVID-19	: Coronavirus Disease
CRITIC	: CRiteria Importance Through Inter-Criteria Correlation
CSFs	: Critical Success Factors
DEA	: Data Envelopment Analysis
DFC	: Deviation from Full Consistency
DMs	: Decision Makers
EAMR	: Evaluation by an Area-based Method of Ranking
EDAS	: Evaluation based on Distance from Average Solution
EDAS-M	: Evaluation Based on Distance from Mean Solution in Minkowski space
ELECTREE	: ELimination and Choice Translating REality
FMEA	: Failure Modes and Effects Analysis
FRAM	: Fuzzy Risk Assessment Model
FUCOM	: Full Consistency Method
FUCOM-F'B	: Fuzzy Full Consistency Method-Bonferroni
GAIA	: Geometric Analysis of Interactive Aid
GIS	: Geographic Information System
GMIR	: Graded Mean Integration Representation
GRA	: Gray Relational Analysis
HRES	: Hybrid Renewable Energy System

IFI	: Intuitionistic Fuzzy Information
IRNs	: Interval Rough Numbers
ITARA	: Indifference Threshold-based Attribute Ratio Analysis
IVq-ROF	: Interval-Valued q-Rung Orthopair Fuzzy
MABAC	: Multi-Attributive Border Approximation Area Comparison
MADM	: Multi Attribute Decision Making
MADM	: Multi-Attribute Decision-Making
MARCOS	: Measurement of Alternatives and Ranking using the COmpromise Solution
MCA	: Multi-Criteria Analysis
MCDM	: Multi Criteria Decision Making
MODM	: Multi Objective Decision Making
MPM	: Mineral Potential Mapping
OLS	: Ordinary Least Square
OSH	: Occupational Health and Safety
OWA	: Ordered Weighted Averaging
PAHO	: Pan American Health Organization
PFNs	: Pythagorean Fuzzy Numbers
PIPRECIA	: PIvot Pairwise RElative Criteria Importance Assessment
PIV	: Proximity Index Value
PROMETHEE	: Preference Ranking Organization METHod for Enrichment Evaluation
QFD	: Quality Function Distribution
RAs	: Resilient Attributes
R-CoCoSo	: Rough Combined Compromise Solution
RF	: Random Forest
R-FUCOM	: Rough Full Consistency Method
ROV	: Range of Value
R-ROV	: Rough Range of Value
RS	: Rank Sum
R-SAW	: Rough SAW
RSs	: Resilient Strategies
R-SWARA	: Rough Step-wise Weight Assessment Ratio Analysis
SAW	: Simple Additive Weighting
SCC	: Spearman Correlation Coefficient

SD	: Standard Deviation
SERVQUAL	: Service Quality
SFA	: Suitability-Feasibility-Acceptability
SMEs	: Small and Medium-sized clothing Enterprises
SWARA	: Step-wise Weight Assessment Ratio Analysis
TFNs	: Triangular Fuzzy Numbers
TOPSIS	: Technique for Order Preference by Similarity to Ideal Solution
TUIK	: Türkiye İstatistik Kurumu
VIKOR	: VIšeKriterijumska Optimizacija I Kompromisno Resenje
WASPAS	: Weighted Aggregated Sum Product Assessment
WHO	: World Health Organization
WPM	: Weighted Product Method

LIST OF SYMBOLS

$\mu_A(x)$	: Membership Function
l	: Lower bound value
m	: Central bound value
u	: Upper bound value
C_j	: Criterion
$\varpi_{C_{j(k)}}$	: Significance of the criteria
$\varphi_{k/(k+1)}$	: Comparative significance
Φ	: Vector of the comparative significance
χ	: DFC value
$\tilde{A}(ID)$	: Ideal solution
$\tilde{A}(AI)$	: Anti-ideal solution
$\tilde{K}_i^+$	: Utility degrees of ideal
$\tilde{K}_i^-$	: Utility degrees of anti-ideal
$f(\tilde{K}_i^+)$	: Utility function of ideal
$f(\tilde{K}_i^-)$	: Utility function of anti-ideal
$f(K_i)$	: Final utility function

1. INTRODUCTION

For thousands of years, mankind has faced many natural disasters such as earthquakes, floods, fires, volcanic eruptions, hurricanes, and epidemics. Among these, epidemics caused by infectious diseases have profoundly affected human history. Epidemics such as the Plague epidemic, also known as the Black Death, bleeding fever, spanish flu, AIDS virus, and SARS have caused the death of many people around the world (Zeren and Hızarcı, 2020).

1.1. Definition of Epidemic and Pandemic

The term "outbreak" is considered synonymous with "epidemic" by epidemiologists, and in the literature these terms are used interchangeably and sometimes even together by researchers (Green et al., 2002). Epidemiologists define an epidemic as *"The occurrence in a community or region of cases of an illness, specific health-related behavior, or other health-related events clearly in excess of normal expectancy"* (Porta, 2014).

There are many ways to define an outbreak in the literature. The most advanced stage is the pandemic, which spreads throughout the world (Zolfani et al., 2020). A pandemic is defined by epidemiologists as *"an epidemic occurring over a very wide area, crossing international boundaries, and usually affecting a large number of people"* (Porta, 2014).

Epidemics, which are described as natural disasters, are spreading faster and reaching serious levels today due to globalization and the ease of transportation that comes with it. It turns into pandemics that affect every segment of society, both nationally and internationally.

1.2. Definition of Field Hospital

Regardless of their source, disasters bring with them many negativities from the moment they occur. During these critical processes, existing health institutions are inadequate and cannot meet the needs. For this reason, field hospitals still offer the most effective solutions for these needs (Bıçakçı and Nevruz, 2021).

In a workshop in El salvador in July 2003, the World Health Organization (WHO) and the Pan American Health Organization (PAHO) defined a field hospital as *"a mobile, self-contained, self-sufficient healthcare facility capable of rapid deployment and expansion or constraction to meet emergency requirements for a specified period of time*". Field hospitals should provide medical care in the affected area to a similar or higher standard than that available before the precipitating event (WHO, 2003).

The area that field hospitals will be established should be determined in advance. This area should be in a safe location, away from dangerous structures and areas where there are risks.

A field hospital may be established in safe buildings (such as schools, sports hall, mosque, cultural centers) that unharmed by the disaster. Field hospitals consist of tents, inflatable modules, prefabricated structures, and portable structures such as trailers or ship containers. The materials used in the construction of field hospitals varies in accordance with type of disaster, the magnitude of the disaster and the country's financial resources. If these materials are kept in warehouses during pre-disaster preparation, these should be checked periodically. (Tekin et al., 2017).

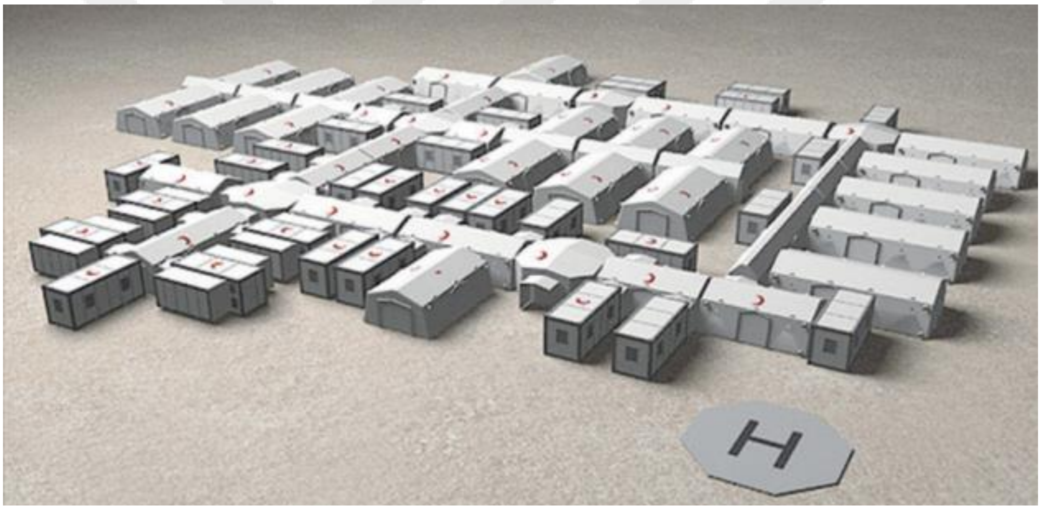

Figure 1.1. Modular field hospital established by Disaster and Emergency Management Authority (AFAD) (resource: Dursun and Karakoç, 2019)

Figure 1.2. Field hospital used for the COVID-19 pandemic (resource: iStock.com)

Coronavirus disease (COVID-19), which came out in Wuhan, China, in December 2019, caused thousands of deaths worldwide. For this reason, on March 12, 2020, the WHO declared a pandemic (Ciotti et al., 2020). The spread of COVID-19 around the world was quite rapid. Almost all countries have been severely affected in many respects. Because of the fast transmission rate of coronavirus disease and uncertainty of demand, the resources and capacity of existing hospitals were inadequate. In addition, treating COVID-19 patients in the same hospital with other patients diagnosed with different diseases and healthcare workers further increased the risk of the pandemic spreading. Existing hospitals had to continue to perform their routine procedures while they responded the excessive demand caused by the pandemic (Aydın and Şeker, 2021). At this point, due to the inadequacy of existing hospitals, it has become necessary for all countries in the world to review their health systems in the post-pandemic period. And also, considering the researches conducted by scientists, it is predicted that there will be more pandemics that will affect all societies in the globalizing world (Yücenur, 2022). Considering these, it is important for policy makers and managers to take precautions and create ready action plans for future pandemics. In this context, field hospitals are among the most suitable solutions (Bıçakçı and Nevruz, 2021).

Therefore, the establishment of field hospitals should be considered essential in case of a possible pandemic in the future to slow down the spread of the pandemic by preventing the transmission of the disease to healthcare workers and patients with different diagnoses in existing hospitals and providing the necessary medical care for patients affected by the pandemic. In the light of the above, the purpose of this study is to discuss the problem of field hospital location selection for pandemics that are expected to increase in the globalizing world. A real case study was conducted in Adana.

Location selection problems, which are the subject of operations research, require the evaluation of more than one alternative by considering many criteria especially conflicting to select a suitable location. In such a problem structure, a compromise must be made between conflicting criteria to choose amoung alternatives. Therefore, MCDM offers effective approach in the resolution of location selection problems (Chakraborty et al., 2013). Traditional MCDM only considers exact decision problems. It does not take into account the uncertainty of group decisions and human preferences (Tzeng and Huang, 2011). However, since human judgments and preferences are often ambiguous, exact values are insufficient for modeling real-life problems (Bayrakdaroğlu and Yalçın, 2013). Therefore, fuzzy set theory was introduced by Zadeh (1965) to find a solution to this situation. In cases where there is uncertainty due to human judgment and preference, a fuzzy MCDM approach is used (Kahraman et al., 2015).

In this study, an optimization-based fuzzy MCDM model based on the subjective evaluations of decision makers, consisting of fuzzy FUCOM and fuzzy MARCOS methods, was proposed. As far as we know, the proposed fuzzy MCDM model in our study was used for the firstly in both hospital location selection and also field hospital location selection problem. For this reason, this study may have a distinction of being the first in the literature. Thus, it is thought that this thesis study may fill this gap in the literature.

In the proposed fuzzy FUCOM & fuzzy MARCOS model, optimum criteria weights were obtained based on the subjective evaluations of decision makers using fuzzy FUCOM. Then alternative locations were ranked using the fuzzy MARCOS method. In addition, the proposed model was validated by conducting a sensitivity analysis. This proposed model was compared with the fuzzy version of some ranking MCDM methods, including TOPSIS, WASPAS, SAW, ARAS, PIV, COPRAS and MABAC. It was observed that the comparison methods and the proposed model had similar results.

The rest of the study is designed as follows: The literature review consists of MCDM literature for hospital location selection, studies on using FUCOM and fuzzy FUCOM method, studies on using MARCOS and fuzzy MARCOS method in Section 2. The stages of the fuzzy FUCOM and fuzzy MARCOS methods are given in Section 3. A real case study was performed in Adana to show the applicability of the proposed model in Section 4. Results and discussion as well as the sensitivity analysis are also provided in Section 4. Conclusions are presented in Section 5. Lastly, recommendations are presented in Section 6.

2. LITERATURE REVIEW

Within the scope of this thesis in this section, the literature was reviewed under three headings: MCDM literature for hospital location selection (including pandemic, field, isolation, temporary hospital location selection), studies conducted using FUCOM and fuzzy FUCOM method, studies conducted using MARCOS and fuzzy MARCOS method. A literature review was conducted methodically.

2.1. MCDM literature for Hospital Location Selection

In this first stage of literature review, studies on hospital location selection (including pandemic, field, isolation, temporary) using MCDM methods are presented.

Wu et al. (2007) proposed a method integrating the modified Delphi and Analytical Hierarchy Process (AHP) methods for the hospital location selection problem in Taiwan. Three alternative locations were evaluated according to six main criteria and the most suitable location was selected. To determine the change in behavior of alternative locations, a sensitivity analysis was performed.

Vahidnia et al. (2009) suggested a methodology combining Geographic Information System (GIS) analysis with Fuzzy AHP for hospital location selection problem in Tehran. While the fuzzy AHP method was utilized to evaluate criteria, the GIS method was utilized to organize and analyze the relevant spatial data. Three defuzzification methods that are fuzzy extent analysis, a-cut method and center-of-area were used for the weights and rankings of the alternatives. As a result, these three methods used for five alternative locations gave the same ranking.

Soltani and Marandi (2011) proposed the integrated GIS-Fuzzy AHP-Fuzzy Analytical Network Process (F-ANP) methodology for the hospital location problem in Shiraz, Iran. Firstly, three alternative locations were determined with the combination of Fuzzy AHP and GIS. Then, the alternative locations were evaluated using the F-ANP method. Lastly, a sensitivity analysis was performed for the criteria used. It was concluded that the weights obtained were quite sensitive to the change in traffic congestion level and land price values.

Chatterjee and Mukherjee (2013) evaluated three potential rural hospital sites in India using AHP method. Three main criteria and eleven sub-criteria were considered. A suitable site for the hospital was determined.

Abdullahi et al. (2014) presented the Ordinary Least Square (OLS) and AHP evaluation model for the hospital location selection in Qazvin, Iran. The results showed that these two methods have similarities.

Vafaei and Oztaysi (2014) proposed an integrated AHP-GIS methodology to calculate the most appropriate location for a field hospital in the event of a possible earthquake in Istanbul. Five alternative locations were evaluated according to five criteria. It was concluded that the most suitable location to build a field hospital was Yıldız Park.

Chatterjee (2015) proposed the Delphi embedded Fuzzy AHP and The PROMETHEE integration to achieve consensus among experts for the healthcare facility location problem in India. While the fuzzy AHP method was used to weight the criteria, the PROMETHEE method was used to rank the alternative locations. This is the first study to use Delphi embedded Fuzzy AHP-PROMETHEE integration in healthcare facility location selection. The Geometric Analysis of Interactive Aid (GAIA) method was used to visually grasp the contradictions between the alternatives according to each criterion. In the sensitivity analysis, it was observed that there was almost no change in the first two positions of the alternative rank list and this revealed the robustness of the integrated MCDM model.

Jalaliyoon et al. (2015) used expert opinion to determine the criteria for the hospital location selection problem in Dominica. The weights of these determined criteria were determined using the AHP method. It was concluded that the criterion with the highest weight was transit, and the criterion with the lowest weight was site orientation.

Kumar et al. (2016) used the fuzzy extended ELECTREE approach for the hospital location problem in the densely populated Indian state of Bihar. This approach accounts for linguistic ambiguity in decision making and ignores inappropriate locations. As a result of the study, alternative locations were ranked.

Eldemir and Önden (2016) proposed the AHP-GIS integrated framework for the problem of the hospital location in Istanbul. The determined decision criteria were weighted with the AHP method, and the suitability map were created using GIS. Then, sensitivity analysis was performed on AHP-GIS integrated framework to measure the effectiveness of alternative scenarios.

With GRA, which is one of the MCDM methods, the behavior of the systems that cannot be overcome with stochastic or fuzzy methods can be predicted with a limited number of data. Şen and Demiral (2016) addressed a new public hospital location selection problem by using GRA and AHP methods. The criteria were weighted with the AHP method, and then gray relational degrees were calculated for alternative locations. As a result, the most suitable location was determined.

Organ and Tekin (2017) suggested Entropy and GRA methods for the selection of the city hospital's establishment location in Denizli, Turkey. The weights of the criteria were determined using the Entropy method, and then five alternative locations were listed with the GRA method. As a result of the study, the optimum location was determined.

Rahimi et al. (2017) used AHP and GIS methods to evaluate the location of existing hospitals in Shiraz, Iran, and to determine the optimum location to establish new hospitals. The weights of the criteria were calculated with the AHP method. It was concluded that existing hospitals are not located in suitable locations.

Şen (2017) applied the Additive Ratio Assessment Method with Gray values (ARAS-G) method for a new public hospital location selection problem. This method allows to determine the value of alternative locations by comparing them with the optimal location. The closest location to the optimum location for the public hospital was chosen as a result of the study.

Kmail et al. (2017) proposed a suitability model using GIS-based Multi-Criteria Analysis (MCA) to build a new hospital in Jenin, Palestine. GIS tools and techniques were used to analyze the list of criteria determined for the new hospital location selection. AHP method was used to weight these criteria. As a result of the study, the most appropriate location to build a new hospital was determined.

Çelikbilek (2018) applied the fuzzy VIKOR method for a private healthcare facility location selection. The final alternative location ranking results of the proposed fuzzy VIKOR approach were validated by fuzzy AHP.

Miç and Antmen (2019) proposed the fuzzy TOPSIS method for regional hospital location selection in Adana, Turkey. As a result of the study, Seyhan district was determined as the best location for the regional hospital location selection.

Zolfani et al. (2020) addressed the problem of temporary hospital location selection in a gray uncertainty environment using CRITIC and CoCoSo methods for Istanbul. Five alternative locations were evaluated according to 10 criteria. The proposed gray-based decision support framework showed the most suitable locations for establishing temporary hospitals for COVID-19 patients.

Wang et al. (2021) proposed a methodology using hybrid fuzzy AHP and Weighted Aggregated Sum Product Assessment (WASPAS) methods for selecting the location of a temporary hospital for COVID-19 patients in Ho Chi Minh City. At the same time, the fuzzy AHP method was used to determine the prioritization of preventive measures to reduce the infectivity of the virus. It was concluded that the best location for a temporary hospital was Cu Chi District and that the most effective preventive measure was limiting travel.

Adalı and Tuş (2021) conducted location selection for a private hospital in Denizli, Turkey. To obtain the weights of the hospital site selection criteria the CRITIC method was used, while the distance-based TOPSIS, EDAS and CODAS methods were used for the complete ranking of alternative locations. This is the first study to integrate the CRITIC method with TOPSIS, EDAS and CODAS methods, and these methods were not used in hospital location selection problems. According to these three methods used, it was concluded that the ranking of the hospital location alternatives gave the same result.

Gül (2021) proposed an innovative fuzzy decision support model in the hospital location problem using intuitionistic fuzzy numbers, which have a better ability to quantify the vagueness in experts' opinions. In this proposed model, it was aimed to limit the subjectivity of experts' opinions by means of objective weighting, and the criteria were weighted with the Ordered Weighted Averaging (OWA) method. Intuitionistic fuzzy VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) was used as the analysis method. This proposed model was applied to a district of Istanbul.

Yılmaz and Atan (2021) conducted a case study for Istanbul by applying the recently proposed fuzzy EDAS method to the hospital location problem for the first time. Since there are few studies on fuzzy EDAS, it was compared with the fuzzy TOPSIS method to increase the intelligibility of the method. As a result of this comparison, different alternative rankings were obtained.

Aydın and Seker (2021) proposed a Delphi-based MCDM model in selecting the most appropriate isolation hospital location to serve patients who only have mild to moderate symptoms and do not require special treatment. A case study was conducted in Istanbul. Nine criteria were weighted by applying the BWM method, and then five alternative locations were ranked by applying the type-2 fuzzy TOPSIS method. It was concluded that the most appropriate location to establish an isolation hospital was Atatürk Airport.

Alkan and Kahraman (2022) integrated circular intuitionistic fuzzy set with the TOPSIS method. This integrated model was applied to the problem of pandemic hospital location selection in Istanbul. It was concluded that the most suitable location for the pandemic hospital in Istanbul was Sancaktepe. To verify the proposed CIF-TOPSIS method and demonstrate its effectiveness, a comparative analysis was made with single-valued intuitionistic fuzzy TOPSIS, picture fuzzy TOPSIS, pythagorean fuzzy TOPSIS methods.

Akpınar and Nisancı (2021) used the AHP method for the problem of selecting a temporary shelter site after a possible disaster. Three alternatives were evaluated according to six criteria. It was concluded that the criterion with the highest weight was shelter size and the most suitable site was determined.

Akpınar and Ilgın (2021) aimed to determine the most suitable location for the field hospital to be built for COVID-19 patients in Izmir, Türkiye by using the Fuzzy Choquet integral, which allows for linguistic assessments. As a result of the study, the most suitable location was determined to be Bornova. In this applied method, it was also concluded which alternative could be best preferred for each of criterion.

Boyacı and Şişman (2022) proposed a model integrating GIS, AHP and TOPSIS methods for pandemic hospital location selection in Samsun. The weights of the criteria were determined with the Pythagorean Fuzzy AHP method. Maps of alternative sites were created using the GIS method, according to the rules determined by the experts and the weighting of the criteria. Then, TOPSIS method was applied to rank the alternatives. Finally, changes in the ranking of alternatives were examined by changing the weight values of the criteria.

Yücenur (2022) conducted field hospital location selection for COVID-19 pandemic and future pandemics. Six alternative European Union countries were evaluated according to five main and 20 sub-criteria. First of all, the importance weights of the criteria were determined using Step-wise Weight Assessment Ratio Analysis (SWARA) method, and then alternatives were ranked using EDAS method. Germany was determined to be the most appropriate European Union country for the field hospital.

Benmoussa et al. (2022) proposed the AHP-GIS-Machine Learning methodology for the hospital site selection problem in Algeria to accelerate the control of the COVID-19 pandemic. GIS combined with AHP was used to evaluate the hospital site selection criteria. Random Forest (RF) method, one of the advanced techniques of machine learning, was used for the pattern of hospital site selection. Thus, the suitability of hospital sites was mapped. As a result of the study, the location where the hospital would be built was predicted with 92.0904% accuracy.

Kheybari et al. (2023) proposed new risk-averse BWM to weight decision criteria for the problem of the temporary hospital location for corona virus patients in Mazandaran province of Iran. Then, the performance of the locations was evaluated through a mathematical model that used optimal ranges of criteria weight as parameters. Finally, a portfolio optimization

model was proposed to find appropriate locations by considering the weights obtained with risk-averse BWM and the distance between cities as parameters.
Mohamed et al. (2023) proposed a methodology integrating fuzzy AHP and fuzzy TOPSIS methods for the selection of pandemic hospital site in Aleppo. This methodology aimed to select the best site among four alternative under uncertainty. A sensitivity analysis was performed at the end of the study to determine the impact of criteria weights on the decision-making process.
Yazdi et al. (2023) proposed a novel multi-attribute decision-making (MADM) model that aims to determine how, when and where to establish a temporary hospital using Pythagorean fuzzy numbers in an uncertain environment. Critical success factors (CSFs) were weighted using the Best-Worst Method, and then the alternatives were ranked using the Evaluation by an Area-based Method of Ranking (EAMR). A sensitivity analysis was performed by comparing the results of this hybrid approach with other alternative approaches.
Hezam et al. (2023) aimed to rank alternative sites for hospital site selection using the Intuitionistic Fuzzy Information (IFI), the Standard Deviation (SD), the Rank Sum (RS) and MARCOS approaches. While objective weights of the criteria were obtained with the IF-SD integrated model, subjective weights of the criteria were obtained with the IF-RS integrated model. Then, the ranking of the alternatives was obtained using the MARCOS method.

2.2. Studies conducted using FUCOM and Fuzzy FUCOM Method

In this second stage of literature review, studies using FUCOM and Fuzzy FUCOM method are presented.
The FUCOM method, which is used to determine the weights of decision criteria in various problems, was proposed by Pamucar et al. (2018).
Pamucar et al. (2018) compared it with the BWM and AHP methods for the verification of the proposed FUCOM method. According to the relationship between the required number of comparisons of the criteria and consistency, it was concluded that the FUCOM method provided better results compared to BWM and AHP methods.
Zavadskas et al. (2018) proposed a noval Rough Range of Value Method (R-ROV) method by combining the Range of Value Method (ROV) method with rough numbers for the selection of automatically guided vehicles (AGV). Decision criteria were weighted with the FUCOM method, and then the alternatives were ranked with the R-ROV method. Rough WASPAS,

Rough SAW and Rough MABAC methods were used to test the reliability of the R-ROV method.

Prentkovskis et al. (2018) proposed a new methodology consisting of three stages to improve the measurement of a company's logistics service quality. This proposed methodology consists of a combination of Delphi-FUCOM-SERVQUAL methods. In the first stage, a survey was applied to customers using the Delphi method. The criteria were determined with this survey. In the second stage, the weight coefficients of the quality dimensions were determined using the FUCOM method. In the third stage, the SERVQUAL (service quality) model was used. A comprehensive statistical analysis was conducted to determine the validity of this methodology. Thus, the validity of the methodology was proven.

Noureddine and Ristic (2019) proposed the new FUCOM-TOPSIS-MABAC integrated model to determine the optimum route for transport of hazardous material. Four alternative routes were evaluated according to five criteria. The criteria were weighted with the FUCOM method, and then alternative routes were ranked with the TOPSIS and MABAC methods. With the sensitivity analysis, the criterion weights were changed by generating 10 scenarios and it was concluded that the ranking did not change. Thus, the reliability of the results obtained from both methods (FUCOM-TOPSIS and FUCOM-MABAC) in selecting optimum route for transport of hazardous material was proven.

Božanić et al. (2019) proposed a methodology integrating FUCOM and Fuzzy MABAC methods in the bridge construction site selection problem. While the FUCOM was used to weight criteria, the fuzzy MABAC was used to rank alternatives. To demonstrate the consistency of the methodology, sensitivity analysis was performed and seven different scenarios were produced by changing the criterion weights. The results showed that introduction of the model into decision-making processes was very useful.

Nenadić (2019) evaluated the dangerous road sections causing traffic accidents on the land belonging to Derventa Municipality of Bosnia and Herzegovina using FUCOM and WASPAS methods.

In order to benefit from solar energy at the highest level, which is one of the renewable and sustainable energy sources Cao et al. (2019) addressed the matter of selecting the most appropriate provider for the installation of solar panels. Criterion weights were determined by integrating SWARA-FUCOM methods using gray numbers, and then the alternatives were ranked using GRA and EDAS methods. It was concluded that the alternative rankings were the same according to both methods.

Stević et al. (2019) developed a new Interval Rough SAW method and integrated it with the FUCOM method for sustainable supplier selection in the lime manufacture company. The combained FUCOM-Interval Rough SAW model aimed to reduce subjectivity and eliminate uncertainties in group decision making. The method was tested with various scenarios. The stability of results was confirmed by computing spearman's correlation coefficient.

To reduce subjectivity and solve complicated models with more potential solutions, Nunić and Stević (2019) proposed a new integrated MCDM model by combining FUCOM and Evaluation Method Based on Distance from Mean Solution in Minkowski space (EDAS-M) methods. This proposed model was tested on the evaluation and selection of an electric vehicle. Criteria weights were obtained using the FUCOM method, and then the alternatives were ranked using the EDAS-M method.

Erceg and Mularifović (2019) addressed the supplier selection problem in a wood production company in Bosnia and Herzegovina. While the FUCOM was utilized in weighting the criteria, the WASPAS was utilized in alternatives ranking. With the sensitivity analysis, the weight coefficients of the criteria were increased and decreased, thus it was seen that the ranking of the alternatives changed. As a result, it was concluded that changing the weight coefficients affected the final result.

Pamucar and Ecer (2020) proposed a noval Fuzzy FUCOM to determine criterion weights as accurately as possible in fuzzy environments. To explain this new method, an example of the green supplier evaluation problem was performed. In addition, a comparison was made between the suggested method and the fuzzy BWM & fuzzy AHP to show its stability and effectiveness.

Demir and Bircan (2020) weighted the criteria affecting private school selection using the BWM and FUCOM. The final values of the weight coefficients of the criteria were obtained using LINGO 17 software.

Yazdani et al. (2020) proposed a decision making model with two-step to determine the most suitable zone for logistics centers in Spain. In the first step of the proposed model, defined zones were compared according to five criteria with data envelopment analysis (DEA) to determine the alternatives that are efficient and inefficient ones. In the second step, the weights of the criteria were calculated using rough FUCOM method, and then the R-CoCoSo method. A sensitivity analysis was applied to verify the soundness of the result obtained.

Ramezanzade et al. (2020) aimed to choose the most effective Hybrid Renewable Energy System (HRES) to provide power consumption for one of Iran's government institutions by applying a novel MCDM model. In their study, while the criteria weights were determined by

AHP, BWM, and FUCOM methods, the alternatives were obtained by EDAS and TOPSIS methods.

MCDM methods are frequently applied in logistics. Stević and Brković (2020) proposed an MCDM model to assess the human resources in a transportation company. 23 employees were evaluated according to five criteria. While the criteria weights were calculated by FUCOM, the alternatives were ranked by the MARCOS method. This proposed model was compared with frequently used MCDM methods (SAW, ARAS, WASPAS, CoCoSo, EDAS, MABAC and TOPSIS).

Božanić et al. (2020) suggested a hybrid methodology involving the FUCOM – Z-number – MABAC model for brigade command post location selection during combat operations. While the criteria weights were computed by the FUCOM method, the alternatives were ranked by the MABAC method modified with the Z-number. The Z-number MABAC method was compared with the fuzzy and classical versions of MABAC method, and it was observed that there were significant differences in the ranking of the alternatives. Therefore, rank correlation control was performed using the spearman coefficient. It was observed that the rank correlation was extremely high and this new proposed model performs well.

Dobrosavljević et al. (2020) suggested a combined MCDM model to demonstrate the degree of contribution of factors in business process management (BPM) to increasing process maturity in small and medium-sized clothing enterprises (SMEs). This integrated model includes FUCOM and fuzzy PIPRECIA methods. The nine criteria considered in this study were weighted by FUCOM and fuzzy PIPRECIA methods. It was concluded that the most effective criterion on BPM application in ready-to-wear apparel industry SMEs is human resources management.

Durmić et al. (2020) presented a combined FUCOM – Rough SAW methodology for supplier selection in order to ensure sustainability in the supply chain method. While the FUCOM method was utilized to obtain the criteria weights, the Rough SAW method was utilized to rank the alternatives. A sensitivity analysis was applied to check the stability of the proposed model. In the first stage, the weights of the criteria were changed and in the second stage, a comparasion was made with the R-ARAS, R-WASPAS and R-MABAC methods. The results showed the stability of the model.

For the purpose of traffic risk assessment, Stević et al. (2020a) proposed the integrated FUCOM-MARCOS method to identify the most risky road sections. The decision criteria were weighted using FUCOM method, and then the alternatives were ranked using fuzzy MABAC method. To show the validity of the results obtained with the extend sensitivity analysis, the weights of the criteria were varied, a comparison was made with other MCDM methods and a reverse ranking matrix was generated. Furthermore, as part of the sensitivity analysis, the Spearman's correlation coefficient was calculated as a statistical indicator of the rank correlation and the standard deviation of the results was calculated. The results of the sensitivity analysis were subject to validation.

Ilieva (2020) proposed the new fuzzy group FUCOM method. In this proposed method, the defuzzified values of the optimal weight coefficients were calculated by Graded Mean Integration Representation formula. Tested on two practical examples to verify its reliability and feasibility, this method was shown that it can obtain appropriate criteria importance.

Badi and Kridish (2020) proposed the FUCOM-CODAS model for the most appropriate municipal solid waste landfill selection in Misurata City, Libya. Weighted criteria were determined by FUCOM, while CODAS ranked areas. With sensitivity analysis, 14 scenarios were created and the stability of the obtained solutions was demonstrated.

Mijajlović et al. (2020) proposed a model based on the integration of FUCOM and fuzzy MARCOS methods to evaluate the current state of 16 spa centers providing different types of services in Bosnia and Herzegovina. While the criteria weights were determined using the FUCOM method, the ranking of the alternatives were determined using the fuzzy MARCOS method. In the sensitivity analysis, the Spearman correlation coefficient (SCC) was calculated and the robustness of the proposed model was tested by creating nine different scenarios and comparing the fuzzy MARCOS method with the fuzzy version of WASPAS, ARAS, SAW, MABAC, TOPSIS, and ARAS methods.

Ecer (2021) discussed the problem of location selection of wind farms. 12 criteria regarding economic, social and environmental dimensions were weighted with the FUCOM method. It was concluded that the most important dimension was the environment, and according to the analysis performed on the basis of sub-criteria, the most important criterion was the wind potential of the place where the wind farm will be located. A sensitivity analysis was carried out to show the stability of the suggested method. With the use of Spearman's correlation coefficient in the sensitivity analysis, it was shown that the FUCOM method has a high correlation with other applied methods.

Pamucar et al. (2021) presented a new MCDM approach based on the fuzzy FUCOM method and the neutrosophic fuzzy MARCOS method for the evaluation of different alternative fuel vehicles (AFVs) in New Jersey, USA for sustainable transportation. It was concluded that the electric vehicle was the best alternative for sustainable transportation compared to other AFV. A comparative analysis was carried out to show how this new proposed multi-criteria method performs.

Stević et al. (2021) proposed a subjective-objective MCDM model for the selection of a suitable delivery vehicle for the needs of a newly established company. Firstly, the objective Importance of CRITIC method and the subjective FUCOM were applied to determine the weights of the criteria. Then, the MARCOS method was used to rank the delivery vehicles. It was determined that the most significant criterion in choosing a delivery vehicle for a transport company was the purchase price and Peugeot Boxer was the best alternative for this transport company.

Stefanović et al. (2021) used the Rough SWARA method to identify the significant of Occupational Health and Safety (OSH) factors in the workplace. The results were compared using the FUCOM method in sensitivity analysis. It was found that there was no important difference between the results obtained by the two methods with regard to the values of the following criteria.

Hoan and Ha (2021) suggested the FUCOM-ARAS approach for evaluating and an appropriate suitable fighter aircraft for the Vietnam People's Air Force. While the criteria weights were obtained by FUCOM, the alternatives were ranked by ARAS. The proposed decision-making model was compared with Weighted Product Method (WPM) and the reliability of the results was mentioned.

Božanić et al. (2021) suggested a hybrid approach involving D-numbers & FUCOM & fuzzy RAFSI to select the construction machinery group. The input parameters for the computation of the weights of the criteria were determined by means of D-numbers. While the criteria weights were obtained by the FUCOM method, the best alternative was selected by the fuzzy RAFSI method. Furthermore, sensitivity analysis was performed by changing the criteria weighting coefficients.

Feizi et al (2021) suggested FUCOM based MOORA and MOOSRA firstly combined MCDM methods in the mineral potential mapping (MPM). At the end of this application, two potential maps were obtained and FUCOM based MOOSRA has been shown to be superior to FUCOM based MOORA.

Vukasović et al. (2021) proposed two novel integrated models in fuzzy form for inventory management. The first proposed model is the combined of the fuzzy version of the FUCOM and EDAS methods, which aims to rank 78 products in terms of four criteria. The second model is to combine the fuzzy FUCOM method and ABC analysis to rank the inventory, taking into account the different importance of the criteria. Lastly, the presented combined fuzzy models were compared with old traditional approaches and it was seen that these proposed integrated fuzzy models showed better performance.

Böyükaslan and Ecer (2021) proposed a model that is the fuzzy version of FUCOM and Bonferroni for determine the priorities of investors investing in cryptocurrencies. The study considered five main criteria and 23 sub criteria. Lastly, it was determined that "strong electronic encryption" and "use of digital signature" was the most significant criteria in the choice of cryptocurrency.

Ulutaş and Karakuş (2021) proposed a new integrated MCDM model including GIS, FUCOM and PIV-F for the location selection problem of a textile manufacturing facility in Sivas province of Turkey. In the study, the fuzzy version of the PIV methodology was newly developed. While the FUCOM method was applied for the weighting of criteria, the PIV-F method was applied for the ranking of alternative sites. PIV-F was compared with fuzzy versions of the three MCDM methods (ARAS, MOORA and MABAC) and it was found that inter-method correlations were very much. Therefore, the validity of the PIV-F method was proven.

To combat COVID-19 and future pandemics, Khan et al. (2022) conducted a study on Pakistan's healthcare (HC) system. The study proposes a novel combined approach based on the evaluation of resilient criteria (RAs) and resilient strategies (RSs). The FUCOM method was applied to prioritise resilient criteria, while Fuzzy Quality Function deployment was applied to prioritise resilient strategies. Consequently, it aimed to make Pakistan's current health system more resilient.

Kılıç et al. (2022) proposed to combine fuzzy FUCOM and fuzzy MARCOS to determine which neighbourhood is most appropriate for purchasing a house in Erzurum, Turkey, according to the consumers' desired location. Three alternative regions were evaluated based on six criteria. While the weighting of the criteria was carried out using the fuzzy FUCOM method, the ranking of the alternative regions was carried out using the fuzzy MARCOS method. It was found that the most significiant criterion for customers when purchasing a house was the price of the house.

Mahendra (2022) discussed the selection of airline companies based on customer preferences in Indonesia. Eight criteria and six alternatives were evaluated using FUCOM and MARCOS methods. It was concluded that the most preferred airline company in Indonesia was Garuda

Indonesia. Consistency analysis was conducted and it was found that Garuda Indonesia was the first choice airline company, consistently ranked first in 15 out of 17 tests.

Chakraborty et al. (2023) proposed the integration of FUCOM and MABAC methods to evaluate Indian National Parks (NPs) for achieving biodiversity and sustainability goals. 39 alternative national parks were evaluated according to nine criteria. It was concluded that Namdapha NP and Manas NP were the two best NPs in India.

Tulun et al. (2023) combined MCDM and GIS techniques for the site selection of a biogas plant to be constructed in the Konya Closed Basin (KCB), the largest closed basin in Turkey. The study consists of three stages. CRITIC and MABAC procedures were used to list KCBs by resource criteria, and then FUCOM procedures were used to weight nine criteria frequently cited in literature, based on expert judgement. The obtained weights were combined with the GIS method to create suitability maps for the biogas facility. These maps were used to determine the most appropriate site for the biogas facility. This is the first study to combine the CRITIC-MABAC-FUCOM and GIS methods for the selection of a site.

Kang et al. (2023) presented an appropriate technique for disposing of paper, plastic and mixed waste in India. Therefore, the integrated FUCOM-MABAC approach was suggested in an interval-valued q-rung orthopair fuzzy (IVq-ROF) framework. While the FUCOM method calculated the weights of the criteria, the MABAC method ranked the alternatives on the basis of the choosen criteria. To confirm the effectiveness of the suggested method, sensitivity analyses were carried out.

2.3. Studies conducted using MARCOS and Fuzzy MARCOS Method

In this last step of the literature review, studies using MARCOS and fuzzy MARCOS method are presented.

Stević et al. (2020b) presented a new MARCOS methodology for selecting sustainable healthcare suppliers in Bosnia and Herzegovina. Eight alternatives were evaluated according to 21 decision criteria. The measurement scale was changed from 1-9 to 1-5. The new MARCOS method was the subject of a validation study in comparison with other MCDM methods.

Chakraborty et al. (2020) proposed a methodology integrating D-numbers and MARCOS method for supplier selection in Indian iron and steel industry. D-numbers were used to resolve uncertainty in the decision making process regarding supplier selection. D-numbers were used to resolve uncertainty in the decision making process regarding supplier selection. Five suppliers were assessed on the basis of the opinions of three decision-makers, according to seven criteria. Thus, it was chosen as the industry's best supplier.

Badi and Pamucar (2020) used an integrated methodology of Gray theory & MARCOS for the optimal selection of suppliers in the Libyan Iron and Steel Company. The first step was to determine the weights of the criteria using the Gray theory. Subsequently, six suppliers were assessed by MARCOS. The combined model was compared with three MCDMs (CODAS, TOPSIS and VIKOR) and the results showed its effectiveness in choosing appropriate suppliers.

Puška et al. (2020) applied the MARCOS method to the assessment of project management software programmes in the United Arab Emirates. It was concluded that Smartsheet was the most suitable project management software.

Ulutaş et al. (2020) proposed an integrated MCDM methodology when selecting the most suitable equipment to perform the logistics activity. While the objective weights of the criteria were calculated using the coefficient of correlation and the S.D., the semi-objective weights of these criteria were determined using the indifference threshold-based ratio analysis method. By combining these two methods, the weights of the criteria were determined. Then, the MARCOS method was used to rank the alternatives. To verify the reliability of the proposed methodology, other MCDM methods were compared.

Özdağoğlu et al. (2020) assessed 166 Turkish universities in terms of five criteria. While the CoCoSo method was applied to determined the criteria weight, the MARCOS method was applied to rank the universities according to their performance. According to study, the proposed methodology was found to be very similar to the URAP report ranking, with Hacettepe University, Middle East Technical University and Istanbul Technical University in the top three.

Đalić et al. (2020) proposed the FUCOM-MARCOS hybrid model for the selection of the most appropriate distribution channel in a company engaged in mixed agricultural production. The weights of the criteria were calculated using the FUCOM method. The alternatives were ranked using the MARCOS method. It was concluded that selling the products through a wholesaler and a retailer was the best alternative.

Stanković et al. (2020) aimed at analysing traffic risk on a 7.4km main road network with 38 sections. To do so, the fuzzy PIPRECIA was used to determine the weights of the criteria. In this study, the new fuzzy MARCOS method was introduced by defining a novel fuzzy scale of linguistic measured in TFNs. Results were compared with fuzzy SAW and fuzzy TOPSIS.

Puška et al. (2021) implied the fuzzy MARCOS for sustainable supplier selection of a company in the food sector. As a result, the most suitable sustainable supplier for this company was selected.

Büyüközkan et al. (2021) proposed an integrated SWOT-based AHP-MARCOS method, the first of such methods to be proposed in the literature for this purpose, to identify and analyse digital transformation strategies. A case study of the airline industry in Turkey was carried out. While the SWOT factors were weighted by employing the fuzzy AHP method, the most appropriate strategy for digital transformation was selected using the fuzzy MARCOS method. Fuzzy TOPSIS and Fuzzy VICTOR are used for comparison

Deveci et al. (2021) proposed a new combined methodology integrating IRNs and BWM-MARCOS methods to select the most preferred offshore wind farm site in the Aegean Sea regions of Turkey. Four alternatives were evaluated according to six main and 23 sub-criteria. Bozcaada was found as the most suitable region in the study.

Since the traditional Failure modes and effects analysis (FMEA) method is insufficient for the risk assessment and prioritisation process, Fan et al. (2021) proposed a new risk priority model integrating BWM and MARCOS methods on the basis of D numbers. D numbers were used to deal with uncertainty in subjective judgments. This proposed new risk priority model was demonstrated in an example application to improve the reliability of rotor blades for aircraft turbines in the aviation industry.

Bouraima et al. (2021) applied Entropy and MARCOS methods to evaluate the performance of Sub-Saharan African railway systems. While the Entropy method was applied for the weighting of criteria, the MARCOS method was applied for the ranking of countries' railway performance. It was concluded that the best alternative in terms of railway performance was Kenya.

Torkayesh et al. (2021) suggested a new integrated methodology for sustainable landfill location selection for healthcare waste system. This proposed model includes GIS, BWM and Grey MARCOS methods. To illustrate the model's applicability, a real-world application was conducted in municipality of Hamedan, Iran.

Taş et al. (2021) presented a fuzzy approach integrating spherical fuzzy SWARA and MARCOS methods for green supplier selection. In this proposed approach, the spherical fuzzy SWARA method was used to compute the criteria weights, while the MARCOS method was used to evaluate the ranking of alternatives. A real-world application was made in a Turkish textile firm. Six alternative suppliers were assessed considering 12 criteria. In conclusion, a suitable green supplier was selected for the textile firm.

Bakır et al. (2021) proposed an integrated fuzzy PIPRECIA-fuzzy MARCOS methodology for regional aircraft selection. Six alternative regional aircraft were assessed considering 14 criteria. It was concluded that the most important criterion was the operational cost and the most preferable aircraft type was the CRJ1000. The outcome of the proposed methodology was verified by means of a sensitivity analysis carried out in three stages.
Ecer and Pamucar (2021) ranked insurance companies in Turkey in terms of health services during the COVID-19 outbreak, by using the fuzzy MARCOS method in an intuitionistic fuzzy framework. The method was verified to show its the stability and effectiveness by performing a sensitivity analysis.
Özdağoğlu et al. (2021) evaluated the performance of the busiest international airports in the world using PIPRECIA-E, SMART and MARCOS methods. While the PIPRECIA-E method was applied to compute criteria weights, the airports were also ranked by applying the SMART and MARCOS methods. The ranking obtained from both methods was the same. It was concluded that China's Beijing Airport was in first place.
Çınaroğlu (2021) used the CRITIC-based MARCOS method to evaluate the innovation and entrepreneurship performances of universities in Turkey in 2020. While the criteria weights were obtained from CRITIC method, the performance level ranking of universities was obtained using the MARCOS method. It was found that the most significant criterion was the intellectual property pool criterion and that Middle East Technical University ranked first in terms of innovation and entrepreneurship.
Zaher and ElGhitany (2021) proposed a neutrosophic MCDM model to optimize the selection of a healthcare organization's blockchain platform. The MARCOS method was used to determine the best blockchain platform to use in healthcare. To overcome the uncertainty, the MARCOS method was integrated with neutrosophic sets.
Wang et al. (2022) proposed a new decision-making model that integrates OPA and MARCOS methods in sustainable supplier selection. While the weights of the criteria were determined using the OPA method, the ranking of the suppliers was calculated using the MARCOS method. A case study of five suppliers in Vietnam's leather and footwear industry was conducted to demonstrate the validity of this new decision-making model.
Khosravi et al. (2022) sought to determine the most appropriate of four organizational patterns for hospitals: budgetary, autonomous, corporate and private. Fuzzy FUCOM and fuzzy MARCOS methods were used to select the most suitable organizational patterns in Iranian hospitals. Decision criteria were weighted with fuzzy FUCOM and then the organizational

structures were ranked with the fuzzy MARCOS method. It was observed that income was the most important criterion in the choice of organizational patterns of hospitals and that the private form was the most appropriate organizational pattern.

Vesković et al. (2022) proposed a model based on fuzzy version of FUCOM, MARCOS and Bonferroni Mean (BM) operator methods to evaluate and select the reach stacker, which is one of the needs of the IRT Belgrade container terminal. A three-stage sensitivity analysis was applied to confirm the proposed model.

Sustainability in supplier selection is of great importance for all organizations. Tuş and Adalı (2022) proposed a model integrating fuzzy version of SWARA and MARCOS methods for the green supplier selection of a company in the textile industry. This proposed integrated model was applied firstly for the green supplier selection problem. While the fuzzy SWARA method was used to weight the evaluation criteria, the fuzzy MARCOS method was used to rank the green suppliers. Model validity was confirmed by sensitivity and comparative analysis.

Zarhaoui et al. (2022) suggested the MARCOS method for sustainable supplier selection in retail sector in Morocco.

Memarpour et al. (2022) proposed the Simulation-spherical fuzzy MARCOS approach to evaluate emergency department processes during the COVID-19 pandemic in a private hospital in Iran. Various scenarios were created using simulation to reduce the transfer rate of patients in the emergency department. With the proposed simulation-SF-MARCOS approach, a new operational patient flow was initiated to reduce the patient transfer rate.

As electric vehicles become more widespread, the need for lithium battery use increases. For this reason, Zolfani et al. (2022) investigated the best country for the construction of a battery for companies in the USA. Bayesian BWM and MARCOS methods were integrated with the suitability-feasibility-acceptability (SFA) strategy. The seven criteria determined based on the SFA strategy were weighted with the Bayesian BWM method and the most important criterion was found to be corporate income tax. With the help of the MARCOS method, it was concluded that the best country for the establishment of the lithium battery industry would be Chile.

Karaaslan et al. (2022) proposed the combined AHP-MARCOS methodology to evaluate the regional priorities of renewable energy resources in Turkey. The criteria weights were compute through the AHP method and it was seen that the most important criterion was investment cost. Alternative rankings were determined for each region using the MARCOS method. It was concluded that the energy sources that should be preferred firstly were wind energy sources in the Marmara and Aegean regions, hydroenergy sources in Mediterranean, Southeastern

Anatolia, Eastern Anatolia, Black Sea Region, and solar energy sources in Central Anatolia Region.

Hezam et al. (2023) proposed an integrated model the IFI, the rank-sum (RS), the standard deviation (SD) and the MARCOS method for hospital site selection. This study used a combined weighting model, providing objective weighting with IF-SD and subjective weighting with IF-RS. Four alternative sites were evaluated according to six main criteria and 18 sub-criteria. In order to demonstrate the applicability of the proposed model, a sensitivity analysis was performed.

Sarıgül et al. (2023a) used MEREC-MARCOS-CoCoSo integration to measure the quality of service of 17 airports that are evaluated as five-star airports by Skytrax in 2021. According to MARCOS and CoCoSo methods, it was concluded that the airport providing the best service quality to passengers was Chubu Centrair Airport, and the airport ranking last in terms of service quality was Tokyo Haneda Airport. Similarly, Sarıgül et al. (2023b) proposed a hybrid approach including CRITIC-MAUT and MARCOS methods to measure the financial performance of six airline companies operating in Europe between the periods of 2019-2021. While the weights of the criteria were calculated using the CRITIC method, the financial performance rankings of the airline companies for the periods of 2019-2021 were obtained using the MAUT and MARCOS methods. Based on the results, a number of policy recommendations were made to improve the financial performance of airlines. Toslak et al. (2023) proposed a model including the integration of PSI, SV and MARCOS methods in the machine selection problem in the peanut butter production factory. The PSI and SV methods were applied to compute the criteria weights. The MARCOS method was used to rank the machines. The MARCOS method was compared with several other MCDM methods. The relations between the rankings obtained from these methods were evaluated using the spearman correlation method.

Badi et al. (2023) suggested a combined approach consisting of AHP-BWM and MARCOS methods in the selection of the most suitable site for the installation of the wind farm. The suggested approach was first applied in the literature. A real case study was conducted in Libya. It was concluded that the most suitable site for the installation of the wind farm was the city of Derna, in the far northeast of the country.

Görçün and Doğan (2023) proposed the fuzzy BWM and fuzzy MARCOS hybrid method for the mobile crane selection problem. A real-world application was made in a large-scale project logistics and heavy transport company in Turkey. According to the results of the application, the most important criterion was "maximum hoist height" and the best mobile crane alternative was A1 Brand-L. 4.2. A sensitivity analysis was carried out in order to test the validity and applicability of this hybrid method.

Altay et al. (2023) proposed the integrated interval type-2 fuzzy BWM-MARCOS model for the optimal location of scooter sharing stations. A real-world application was conducted in a university campus. The proposed model was compared with IT2F-TOPSIS. In addition, a sensitivity analysis was conducted to test how changes in criterion weights affect the ranking of alternative locations.

Koohathongsumrit and Chankham (2023) presented a new combined methodology for selecting the optimal route for transportation in multimodal supply chains. The combined methodology includes fuzzy risk assessment model (FRAM), BWM and MARCOS method. The usefulness and applicability of this proposed methodology was demonstrated through an empirical study.

As seen in the detailed literature review, FUCOM and MARCOS methods and their fuzzy versions have been used in many decision-making problems. However, to the best of our knowledge, there is no study using the integration of fuzzy FUCOM & fuzzy MARCOS in both hospital location selection and field hospital location selection problems. Therefore, this thesis study may be the first to apply the combined fuzzy FUCOM & fuzzy MARCOS method to the field hospital location selection problem.

3. MATERIALS AND METHODS

In this section of the thesis, Multi-Criteria Decision Making (MCDM), Fuzzy Set Theory, Triangular Fuzzy Numbers (TFNs), Fuzzy FUCOM method and Fuzzy MARCOS method are presented.

3.1. Multi-Criteria Decision Making (MCDM)

Decision makers often cope with problems that involve multiple and conflicting criteria. These problems may range from a simple problem that such as the purchase of a car to large and complex problems that affect entire nations (Yoon and Hwang, 1995). While instant decisions taken in daily life vary according to people's experiences, preferences and intuition, managers must make decisions after a logical process. In other words, decision making is a process that is constantly encountered at every stage of life and whose effects can change. Every decision has one or more consequences. Wrong decisions can lead to huge financial losses. For this reason, the decisions made by managers are of serious importance for the business, institution, society, etc (İmamoğlu, 2015).

In this thesis study, the problem of field hospital location selection in Adana province was addressed by using fuzzy MCDM methods.

Location selection problems have a complex structure because many alternatives are evaluated simultaneously with many main and sub-criteria. MCDM, one of the methods for solving these complex problems, has been widely used in the literature. There are two basic approaches to MCDM problems in the literature: Multi Objective Decision Making (MODM) and Multi Attribute Decision Making (MADM). MADM approach, the most well-known branch of decision making, refers to choosing and ranking among a limited number of decision alternatives in the presence of multiple and often conflicting criteria. On the other hand, MODM approach refers to meeting conflicting objectives in an optimal way. In the MODM approach, unlike MADM approach, the number of decision alternatives is infinite. A mathematical framework for designing decision alternatives is provided by the MODM approach (Kahraman, 2008).

3.2. Fuzzy Set Theory

Conventional MCDM only considers crisp values and is inadequate for specific real-world problems such as group decisions and uncertain preferences (Tzeng and Huang, 2011).
For this reason, fuzzy set theory was first introduced by Zadeh in 1965 as an extension of classic set theory to deal with uncertainty in decision making. In classic set theory, if a member is in the cluster, its membership value is 1, otherwise 0. However, in fuzzy set theory, the membership value takes value between 0 and 1 (Zadeh, 1965; Banihashemi et al., 2021). According to fuzzy set theory, a fuzzy set is defined by functions with membership degrees whose elements vary in the range [0,1]. A membership function represented by $\mu_A(x)$ expresses the degree to which the elements of the set belong to the set (Altaş, 1999; Kabak and Erdebilli, 2021). A fuzzy set can be represented as $A = \{(x, \mu_A(x)),\ x \in X\}$, where x is the definite elements of the set and $\mu_A(x)$ is a function of membership in the closed interval [0,1] so $0 \le \mu_A(x) \le 1$.
The fuzzy sets proposed by Zadeh (1965) are called "classic fuzzy sets". In the following years, various extensions of fuzzy sets were developed by researchers.

3.3. Triangular Fuzzy Numbers (TFNs)

In fuzzy set theory, operations are performed by assigning membership functions to linguistic variables. Fuzzy numbers are used to perform these operations, thus eliminating uncertainty. There are various versions of fuzzy numbers in the literature, of which TFNs and trapezoidal fuzzy numbers are the most commonly used (Ecer, 2007). TFNs are the most commonly used fuzzy numbers due to their ease of use and ability to be clearly interpreted (Sanchez and Gomez, 2003). For this reason, TFNs were used in this thesis study.
Some definitions of TFNs are explained below (Pamucar et al., 2021).
Definition 1: A TFN is an indication of the relative strength of each of the pairs of factors in the same hierarchy, could be shown as $T = (l, m, u)$ where $l \le m \le u$. In a fuzzy event, the l value indicates the lower bound value, the m value indicates the central bound value, and the u value indicates the upper bound value.
The membership function of T TFN can be described as in Equation (3.1).

$$\mu_T(x)=\begin{cases}0, & x<l\\ (x-l)/(m-l), & l\le x\le m\\ (u-x)/(u-m), & m\le x\le u\\ 0, & x>u\end{cases} \tag{3.1}$$

The membership function of the triangular fuzzy number is shown in figure 3.1.

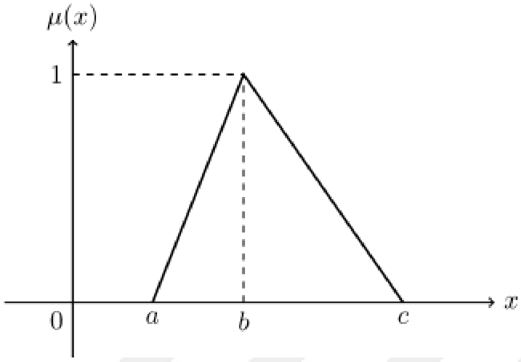

Figure 3.1. The membership function of the TFN (Zhou et al., 2016)

Consider two TFNs $T_1=(l_1,m_1,u_1)$ and $T_2=(l_2,m_2,u_2)$. The basic arithmetic operations of two fuzzy numbers T_1 and T_2 are shown in the equations below.

$$(l_1,m_1,u_1)\oplus(l_2,m_2,u_2)=(l_1+l_2,m_1+m_2,u_1+u_2) \tag{3.2}$$

$$(l_1,m_1,u_1)\otimes(l_2,m_2,u_2)=(l_1l_2,m_1m_2,u_1u_2) \tag{3.3}$$

$$(l_1,m_1,u_1)/(l_2,m_2,u_2)\cong(l_1/u_2,m_1/m_2,u_1/l_2)\ for\, l_i>0,m_i>0,u_i>0 \tag{3.4}$$

$$(l_i,m_i,u_i)^{-1}\approx\left(\frac{1}{u_i},\frac{1}{m_i},\frac{1}{l_i}\right) for\, l_i>0,m_i>0,u_i>0 \tag{3.5}$$

Definition 2: The graded mean integration representation (GMIR)

Assuming that a_j is a triangular fuzzy number (l_j,m_j,u_j); GMIR of a_j $(R(a_j))$ can be calculated using Equation (3.6).

$$R(a_j)=\frac{l_j+4m_j+u_j}{6} \tag{3.6}$$

3.4. Fuzzy FUCOM Method

Full Consistency Method (FUCOM) is a novel MCDM method proposed by Pamučar et al. in 2018. The FUCOM method, one of the subjective weighting methods, is based on linear programming (Ecer, 2021). In the FUCOM method, two conditions should be met to obtain optimal weight coefficients values. The first condition is that the relationships among the weighting coefficients of the criteria should correspond to the comparative priority of the criteria. The second condition is that the final values of the weighting coefficients should satisfy the mathematical condition of transitivity. Once the constraints are defined and the mathematical model is solved, the optimal weight values are obtained. Besides these optimal weight values, the DFC degree is also determined. The DFC ensures the validity of the model through the computation of the error value of the weight coefficients obtained. FUCOM method has advantages over other MCDM methods such as AHP, BWM, ANP that are used for the weighting of the criteria: (1) It requires fewer pairwise comparisons (only n-1). (2) This method applies a simplified algorithm to compute criteria weights. (3) DFC is calculated, thus allowing the model to be validated the model by calculating the error value of the obtained weight coefficients. Moreover, the FUCOM method decreases the subjective influence and the inconsistency of the preferences of the experts on the final values of criteria weights (Pamucar et al., 2018; Ecer, 2021).

Fuzzy FUCOM method, which is a fuzzy extension of the FUCOM method, was introduced by Pamucar and Ecer (2020). Due to its utilization and ease of application, FUCOM has attracted attention of many researchers in literature and has been used to solve various complex problems (Pamucar et al., 2021). The conventional FUCOM method uses only crisp numbers without considering the uncertainty within the human's judgments (Tang et al., 2021).

Within the scope of the study, the FUCOM method was combined with TFNs, taking into account the uncertainty in human judgments. Thus, the criteria weights were determined by the fuzzy FUCOM method.

The steps of the Fuzzy FUCOM method are as follows (Pamučar et al., 2018; Pamučar and Ecer, 2020).

Step 1: Determine the decision criteria/sub-criteria

In multi-criteria models to evaluate alternatives, decision criteria/sub-criteria are defined. Here, the number of decision criteria j ranges from 1 to n $(j = \{1,2,3,...,n\})$ that are represented by a set $C = \{C_1, C_2, ..., C_n\}$.

Step 2: Rank the decision criteria/sub-criteria

Decision criteria/sub-criteria are ranked by decision makers according to the significance of the criteria, i.e. from the criterion expected to have the highest weight coefficient to the criterion expected to have the lowest weight coefficient (Kılıç et al., 2022). Thus, the decision criteria ranking is obtained:

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \tag{3.7}$$

$C_{j(k)}$, where j represents the criterion; k represents the order of the C_j criteria for the decision maker. When ranking the decision criteria from largest to smallest in order of importance “=” should be used instead of “>” when two adjacent elements have equal importance (Tang et al., 2021).

Step 3: Comparison of criteria using TFNs

The criteria are compared with each other on the basis of a pre-defined linguistic scale. Fuzzy linguistic variables are used to compare the criteria with each other and the comparison is made with respect to the first-ranked (most significant) criterion. Therefore, fuzzy criterion significance $(\varpi_{C_{j(k)}})$ is obtained for all criteria. Since the first-ranked criterion is compared with itself, an n-1 comparison is made between the remaining criteria. Based on the defined significance of criteria, the fuzzy comparative significance $(\varphi_{k/(k+1)})$ is determined by using Equation (3.8).

$$\varphi_{k/(k+1)} = \frac{\varpi_{C_{j(k+1)}}}{\varpi_{C_{j(k)}}} = \frac{(\varpi_{C}{}^{l}{}_{j(k+1)}, \varpi_{C}{}^{m}{}_{j(k+1)}, \varpi_{C}{}^{u}{}_{j(k+1)})}{(\varpi_{C}{}^{l}{}_{j(k)}, \varpi_{C}{}^{m}{}_{j(k)}, \varpi_{C}{}^{u}{}_{j(k)})} \tag{3.8}$$

In this way, a fuzzy vector of the comparative significance of the criteria is obtained, as shown in Equation (3.9).

$$\Phi = (\varphi_{1/2}, \varphi_{2/3}, ..., \varphi_{k/(k+1)}) \tag{3.9}$$

where $\varphi_{k/(k+1)}$ represents the significance that the criterion of $C_{j(k)}$ rank has with respect to the criterion of $C_{j(k+1)}$ rank.

Step 4: Calculate the optimal fuzzy weights $(w_1, w_2, ..., w_n)^T$

In this step, the final values of the fuzzy weight coefficients of the criteria are calculated. The final values of the weight coefficients should meet the following two conditions:

Condition 1 The ratio of weight coefficients of criteria $C_{j(k)}$ and $C_{j(k+1)}$ should be equal to their comparative significance $\varphi_{k/(k+1)}$ defined in Step 3. This condition is shown in Equation (3.10).

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3.10}$$

Condition 2 Other condition is that final values of weight coefficients should meet mathematical transitivity, $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$ and $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$. Thus, the other condition that the final values of the weight coefficients should be met is given in Equation (3.11).

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{3.11}$$

Maximum consistency i.e. full consistency occurs when the above *Condition 1* and *Condition* 2 are met. In this case, the value of the coefficient of Deviation from Full Consistency (DFC) is accepted to be 0 (zero) ($\chi = 0$) or close to zero.

To determine the optimal fuzzy values of the weight coefficients of the decision criteria, the mathematical model is solved to obtain the final values of the weights $(w_1, w_2, ..., w_n)^T$ and the DFC value, χ. This mathematical model is defined as in Equation (3.12).

$$\begin{cases} \min \chi \\ s.t. \\ \left| w_k - w_{k+1} \otimes \varphi_{k/(k+1)} \right| \leq \chi, \ \forall_j \\ \left| w_k - w_{k+2} \otimes \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \leq \chi, \ \forall_j \\ \sum_{j=1}^{n} w_j = 1, \ \forall_j, \\ w_j^l \leq w_j^m \leq w_j^u, \\ w_j^l \geq 0, \ \forall_j \\ j = 1, 2, ..., n \end{cases} \tag{3.12}$$

where $w_j = (w_j^l \leq w_j^m \leq w_j^u)$, $\varphi_{k/(k+1)} = (\varphi_{k/(k+1)}^l, \varphi_{k/(k+1)}^m, \varphi_{k/(k+1)}^u)$ and

$\varphi_{(k+1)/(k+2)} = (\varphi_{(k+1)/(k+2)}{}^l, \varphi_{(k+1)/(k+2)}{}^m, \varphi_{(k+1)/(k+2)}{}^u)$.

After the optimal fuzzy values of the weight coefficients are found, the exact weight coefficients of the criteria are obtained using GMIR (Equation 3.6). It is concluded that the decision criterion with the highest weight is the most important decision criterion.

3.5. Fuzzy MARCOS Method

MARCOS (Measurement of Alternatives and Ranking Using a Compromise Solution), a relatively new approach to MCDM, was proposed by Stević et al. (2020). The MARCOS method is fundamentally on the basis of the relationship between alternatives and reference values (anti-ideal and ideal alternatives). Based upon this relationship, the utility functions of the alternatives are identified and a compromise ranking is made in terms of ideal and anti-ideal solutions. Decision preferences are defined using utility functions that represent an alternative's position relative to anti-ideal and ideal (Stevic et al., 2020; Karaaslan et al., 2022). Therefore, the best choice is the one that is closest to the ideal point and farthest from the anti-ideal point (Badi et al., 2023).

The MARCOS method has a few advantages: (1) This method evaluates the anti-ideal and ideal solution when constructing the initial matrix. (2) The degree of utility for the ideal and anti-ideal solution is more closely determined. (3) Considers a wide range of criteria and alternatives while maintaining method stability (Karaaslan et al., 2022).

In addition, the MARCOS method has a simple and easy-to-implement structure compared to other MCDM methods.

To obtain more precise results in an uncertain environment, the fuzzy version of the MARCOS method was first applied by Stanković et al. in 2020. Unlike MARCOS, it defines fuzzy ideal and fuzzy anti-ideal rather than exact reference values. It detects relationships between alternatives and fuzzy reference values and defines utility levels related to fuzzy ideal and fuzzy anti-ideal solutions to rank alternatives (Tuş and Adalı, 2022).

Within the scope of this thesis study, the MARCOS method was combined with TFNs, taking into account the uncertainty in human judgments. Thus, the fuzzy MARCOS method was applied for ranking the alternative locations.

Below are the steps of the fuzzy MARCOS method (Stanković et al., 2020)

Step 1: Construct the initial fuzzy decision-making matrix

An initial fuzzy decision matrix consisting of n criteria and m alternative sets is constructed. In case of more than one DM, expert evaluation matrices are combined (Karaaslan et al., 2022).

Step 2: Construct the extended initial fuzzy decision matrix

The extended initial fuzzy decision matrix ($\tilde{X}$) is carried out by the determination of the fuzzy anti-ideal $\tilde{A}(AI)$ and fuzzy ideal $\tilde{A}(ID)$ solution as shown in Equation (3.13).

$$\tilde{X} = \begin{array}{c} \\ \tilde{A}(AI) \\ A_1 \\ A_2 \\ \cdots \\ A_m \\ \tilde{A}(ID) \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{ai1} & \tilde{x}_{ai2} & \cdots & \tilde{x}_{ain} \\ \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \tilde{x}_{m1} & \tilde{x}_{22} & \cdots & \tilde{x}_{mn} \\ \tilde{x}_{id1} & \tilde{x}_{id2} & \cdots & \tilde{x}_{idn} \end{bmatrix} \end{array} \tag{3.13}$$

The fuzzy $\tilde{A}(ID)$ is the best alternative while the fuzzy $\tilde{A}(AI)$ is an alternative with the worst performance. According to type of the criteria (benefit or cost) $\tilde{A}(ID)$ and $\tilde{A}(AI)$ are obtained by using Equations (3.14) and (3.15):

$$\tilde{A}(ID) = \max_i \tilde{x}_{ij} \ if \ \ j \in B \ and \ \min_i \tilde{x}_{ij} \ if \ \ j \in C \tag{3.14}$$

$$\tilde{A}(AI) = \min_i \tilde{x}_{ij} \ if \ \ j \in B \ and \ \max_i \tilde{x}_{ij} \ if \ \ j \in C \tag{3.15}$$

where B stands for the benefit criteria that need to be maximized and C stands for the cost criteria that need to be minimized.

Step 3: Normalization of the extended initial fuzzy decision matrix

Normalized fuzzy matrix $\tilde{N} = \left[\tilde{n}_{ij}\right]_{mxn}$ is performed by using the Equation (3.16) and Equation (3.17).

$$\tilde{n}_{ij} = (n_{ij}^l, n_{ij}^m, n_{ij}^u) = \left(\frac{x_{ij}^l}{x_{id}^u}, \frac{x_{ij}^m}{x_{id}^u}, \frac{x_{ij}^u}{x_{id}^u} \right) \ if \ \ j \in B \tag{3.16}$$

$$\tilde{n}_{ij} = (n_{ij}^l, n_{ij}^m, n_{ij}^u) = \left(\frac{x_{id}^l}{x_{ij}^u}, \frac{x_{id}^l}{x_{ij}^m}, \frac{x_{id}^l}{x_{ij}^l} \right) \ if \ \ j \in C \tag{3.17}$$

where the elements $x_{ij}^l, x_{ij}^m, x_{ij}^u$ and $x_{id}^l, x_{id}^m, x_{id}^u$ stands for the elements of the initial fuzzy decision-making matrix.

Step 4: The determination of a weighted extended initial fuzzy decision matrix

The weighted extended initial fuzzy decision matrix $\tilde{V} = \left[\tilde{v}_{ij}\right]_{mxn}$ is obtained by multiplying the normalized fuzzy matrix elements by the criterion weights $\tilde{w}_j$ as shown in equation (3.18).

$$\tilde{v}_{ij} = (v_{ij}^l, v_{ij}^m, v_{ij}^u) = \tilde{n}_{ij} \otimes \tilde{w}_j = (n_{ij}^l \times w_j^l, n_{ij}^m \times w_j^m, n_{ij}^u \times w_j^u) \tag{3.18}$$

Step 5: Calculation of the utility degree of alternatives $(\tilde{K}_i)$

The utility degree of alternatives $\tilde{K}_i$ regarding the ideal and anti-ideal solution are calculated by using the Equation (3.19) and Equation (3.20).

$$\tilde{K}_i^+ = \frac{\tilde{S}_i}{\tilde{S}_{id}} = \left(\frac{s_i^l}{s_{id}^u}, \frac{s_i^m}{s_{id}^m}, \frac{s_i^u}{s_{id}^l} \right) \tag{3.19}$$

$$\tilde{K}_i^- = \frac{\tilde{S}_i}{\tilde{S}_{ai}} = \left(\frac{s_i^l}{s_{ai}^u}, \frac{s_i^m}{s_{ai}^m}, \frac{s_i^u}{s_{ai}^l} \right) \tag{3.20}$$

where $\tilde{K}_i^+$ and $\tilde{K}_i^-$ stands for the utility degrees of ideal and anti-ideal solutions; $\tilde{S}_i$ stands for the sum of the elements of the weighted fuzzy matrix $\tilde{V}$ as shown in Equation (3.21).

$$\tilde{S}_i = \sum_{i=1}^{n} \tilde{v}_{ij} \tag{3.21}$$

Step 6: Calculation of fuzzy matrix $\tilde{T}_i$ using Equation (X)

$$\tilde{T}_i = \tilde{t}_i = (t_i^l, t_i^m, t_i^u) = \tilde{K}_i^+ \oplus \tilde{K}_i^- = (k_i^{+l} + k_i^{-l}, k_i^{+m} + k_i^{-m}, k_i^{+u} + k_i^{-u}) \tag{3.22}$$

Then, determination of a new fuzzy number $\tilde{D}$ using Equation (3.23)

$$\tilde{D} = (d^l, d^m, d^u) = \max_i \tilde{t}_{ij} \tag{3.23}$$

and then, defuzzify the number $\tilde{D}$ by using the following expression $df_{crisp} = \dfrac{l + 4m + u}{6}$.

Step 7: Determination of utility functions regarding to ideal $f(\tilde{K}_i^+)$ and anti-ideal $f(\tilde{K}_i^-)$ solutions

The utility functions of each alternative regarding to the ideal and anti- ideal solutions are calculated by using Equation (3.24) and Equation (3.25).

$$f(\tilde{K}_i^+) = \frac{\tilde{K}_i^-}{df_{crisp}} = \left(\frac{k_i^{-l}}{df_{crisp}}, \frac{k_i^{-m}}{df_{crisp}}, \frac{k_i^{-u}}{df_{crisp}} \right) \tag{3.24}$$

$$f(\tilde{K}_i^-) = \frac{\tilde{K}_i^+}{df_{crisp}} = \left(\frac{k_i^{+l}}{df_{crisp}}, \frac{k_i^{+m}}{df_{crisp}}, \frac{k_i^{+u}}{df_{crisp}} \right) \tag{3.25}$$

To compute the final utility function of alternatives, the utility degree $\tilde{K}_i^+$, $\tilde{K}_i^-$ and the utility function $f(\tilde{K}_i^+)$, $f(\tilde{K}_i^-)$ are defuzzificated.

Step 8: Determination of the final utility function of alternatives $f(K_i)$ by using Equation (3.26)

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \dfrac{1 - f(K_i^+)}{f(K_i^+)} + \dfrac{1 - f(K_i^-)}{f(K_i^-)}} \tag{3.26}$$

Step 9: The alternatives are ranked with regard to the final values of utility functions

The values of the final utility functions of the alternatives are ranked from the highest to the lowest. The highest final utility alternative is the best alternative.

4. RESULTS AND DISCUSSIONS

In this section of the thesis, the application of the proposed fuzzy FUCOM & fuzzy MARCOS model for the location selection of a field hospital for future pandemics is presented. The flow diagram of the proposed model is shown in Figure 4.1.

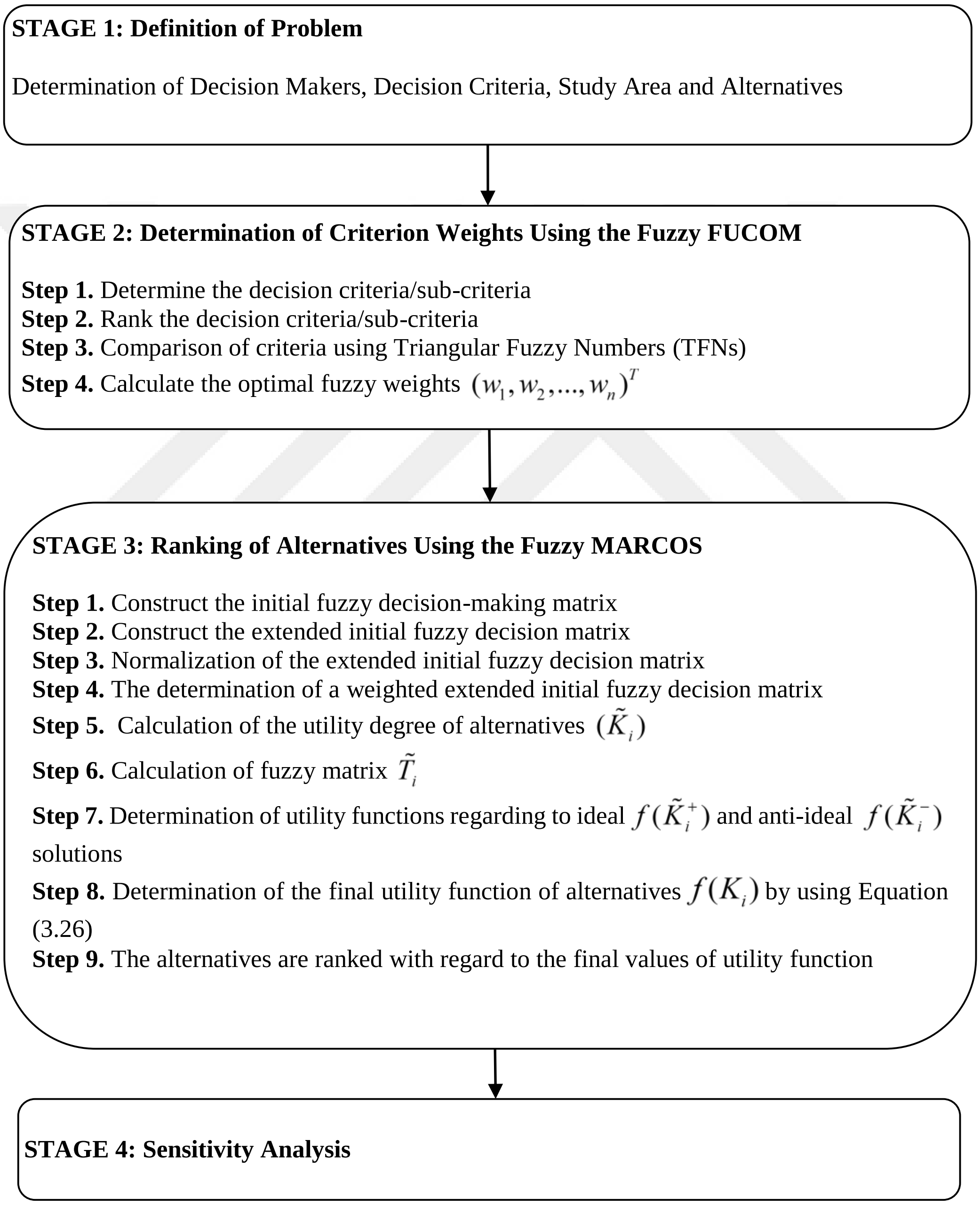

Figure 4.1. Flow diagram of the proposed fuzzy FUCOM & fuzzy MARCOS model

4.1. Purpose of This Study

The aim of this thesis study, field hospital location selection in case of a possible pandemic in the future to slow down the spread of the pandemic by preventing the transmission of the disease to healthcare workers and patients with different diagnoses in existing hospitals and providing the necessary medical care for patients affected by the pandemic.

4.1.1. Study Area

Adana, one of the largest cities in Turkey, was chosen for case in this study. The population of Adana is 2.274.106 according to the TUIK 2022 and it covers an area of 13.844 km^2 which seventh largest metropolitan city of Turkey (TUIK, 2022). Adana population density is 163/km^2. It has a total of 15 districts and municipalities, 5 of which are central districts (“Adana(il)”, 2023). The Figure 4.2 shows the location of Adana in Türkiye.

Figure 4.2. Adana Province’s Location in Turkey Map (resource: “Adana(il)”, 2023)

4.1.2. Definition of Decision Makers

In the location selection problems, it is crucial to select relevant decision makers to evaluate of criteria and alternatives. Within the framework of this thesis study, the decision-making team consists of 6 expert decision makers (DMs). 4 DMs working in Adana Metropolitan Municipality (Department of Planning and Urbanization, Department of Studies and Projects and Department of Disaster Affairs), 1 DM working in Adana Provincial Health Directorate Department of Public Health Services and 1 DM working in Adana City Training and Research

Hospital Department of Infectious Disease were included in the decision-making process. All DMs have at least 15 years of experience. The profile of decision makers is shown in Table 4.1.

Table 4.1. Profile of DMs

# of DMs	Institution	Department	Profession of DMs
2	Adana Metropolitan Municipality	Department of Planning and Urbanization	Topographical Engineer
			Urban Planner
1	Adana Metropolitan Municipality	Department of Studies and Projects	Architect
1	Adana Metropolitan Municipality	Department of Disaster Affairs	Disaster Management Specialist
1	Adana Provincial Health Directorate	Department of Public Health Services	Doctor
1	Adana City Training and Research Hospital	Infectious Disease	Nurse

4.1.3. Definition of Criteria

In order to determine the decision criteria, studies on "hospital location selection", "field hospital location selection", "pandemic hospital location selection", "isolation hospital location selection" and "temporary hospital location selection" were examined. The suitability of the criteria obtained from these studies for our problem was evaluated together with decision makers. In accordance with the literature review and the views of decision makers, it was decided to use the following 4 main criteria and 18 sub-criteria for location selection of a field hospital that can be established in Adana in case of pandemics. While 8 of these decision criteria are cost-based criteria that should be minimized by the alternatives, the remaining 10 criteria are benefit-based criteria that should be maximized by the alternatives. The decision criteria are displayed in Table 4.2.

Table 4.2. Decision Criteria

Main Criteria	Sub-criteria
C_1-Accessibility	C_{11} Proximity to arterial roads
	C_{12} Distance from densely populated residential areas
	C_{13} Transportation alternatives
	C_{14} Traffic density of the main roads
	C_{15} Easy access for vehicles
C_2-Environmental Factors	C_{21} Green space adequacy
	C_{22} Air pollution
	C_{23} Water pollution
	C_{24} Noise pollution
	C_{25} Waste disposal
C_3-Economic Factors	C_{31} Construction cost
	C_{32} Land ownership
	C_{33} Income level
C_4-Land Characteristics	C_{41} Land width
	C_{42} Future expansion potential
	C_{43} Construction time
	C_{44} Infrastructure
	C_{45} Natural disaster risk

C_1 Accessibility

When determining establishment locations, it should be aimed for individuals to reach them quickly, reliably and economically (Yılmaz and Atan, 2021).

C_{11} Proximity to arterial roads: Arterial roads are an important part of urban road systems. Therefore, the field hospital should be close to arterial roads.

C_{12} Distance from densely populated residential areas: Because of the risk of spreading the disease, the field hospital should be built far away from the the regions that people live commonly.

C_{13} Transportation alternatives: The field hospital should be access by various means such as car, bus, subway etc.

C_{14} Traffic density of the main roads: For fast and safe transportation, traffic density of main roads near the field hospital should be low.

C_{15} Easy access for vehicles: The field hospital should be easily access by ambulance, car, bus, subway etc.

***C_2* Environmental Factors**

C_{21} Green space adequacy: Since this field hospital isolates patients from their relatives and society, it should provide adequate green spaces where they can socialize as well as medical care.

C_{22} Air pollution: The field hospital should be located in an area with low air pollution.

C_{23} Water pollution: The field hospital should be located in an area with low water pollution.

C_{24} Noise Pollution: The field hospital should be located in an area with low noise pollution.

C_{25} Waste disposal: All types of waste must be disposed of quickly and safely without harming the environment or people.

***C_3* Economic Factors**

C_{31} Construction cost: It refers to land, operation and machinery-material costs. The selected site for the field hospital should be constructed at a low cost.

C_{32} Land ownership: The fact that the land of the field hospital belongs to the treasury will facilitate the functioning of official procedures and reduce the cost of land.

C_{33} Income level: Poor people require higher level and longer periods of medical care (Epstein et al., 1990). For this reason, it would be more beneficial to build the field hospital in an area close to where low-income people live.

***C_4* Land Characteristics**

C_{41} Land width: Since the number of people who may be affected by the pandemic is uncertain, the land should be as large as possible.

C_{42} Future expansion potential: The land should be suitable for long-term expansion to increase service capacity in emergency situations.

C_{43} Construction time: The field hospital should be quickly built in a short time period.

C_{44} Infrastructure: It refers to the availability of electricity, water, sewage and communication infrastructure of the field hospital land. To prevent possible hygiene problems selected sites should be at a practical distance from the sewage system. On the other hand, easy access to electrical infrastructure should be provided (Fardi et al., 2022).

C_{45} Natural disaster risk: The land of field hospital should have a low risk of natural disasters (earthquake, flood, landslide, etc).

The hierarchical structure for location selection of a field hospital for pandemics is given in Figure 4.3 and the studies that reference the criteria used within the scope of this thesis study are given in the Table 4.3.

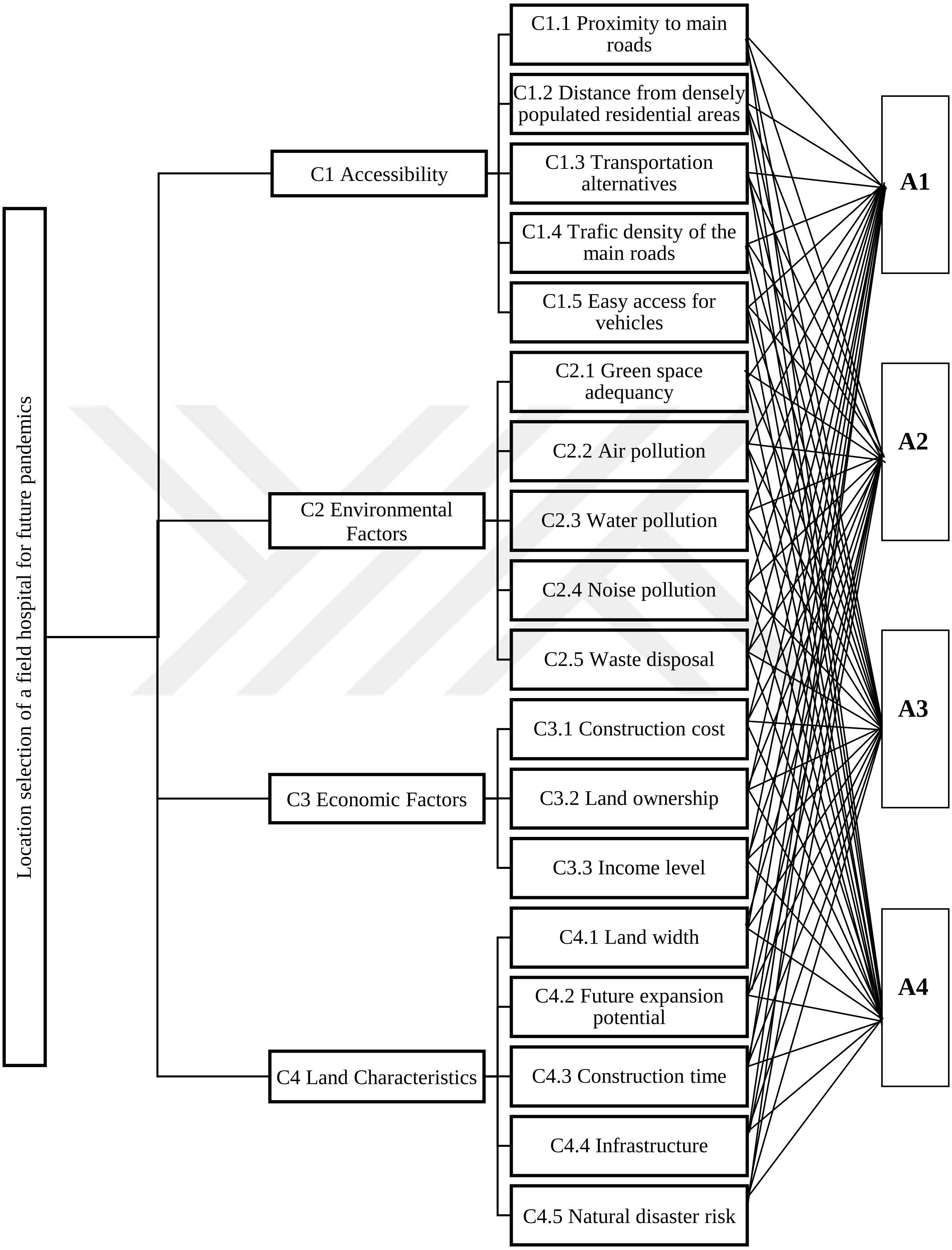

Figure 4.3. The hierarchical structure of location selection of a field hospital for future pandemics

Table 4.3. References of Decision Criteria

Main Criteria	Sub-criteria	Type	References
C_1 Accessibility	C_{11} Proximity to main roads	max	Vahidnia et al. (2009), Soltani and Marandi (2011), Chatterjee (2015), Rahimi et al. (2017), Barutçu and Ic (2022), Kheybari et al. (2023)
	C_{12} Distance from densely populated residential areas	max	İnce et al. (2016), Miç and Antmen (2019), Zolfani et al. (2020), Gül (2021), Akpınar and Ilgın (2021), Wang et al. (2021),
	C_{13} Transportation alternatives	max	İnce et al. (2016), Alkan and Kahraman (2022), Akpınar and Ilgın (2021), Kheybari et al. (2023), Barutçu and Ic (2022)
	C_{14} Traffic density of the main roads	min	İnce et al. (2016), Şen (2017), Minç and Antmen (2019), Barutçu and Ic (2022), Hezam et al. (2023)
	C_{15} Easy access for vehicles	max	Çelikbilek (2018), Şahin et al. (2019), Adalı and Tuş (2019), Aydın and Şeker (2021)
C_2 Environmental factor	C_{21} Green space adequacy	max	Dell'Ovo et al. (2017), Aydın and Şeker (2021)
	C_{22} Air pollution	min	Dell'Ovo et al. (2017), Şahin et al. (2019), Adalı and Tuş (2019), Akpınar and Ilgın (2021), Yücenur (2022), Hezam et al. (2023)
	C_{23} Water pollution	min	Adalı and Tuş (2019), Akpınar and Ilgın (2021), Yücenur (2022), Hezam et al. (2023)
	C_{24} Noise pollution	min	Dell'Ovo et al. (2017), Adalı and Tuş (2019), Akpınar and Ilgın (2021), Yücenur (2022), Hezam et al. (2023)
	C_{25} Waste disposal	max	Alkan and Kahraman (2022), Kheybari et al. (2023),
C_3 Economic Factors	C_{31} Construction cost	min	Chatterjee and Mukherjee (2013), Kumar et al. (2016), Şen (2017), Çelikbilek (2018), Alkan and Kahraman (2022), Yücenur (2022)
	C_{32} Land Ownership	max	Chatterjee and Mukherjee (2013), Dell'Ovo et al. (2017), Akpınar and Ilgın (2021), Alkan and Kahraman (2022), Yılmaz and Atan (2021)
	C_{33} Income level	min	Kumar et al. (2016), İnce et al. (2016), Şahin et al. (2019), Gül (2021), Yılmaz and Atan (2021)
C_4 Land Characteristics	C_{41} Land width	max	Şen (2017), Akpınar and Nişancı (2021), Barutçu and Ic (2022)
	C_{42} Future expansion potential	max	Şen (2017), Adalı and Tuş (2019), Zolfani et al. (2020), Wang et al. (2021)
	C_{43} Construction time	min	Vafaei and Oztaysi (2014), Şen (2017), Aydın and Şeker (2021)
	C_{44} Infrastructure	max	İnce et al. (2016), Alkan and Kahraman (2022), Akpınar and Nişancı (2021), Yücenur (2022)
	C_{45} Natural disaster risk	min	Adalı and Tuş (2019), Barutçu and Ic (2022), Yücenur (2022)

4.1.4. Definition of Alternatives

Alternative locations were determined by 4 decision makers working in the Department of Planning and Urbanization, Department of Studies and Projects and Department of Disaster Affairs at Adana Metropolitan Municipality. The alternative locations determined by the decision makers are listed below:

BOSSA DENIM Factory (old area) (A1): This is an area of approximately 85.000 m^2 and privately owned. This is located nearly Adana Asri Cemetery, Optimum Adana Shopping Mall and Adana HiltonSA Hotel. Figure 4.4 shows the alternative location in the map.

Figure 4.4. Location of BOSSA DENIM Factory (old area) (A1) in map (resource: Netcad)

TUYAP Adana Fair and Congress Center Surrounding (A2): This is an area of approximately 24.000 m^2 and treasury owned. This is located nearly TUYAP Adana Fair and Congress Center. Figure 4.5 shows the alternative location in the map.

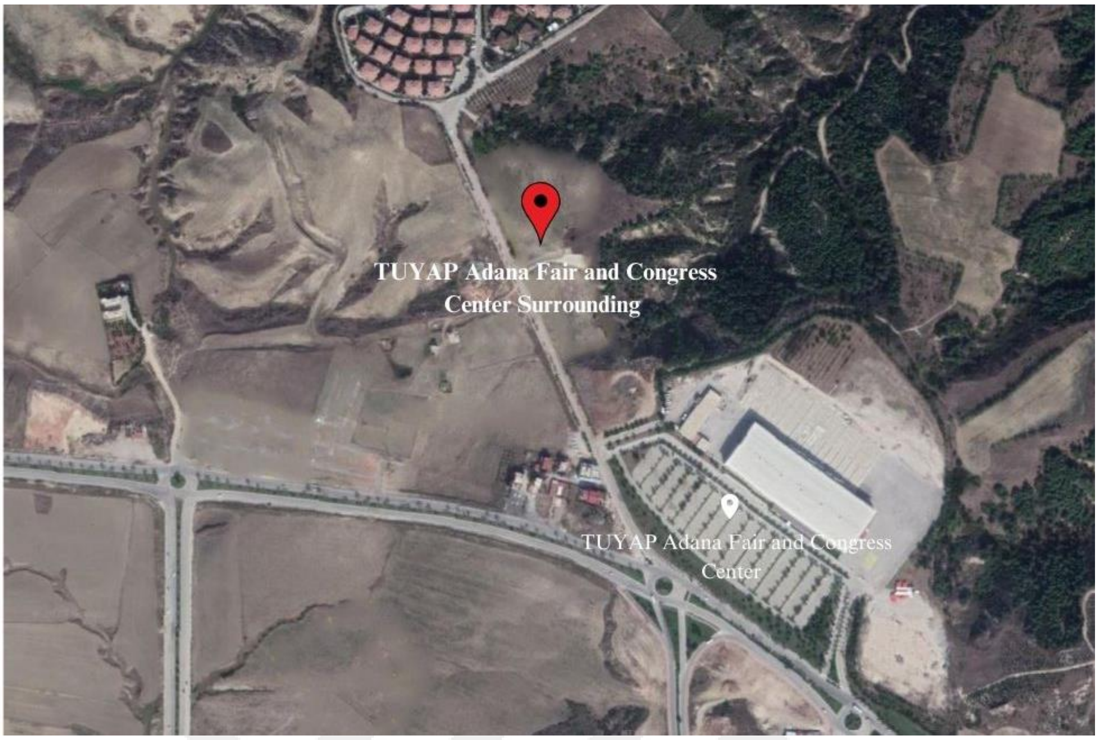

Figure 4.5. Location of TUYAP Adana Fair and Congress Center Surrounding (A2) in map (resource: Netcad)

Karaisalı Highway Junction (A3): This is an area of approximately 66.000 m^2 and privately owned. This is located next to the Karaisalı Highway Junction. Figure 4.6 shows the alternative location in the map.

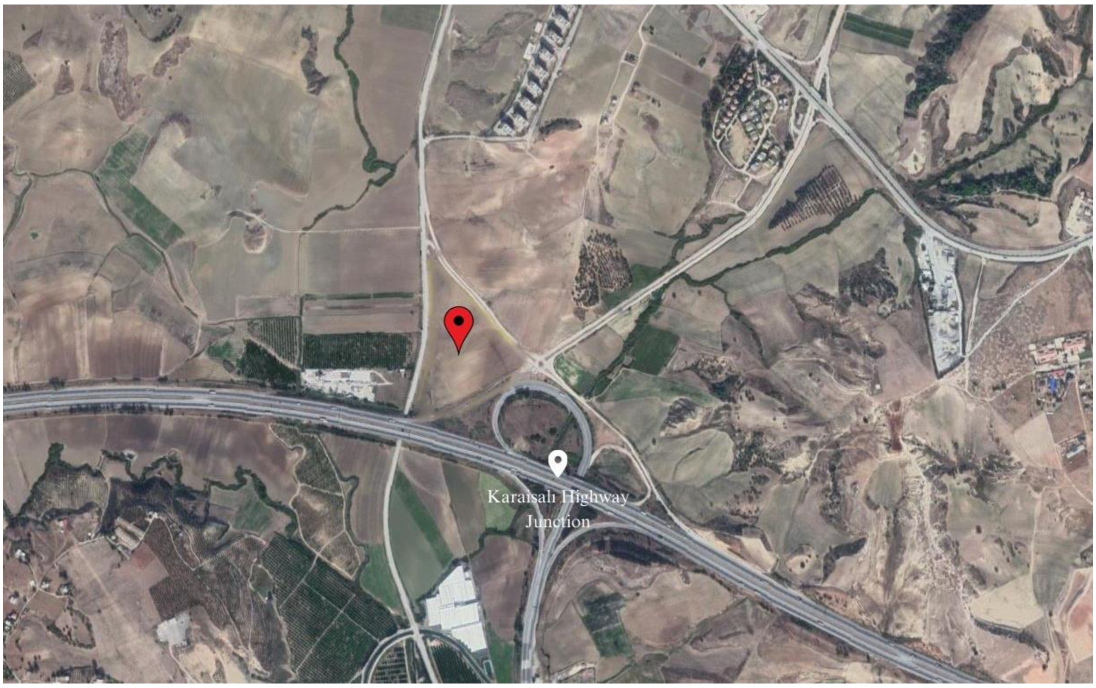

Figure 4.6. Location of Karaisalı Highway Junction (A3) in map (resource: Netcad)

Adana Northern Junction Surrounding (A4): This is an area of approximately 23.000 m^2 and treasury owned. This is located nearly Adana Northern Junction and M1 Adana Shopping Mall. Figure 4.7 shows the alternative location in the map.

Figure 4.7. Location of Adana Northern Junction Surrounding (A4) in map (resource: Netcad)

4.2. Determination of criteria weights using Fuzzy FUCOM

Step 1: Determine the decision criteria/sub-criteria

First of all, decision criteria were determined for the field hospital location selection problem. The decison criteria used in the literature were examined, and then these decision criteria obtained from the literature were evaluated with decision makers for their suitability to the structure of our problem. 4 main criteria and 18 sub-criteria were determined by consensus of decision makers. The decision criteria used within the scope of this thesis are listed in the Table 4.2.

Step 2: Rank the decision criteria/sub-criteria

In order to determine the weights of the criteria using the fuzzy FUCOM method, decision makers (DM1, DM2, …, DM6) were first asked to rank the main criteria and sub-criteria according to their significance. The ranking is done from the criterion expected to have the highest weight coefficient to the criterion expected to have the lowest weight coefficient.

Accordingly, the rank of significance of the main criteria and sub-criteria by decision makers is given in Table 4.4.

Table 4.4. Rank the decision criteria by decision makers

Criteria	DMs	Ranking of criteria
Main Criteria	DM1	$C_1>C_4>C_3>C_2$
	DM2	$C_1>C_3>C_4>C_2$
	DM3	$C_1>C_4>C_3>C_2$
	DM4	$C_1>C_4>C_2>C_3$
	DM5	$C_1>C_3>C_4>C_2$
	DM6	$C_1>C_3>C_4>C_2$
Sub-criteria of C_1	DM1	$C_{13}>C_{14}>C_{11}>C_{15}>C_{12}$
	DM2	$C_{11}>C_{12}>C_{13}>C_{15}>C_{14}$
	DM3	$C_{14}>C_{15}>C_{11}>C_{13}>C_{12}$
	DM4	$C_{13}>C_{11}>C_{12}>C_{14}>C_{15}$
	DM5	$C_{15}>C_{13}>C_{14}>C_{11}>C_{12}$
	DM6	$C_{15}>C_{14}>C_{13}>C_{12}>C_{11}$
Sub-criteria of C_2	DM1	$C_{25}>C_{22}=C_{23}=C_{24}>C_{21}$
	DM2	$C_{25}>C_{21}>C_{22}=C_{23}=C_{24}$
	DM3	$C_{22}>C_{24}>C_{25}>C_{23}>C_{21}$
	DM4	$C_{22}=C_{23}=C_{24}>C_{21}>C_{25}$
	DM5	$C_{25}>C_{22}>C_{24}>C_{23}>C_{21}$
	DM6	$C_{25}>C_{24}>C_{22}>C_{23}>C_{21}$
Sub-criteria of C_3	DM1	$C_{31}>C_{32}>C_{33}$
	DM2	$C_{32}>C_{31}>C_{33}$
	DM3	$C_{32}>C_{33}>C_{31}$
	DM4	$C_{32}>C_{33}>C_{31}$
	DM5	$C_{33}>C_{32}>C_{31}$
	DM6	$C_{33}>C_{32}>C_{31}$
Sub-criteria of C_4	DM1	$C_{41}>C_{44}>C_{45}>C_{42}>C_{43}$
	DM2	$C_{42}>C_{43}>C_{45}>C_{44}>C_{41}$
	DM3	$C_{42}>C_{41}>C_{45}>C_{44}>C_{43}$
	DM4	$C_{43}>C_{41}>C_{44}>C_{42}>C_{45}$
	DM5	$C_{41}>C_{45}>C_{44}>C_{43}>C_{42}$
	DM6	$C_{41}>C_{44}>C_{43}>C_{45}>C_{42}$

Step 3: Comparison of criteria using Triangular Fuzzy Numbers (TFNs)

The linguistic scale used by decision makers to evaluate the criteria is given in Table 4.5. This table includes linguistic variables, abbreviations of linguistic variables, and triangular fuzzy numbers corresponding to these variables.

Table 4.5. Linguistic Scale (Chou et al., 2012; Taşkent and Delice, 2021; Gölcük et al., 2022)

Linguistic Variable	TFNs
Equally Importance (EI)	(1, 1, 1)
Very Weak Importance (VWI)	(1, 2, 3)
Weak Importance (WI)	(2, 3, 4)
Moderately Weak Importance (MWI)	(3, 4, 5)
Moderately Importance (MI)	(4, 5, 6)
Moderately Strongly Importance (MSI)	(5, 6, 7)
Strongly Importance (SI)	(6, 7, 8)
Very Strongly Importance (VSI)	(7, 8, 9)
Absolutely Importance (AI)	(8, 9, 10)

Using the linguistic scale shown in Table 4.5 decision makers determined the significance levels of the criteria they placed first in the order of significance compared to other criteria.

The triangular fuzzy number equivalents of the linguistic variables used in the evaluation are given in the Table 4.6.

Table 4.6. TFNs equivalents of the linguistic variables used in the evaluation

	DMs	Linguistic Variables and Triangular Fuzzy Numbers (TFNs)				
		C₁	***C₂***	***C₃***	***C₄***	
Main Criteria	**DM1**	EI (1,1,1)	VSI (7,8,9)	MI (4,5,6)	MWI (3,4,5)	
	DM2	EI (1,1,1)	MSI (5,6,7)	WI (2,3,4)	MWI (3,4,5)	
	DM3	EI (1,1,1)	SI (6,7,8)	MI (4,5,6)	MWI (3,4,5)	
	DM4	EI (1,1,1)	MWI (3,4,5)	MSI (5,6,7)	WI (2,3,4)	
	DM5	EI (1,1,1)	MSI (5,6,7)	WI (2,3,4)	MWI (3,4,5)	
	DM6	EI (1,1,1)	SI (6,7,8)	MWI (3,4,5)	MI (4,5,6)	
		C_{11}	***C_{12}***	***C_{13}***	***C_{14}***	***C_{15}***
Sub-criteria of C_1	**DM1**	MWI (3,4,5)	MSI (5,6,7)	EI (1,1,1)	WI (2,3,4)	MI (4,5,6)
	DM2	EI (1,1,1)	VWI (1,2,3)	WI (2,3,4)	MSI (5,6,7)	MWI (3,4,5)
	DM3	WI (2,3,4)	MI (4,5,6)	MWI (3,4,5)	EI (1,1,1)	VWI (1,2,3)
	DM4	VWI (1,2,3)	WI (2,3,4)	EI (1,1,1)	MWI (3,4,5)	SI (6,7,8)
	DM5	MI (4,5,6)	MSI (5,6,7)	VWI (1,2,3)	WI (2,3,4)	EI (1,1,1)
	DM6	MSI (5,6,7)	MWI (3,4,5)	WI (2,3,4)	VWI (1,2,3)	EI (1,1,1)
		C_{21}	***C_{22}***	***C_{23}***	***C_{24}***	***C_{25}***
Sub-criteria of C_2	**DM1**	MWI (3,4,5)	WI (2,3,4)	WI (2,3,4)	WI (2,3,4)	EI (1,1,1)
	DM2	WI (2,3,4)	MI (4,5,6)	MI (4,5,6)	MI (4,5,6)	EI (1,1,1)
	DM3	MSI(5,6,7)	EI (1,1,1)	MI (4,5,6)	VWI (1,2,3)	WI (2,3,4)
	DM4	WI (2,3,4)	EI (1,1,1)	EI (1,1,1)	EI (1,1,1)	MWI (3,4,5)
	DM5	MI (4,5,6)	WI (2,3,4)	WI (2,3,4)	WI (2,3,4)	EI (1,1,1)
	DM6	MSI (5,6,7)	MWI (3,4,5)	MI (4,5,6)	WI (2,3,4)	EI (1,1,1)
		C_{31}	***C_{32}***	***C_{33}***		
Sub-criteria of C_3	**DM1**	EI (1,1,1)	WI (2,3,4)	MI (4,5,6)		
	DM2	WI (2,3,4)	EI (1,1,1)	MI (4,5,6)		
	DM3	MI (4,5,6)	EI (1,1,1)	VWI (1,2,3)		
	DM4	MSI (5,6,7)	EI (1,1,1)	WI (2,3,4)		
	DM5	MSI (5,6,7)	VWI (1,2,3)	EI (1,1,1)		
	DM6	MI (4,5,6)	VWI (1,2,3)	EI (1,1,1)		
		C_{41}	***C_{42}***	***C_{43}***	***C_{44}***	***C_{45}***
Sub-criteria of C_4	**DM1**	EI (1,1,1)	MSI (5,6,7)	SI (6,7,8)	MWI (3,4,5)	MI (4,5,6)
	DM2	MI (4,5,6)	EI (1,1,1)	VWI (1,2,3)	MWI (3,4,5)	WI (2,3,4)
	DM3	VWI (1,2,3)	EI (1,1,1)	SI (6,7,8)	MSI (5,6,7)	MI (4,5,6)
	DM4	WI (2,3,4)	MSI (5,6,7)	EI (1,1,1)	MWI (3,4,5)	SI (6,7,8)
	DM5	EI (1,1,1)	MI (4,5,6)	MWI (3,4,5)	WI (2,3,4)	VWI (1,2,3)
	DM6	EI (1,1,1)	MSI (5,6,7)	MWI (3,4,5)	VWI (1,2,3)	MI (4,5,6)

Step 4: Calculate the optimal fuzzy weights $(w_1, w_2, ..., w_n)^T$

For each DM, the comparative significance of the main criteria and sub-criteria $\varphi_{k/(k+1)}$ and the mathematical transitivity condition $\varphi_{k/(k+2)}$ values were calculated.

For DM1, the comparative significance and the mathematical transitivity condition values of the main criteria are given below. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6.

For DM1,

Using Equation (3.10), the comparative significance of the main criteria are defined as follows:

$$\varphi_{C1/C4} = \varpi_{C1} / \varpi_{C4} = (3,4,5) / (1,1,1) = (3,4,5)$$
$$\varphi_{C4/C3} = \varpi_{C4} / \varpi_{C3} = (4,5,6) / (3,4,5) = (0.8,1.25,2)$$
$$\varphi_{C3/C2} = \varpi_{C3} / \varpi_{C2} = (7,8,9) / (4,5,6) = (1.167,1.6,2.25)$$

A fuzzy vector of the comparative significance of the decision criteria are defined as

$\Phi = ((3,4,5),(0.8,1.25,2),(1.167,1.6,2.25))$.

Using Equation (3.11), the mathematical transitivity of the main criteria are defined as follows:

$$\varpi_{C1} / \varpi_{C3} = (3,4,5) \otimes (0.8,1.25,2) = (2.4,5,10)$$
$$\varpi_{C4} / \varpi_{C2} = (0.8,1.25,2) \otimes (1.167,1.6,2.25) = (0.93,2,4.5)$$

The mathematical model created to determine the optimum weights of the main criteria for DM1 using Equation (3.12) is given below.

$$Min x$$
$$\left|w_1^l - 3w_4^u\right| \le x, \left|w_4^l - 0.8w_3^u\right| \le x, \left|w_3^l - 1.167w_2^u\right| \le x$$
$$\left|w_1^m - 4w_4^m\right| \le x, \left|w_4^m - 1.25w_3^m\right| \le x, \left|w_3^m - 1.6w_2^m\right| \le x$$
$$\left|w_1^u - 5w_4^l\right| \le x, \left|w_4^u - 2w_3^l\right| \le x, \left|w_3^u - 2.25w_2^l\right| \le x$$
$$\left|w_1^l - 2.4w_3^u\right| \le x, \left|w_4^l - 0.93w_2^u\right| \le x$$
$$\left|w_1^m - 5w_3^m\right| \le x, \quad \left|w_4^m - 2w_2^m\right| \le x$$
$$\left|w_1^u - 10w_3^l\right| \le x \quad \left|w_4^u - 4.5w_2^l\right| \le x$$
$$(w_1^l + 4w_1^m + w_1^u)/6 + (w_2^l + 4w_2^m + w_2^u)/6 + (w_3^l + 4w_3^m + w_3^u)/6 + (w_4^l + 4w_4^m + w_4^u)/6 = 1$$
$$w_1^l \le w_1^m \le w_1^u,\ w_2^l \le w_2^m \le w_2^u, w_3^l \le w_3^m \le w_3^u,\ w_4^l \le w_4^m \le w_4^u$$
$$0 \le w_1^l, 0 \le w_2^l,\ 0 \le w_3^l, 0 \le w_4^l$$

"LINGO 19.0" software was used to solve this mathematical model. Thus, the optimum weights of the main criteria for DM1 were calculated. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6 to calculate the optimum weights of the main criteria.

For DM1, the comparative significance and the mathematical transitivity condition values of the sub-criteria of C1 are given below. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6.

For DM1,

Using Equation (3.10), the comparative significance of the sub-criteria of C1 are defined as follows:

$$\varphi_{C13/C14} = \varpi_{C13} / \varpi_{C14} = (2,3,4) / (1,1,1) = (2,3,4)$$
$$\varphi_{C14/C11} = \varpi_{C14} / \varpi_{C11} = (3,4,5) / (2,3,4) = (0.75,1.33,2.5)$$
$$\varphi_{C11/C15} = \varpi_{C11} / \varpi_{C15} = (4,5,6) / (3,4,5) = (0.8,1.25,2)$$
$$\varphi_{C15/C12} = \varpi_{C15} / \varpi_{C12} = (5,6,7) / (4,5,6) = (0.833,1.2,1.75)$$

A fuzzy vector of the comparative significance of the decision criteria are defined as

$\Phi = ((2,3,4),(0.75,1.33,2.5),(0.8,1.25,2),(0.833,1.2,1.75))$.

Using Equation (3.11), the mathematical transitivity of the sub-criteria of C1 are defined as follows:

$$\varpi_{C13} / \varpi_{C11} = (2,3,4) \otimes (0.75,1.33,2.5) = (1.5,4,10)$$
$$\varpi_{C14} / \varpi_{C15} = (0.75,1.33,2.5) \otimes (0.8,1.25,2) = (0.6,1.66,5)$$
$$\varpi_{C11} / \varpi_{C12} = (0.8,1.25,2) \otimes (0.833,1.2,1.75) = (0.67,1.5,3.5)$$

The mathematical model created to determine the optimum weights of the sub-criteria of C1 for DM1 using Equation (3.12) is given below.

$$Min x$$
$$\left|w_{13}^{l} - 2w_{14}^{u}\right| \le x, \left|w_{14}^{l} - 0.75w_{11}^{u}\right| \le x, \left|w_{11}^{l} - 0.8w_{15}^{u}\right| \le x, \left|w_{15}^{l} - 0.833w_{12}^{u}\right| \le x$$
$$\left|w_{13}^{m} - 3w_{14}^{m}\right| \le x, \left|w_{14}^{m} - 1.33w_{11}^{m}\right| \le x, \left|w_{11}^{m} - 1.25w_{15}^{m}\right| \le x, \left|w_{15}^{m} - 1.2w_{12}^{m}\right| \le x$$
$$\left|w_{13}^{u} - 4w_{14}^{l}\right| \le x, \left|w_{14}^{u} - 2.5w_{11}^{l}\right| \le x, \left|w_{11}^{u} - 2w_{15}^{l}\right| \le x, \left|w_{15}^{u} - 1.75w_{12}^{l}\right| \le x$$
$$\left|w_{13}^{l} - 1.5w_{11}^{u}\right| \le x, \left|w_{14}^{l} - 0.6w_{15}^{u}\right| \le x, \left|w_{11}^{l} - 0.67w_{12}^{u}\right| \le x$$
$$\left|w_{13}^{m} - 4w_{11}^{m}\right| \le x, \left|w_{14}^{m} - 1.66w_{15}^{m}\right| \le x, \left|w_{11}^{m} - 1.5w_{12}^{m}\right| \le x$$
$$\left|w_{13}^{u} - 10w_{11}^{l}\right| \le x, \left|w_{14}^{u} - 5w_{15}^{l}\right| \le x, \left|w_{11}^{u} - 3.5w_{12}^{l}\right| \le x$$
$$(w_{11}^{l} + 4w_{11}^{m} + w_{11}^{u})/6 + (w_{12}^{l} + 4w_{12}^{m} + w_{12}^{u})/6 + (w_{13}^{l} + 4w_{13}^{m} + w_{13}^{u})/6 +$$
$$(w_{14}^{l} + 4w_{14}^{m} + w_{14}^{u})/6 + (w_{15}^{l} + 4w_{15}^{m} + w_{15}^{u})/6 = 1$$
$$w_{11}^{l} \le w_{11}^{m} \le w_{11}^{u},\ w_{12}^{l} \le w_{12}^{m} \le w_{12}^{u}, w_{13}^{l} \le w_{13}^{m} \le w_{13}^{u}, w_{14}^{l} \le w_{14}^{m} \le w_{14}^{u}, w_{15}^{l} \le w_{15}^{m} \le w_{15}^{u}$$
$$0 \le w_{11}^{l}, 0 \le w_{12}^{l}, 0 \le w_{13}^{l}, 0 \le w_{14}^{l}, 0 \le w_{15}^{l}$$

"LINGO 19.0" software was used to solve this mathematical model. Thus, the optimum weights of the sub-criteria of C1 for DM1 were calculated. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6 to calculate the optimum weights of the sub-criteria of C1. For DM1, the comparative significance and the mathematical transitivity condition values of the sub-criteria of C2 are given below. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6.

For DM1,

Using Equation (3.10), the comparative significance of the sub-criteria of C2 are defined as follows:

$$\varphi_{C25/C22} = \varpi_{C25} / \varpi_{C22} = (2,3,4)/(1,1,1) = (2,3,4)$$
$$\varphi_{C22/C23} = \varpi_{C22} / \varpi_{C23} = (2,3,4)/(2,3,4) = (0.5,1,2)$$
$$\varphi_{C23/C24} = \varpi_{C23} / \varpi_{C24} = (2,3,4)/(2,3,4) = (0.5,1,2)$$
$$\varphi_{C24/C21} = \varpi_{C24} / \varpi_{C21} = (3,4,5)/(2,3,4) = (0.75,1.333,2.5)$$

A fuzzy vector of the comparative significance of the decision criteria are defined as

$\Phi = ((2,3,4),(0.5,1,2),(0.5,1,2),(0.75,1.333,2.5))$.

Using Equation (3.11), the mathematical transitivity of the sub-criteria of C2 are defined as follows:

$$\varpi_{C25} / \varpi_{C23} = (2,3,4) \otimes (0.5,1,2) = (1,3,8)$$
$$\varpi_{C22} / \varpi_{C24} = (0.5,1,2) \otimes (0.5,1,2) = (0.25,1,4)$$
$$\varpi_{C23} / \varpi_{C21} = (0.5,1,2) \otimes (0.75,1.333,2.5) = (0.375,1.333,5)$$

The mathematical model created to determine the optimum weights of the sub-criteria of C2 for DM1 using Equation (3.12) is given below.

$$Min x$$
$$\left|w_{25}^{l} - 2w_{22}^{u}\right| \le x,\ \left|w_{22}^{l} - 0.5w_{23}^{u}\right| \le x,\ \left|w_{23}^{l} - 0.5w_{24}^{u}\right| \le x, \left|w_{24}^{l} - 0.75w_{21}^{u}\right| \le x$$
$$\left|w_{25}^{m} - 3w_{22}^{m}\right| \le x,\ \left|w_{22}^{m} - 1w_{23}^{m}\right| \le x, \left|w_{23}^{m} - 1w_{24}^{m}\right| \le x, \left|w_{24}^{m} - 1.333w_{21}^{m}\right| \le x$$
$$\left|w_{25}^{u} - 4w_{22}^{l}\right| \le x,\ \left|w_{22}^{u} - 2w_{23}^{l}\right| \le x, \left|w_{23}^{u} - 2w_{24}^{l}\right| \le x,\ \left|w_{24}^{u} - 2.5w_{21}^{l}\right| \le x$$
$$\left|w_{25}^{l} - 1w_{23}^{u}\right| \le x,\ \left|w_{22}^{l} - 0.25w_{24}^{u}\right| \le x,\ \left|w_{23}^{l} - 0.375w_{21}^{u}\right| \le x$$
$$\left|w_{25}^{m} - 3w_{23}^{m}\right| \le x,\ \left|w_{22}^{m} - 1w_{24}^{m}\right| \le x,\ \left|w_{23}^{m} - 1.333w_{21}^{m}\right| \le x$$
$$\left|w_{25}^{u} - 8w_{23}^{l}\right| \le x,\ \left|w_{22}^{u} - 4w_{24}^{l}\right| \le x, \left|w_{23}^{u} - 5w_{21}^{l}\right| \le x$$
$$(w_{21}^{l} + 4w_{21}^{m} + w_{21}^{u})/6 + (w_{22}^{l} + 4w_{22}^{m} + w_{22}^{u})/6 + (w_{23}^{l} + 4w_{23}^{m} + w_{23}^{u})/6 +$$
$$(w_{24}^{l} + 4w_{24}^{m} + w_{24}^{u})/6 + (w_{25}^{l} + 4w_{25}^{m} + w_{25}^{u})/6 = 1$$
$$w_{21}^{l} \le w_{21}^{m} \le w_{21}^{u},\ w_{22}^{l} \le w_{22}^{m} \le w_{22}^{u},\ w_{23}^{l} \le w_{23}^{m} \le w_{23}^{u},\ w_{24}^{l} \le w_{24}^{m} \le w_{24}^{u},\ w_{25}^{l} \le w_{25}^{m} \le w_{25}^{u}$$
$$0 \le w_{21}^{l},\ 0 \le w_{22}^{l},\ 0 \le w_{23}^{l},\ 0 \le w_{24}^{l},\ 0 \le w_{25}^{l}$$

"LINGO 19.0" software was used to solve this mathematical model. Thus, the optimum weights of the sub-criteria of C2 for DM1 were calculated. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6 to calculate the optimum weights of the sub-criteria of C2.

For DM1, the comparative significance and the mathematical transitivity condition values of the sub-criteria of C3 are given below. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6.

For DM1,

Using Equation (3.10), the comparative significance of the sub-criteria of C3 are defined as follows:

$$\varphi_{C31/C32} = \varpi_{C31} / \varpi_{C32} = (2,3,4)/(1,1,1) = (2,3,4)$$
$$\varphi_{C32/C33} = \varpi_{C32} / \varpi_{C33} = (4,5,6)/(2,3,4) = (1,1.67,3)$$

A fuzzy vector of the comparative significance of the decision criteria are defined as

$\Phi = ((2,3,4),(1,1.67,3))$.

Using Equation (3.11), the mathematical transitivity of the sub-criteria of C3 are defined as follows:

$$\varpi_{C31} / \varpi_{C33} = (2,3,4) \otimes (1,1.67,3) = (2,5,12)$$

The mathematical model created to determine the optimum weights of the sub-criteria of C3 for DM1 using Equation (3.12) is given below.

$$Min x$$
$$\left|w_{31}^{l} - 2w_{32}^{u}\right| \le x, \left|w_{32}^{l} - 1w_{33}^{u}\right| \le x$$
$$\left|w_{31}^{m} - 3w_{32}^{m}\right| \le x, \left|w_{32}^{m} - 1.67w_{33}^{m}\right| \le x$$
$$\left|w_{31}^{u} - 4w_{32}^{l}\right| \le x, \left|w_{32}^{u} - 3w_{33}^{l}\right| \le x$$
$$\left|w_{31}^{l} - 2w_{33}^{u}\right| \le x$$
$$\left|w_{31}^{m} - 5w_{33}^{m}\right| \le x$$
$$\left|w_{31}^{u} - 12w_{33}^{l}\right| \le x$$
$$(w_{31}^{l} + 4w_{31}^{m} + w_{31}^{u})/6 + (w_{32}^{l} + 4w_{32}^{m} + w_{32}^{u})/6 + (w_{33}^{l} + 4w_{33}^{m} + w_{33}^{u})/6 = 1$$
$$w_{31}^{l} \le w_{31}^{m} \le w_{31}^{u},\ w_{32}^{l} \le w_{32}^{m} \le w_{32}^{u},\ w_{33}^{l} \le w_{33}^{m} \le w_{33}^{u}$$
$$0 \le w_{31}^{l},\ 0 \le w_{32}^{l},\ 0 \le w_{33}^{l}$$

"LINGO 19.0" software was used to solve this mathematical model. Thus, the optimum weights of the sub-criteria of C3 for DM1 were calculated. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6 to calculate the optimum weights of the sub-criteria of C3.

For DM1, the comparative significance and the mathematical transitivity condition values of the sub-criteria of C4 are given below. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6.

For DM1,

Using Equation (3.10), the comparative significance of the sub-criteria of C4 are defined as follows:

$$\varphi_{C41/C44} = \varpi_{C41} / \varpi_{C44} = (3,4,5)/(1,1,1) = (3,4,5)$$
$$\varphi_{C44/C45} = \varpi_{C44} / \varpi_{C45} = (4,5,6)/(3,4,5) = (0.8,1.25,2)$$
$$\varphi_{C45/C42} = \varpi_{C45} / \varpi_{C42} = (5,6,7)/(4,5,6) = (0.833,1.2,1.75)$$
$$\varphi_{C42/C43} = \varpi_{C42} / \varpi_{C43} = (6,7,8)/(5,6,7) = (0.85,1.167,1.6)$$

A fuzzy vector of the comparative significance of the decision criteria are defined as

$$\Phi = ((3,4,5),(0.8,1.25,2),(0.833,1.2,1.75),(0.85,1.167,1.6)).$$

Using Equation (3.11), the mathematical transitivity of the sub-criteria of C4 are defined as follows:

$$\varpi_{C41} / \varpi_{C45} = (3,4,5) \otimes (0.8,1.25,2) = (2.4,5,10)$$
$$\varpi_{C44} / \varpi_{C42} = (0.8,1.25,2) \otimes (0.833,1.2,1.75) = (0.67,1.5,3.5)$$
$$\varpi_{C45} / \varpi_{C43} = (0.833,1.2,1.75) \otimes (0.85,1.167,1.6) = (0.70,1.40,2.8)$$

The mathematical model created to determine the optimum weights of the sub-criteria of C4 for DM1 using Equation (3.12) is given below.

$$Minx$$
$$\left|w_{41}^{l} - 3w_{44}^{u}\right| \le x, \left|w_{44}^{l} - 0.8w_{45}^{u}\right| \le x, \left|w_{45}^{l} - 0.833w_{42}^{u}\right| \le x, \left|w_{42}^{l} - 0.85w_{43}^{u}\right| \le x$$
$$\left|w_{41}^{m} - 4w_{44}^{m}\right| \le x, \left|w_{44}^{m} - 1.25w_{45}^{m}\right| \le x, \left|w_{45}^{m} - 1.2w_{42}^{m}\right| \le x, \left|w_{42}^{m} - 1.167w_{43}^{m}\right| \le x$$
$$\left|w_{41}^{u} - 5w_{44}^{l}\right| \le x, \left|w_{44}^{u} - 2w_{45}^{l}\right| \le x, \left|w_{45}^{u} - 1.75w_{42}^{l}\right| \le x, \left|w_{42}^{u} - 1.6w_{43}^{l}\right| \le x$$
$$\left|w_{41}^{l} - 2.4w_{45}^{u}\right| \le x, \left|w_{44}^{l} - 0.67w_{42}^{u}\right| \le x, \left|w_{45}^{l} - 0.70w_{43}^{u}\right| \le x$$
$$\left|w_{41}^{m} - 5w_{45}^{m}\right| \le x, \left|w_{44}^{m} - 1.5w_{42}^{m}\right| \le x, \left|w_{45}^{m} - 1.40w_{43}^{m}\right| \le x$$
$$\left|w_{41}^{u} - 10w_{45}^{l}\right| \le x, \left|w_{44}^{u} - 3.5w_{42}^{l}\right| \le x, \left|w_{45}^{u} - 2.8w_{43}^{l}\right| \le x$$
$$(w_{41}^{l} + 4w_{41}^{m} + w_{41}^{u})/6 + (w_{42}^{l} + 4w_{42}^{m} + w_{42}^{u})/6 + (w_{43}^{l} + 4w_{43}^{m} + w_{43}^{u})/6 +$$
$$(w_{44}^{l} + 4w_{44}^{m} + w_{44}^{u})/6 + (w_{45}^{l} + 4w_{45}^{m} + w_{45}^{u})/6 = 1$$
$$w_{41}^{l} \le w_{41}^{m} \le w_{41}^{u}, w_{42}^{l} \le w_{42}^{m} \le w_{42}^{u}, w_{43}^{l} \le w_{43}^{m} \le w_{43}^{u}, w_{44}^{l} \le w_{44}^{m} \le w_{44}^{u}, w_{45}^{l} \le w_{45}^{m} \le w_{45}^{u}$$
$$0 \le w_{41}^{l}, 0 \le w_{42}^{l}, 0 \le w_{43}^{l}, 0 \le w_{44}^{l}, 0 \le w_{45}^{l}$$

"LINGO 19.0" software was used to solve this mathematical model. Thus, the optimum weights of the sub-criteria of C4 for DM1 were calculated. The same procedures were carried out for DM2, DM3, DM4, DM5 and DM6 to calculate the optimum weights of the sub-criteria of C4. The fuzzy criteria weights of each decision maker for the main criteria and the value of the coefficient of Deviation from Full Consistency (DFC) are given in the Table 4.7.

The fuzzy criteria weights of each decision maker for the sub-criteria of C1, C2, C3, C4 and the values of the coefficient of Deviation from Full Consistency (DFC) are given in the Table 4.8, Table 4.9, Table 4.10, Table 4.11, respectively.

Table 4.7. Fuzzy criteria weights of each DM for the main criteria

	C_1			C_2			C_3			C_4			DFC(χ)
	l	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	
DM1	0.399	0.644	0.793	0.044	0.099	0.113	0.084	0.138	0.146	0.149	0.149	0.149	**0.047**
DM2	0.297	0.598	0.725	0.041	0.120	0.140	0.166	0.179	0.179	0.079	0.157	0.157	**0.061**
DM3	0.394	0.636	0.783	0.049	0.111	0.130	0.083	0.137	0.144	0.147	0.147	0.147	**0.047**
DM4	0.297	0.598	0.725	0.079	0.157	0.157	0.041	0.120	0.140	0.166	0.179	0.179	**0.061**
DM5	0.297	0.598	0.725	0.041	0.120	0.140	0.166	0.179	0.179	0.079	0.157	0.157	**0.061**
DM6	0.394	0.636	0.783	0.049	0.111	0.130	0.147	0.147	0.147	0.083	0.137	0.144	**0.047**
Geometric mean	0.343	0.618	0.755	0.049	0.118	0.134	0.103	0.148	0.155	0.111	0.154	0.155	

Table 4.8. Fuzzy criteria weights of each DM for the sub-criteria of C1

	C_{11}			C_{12}			C_{13}			C_{14}			C_{15}			DFC(χ)
	l	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	
DM1	0.068	0.138	0.138	0.055	0.115	0.115	0.261	0.525	0.627	0.143	0.157	0.157	0.042	0.126	0.149	**0.053**
DM2	0.163	0.495	0.499	0.144	0.231	0.231	0.047	0.142	0.142	0.036	0.098	0.098	0.030	0.149	0.152	**0.067**
DM3	0.046	0.139	0.139	0.041	0.119	0.119	0.029	0.146	0.149	0.159	0.485	0.489	0.141	0.226	0.226	**0.066**
DM4	0.146	0.234	0.234	0.048	0.144	0.144	0.165	0.502	0.506	0.030	0.151	0.154	0.032	0.083	0.083	**0.068**
DM5	0.025	0.118	0.118	0.041	0.107	0.114	0.148	0.235	0.235	0.048	0.145	0.145	0.166	0.506	0.512	**0.069**
DM6	0.036	0.098	0.098	0.030	0.149	0.152	0.047	0.142	0.142	0.144	0.230	0.230	0.163	0.495	0.499	**0.067**
Geometric mean	0.064	0.172	0.172	0.052	0.139	0.141	0.086	0.238	0.247	0.075	0.183	0.184	0.073	0.211	0.218	

Table 4.9. Fuzzy criteria weights of each DM for the sub-criteria of C2

	C_{21}			C_{22}			C_{23}			C_{24}			C_{25}			DFC (χ)
	l	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	
DM1	0.045	0.149	0.149	0.104	0.142	0,142	0.067	0.162	0.162	0.051	0.172	0.172	0.223	0.477	0.477	**0.060**
DM2	0.146	0.159	0.159	0.056	0.114	0.114	0.045	0.123	0.151	0.071	0.136	0.136	0.273	0.523	0.631	**0.045**
DM3	0.041	0.107	0.114	0.166	0.506	0.512	0.025	0.118	0.118	0.148	0.235	0.235	0.048	0.145	0.145	**0.069**
DM4	0.077	0.103	0.108	0.277	0.277	0.277	0.246	0.277	0.277	0.246	0.277	0.277	0.031	0.077	0.144	**0.030**
DM5	0.038	0.115	0.115	0.107	0.147	0.147	0.052	0.178	0.178	0.069	0.168	0.168	0.231	0.493	0.493	**0.062**
DM6	0.055	0.115	0.115	0.068	0.138	0.138	0.042	0.126	0.149	0.143	0.157	0.157	0.261	0.525	0.627	**0.053**
Geometric mean	0.059	0.123	0.125	0.112	0.189	0.189	0.059	0.156	0.166	0.104	0.185	0.185	0.133	0.299	0.353	

Table 4.10. Fuzzy criteria weights of each DM for the sub-criteria of C3

	C31			***C32***			***C33***			**DFC(χ)**
	l	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	
DM1	0.433	0.649	0.866	0.216	0.216	0.217	0.072	0.130	0.217	**0.000**
DM2	0.216	0.216	0.216	0.433	0.649	0.865	0.072	0.130	0.216	**0.000**
DM3	0.049	0.117	0.219	0.292	0.585	0.877	0.292	0.292	0.292	**0.000**
DM4	0.063	0.111	0.177	0.443	0.665	0.886	0.222	0.222	0.222	**0.000**
DM5	0.043	0.100	0.179	0.299	0.299	0.299	0.299	0.598	0.897	**0.000**
DM6	0.049	0.117	0.219	0.292	0.292	0.292	0.292	0.585	0.877	**0.000**
Geometric mean	0.092	0.166	0.257	0.319	0.410	0.483	0.176	0.269	0.366	

Table 4.11. Fuzzy criteria weights of each DM for the sub-criteria of C4

	C41			***C42***			***C43***			***C44***			***C45***			**DFC(χ)**
	l	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	
DM1	0.349	0.563	0.693	0.049	0.115	0.138	0.061	0.107	0.107	0.130	0.130	0.130	0.073	0.121	0.128	**0.041**
DM2	0.041	0.119	0.119	0.159	0.485	0.489	0.141	0.226	0.226	0.029	0.146	0.149	0.046	0.139	0.139	**0.066**
DM3	0.172	0.247	0.247	0.193	0.549	0.571	0.057	0.097	0.097	0.029	0.100	0.107	0.035	0.104	0.104	**0.054**
DM4	0.150	0.161	0.161	0.037	0.108	0.126	0.268	0.539	0.653	0.071	0.142	0.142	0.053	0.108	0.108	**0.055**
DM5	0.159	0.485	0.489	0.041	0.120	0.120	0.029	0.146	0.149	0.046	0.139	0.139	0.141	0.226	0.226	**0.066**
DM6	0.177	0.531	0.531	0.051	0.106	0.106	0.039	0.118	0.118	0.157	0.236	0.236	0.029	0.118	0.123	**0.058**
Geometric mean	0.148	0.297	0.308	0.070	0.186	0.199	0.073	0.167	0.173	0.062	0.144	0.146	0.054	0.131	0.133	

In order to combine the opinions of decision makers, the geometric mean is often preferred in the literature. Therefore, in this study, the geometric mean was used to combine the opinions of decision makers (Kılıç et al., 2022; Hoan and Ha, 2021).

The opinions of DMs were combined using Equation (4.1) to obtain the final fuzzy weights of criteria.

$$w_n = \sqrt[n]{w_1^1 \otimes w_1^2 \otimes w_1^3 \otimes \ldots \otimes w_n^m} \tag{4.1}$$

where M stands for the number of decision makers and $M = \{1,2,3,\ldots,m\}$. The final fuzzy weights of criteria are given in Table 4.12.

Table 4.12. Final fuzzy weights of criteria

Main criteria	**Fuzzy weight**	**Sub-criteria of C_1**	**Fuzzy weight**
C_1	(0.343, 0.618, 0.755)	C_{11}	(0.064, 0.172, 0.172)
C_2	(0.049, 0.118, 0.134)	C_{12}	(0.052, 0.139, 0.141)
C_3	(0.103, 0.148, 0.155)	C_{13}	(0.086, 0.238, 0.247)
C_4	(0.111, 0.154, 0.155)	C_{14}	(0.075, 0.183, 0.184)
		C_{15}	(0.073, 0.211, 0.218)
Sub-criteria of C_2	**Fuzzy weight**	**Sub-criteria of C_3**	**Fuzzy weight**
C_{21}	(0.059, 0.123, 0.125)	C_{31}	(0.092, 0.166, 0.257)
C_{22}	(0.112, 0.189, 0.189)	C_{32}	(0.319, 0.410, 0.483)
C_{23}	(0.059, 0.156, 0.166)	C_{33}	(0.176, 0.269, 0.366)
C_{24}	(0.104, 0.185, 0.185)		
C_{25}	(0.133, 0.299, 0.353)		
Sub-criteria of C_4	**Fuzzy weight**		
C_{41}	(0.148, 0.297, 0.308)		
C_{42}	(0.070, 0.186, 0.199)		
C_{43}	(0.073, 0.167, 0.173)		
C_{44}	(0.062, 0.144, 0.146)		
C_{45}	(0.054, 0.131, 0.133)		

After determining the final fuzzy weights of the criteria, the defuzzification was performed using Equation (3.6) to eliminate the uncertainty and obtain the exact weight values of the criteria.

$$wC_1 = (wC_1^l, wC_1^m, wC_1^u) = (0.343, 0.618, 0.755)$$

$$wC_1 = (0.343 + 4*0.618 + 0.755) / 6 = 0.595$$

$$wC_{11} = (wC_{11}^l, wC_{11}^m, wC_{11}^u) = (0.064, 0.172, 0.172)$$

$$wC_{11} = (0.064 + 4*0.172 + 0.172) / 6 = 0.154$$

The exact weight values of the criteria obtained as a result of the defuzzification are given in Table 4.13.

Table 4.13. Exact weight values of the criteria

Main criteria	Exact weight	Sub-criteria of C_1	Exact weight
C_1	0.595	C_{11}	0.154
C_2	0.109	C_{12}	0.125
C_3	0.142	C_{13}	0.214
C_4	0.147	C_{14}	0.165
		C_{15}	0.189
Sub-criteria of C_2	**Exact weight**	**Sub-criteria of C_3**	**Exact weight**
C_{21}	0.113	C_{31}	0.169
C_{22}	0.176	C_{32}	0.407
C_{23}	0.142	C_{33}	0.270
C_{24}	0.172		
C_{25}	0.281		
Sub-criteria of C_4	**Exact weight**		
C_{41}	0.274		
C_{42}	0.169		
C_{43}	0.152		
C_{44}	0.131		
C_{45}	0.118		

C_1: Accessibility, C_2: Environmental Factors, C_3: Economic Factors, C_4: Land Characteristics, C_{11}: Proximity to main roads, C_{12}: Distance from densely populated residential areas, C_{13}: Transportation alternatives, C_{14}: Trafic density of the main roads, C_{15}: Easy access for vehicles, C_{21}: Green space adequacy, C_{22}: Air pollution, C_{23}: Water pollution, C_{24}: Noise pollution, C_{25}: Waste disposal, C_{31}: Construction cost, C_{32}: Land Ownership, C_{33}: Income Level, C_{41}: Land width, C_{42}: Future expansion potential, C_{43}:Construction time, C_{44}: Infrastructure, C_{45}: Natural Disaster Risk

After the defuzzification, the global weight values of the criteria were calculated. The weights of the main criteria and the local weights of the subcriteria are multiplied to obtain the global weights of the criteria. In addition, as per the basis of MCDM methods, the sum of criterion weights should be 1. Therefore, the global weight values for each criterion are normalized. As a result of this normalization, the final weights values of the criteria calculated using the Fuzzy FUCOM are presented in the Table 4.14.

Table 4.14. Final weights of criteria

Main criteria	Sub-criteria	Local weight	Global weight	Normalized weight
Accessibility (*C_1*) (0.595)	Proximity to main roads (*C_{11}*)	0.154	0.091	**0.108**
	Distance from densely populated residential areas (*C_{12}*)	0.125	0.074	**0.088**
	Transportation alternatives (*C_{13}*)	0.214	0.128	**0.151**
	Trafic density of the main roads (*C_{14}*)	0.165	0.098	**0.116**
	Easy access for vehicles (*C_{15}*)	0.189	0.112	**0.133**
Environmental Factors (*C_2*) (0.109)	Green space adequacy (C_{21})	0.113	0.012	**0.015**
	Air pollution (*C_{22}*)	0.176	0.019	**0.023**
	Water pollution (*C_{23}*)	0.142	0.016	**0.018**
	Noise pollution (*C_{24}*)	0.172	0.019	**0.022**
	Waste disposal (*C_{25}*)	0.281	0.031	**0.036**
Economic Factors (*C_3*) (0.142)	Construction cost (*C_{31}*)	0.169	0.024	**0.028**
	Land Ownership (*C_{32}*)	0.407	0.058	**0.068**
	Income Level (*C_{33}*)	0.270	0.038	**0.045**
Land Characteristics (*C_4*) (0.147)	Land width (*C_{41}*)	0.274	0.040	**0.048**
	Future expansion potential (*C_{42}*)	0.169	0.025	**0.029**
	Construction time (*C_{43}*)	0.152	0.022	**0.026**
	Infrastructure (*C_{44}*)	0.131	0.019	**0.023**
	Natural Disaster Risk (*C_{45}*)	0.118	0.017	**0.021**

According to the Table 4.14 the most significant main criterion is accessibility having 59.5%, followed by land characteristics (14.7%), economic factors (14.2%) and environmental factors (10.9%). Further transportation alternatives criterion was ranked as the priority sub-criterion from the accessibility dimension, whereas land width was the most crucial sub-criteria for the land characteristics. Land ownership was ranked first in the ranking as per the economic factors aspect as well. Waste disposal was the most significant sub-criteria in terms of environmental factors aspects, respectively.

The normalized criteria weights derived from the fuzzy FUCOM method were utilized in the fuzzy MARCOS method to evaluate alternatives.

4.3. Ranking of alternatives using the Fuzzy MARCOS method

Step 1: Construct the initial fuzzy decision-making matrix

The linguistic scale used by decision makers to evaluate the alternatives is given in Table 4.5. In order to facilitate the evaluation of alternatives, the same linguistic scale used in the fuzzy FUCOM method was used. First of all, the alternatives were evaluated according to the criteria by each decision maker (DM1, DM2, DM3, DM4, DM5 and DM6) using the scale in Table 4.5.

The linguistic expressions of decision makers are converted into triangular fuzzy numbers and given in Table 4.15, Table 4.16, Table 4.17, Table 4.18, Table 4.19, Table 4.20.

Table 4.15 Fuzzy Matrix Evaluation of DM1 Based on Linguistic Expressions

	A1	**A2**	**A3**	**A4**
C_{11}	(7,8,9)	(5,6,7)	(5,6,7)	(7,8,9)
C_{12}	(1,1,1)	(3,4,5)	(5,6,7)	(1,2,3)
C_{13}	(8,9,10)	(5,6,7)	(2,3,4)	(7,8,9)
C_{14}	(7,8,9)	(3,4,5)	(2,3,4)	(6,7,8)
C_{15}	(7,8,9)	(5,6,7)	(4,5,6)	(6,7,8)
C_{21}	(1,2,3)	(5,6,7)	(4,5,6)	(3,4,5)
C_{22}	(5,6,7)	(3,4,5)	(2,3,4)	(4,5,6)
C_{23}	(3,4,5)	(3,4,5)	(3,4,5)	(3,4,5)
C_{24}	(5,6,7)	(3,4,5)	(2,3,4)	(4,5,6)
C_{25}	(5,6,7)	(5,6,7)	(5,6,7)	(5,6,7)
C_{31}	(7,8,9)	(5,6,7)	(6,7,8)	(4,5,6)
C_{32}	(1,1,1)	(8,9,10)	(1,2,3)	(7,8,9)
C_{33}	(4,5,6)	(6,7,8)	(3,4,5)	(6,7,8)
C_{41}	(7,8,9)	(5,6,7)	(6,7,8)	(5,6,7)
C_{42}	(1,2,3)	(7,8,9)	(7,8,9)	(1,2,3)
C_{43}	(5,6,7)	(5,6,7)	(5,6,7)	(5,6,7)
C_{44}	(8,9,10)	(6,7,8)	(5,6,7)	(7,8,9)
C_{45}	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)

Table 4.16. Fuzzy Matrix Evaluation of DM2 Based on Linguistic Expressions

	A1	**A2**	**A3**	**A4**
C_{11}	(8,9,10)	(6,7,8)	(5,6,7)	(7,8,9)
C_{12}	(1,2,3)	(5,6,7)	(6,7,8)	(1,2,3)
C_{13}	(7,8,9)	(5,6,7)	(3,4,5)	(6,7,8)
C_{14}	(7,8,9)	(5,6,7)	(2,3,4)	(7,8,9)
C_{15}	(6,7,8)	(7,8,9)	(5,6,7)	(7,8,9)
C_{21}	(1,2,3)	(6,7,8)	(4,5,6)	(4,5,6)
C_{22}	(7,8,9)	(2,3,4)	(3,4,5)	(5,6,7)
C_{23}	(5,6,7)	(2,3,4)	(3,4,5)	(5,6,7)
C_{24}	(7,8,9)	(3,4,5)	(2,3,4)	(5,6,7)
C_{25}	(5,6,7)	(4,5,6)	(2,3,4)	(5,6,7)
C_{31}	(7,8,9)	(5,6,7)	(6,7,8)	(4,5,6)
C_{32}	(1,1,1)	(8,9,10)	(1,2,3)	(7,8,9)
C_{33}	(5,6,7)	(6,7,8)	(4,5,6)	(5,6,7)
C_{41}	(7,8,9)	(5,6,7)	(6,7,8)	(4,5,6)
C_{42}	(2,3,4)	(7,8,9)	(7,8,9)	(2,3,4)
C_{43}	(5,6,7)	(5,6,7)	(5,6,7)	(5,6,7)
C_{44}	(6,7,8)	(6,7,8)	(4,5,6)	(6,7,8)
C_{45}	(4,5,6)	(1,2,3)	(1,2,3)	(2,3,4)

Table 4.17. Fuzzy Matrix Evaluation of DM3 Based on Linguistic Expressions

	A1	A2	A3	A4
C_{11}	(6,7,8)	(5,6,7)	(4,5,6)	(7,8,9)
C_{12}	(1,1,1)	(6,7,8)	(7,8,9)	(1,2,3)
C_{13}	(7,8,9)	(3,4,5)	(2,3,4)	(6,7,8)
C_{14}	(6,7,8)	(5,6,7)	(2,3,4)	(7,8,9)
C_{15}	(7,8,9)	(7,8,9)	(6,7,8)	(7,8,9)
C_{21}	(2,3,4)	(5,6,7)	(4,5,6)	(3,4,5)
C_{22}	(7,8,9)	(2,3,4)	(2,3,4)	(3,4,5)
C_{23}	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)
C_{24}	(7,8,9)	(4,5,6)	(2,3,4)	(5,6,7)
C_{25}	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)
C_{31}	(7,8,9)	(4,5,6)	(6,7,8)	(4,5,6)
C_{32}	(1,2,3)	(7,8,9)	(1,2,3)	(7,8,9)
C_{33}	(3,4,5)	(6,7,8)	(3,4,5)	(6,7,8)
C_{41}	(7,8,9)	(5,6,7)	(6,7,8)	(4,5,6)
C_{42}	(1,2,3)	(8,9,10)	(7,8,9)	(1,2,3)
C_{43}	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)
C_{44}	(6,7,8)	(5,6,7)	(5,6,7)	(5,6,7)
C_{45}	(4,5,6)	(3,4,5)	(3,4,5)	(3,4,5)

Table 4.18. Fuzzy Matrix Evaluation of DM4 Based on Linguistic Expressions

	A1	A2	A3	A4
C_{11}	(7,8,9)	(6,7,8)	(5,6,7)	(7,8,9)
C_{12}	(1,2,3)	(5,6,7)	(5,6,7)	(1,2,3)
C_{13}	(7,8,9)	(6,7,8)	(2,3,4)	(6,7,8)
C_{14}	(6,7,8)	(5,6,7)	(2,3,4)	(5,6,7)
C_{15}	(8,9,10)	(8,9,10)	(5,6,7)	(6,7,8)
C_{21}	(1,2,3)	(5,6,7)	(4,5,6)	(3,4,5)
C_{22}	(7,8,9)	(5,6,7)	(5,6,7)	(5,6,7)
C_{23}	(7,8,9)	(5,6,7)	(4,5,6)	(4,5,6)
C_{24}	(7,8,9)	(5,6,7)	(4,5,6)	(6,7,8)
C_{25}	(7,8,9)	(7,8,9)	(6,7,8)	(6,7,8)
C_{31}	(6,7,8)	(5,6,7)	(6,7,8)	(5,6,7)
C_{32}	(1,1,1)	(7,8,9)	(2,3,4)	(7,8,9)
C_{33}	(4,5,6)	(4,5,6)	(4,5,6)	(5,6,7)
C_{41}	(8,9,10)	(6,7,8)	(7,8,9)	(5,6,7)
C_{42}	(3,4,5)	(5,6,7)	(6,7,8)	(3,4,5)
C_{43}	(3,4,5)	(3,4,5)	(3,4,5)	(3,4,5)
C_{44}	(7,8,9)	(6,7,8)	(5,6,7)	(6,7,8)
C_{45}	(4,5,6)	(3,4,5)	(3,4,5)	(3,4,5)

Table 4.19. Fuzzy Matrix Evaluation of DM5 Based on Linguistic Expressions

	A1	A2	A3	A4
C_{11}	(7,8,9)	(6,7,8)	(4,5,6)	(7,8,9)
C_{12}	(1,1,1)	(5,6,7)	(6,7,8)	(1,1,1)
C_{13}	(7,8,9)	(6,7,8)	(2,3,4)	(7,8,9)
C_{14}	(6,7,8)	(5,6,7)	(2,3,4)	(6,7,8)
C_{15}	(6,7,8)	(7,8,9)	(5,6,7)	(7,8,9)
C_{21}	(1,2,3)	(5,6,7)	(4,5,6)	(3,4,5)
C_{22}	(7,8,9)	(5,6,7)	(5,6,7)	(5,6,7)
C_{23}	(5,6,7)	(5,6,7)	(4,5,6)	(4,5,6)
C_{24}	(7,8,9)	(5,6,7)	(3,4,5)	(6,7,8)
C_{25}	(6,7,8)	(6,7,8)	(6,7,8)	(6,7,8)
C_{31}	(7,8,9)	(4,5,6)	(6,7,8)	(4,5,6)
C_{32}	(1,1,1)	(8,9,10)	(2,3,4)	(7,8,9)
C_{33}	(5,6,7)	(5,6,7)	(4,5,6)	(5,6,7)
C_{41}	(7,8,9)	(5,6,7)	(6,7,8)	(4,5,6)
C_{42}	(2,3,4)	(6,7,8)	(6,7,8)	(2,3,4)
C_{43}	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)
C_{44}	(7,8,9)	(7,8,9)	(5,6,7)	(6,7,8)
C_{45}	(4,5,6)	(3,4,5)	(3,4,5)	(3,4,5)

Table 4.20. Fuzzy Matrix Evaluation of DM6 Based on Linguistic Expressions

	A1	A2	A3	A4
C_{11}	(7,8,9)	(5,6,7)	(4,5,6)	(7,8,9)
C_{12}	(1,2,3)	(6,7,8)	(7,8,9)	(1,2,3)
C_{13}	(7,8,9)	(3,4,5)	(1,2,3)	(6,7,8)
C_{14}	(7,8,9)	(4,5,6)	(2,3,4)	(7,8,9)
C_{15}	(7,8,9)	(6,7,8)	(5,6,7)	(7,8,9)
C_{21}	(2,3,4)	(6,7,8)	(4,5,6)	(3,4,5)
C_{22}	(6,7,8)	(4,5,6)	(3,4,5)	(5,6,7)
C_{23}	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)
C_{24}	(6,7,8)	(3,4,5)	(2,3,4)	(6,7,8)
C_{25}	(5,6,7)	(5,6,7)	(5,6,7)	(5,6,7)
C_{31}	(6,7,8)	(5,6,7)	(6,7,8)	(4,5,6)
C_{32}	(1,1,1)	(7,8,9)	(1,2,3)	(7,8,9)
C_{33}	(4,5,6)	(6,7,8)	(3,4,5)	(6,7,8)
C_{41}	(7,8,9)	(5,6,7)	(6,7,8)	(5,6,7)
C_{42}	(2,3,4)	(7,8,9)	(6,7,8)	(2,3,4)
C_{43}	(5,6,7)	(5,6,7)	(5,6,7)	(5,6,7)
C_{44}	(7,8,9)	(6,7,8)	(6,7,8)	(7,8,9)
C_{45}	(3,4,5)	(3,4,5)	(3,4,5)	(3,4,5)

Each DM's evaluations of alternative-criteria were combined using the geometric mean. The initial fuzzy decision matrix constructed using the geometric mean is given in the Table 4.21.

Table 4.21. Initial Fuzzy Decision Matrix

	A1	A2	A3	A4
C_{11}	(6.976,7.979,8.981)	(5.477,6.481,7.483)	(4.472,5.477,6.481)	(7,8,9)
C_{12}	(1,1.414,1.732)	(4.880,5.904,6.919)	(5.944,6.952,7.958)	(1,1.782,2.498)
C_{13}	(7.158,8.159,9.159)	(4.481,5.518,6.542)	(1.906,2.942,3.957)	(6.316,7.319,8.320)
C_{14}	(6.481,7.483,8.485)	(4.424,5.440,6.450)	(2,3,4)	(6.287,7.294,8.299)
C_{15}	(6.799,7.803,8.807)	(6.596,7.605,8.613)	(4.966,5.972,6.976)	(6.649,7.652,8.653)
C_{21}	(1.260,2.289,3.302)	(5.313,6.316,7.319)	(4,5,6)	(3.147,4.152,5.154)
C_{22}	(6.450,7.458,8.463)	(3.260,4.318,5.353)	(3.107,4.160,5.192)	(4.424,5.440,6.450)
C_{23}	(4.509,5.536,6.556)	(3.659,4.702,5.727)	(3.634,4.642,5.646)	(3.957,4.966,5.972)
C_{24}	(6.450,7.458,8.463)	(3.732,4.752,5.766)	(2.402,3.427,4.442)	(5.277,6.287,7.294)
C_{25}	(5.253,6.265,7.274)	(5.061,6.078,7.090)	(4.394,5.459,6.498)	(5.119,6.127,7.133)
C_{31}	(6.649,7.652,8.653)	(4.642,5.646,6.649)	(6,7,8)	(4.152,5.154,6.156)
C_{32}	(1,1.122,1.201)	(7.483,8.485,9.487)	(1.260,2.289,3.302)	(7,8,9)
C_{33}	(4.107,5.119,6.127)	(5.440,6.450,7.458)	(3.238,4.263,5.277)	(5.477,6.481,7.483)
C_{41}	(7.158,8.159,9.159)	(5.154,6.156,7.158)	(6.156,7.158,8.159)	(4.472,5.477,6.481)
C_{42}	(1.698,2.749,3.772)	(6.596,7.605,8.613)	(6.481,7.483,8.485)	(1.698,2.749,3.772)
C_{43}	(4.263,5.277,6.287)	(4.263,5.277,6.287)	(4.263,5.277,6.287)	(4.263,5.277,6.287)
C_{44}	(6.799,7.803,8.807)	(5.972,6.976,7.979)	(4.966,5.972,6.976)	(6.127,7.133,8.137)
C_{45}	(3.026,4.135,5.185)	(2.080,3.175,4.217)	(2.080,3.175,4.217)	(2.335,3.397,4.424)

Step 2: Construct the extended initial fuzzy decision matrix

Extended initial fuzzy decision matrix was obtained by adding fuzzy ideal $\tilde{A}(ID)$ and anti-ideal $\tilde{A}(AI)$ solutions to the initial fuzzy decision matrix using Equation (3.14) and Equation (3.15). Fuzzy $\tilde{A}(ID)$ solution means ideal, that is, the best solution, and represents the solution that maximizes the benefit criteria and minimizes the cost criteria. On the other hand, Fuzzy $\tilde{A}(AI)$ solution means anti-ideal, that is, the worst solution, and represents the solution that minimizes the benefit criteria and maximizes the cost criteria.

C_{11}, C_{12}, C_{13}, C_{15}, C_{21}, C_{25}, C_{32}, C_{41}, C_{42} and C_{44} are benefit criteria, while C_{14}, C_{22}, C_{23}, C_{24}, C_{31}, C_{33}, C_{43} ve C_{45} are cost criteria.

The extended initial fuzzy decision matrix is given in Table 4.22.

Step 3: Normalization of the extended initial fuzzy decision matrix

The extended initial fuzzy decision matrix $\tilde{X}$ was normalized using Equation (3.16) and (3.17). Normalization is performed depending on the type of criteria (benefit or cost). The normalized extended initial fuzzy decision matrix is given in Table 4.23.

Step 4: The determination of a weighted extended initial fuzzy decision matrix

The weighted extented initial fuzzy decision matrix was obtained by multiplying the weights of the criteria obtained by the fuzzy FUCOM method with the normalized extented initial fuzzy decision matrix. This process was performed using Equation (3.18). The weighted extended initial fuzzy decision matrix is given in Table 4.24.

Table 4.22. Extended Initial Fuzzy Decision Matrix

	ID	A1	A2	A3	A4	AI
C_{11}	(7,8,9)	(6.976,7.979,8.981)	(5.477,6.481,7.483)	(4.472,5.477,6.481)	(7,8,9)	(4.472,5.477,6.481)
C_{12}	(5.944,6.952,7.958)	(1,1.414,1.732)	(4.880,5.904,6.919)	(5.944,6.952,7.958)	(1,1.782,2.498)	(1,1.414,1.732)
C_{13}	(7.158,8.159,9.159)	(7.158,8.159,9.159)	(4.481,5.518,6.542)	(1.906,2.942,3.957)	(6.316,7.319,8.320)	(1.906,2.942,3.957)
C_{14}	(2,3,4)	(6.481,7.483,8.485)	(4.424,5.440,6.450)	(2,3,4)	(6.287,7.294,8.299)	(6.481,7.483,8.485)
C_{15}	(6.799,7.803,8.807)	(6.799,7.803,8.807)	(6.596,7.605,8.613)	(4.966,5.972,6.976)	(6.649,7.652,8.653)	(4.966,5.972,6.976)
C_{21}	(5.313,6.316,7.319)	(1.260,2.289,3.302)	(5.313,6.316,7.319)	(4,5,6)	(3.147,4.152,5.154)	(1.260,2.289,3.302)
C_{22}	(3.107,4.160,5.192)	(6.450,7.458,8.463)	(3.260,4.318,5.353)	(3.107,4.160,5.192)	(4.424,5.440,6.450)	(6.450,7.458,8.463)
C_{23}	(3.634,4.642,5.646)	(4.509,5.536,6.556)	(3.659,4.702,5.727)	(3.634,4.642,5.646)	(3.957,4.966,5.972)	(4.509,5.536,6.556)
C_{24}	(2.402,3.427,4.442)	(6.450,7.458,8.463)	(3.732,4.752,5.766)	(2.402,3.427,4.442)	(5.277,6.287,7.294)	(6.450,7.458,8.463)
C_{25}	(5.253,6.265,7.274)	(5.253,6.265,7.274)	(5.061,6.078,7.090)	(4.394,5.459,6.498)	(5.119,6.127,7.133)	(4.394,5.459,6.498)
C_{31}	(4.152,5.154,6.156)	(6.649,7.652,8.653)	(4.642,5.646,6.649)	(6,7,8)	(4.152,5.154,6.156)	(6.649,7.652,8.653)
C_{32}	(7.483,8.485,9.487)	(1,1.122,1.201)	(7.483,8.485,9.487)	(1.260,2.289,3.302)	(7,8,9)	(1,1.122,1.201)
C_{33}	(3.238,4.263,5.277)	(4.107,5.119,6.127)	(5.440,6.450,7.458)	(3.238,4.263,5.277)	(5.477,6.481,7.483)	(5.477,6.481,7.483)
C_{41}	(7.158,8.159,9.159)	(7.158,8.159,9.159)	(5.154,6.156,7.158)	(6.156,7.158,8.159)	(4.472,5.477,6.481)	(4.472,5.477,6.481)
C_{42}	(6.596,7.605,8.613)	(1.698,2.749,3.772)	(6.596,7.605,8.613)	(6.481,7.483,8.485)	(1.698,2.749,3.772)	(1.698,2.749,3.772)
C_{43}	(4.263,5.277,6.287)	(4.263,5.277,6.287)	(4.263,5.277,6.287)	(4.263,5.277,6.287)	(4.263,5.277,6.287)	(4.263,5.277,6.287)
C_{44}	(6.799,7.803,8.807)	(6.799,7.803,8.807)	(5.972,6.976,7.979)	(4.966,5.972,6.976)	(6.127,7.133,8.137)	(4.966,5.972,6.976)
C_{45}	(2.080,3.175,4.217)	(3.026,4.135,5.185)	(2.080,3.175,4.217)	(2.080,3.175,4.217)	(2.335,3.397,4.424)	(3.026,4.135,5.185)

Table 4.23. Normalized Extended Initial Fuzzy Decision Matrix

	ID	A1	A2	A3	A4	AI
C_{11}	(0.778,0.889,1)	(0.775,0.887,0.998)	(0.609,0.720,0.831)	(0.497,0.609,0.720)	(0.778,0.889,1)	(0.497,0.609,0.720)
C_{12}	(0.747,0.874,1)	(0.126,0.178,0.218)	(0.613,0.742,0.869)	(0.747,0.874,1)	(0.126,0.224,0.314)	(0.126,0.178,0.218)
C_{13}	(0.781,0.891,1)	(0.781,0.891,1)	(0.489,0.602,0.714)	(0.208,0.321,0.432)	(0.690,0.799,0.908)	(0.208,0.321,0.432)
C_{14}	(0.500,0.667,1)	(0.236,0.267,0.309)	(0.310,0.368,0.452)	(0.500,0.667,1)	(0.241,0.274,0.318)	(0.236,0.267,0.309)
C_{15}	(0.772,0.886,1)	(0.772,0.886,1)	(0.749,0.864,0.978)	(0.564,0.678,0.792)	(0.755,0.869,0.983)	(0.564,0.678,0.792)
C_{21}	(0.726,0.863,1)	(0.172,0.313,0.451)	(0.726,0.863,1)	(0.547,0.683,0.820)	(0.430,0.567,0.704)	(0.172,0.313,0.451)
C_{22}	(0.598,0.747,1)	(0.367,0.417,0.482)	(0.580,0.720,0.953)	(0.598,0.747,1)	(0.482,0.571,0.702)	(0.367,0.417,0.482)
C_{23}	(0.644,0.783,1)	(0.554,0.656,0.806)	(0.635,0.773,0.993)	(0.644,0.783,1)	(0.609,0.732,0.918)	(0.554,0.656,0.806)
C_{24}	(0.541,0.701,1)	(0.284,0.322,0.372)	(0.417,0.505,0.644)	(0.541,0.701,1)	(0.329,0.382,0.455)	(0.284,0.322,0.372)
C_{25}	(0.722,0.861,1)	(0.722,0.861,1)	(0.696,0.835,0.975)	(0.604,0.750,0.893)	(0.704,0.842,0.981)	(0.604,0.750,0.893)
C_{31}	(0.674,0.805,1)	(0.480,0.543,0.624)	(0.624,0.735,0.894)	(0.519,0.593,0.692)	(0.674,0.805,1)	(0.480,0.543,0.624)
C_{32}	(0.789,0.894,1)	(0.105,0.118,0.127)	(0.789,0.894,1)	(0.133,0.241,0.348)	(0.738,0.843,0.949)	(0.105,0.118,0.127)
C_{33}	(0.614,0.760,1)	(0.528,0.632,0.788)	(0.434,0.502,0.595)	(0.614,0.760,1)	(0.433,0.500,0.591)	(0.433,0.500,0.591)
C_{41}	(0.781,0.891,1)	(0.781,0.891,1)	(0.563,0.672,0.781)	(0.672,0.781,0.891)	(0.488,0.598,0.708)	(0.488,0.598,0.708)
C_{42}	(0.766,0.883,1)	(0.197,0.319,0.438)	(0.766,0.883,1)	(0.752,0.869,0.985)	(0.197,0.319,0.438)	(0.197,0.319,0.438)
C_{43}	(0.678,0.808,1)	(0.678,0.808,1)	(0.678,0.808,1)	(0.678,0.808,1)	(0.678,0.808,1)	(0.678,0.808,1)
C_{44}	(0.772,0.886,1)	(0.772,0.886,1)	(0.678,0.792,0.906)	(0.564,0.678,0.792)	(0.696,0.810,0.924)	(0.564,0.678,0.792)
C_{45}	(0.493,0.655,1)	(0.401,0.503,0.687)	(0.493,0.655,1)	(0.493,0.655,1)	(0.470,0.612,0.891)	(0.401,0.503,0.687)

Table 4.24. Weighted Extended Initial Fuzzy Decision Matrix

	ID	**A1**	**A2**	**A3**	**A4**	**AI**
C_{11}	(0.084,0.096,0.108)	(0.084,0.096,0.108)	(0.066,0.078,0.090)	(0.054,0.066,0.078)	(0.084,0.096,0.108)	(0.054,0.066,0.078)
C_{12}	(0.066,0.077,0.088)	(0.011,0.016,0.019)	(0.054,0.065,0.077)	(0.066,0.077,0.088)	(0.011,0.020,0.028)	(0.011,0.016,0.019)
C_{13}	(0.118,0.135,0.151)	(0.118,0.135,0.151)	(0.074,0.091,0.108)	(0.031,0.048,0.065)	(0.104,0.121,0.137)	(0.031,0.048,0.065)
C_{14}	(0.058,0.078,0.116)	(0.027,0.031,0.036)	(0.036,0.043,0.053)	(0.058,0.078,0.116)	(0.028,0.032,0.037)	(0.027,0.031,0.036)
C_{15}	(0.103,0.118,0.133)	(0.103,0.118,0.133)	(0.100,0.115,0.130)	(0.075,0.090,0.106)	(0.101,0.116,0.131)	(0.075,0.090,0.106)
C_{21}	(0.011,0.013,0.015)	(0.003,0.005,0.007)	(0.011,0.013,0.015)	(0.008,0.010,0.012)	(0.006,0.008,0.010)	(0.003,0.005,0.007)
C_{22}	(0.014,0.017,0.023)	(0.008,0.009,0.011)	(0.013,0.016,0.022)	(0.014,0.017,0.023)	(0.011,0.013,0.016)	(0.008,0.009,0.011)
C_{23}	(0.012,0.014,0.018)	(0.010,0.012,0.015)	(0.012,0.014,0.018)	(0.012,0.014,0.018)	(0.011,0.013,0.017)	(0.010,0.012,0.015)
C_{24}	(0.012,0.016,0.022)	(0.006,0.007,0.008)	(0.009,0.011,0.014)	(0.012,0.016,0.022)	(0.007,0.008,0.010)	(0.006,0.007,0.008)
C_{25}	(0.026,0.031,0.036)	(0.026,0.031,0.036)	(0.025,0.030,0.035)	(0.022,0.027,0.032)	(0.026,0.031,0.036)	(0.022,0.027,0.032)
C_{31}	(0.019,0.023,0.028)	(0.014,0.015,0.018)	(0.018,0.021,0.025)	(0.015,0.017,0.020)	(0.019,0.023,0.028)	(0.014,0.015,0.018)
C_{32}	(0.054,0.061,0.068)	(0.007,0.008,0.009)	(0.054,0.061,0.068)	(0.009,0.017,0.024)	(0.050,0.058,0.065)	(0.007,0.008,0.009)
C_{33}	(0.028,0.034,0.045)	(0.024,0.029,0.036)	(0.020,0.023,0.027)	(0.028,0.034,0.045)	(0.020,0.023,0.027)	(0.020,0.023,0.027)
C_{41}	(0.037,0.042,0.048)	(0.037,0.042,0.048)	(0.027,0.032,0.037)	(0.032,0.037,0.042)	(0.023,0.028,0.034)	(0.023,0.028,0.034)
C_{42}	(0.022,0.026,0.029)	(0.006,0.009,0.013)	(0.022,0.026,0.029)	(0.022,0.026,0.029)	(0.006,0.009,0.013)	(0.006,0.009,0.013)
C_{43}	(0.018,0.021,0.026)	(0.018,0.021,0.026)	(0.018,0.021,0.026)	(0.018,0.021,0.026)	(0.018,0.021,0.026)	(0.018,0.021,0.026)
C_{44}	(0.018,0.020,0.023)	(0.018,0.020,0.023)	(0.015,0.018,0.021)	(0.013,0.015,0.018)	(0.016,0.018,0.021)	(0.013,0.015,0.018)
C_{45}	(0.010,0.013,0.021)	(0.008,0.010,0.014)	(0.010,0.013,0.021)	(0.010,0.013,0.021)	(0.010,0.013,0.018)	(0.008,0.010,0.014)

Step 5: Calculation of the utility degree of alternatives $(\tilde{K}_i)$

The utility degree of alternatives $\tilde{K}_i$ regarding the ideal and anti-ideal solution was calculated by using the Equation (3.19), Equation (3.20) and Equation (3.21).

$\tilde{S}_i$ values and utility degrees of alternatives $(\tilde{K}_i^+,\ \tilde{K}_i^-)$ are given in the Table 4.25.

Table 4.25. The Utility Degree of Alternatives $\tilde{K}_i$

	$\tilde{S}_i$	$\tilde{K}_i^+$	$\tilde{K}_i^-$
ID	(0.710,0.836,1)	-	-
A1	(0.528,0.616,0.710)	(0.528,0.737,1.001)	(0.987,1.389,1.991)
A2	(0.584,0.692,0.817)	(0.584,0.828,1.151)	(1.091,1.563,2.290)
A3	(0.498,0.624,0.786)	(0.498,0.747,1.108)	(0.931,1.409,2.204)
A4	(0.551,0.652,0.762)	(0.551,0.779,1.074)	(1.030,1.470,2.137)
AI	(0.357,0.443,0.535)	-	-

Step 6: Calculation of fuzzy matrix $\tilde{T}_i$ **using Equation (3.22)**

$\tilde{T}_i$ value expresses the sum of the distance values according to the ideal and anti-ideal solution value. $\tilde{T}_i$ values were calculated using Equation (3.22) and $\tilde{T}_i$ and $\tilde{T}_{i\max}$ values are given in Table 4.26.

Table 4.26. $\tilde{T}_i$ Values

	$\tilde{T}_i$
A1	(1.516,2.126,2.992)
A2	(1.674,2.391,3.440)
A3	(1.429,2.155,3.312)
A4	(1.581,2.250,3.212)
$\tilde{T}_{i\max}$	(1.674,2.391,3.440)

And then, the $\tilde{T}_{i\max}$ value was defuzzified as shown below

$$\tilde{T}_{i\max} = (t_{i\max}^l, t_{i\max}^m, t_{i\max}^u) = (1.674,\ 2.391,\ 3.440)$$

$$\tilde{T}_{i\max} = \frac{t_{i\max}^l + 4 * t_{i\max}^m + t_{i\max}^u}{6}$$

$$\tilde{T}_{i\max} = \frac{1.674 + 4 * 2.391 + 3.440}{6} = 2.446$$

Step 7: Determination of utility functions regarding to ideal $f(\tilde{K}_i^+)$ and anti-ideal $f(\tilde{K}_i^-)$ solutions

The utility functions regarding to ideal $f(\tilde{K}_i^+)$ and anti-ideal $f(\tilde{K}_i^-)$ solutions were calculated using Equation (3.24) and Equation (3.25) and these values are given in the Table 4.27.

Table 4.27. Utility Functions Regarding To Ideal $f(\tilde{K}_i^+)$ and Anti-ideal $f(\tilde{K}_i^-)$ Solutions

	$f(\tilde{K}_i^+)$	$f(\tilde{K}_i^-)$
A1	(0.404,0.568,0.814)	(0.216,0,301,0.409)
A2	(0.446,0.639,0.936)	(0.239,0.339,0.470)
A3	(0.381,0.576,0.901)	(0.204,0.305,0.453)
A4	(0.421,0.601,0.874)	(0.225,0.319,0.439)

After utility functions regarding to ideal and anti-ideal solutions were determined, $\tilde{K}_i^+, \tilde{K}_i^-, f(\tilde{K}_i^+), f(\tilde{K}_i^-)$ values were defuzzified.

Step 8: Determination of the final utility function of alternatives $f(\tilde{K}_i)$ by using Equation (3.26)

The utility function was calculated for each alternative location using Equation (3.26). The calculated final utility function values of the alternatives $f(\tilde{K}_i)$ and alternative rankings based on $f(\tilde{K}_i)$ are given in the Table 4.28.

Table 4.28. Alternative Rankings Based on $f(\tilde{K}_i)$

	$\tilde{K}_i^+$	$\tilde{K}_i^-$	$f(\tilde{K}_i^+)$	$f(\tilde{K}_i^-)$	$f(\tilde{K}_i)$	**Ranking**
A1	0.746	1.423	0.582	0.305	0.542	**4**
A2	0.841	1.605	0.656	0.344	0.713	**1**
A3	0.765	1.461	0.597	0.313	0.575	**3**
A4	0.791	1.508	0.616	0.323	0.618	**2**

To select the best alternative, $f(\tilde{K}_i)$ the values were ranked from largest to smallest. The alternative with the largest $f(\tilde{K}_i)$ value is the best alternative location.

According to the results of the fuzzy MARCOS method (in Table 4.28), it was concluded that the most suitable location for the field hospital is TUYAP Adana Fair and Congress Center Surrounding (A2), followed by Adana Northern Junction Surrounding (A4) and Karaisalı Highway Junction (A3) alternatives, and the worst alternative location is BOSSA DENIM Factory-old area (A1).

4.4. Sensitivity Analysis

In the last section of this thesis, sensitivity analysis was performed to demonstrate the validity and accuracy of the proposed fuzzy MCDM model. The validity of the ranking results obtained from the fuzzy MARCOS method was also shown by means of fuzzy version of some other ranking MCDM methods (TOPSIS, WASPAS, SAW, ARAS, COPRAS, PIV and MABAC) which are widely used in the literature and proven their validation in many studies (Stanković et al., 2020; Gölcük et al., 2022; Görçün and Doğan, 2023; Ecer and Pamucar, 2021; Büyüközkan et al., 2021; Tuş and Adalı, 2022; Vesković et al., 2022; Wang et al., 2022).
The alternative ranking obtained from our proposed fuzzy MCDM model and the fuzzy FUCOM based MCDM methods mentioned seven fuzzy MCDM methods is depicted in Table 4.29.

Table 4.29. Comparative ranking of fuzzy FUCOM-based MCDM methods

	Fuzzy MARCOS	**Fuzzy TOPSIS**	**Fuzzy WASPAS**	**Fuzzy SAW**	**Fuzzy ARAS**	**Fuzzy COPRAS**	**Fuzzy PIV**	**Fuzzy MABAC**
A1	**4**	4	4	4	4	4	3	3
A2	**1**	1	1	1	1	1	1	1
A3	**3**	3	3	3	2	2	4	4
A4	**2**	2	2	2	3	3	2	2

According to the results shown in Table 4.29, the alternative A2 ranks first in all applied fuzzy MCDM methods. While the ranking results of the fuzzy MARCOS method are completely consistent with the fuzzy TOPSIS, fuzzy WASPAS and fuzzy SAW methods, the differences are quite small with the fuzzy ARAS, fuzzy COPRAS, fuzzy PIV and fuzzy MABAC methods. As a result, the fuzzy FUCOM & fuzzy MARCOS model proposed in this thesis presented similar results when compared to other fuzzy MCDM methods. It was seen that the best alternative was A2 in all applied methods. Thus, with this sensitivity analysis, the accuracy and validity of the proposed fuzzy FUCOM & fuzzy MARCOS model has been proven.

5. CONCLUSIONS

Human beings have struggled with many natural disasters such as earthquakes, floods, fires, volcanic eruptions, hurricanes and epidemics. Among these natural disasters, epidemics have deeply affected societies and caused the death of hundreds of people. The coronavirus disease (COVID-19), which the whole world has been struggling with recently, has turned into a pandemic that has caused the death of thousands of people worldwide. In this process, the resources and capacity of existing hospitals were insufficient due to the rapid transmission rate of COVID-19 and uncertainty of demand. Some countries looked for solution to this situation by building field hospitals. Since it is predicted that increase the number of pandemics in the coming years authorities and policymakers need to take precautions. Therefore, in this thesis study, field hospital location selection in case of a possible pandemic in the future to slow down the spread of the pandemic.

In this study, an optimization-based fuzzy FUCOM & fuzzy MARCOS model based on the subjective evaluations of decision makers was proposed for field hospital location selection in Adana. As a result of extensive literature review, the proposed fuzzy MCDM model has not been found to be used in both hospital location selection problem and also field hospital location selection problem. Therefore, it is thought that this thesis study would contribute to the literature.

According to the results of the proposed combined fuzzy MCDM model, TÜYAP Adana Fair and Congress Center Surroundings (A2) is determined as the most suitable field hospital location in Adana. In the ranking, Adana Northern Junction Surrounding (A4) and Karaisalı Highway Junction (A3), and BOSSA DENIM Factory-old area (A1) are obtained as the second, third and fourth locations, respectively.

In this thesis study, a sensitivity analysis is applied to test the accuracy and validity of the proposed fuzzy MCDM model by comparing other ranking MCDM methods. According to the comparative results, the A2 alternative rank first in both our model and all applied other MCDM methods combined with fuzzy FUCOM method. As a result, this study will shed light on future pandemics.

6. RECOMMENDATIONS

In future studies, other fuzzy numbers can be used instead of Triangular Fuzzy Numbers (TFNs). In addition, in this thesis study, alternative locations were determined according to the opinions of decision makers. These alternative locations can be determined using Geographic Information System (GIS). Besides, in future studies, other methods of multi-criteria decision-making can also be used in order to location selection of field hospital.

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