ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

A NOVEL PICTURE FUZZY ELECTRE METHOD AND ITS APPLICATION TO LONG-TERM SHELTER SITE SELECTION AFTER AN EARTHQUAKE: THE CASE OF ANTAKYA

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

ÖZGÜN GÖRÜNTÜ BULANIK SAYI ELECTRE METODU VE DEPREM SONRASI UZUN VADELİ GEÇİCİ YERLEŞİM BÖLGESİ SEÇİMİ ÜZERİNE UYGULAMASI: ANTAKYA ÖRNEĞİ

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Beril AKKAYA, a M.Sc. student of ITU Graduate School student ID 507201123 successfully defended the thesis entitled "A NOVEL PICTURE FUZZY ELECTRE METHOD AND ITS APPLICATION TO LONG-TERM SHELTER SITE SELECTION AFTER AN EARTHQUAKE: THE CASE OF ANTAKYA", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my dear father, Ali

FOREWORD

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Beril AKKAYA
(Industrial Engineer)

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ABBREVIATIONS

AHP	: Analytical Hierarchy Process
EDAS	: Evaluation Based on Distance From Average solution
ELECTRE	: Elimination and Choice Translating Reality
IF ELECTRE	: Intuitionistic Fuzzy ELECTRE
MABAC	: Multi-Attribute Border Approximation Area Comparison
MAIRCA	: Multi-Atributive Ideal-Real Comparative Analysis
MCDM	: Multi-Criteria Decision-Making
MOMP	: Multi-Objective Mathematical Programming
PiF ELECTRE	: Picture Fuzzy ELECTRE
SWARA	: Step Wise Weight Assessment Ratio Analysis
FFS	: Fermatean Fuzzy Sets
IF	: Intuitionistic Fuzzy
IFN	: Intuitionistic Fuzzy Number
IFS	: Intuitionistic Fuzzy Sets
IT2FS	: Interval Type-2 Fuzzy Sets
PFS	: Pythagorean Fuzzy Sets
PiF	: Picture Fuzzy
PiFN	: Picture Fuzzy Number
PiFS	: Picture Fuzzy Sets
q-ROF	: q-Rung Orthopair Fuzzy
SF	: Spherical Fuzzy
t-SF	: T-Spherical Fuzzy
t-SFS	: T-Spherical Fuzzy Sets
T2FS	: Type-2 Fuzzy Sets

SYMBOLS

S	: Score function
A	: Accuracy function
$\boldsymbol{\mu}_A(\boldsymbol{x})$	: Positive membership degree of PiFN A
$\boldsymbol{\eta}_A(\boldsymbol{x})$	: Neutral membership degree of PiFN A
$\boldsymbol{\nu}_A(\boldsymbol{x})$	: Negative membership degree of PiFN A
$\boldsymbol{\pi}_A(\boldsymbol{x})$	: Refusal membership degree of PiFN A
$\mathbf{d_h(X_{kj},X_{lj})}$	: Hamming distance between alternative k and l with respect to criterion j
$\mathbf{d_e(X_{kj},X_{lj})}$	: Euclidean distance between alternative k and l with respect to criterion j
M	: Fuzzy decision matrix
$\mathbf{w_j}$	: Weight of criterion j
$\mathbf{SC_{kl}}$	: Strong concordance set of alternative k with respect to j
$\mathbf{C_{kl}}$	: Concordance set of alternative k with respect to j
$\mathbf{MC_{kl}}$	: Moderate concordance set of alternative k with respect to j
$\mathbf{WC_{kl}}$	: Weak concordance set of alternative k with respect to j
$\mathbf{SD_{kl}}$	: Strong discordance set of alternative k with respect to j
$\mathbf{D_{kl}}$	: Discordance set of alternative k with respect to j
$\mathbf{MD_{kl}}$	: Moderate discordance set of alternative k with respect to j
$\mathbf{WD_{kl}}$	: Weak discordance set of alternative k with respect to j
$\mathbf{g_{kl}}$	: Concordance index of alternative k with respect to j
$\mathbf{h_{kl}}$	: Discordance index of alternative k with respect to j
$\mathbf{k_{kl}}$	: Concordance dominance matrix index of alternative k with respect to j
$\mathbf{l_{kl}}$	: Discordance dominance matrix index of alternative k with respect to j
$\mathbf{r_{kl}}$	: Aggregate dominance matrix index of alternative k with respect to j
$\bar{\boldsymbol{T}}_{kl}$	: Final value of alternative k
$\boldsymbol{\beta}_j$	: Comparative importance degree of criterion j
$\mathbf{p_j}$	: Comparative importance index of criterion j
$\mathbf{r_j}$	: Importance degree of criterion j

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SUMMARY

Decision-making is an essential part of human life, involving continuous choices made by individuals, institutions, and companies. While some decisions are straightforward, others are more complex and require specific methodologies to reach conclusions. These methodologies are developed to address the challenges of decision-making. Decision-making can be categorized into single and multi-criteria approaches. Decision-making environments can be classified based on the availability and certainty of information. In deterministic environments the decision-making process is fairly straightforward as the information is known and certain, whereas in risky and uncertain environments, the process becomes more challenging. In addition to these classifications, fuzzy decision-making environments address circumstances where even defining the boundaries of goals and constraints becomes a complex task. Traditional multi-criteria decision-making approaches, designed for precise information are not suitable for such problems. Fuzzy methods allow for the representation of ambiguous or imprecise information through partial memberships dissimilarly to crisp sets. Fuzzy settings have been shown to be more beneficial when dealing with problems that heavily rely on human judgement, as they account for linguistic expressions of people during the evaluation of alternatives and criteria in MCDM problems. Consequently, many MCDM methods are extended to fuzzy settings. MCDM methods encompass hierarchical approaches, multi-objective mathematical programming, and outranging methods. Outranking methods rely on pairwise comparison of criteria to determine the best alternative, or the ranking of the alternatives. Among the outranging methods, the ELECTRE methods family is widely used. They are utilized for alternative selection problems, ranking of the alternatives, and assigning them to pre-defined categories. Various fuzzy extensions of the ELECTRE methods exist, enabling the representation of vagueness and ambiguities. Picture fuzzy sets excel in representing human consideration, expressing the thoughts in terms of positivity, neutrality, negativity, and refusal. However, only ELECTRE methods integrated with other methods such as EDAS and TODIM were extended to picture fuzzy settings and a complete ELECTRE method extension has not been made. The motivation behind this thesis is to address the absence of a picture fuzzy ELECTRE method in the existing literature, despite the potential of picture fuzzy sets to capture the impreciseness in human thought. The goal of the study is to extend the ELECTRE method to the picture fuzzy environment. Additionally, the devastating earthquakes that occurred in Turkey, on February 6, 2023, serve as an additional motivation for conducting an experimental study to aid decision-making

in the affected region, particularly in Hatay. The main objective of this thesis is to propose a methodology for the selection of long-term shelter site selection following this disaster along with an effective application analysis to ensure its practicality. To ensure the relevance and accuracy of the study, decision-makers from various fields of expertise related to the subject are involved. The criteria for evaluation of the problem are determined by a literature review. Criteria weights are evaluated by the experts, then criteria weights are finalized by using SWARA method. The alternative locations also proposed by a local scholar. The expert also evaluated alternatives with PiF linguistic scale to construct initial decision matrix. After the procedure of the method is completed, the best alternative for shelter site is decided as North Side of the Asi River. A sensitivity analysis by assigning different weights to different types of concordance and discordance sets and using different distance measures are performed, and the results indicates the consistency of method and the solutions. Finally, a comparative study is conducted with the TOPSIS method and MAIRCA-ELECTRE methodology.

ÖZGÜN GÖRÜNTÜ BULANIK SAYI ELECTRE METODU VE DEPREM SONRASI UZUN VADELİ GEÇİCİ YERLEŞİM BÖLGESİ SEÇİMİ ÜZERİNE UYGULAMASI: ANTAKYA ÖRNEĞİ

ÖZET

Karar verme, varoluşun en önemli parçalarından biridir. Yaşamı boyunca, her insan sürekli olarak önemli veya önemsiz kararlar vermektedir. Tıpkı insanlar gibi kurumlar, şirketler, vakıflar benzeri tüm yapılar varlıklarını bu sürekli olan karar verme süreci sayesinde sürdürmektedirler. Her ne kadar karar verme tüm bu yapılar için kesintisiz ve sürekli devam eden bir süreç olsa da, bazı konular veya problemler kolaylıkla karar vermek için fazlasıyla karmaşıktır. Karar verme yöntemleri bu tarz karmaşık problemlerle baş edebilmek için geliştirilmişlerdir.

Tek kritere dayalı karar verme daha basit bir süreç olarak ele alınabilirken, birden fazla kritere göre değerlendirilmesi gereken problemler daha karmaşık yaklaşımlar gerektirmektedir. Bu tür problemlerin üstesinden gelmek amacıyla ortaya konan metotlar, çok kriterli karar verme (ÇKKV) yöntemleri olarak adlandırılmaktadırlar.

Ayrıca, karar verme ortamları elde mevcuy bulunan veya bulunması gereken bilgiler göz önünde bulundurarak bazı sınıflara ayrılmaktadır. Örneğin, deterministik ortam kesin bilgiler içermektedir ve herhangi bir belirsizlik durumu bu ortamda yoktur. Riskli ve belirsiz ortamlarda ise problemler belirsiz bilgiler içermektedir. Riskli ortamlarda olası sonuçlar az çok bilinir ve öngörülebilirken, belirsizlik ortamında bilgi eksiklikleri nedeniyle sonuçlara olasılık atamak bile başlı başına karmaşık bir iştir. Bunlara ek olarak, problemin amaç veya kısıtlarının sınırlarının dahi belirlenmesinin zorlu bir görev olduğu bulanık karar verme ortamı bulunmaktadır.

Gözlem kümeleri arasında kolay tanımlanabilir sınırların olmadığı bu ÇKKV problemleriyle baş edebilme ihtiyacı bulanık ÇKKV yöntemlerini ortaya çıkarmıştır. Bu tarz problemlerin herhangi bir belirsizlik olmayan durumları değerlendirmek için geliştirilmiş olan klasik yaklaşımlarla ele alınması genellikle elverişsizdir. Bulanık yöntemlerin, kısmi üyeliklere de olanak verebilmeleri sayesinde, bu tarz problemlerin temsilinde ve değerlendirilmesinde daha esnek ve verimli oldukları söylenebilir. Klasik kümelerden farklı olarak bulanık kümeler, gerçek hayat problemlerinde karşılaşılan kuşkulu bilgilerle ve kararsızlıklarla çalışmayı mümkün kılmaktadırlar.

Ayrıyeten, problemlerin çoğu klasik kümelerle temsil edilmesi verimsiz olabilecek insan düşüncelerine dayanmaktadır. Bulanık anlayışın en önemli özelliklerinden birisi, kriter ve alternatiflerin değerlendirilmesi süreçlerinde insan fikirlerinin sözel ölçütlerle temsil edilmesine olanak sağlamasıdır. Bu sözel değerlendirme ölçütleri daha sonra bulanık kümelerle ilişkili üyelik fonksiyonları kullanılarak üyelik dereceleri ile gösterilmektedir.

Bu özellikler karar verme süreçlerini güçlendirdiğinden, birçok ÇKKV yöntemi bulanık ortamlar için de uyarlanmıştır. Bulanık tercihler ve nitelik değerlendirmeleri içeren problemleri değerlendirmek için birçok bulanık yöntem geliştirilmiştir. Klasik ÇKKV yöntemleri problem çözme yaklaşımlarınadayalı olarak sınıflandırılmış olduklarından, bu yöntemlerin bulanık uzantıları da aynı mantıkla sınıflandırılmaktadırlar.

ÇKKV yöntemleri hiyerarşik yaklaşımlar, çok amaçlı matematiksel programlama ve üstünlük yöntemleri olarak sınıflandırılabilirler. Hiyerarşik yaklaşımlar, sorunları hiyerarşik ilişkiler kapsamı içerisinde ele almaktadır. Bu yaklaşımlarda, hiyerarşik olarak en tepede bulunan amaca ulaşmak için birbirini telafi edebilen kriterler değerlendirilir. Çok amaçlı matematiksel programlama, pareto-optimal çözümlere ulaşmayı amaçlayan yöntemlerdir. Klasik optimizasyon yöntemlerinden farklı olarak birden çok amaç içeren problemleri çözmek için kullanılırlar. Bu nedenle de optimal bir çözüme ulaşmak olası bir senaryo değildir, çünkü amaçlardan birine ulaşmak en az bir diğer amaçtan fedakarlık etmeyi gerektirmektedir. Son sınıflandırma, üstünlük yöntemleridir. Üstünlük yöntemleri, kriterlerin ikili karşılaştırmaları ile alternatifler arasında kurulan üstünlük ilişkilerine dayanmaktadır. Bu üstünlük ilişkileri kullanılarak problemin türüne bağlı olarak alternatifler sıralanır veya en iyi alternatife ulaşılır. Üstünlük yöntemleri, problemleri kriterlerin birbirini telafi edemeyeceği anlayışıyla ele alır. Bu anlayış; bir alternatifin bir kriter açısından göstermiş olduğu düşük performansın, başka bir kriterde iyi performans göstermesiyle telafi edemeyeceği anlamına gelmektedir.

Üstünlük yöntemleri içerisinde ilk olarak geliştirilen ve en yaygın olarak kullanılan yöntem ELECTRE metot ailesidir. ELECTRE metot ailesi, farklı problem türleri için geliştirilmiş farklı versiyonlardan oluşmaktadır. ELECTRE I seçim problemlerinin çözümünde kullanılırken, ELECTRE II, III ve IV alternatiflerin sıralanmasını amaçlayan problemlerin, ELECTRE TRI ise atama problemlerinin çözümünde kullanılmaktadırlar.

Literatürde ELECTRE yöntemlerinin çeşitli bulanık kümeler için geliştirilmiş versiyonları bulunmaktadır. Bulanık kümelerin belirsizliği, kararsızlığı ifade etme yetenekleri farklı olduğundan, her bir farklı bulanık küme için geliştirilmiş ELECTRE yöntemi de temsil kapasitesi açısından değişkenlik göstermektedir. Bu nedenle, yeni bulanık ELECTRE yöntemi versiyonları devamlı geliştirilmektedir.

Görüntü bulanık kümeleri, insan düşüncesini temsil etme açısından niteliklidirler. Pozitif, nötr, negatif ve karar vermeyi reddetme açısından insan düşüncelerini ifade edebilmektedirler. Belirsizlikleri temsil etme konusunda iyi bir niteliğe sahip olmalarına rağmen, görüntü bulnaık ortamda uygulanabilir özgün bir ELECTRE yöntemi henüz literatürde bulunmamaktadır, yalnızca görüntü bulanık ortamında EDAS ve TODIM gibi diğer yöntemlerle birleştirilmiş bazı bütünleşik ELECTRE yöntemleri bulunmaktadır.

Görüntü bulanık kümelerin insan düşüncelerini temsil kapasitesinin güçlü olmasına rağmen literatürde görüntü bulanık ELRECTRE yöntemi yer almaması bu tez çalışmasının temel motivasyon kaynağıdır. ELECTRE yöntemi bulanık sayı kümeleri tarafından temsil edilen sözel değerlendirme ölçütleriyle uyumlu çalışabilen güçlü bir ÇKKV yöntemi olduğundan, görüntü bulanık ELECTRE yöntemi üzerine çalışmaya değerdir. Bu nedenlerle çalışmanın asıl amacı özgün bir görüntü bulanık ELECTRE yöntemi geliştirerek literatüre katkıda bulunmaktır.

Öte yandan, metotun uygulanacağı problem açısından tezin bir başka motivasyon kaynağı daha bulunmaktadır. 6 Şubat 2023'te Türkiye'de 10'dan fazla ilden oluşan çok geniş bir bölgeyi etkileyen yıkıcı depremler meydana gelmiştir. Bölgede 9 saat arayla 7.7 M ve 7.6 M büyüklüğünde iki büyük deprem meydana gelmiş ve 14 gün sonra Hatay ilinde 6.4 M büyüklüğünde başka bir deprem daha yaşanmıştır. Bu depremler bölgede çok büyük hasar bırakmış, 50.000'den fazla insanın hayatını kaybetmesine ve yaklaşık 1,5 milyon insanın evsiz kalmasına sebep olmuştur. Üç ilçesi neredeyse tamamen yıkılan Hatay, depremden en ciddi şekilde etkilenen şehirlerden biri olmuştur.

Bu tez çalışmasının amaçlarından birisi, deprem felaketinden sonra uzun vadeli geçici yerleşim bölgesi seçimi için uygun bir metodoloji önermek ve benzer durumlarda kullanılabilirliğinden emin olmak adına gerçekçi bir uygulama çalışması yapmaktır. Vakanın gerçeğe dayalı olarak ele alınmasını sağlamak için; çalışmanın karar vericileri, konu ile ilgili farklı alanlardan uzmanlar arasından seçilmiştir. Kriterler ve ağırlıkları bu uzmanların değerlendirmeleri sonucunda SWARA yöntemi kullanılarak hesaplanmıştır. Ayrıca, alternatif bölge seçenekleri yine bölgeye hakim olan bir uzman tarafından önerilmiş, sözel değerlendirme skalası kullanılarak değerlendirilmiştir.

Yöntemin uygulanması sonucunda geçici yerleşim bölgesi için en iyi alternatif Asi Nehri Kuzeyi olarak belirlenmiştir. Daha sonrasında, farklı uyum ve uyumsuzluk kümelerine farklı ağırlıklar atanarak, ve farklı uzaklık görüntü bulanık ölçüm metotları kullanılarak bir duyarlılık analizi çalışması yapılmıştır. Bu çalışmayla sonuçların ve yöntemin duyarlılığı ve tutarlılığı analiz edilmiştir. Son olarak, TOPSIS ve MAIRCA-ELECTRE yöntemleri ile karşılaştırmalı analiz çalışması yapılarak sonuçların bu yöntemlerle uyumu değerlendirilmiştir.

1. INTRODUCTION

Decision-making is one of the most crucial aspects of existence. During the lifetime, every human being makes significant or insignificant decisions continuously. Like humans, all entities such as institutions, companies, foundations resist their presence on decisions. Even though the decision-making is a continual process, some decisions are indeed complex to sharply come to a conclusion. Thus, decision-making methodologies derives from this exigency.

Decision-making based on a single-criteria may be concerned as a more straight-forward process, while the problems that should evaluate based on multiple criteria require more complicated approaches. The methodologies that aim to handle these types of problems are entitled as multi-criteria decision-making (MCDM) methods.

Further, there are several distinctions of decision-making environments that classified according to required or available information. In deterministic environment, information is definitely known and free of uncertainty. In deterministic environment, decision-making process is simpler. On the other hand, in risky and uncertainty environments, problems comprise indefinite information. While in risky environment possible outcomes are more or less known and predictable, in uncertainty environment, derives from the lack of information, even assigning probabilities to outcomes is a complicated job. Apart from them, there is a fuzzy decision-making environment that even defining the boundaries of goals and constraint are a complex assignment.

Fuzzy MCDM methods are arise from the need to handle MCDM problems when there is a absence of well definable limits between set of observations. Such problems are mostly inconvenient to handle with classical approaches that are originally developed to evaluate situations with absence of any vague or imprecise information. Fuzzy methods are more resilient in representation of such problems by enabling partial memberships. Different from crisp sets, fuzzy sets allow to operate with real-world problems with ambiguities or hesitant information.

Further, most of the problems are relying on human consideration that is inefficient to demonstrated by crisp sets. One of the most important characteristics of fuzzy settings is that they allow linguistic representation of human thinking during the process of the alternatives and criteria evaluation in MCDM problems. This linguistic expressions then demonstrated by membership degrees using membership functions associated with fuzzy sets.

As these characteristics empower the decision-making processes, many MCDM methods are extended to fuzzy settings. There are many fuzzy frameworks to analyse problems with fuzzy preferences and attribute evaluations. Since MCDM methods have classifications based on their approaches to handle problems, fuzzy extensions of these methodologies also categorized according to them.

MCDM methods can be classified as hierarchical approaches, multi-objective mathematical programming, and outranking methods. Hierarchical approaches regard problems within the concept of hierarchical relations. There exist a top level objective that should be reached by evaluating compensatory criteria. Multi-objective mathematical programming is the methodologies that serve to reach pareto-optimal solutions. They are differentiated from classical optimization techniques in terms of consisting multiple objectives, thus achieving an optimal solutions is not a possible scenario as searching for an objective requires to compensate at least of the rests. The last classification is the outranking methods. The outranking methods relies on outranking relations between alternatives constructed by pairwise comparisons of criteria. By utilization of the outranking relations, different types of problems reaches a conclusion of a best alternative or ranking of the alternatives. Outranking methods considers non-compensatory relations between criteria, which means that a low performance of an alternative on a criterion can not be compensated by a well performing on another one.

The first introduced and and most widely used outranking methodology is the ELECTRE methods family. The ELECTRE methods family consist of different types of methods that are developed for different types of problems. While ELECTRE I is serve for selection problems, ELECTRE II, III, and IV most commonly used in problems that searching the ranking of alternatives, and ELECTRE TRI is developed for assignment problems.

There are various types of fuzzy extensions of the ELECTRE methods in the literature. As the capabilities of fuzzy sets to express vagueness and ambiguities differs, each fuzzy ELECTRE versions are differentiated in terms of representation capacity. Thus, new extensions of the methods have appeared continuously.

Picture fuzzy sets are qualified in term of representation capacity of human consideration. They can express the human thoughts in terms of positivity, neutrality, negativity and refusal. Even they have decent ability to represent ambiguities, a complete ELECTRE method have not extended to picture fuzzy environment yet, there exist only some ELECTRE methods integrated with other methods such as EDAS and TODIM in picture fuzzy environment.

1.1 Motivation and Purpose of Thesis

The main motivation of the thesis is the absence of picture fuzzy ELECTRE method in the literature despite of the fact that the representation capacity of picture fuzzy sets in terms of impreciseness in human thoughts are very high. As ELECTRE is a powerful outranking methodology that suits linguistic decision terms demonstrated by fuzzy sets, extension of picture fuzzy ELECTRE is remarkable to consider. Thus, the aim of the study is extending the ELECTRE method in picture fuzzy environment.

On the other hand, for experimental study, another motivation is exist. On February 6, 2023, a devastating earthquake happened in Turkey that affect an enormous region consist of more than 10 provinces. Two earthquakes of magnitudes M 7.7 and M 7.6 occurred 9 hours in between, and after 14 days an earthquake magnitude of M 6.4 occurred in Hatay. These earthquakes left tremendous damage on the region, more than 50,000 people died and around 1.5 million people lost their homes. Hatay was one of the most seriously affected province that three districts are almost totally collapsed.

One of the purposes of this thesis is proposing a suitable methodology for a long-term shelter site selection after the earthquake disaster and an effective application analysis to ensure that it can be applied in such cases. To insure that the case is handled based on reality, decision-makers of the study are selected from different processional experts on the related to subject.

1.2 Outline of Thesis

The rest of the thesis is organized as follows. A comprehensive information about fuzzy MCDM methodologies is presented in Chapter 2. First a brief information about single-criterion and multi-criteria decision analysis is given, after the decision making environments are analyzed, then classification of MCDM methods are explained, and finally chapter is concluded with comprehensive literature review on fuzzy extensions of ELECTRE methods. In Chapter 3, extension of ordinary fuzzy sets are provided with information about necessary computational definitions for the proposed methodology. The inspired IF ELECTRE method explained in detail in Chapter 4, novel picture fuzzy concordance and discordance sets are defined, then a novel picture fuzzy ELECTRE method is proposed with detailed explanation of procedure. In Chapter 5, the application of proposed method in long-term shelter site selection problem after earthquake in Antakya is proposed. In the same chapter, a sensitivity analysis by assigning different weights to different types of concordance and discordance sets and using different distance measures are conducted and a comparative analysis is provided. Lastly, the study is concludes in Chapter 6 with limitations of study and feature study directions.

2. FUZZY MULTI-CRITERIA DECISION-MAKING

2.1 Decision-Making: Single Criterion and Multi-Criteria

Single criterion is a decision-making method that only one criterion is considered during the decision-making process. This method can be used in decision making processes where a single factor is dominant and clear enough. If there is no other significant factor to be taken into consideration, using this method makes sense as it is also very easy to apply. Masud [1] claims that the single criterion decision making method is valid when there is no uncertainty about the outcome values [1]. Besides, according to Pohekar and Ramachandran [2], this approach enhances the decision-making quality by making problems more clear, rational and productive.

On the other hand, decisions based on one criterion are subject to certain limits. First of all, this method assumes that all alternatives have a similar character and variables can be reduced to a single factor, which often decreases the probability of obtaining objective results. In addition, absence of other factors to compare the factor that is considered eliminates the possibility of awareness about the real effects of the factor. Further, the problems of the real world generally tend do comprise of various aspects. Pohekar and Ramachandran [2] argues that this approach enhances the decision-making quality by making problems more clear, rational and productive, however, today, even in most capitalist economies, there are social and environmental aspects that are taken into account, as they imposed by governmental regulations as well as public considerations.

In real world, most of the problems consist of multiple criteria and analysis of a single criterion that will lead to the best decision is usually insufficient to deal them. Aruldoss et al. [3] mention that the definition of the problem structure and an explicit evaluation of a number of criteria are important. Hence, handling problems with such one-dimensional approach is an underestimation of the problem structures and may drive us unrealistic conclusions [4]. A more convincing approach would be to consider all relevant factors associated with this problem at the same time. Multi-criteria decision-making provides many methodologies to easier dealing with such problems. MCDM indicates the decision-making process while dealing with complex situations comprising multiple conflicted criteria.

MCDM methods serves for understanding, modelling and analysing problems consist of multiple criteria, as well as making decision or conclusions about these problems. These approaches help to numeric representation of problems as a model which ease to understand and deal with them [5]. As various kind of problems exist, there are several numbers of MCDM methods and prospective ones most likely to appear.

2.2 Decision Making Environments

2.2.1 Deterministic environment

In the context of multi-criteria decision-making, deterministic environment refers to situations where all input data and parameters are known precisely. In other word, all information related to evaluation process is assumed to be complete and free of uncertainty. Yang and Wang stated [6] that all uncertainty factors are simplified or ignored in deterministic environment. There are no unknowns, variability, or risk factors involved, therefore, without any need for probabilistic analysis or consideration of uncertainties, the decision-making process entirely relies on available data and predetermined rules. According to the available data, the results of different decision alternatives can be predicted sharply in such an environment.

The deterministic environment can be criticized for oversimplifying the decision-making process by assuming full information and certainty. However, in realistic cases, there is often a small or large amount of uncertainty, and these uncertainties must be taken into account in order to achieve reliable and realistic conclusions.

2.2.2 Risky environment

Mishra [7] states that almost every decision made by human being includes possibility of risky outcomes. Risk means that some parameters cause probabilistic results.

Further, he defines the risk in possible outcomes as the known and predictable variances in the consequences. Bejleri et al. [8] claims that once the decision makers have some perception of the states of nature, they have ability to determine some subjective probabilities to each state occurring. These types of problems can classified as decision-making under risk. According to Rowe [9], the probability is substituting for certainty in such cases, which may be interpreted as an alternative to precise knowledge.

As security conditions are absent, it is possible to say that decision making occurs under risky environment and probability theory has a special importance when we can make reliable predictions based on certain probabilities. In such cases, Taghavifard et al. [10] argue that risk management, or risk elimination, is an effort undertaken by decision-makers. Nevertheless, some other risks may increase as a result of the elimination of one risk. Further, they suggest that in order to effectively manage risks, an assessment on its subsequent impact on outcome must be carried out. The decision process should allow for the consideration of alternative strategies before a decision is taken and the principle that minimizes or maximizes the expected pay-off should be accepted, depends on the case.

2.2.3 Uncertainity environment

Decision-making is mostly the process of making decisions under the risky and uncertain conditions. It is frequently possible to ascertain probabilities to state of natures, nevertheless in some cases assigning probabilities may not be possible. The decision environment of these types of problem can be classified as uncertainty environment.

Kahraman [11] states that the uncertainty arises solely from the lack of information. For instance, unreliable sources of information such as recklessness during the data collection processes or faulty analysis of problems lead to uncertainty. In some cases, uncertainty arises from system errors such as input errors, data transmission incidents, delays during operations, software mismatches and information corrupted by a failure or sabotage. Uncertainty, as a result of the methods for gathering information that require estimation or evaluation, can sometimes be an inevitable consequence. He also implies that, in other cases, the constraints imposed by the model are the cause of the uncertainty. For instance, there will be a risk of ambiguity in the description of work if a database schema allows to store at most two occupations per employee. In the same way a modeler might be forced to make use of approximation and sampling techniques when there is such a great amount of information that must be described in terms of an actual world object.

The relevant information available without certain information might take a variety of forms in which cases there are various levels of uncertainty for each relevant information [11]. Not only the consequences of such a decision are unpredictable under full uncertainty, but also very little confidence is given to any possible situations or possibilities for their occurrence [8]. Moreover, the decision structure will be inadequate, with limited or doubtful information. On the other hand, it is very rare to find conditions of complete uncertainty. Like precise knowledge, complete uncertainties have very little chance to be occur in practice.

2.2.4 Fuzzy environment

According to Bellman and Zadeh [12], fuzzy decision-making refers to a decision process that the objectives and constraints are fuzzy which means that there are groups of alternatives which do not have sharply defined limits, such as goals and constraints. Kahraman [11] claims that generally the word 'fuzzy' refers to the situations that attributes or goals cannot be described simply because there is absence of well definable limits between the set of observations. Further he mentions that such problems are hard to be effectively addressed by traditional decision-making methodologies as they are originally suit to problems that the performance of the criteria are known without any hesitation and, therefore, can be represented by crisp numbers. Bellman and Zadeh [12] states that in fuzzy decision-making approaches, fuzzy goals and fuzzy constraints can be defined in fuzzy sets.

Fuzzy logic can be described as a branch of mathematics that allow to simulate real-word cases as human-beings. It provides a simple way of reasoning by accepting that many problems are relying on vague, ambiguous and imprecise information. Every statement in the classical mathematical understanding may be true or false; i.e. it must have a crisp value of 1 or 0. There are strict membership requirements in crisp sets. On the other hand, fuzzy sets provide more flexibility for membership requirements by empowering a partial membership of a set. In reality most instances have some sort of degree, and avoiding this fact by exact thinking is in fact, limiting the possible cases of expressions [11]. Thus, boolean logic can be considered as a subset of fuzzy logic. Further humans play an inevitable role in decision making, since decisions should be made on the basis of subjective views of decision-makers instead of taking only quantitative probability measures. Hence, there is a need for fuzzy decision making.

The main deficiency of classical methodologies is that they ignore the fact that human thinking is hard to represent by crisp values. Human decisions are mostly including ambiguities, uncertainties, hesitancies, and even refusals. Demonstration with crisp values is not suitable to express opinions with these constraints. Further, with utilization of a fuzzy set theory, we are able to integrate unquantifiable, incomplete, non-available information and partial indecipherable information into decision models.

In a fuzzy setting, criteria and alternatives are expressed using linguistic variables and fuzzy sets, and the membership functions associated with these fuzzy sets describe the degree of membership of each criterion or alternative. For the most part, the usage of fuzzy sets in decision-making consisted of extensions of classic understandings, i.e., fuzzifications of the classical decision-making theories. Various decision-making methods have extended to fuzzy environment and provide frameworks for ranking or choosing alternatives based on fuzzy preferences and criteria with consideration of uncertainty and fuzziness associated with the decision problems. Further, to be used in a wide range of optimization techniques, fuzzy sets contain powerful features, and multi-criteria decision-making is one of these. Nevertheless, as the computational processes of fuzzy attributes are more complex than crisp ones, Chen et al. [13] claims that if the knowledge about problem data is rely on exact information, it should be avoided to use fuzzy setting for demonstrating them.

2.3 Classification of MCDM Methods

Decision-making is one of the most crucial processes in all operations. As the concept comprises many complexities and impreciseness, there is a need for systematic approaches. This need drives many multi-criteria decision-making (MCDM) methodologies in the literature. MCDM methods are systematic quantitative instruments that increase decision-makers' capability to handle complex objective and subjective criteria [14]. They serve as a practical framework, improving decision accuracy while reducing cost and time [15]. The classical MCDM method can be classified as hierarchical approaches, multi-objective mathematical programming, and outranking methods.

Hierarchical methods approach problems by evaluation of alternative scenarios by considering trade-offs between them. The evaluation process based on a hierarchy of attributes. These methods regard criteria as compensative, which means that an alternative can balance its low performance on a criterion by well performing on another one [16].

These approaches deal with problems mainly with considering hierarchical relations within attributes of the problems by considering the objective on the top level and criteria on the lowest [17]. The criteria also are ranked by criteria weights calculations. The process is based on the evaluation of alternative with regarding to the criteria.

According to Demirel et al. [18], one of the most widely used hierarchical approach AHP. [19] A systemic and pragmatic approach is used to arrive at a conclusion in this method. The method can be applied various types of problems and fields. AHP evaluates hierarchical criteria with pairwise comparisons, the hierarchy of criteria is satisfied by gathering them under main criteria groups. AHP provides an efficient methodology to deal with complex problems by this feature.

Multi-objective mathematical programming (MOMP) is another family of MCDM methods. MOMP is an genuinely popular approach in fields such as operation research, engineering and management sciences [19]. According to Mavrotas [20], while the output of classical mathematical programming is an optimal solution as the solution belongs to one objective that is a straightforward task, it is not the case in MOMP. There are at least two objective functions in MOMP, and, in fact, reaching an optimal conclusion that optimizes all objective functions mostly impossible. In such cases, unlike an optimal solution, the decision makers pursue "the most preferred" option. The concept of optimality shall be replaced by the idea of pareto-optimality or efficiency in MOMP. The solutions that cannot be developed with a single objective without sacrificing performance in at least one of the remaining objectives are non-inferior solutions. Among the pareto-optimal solutions of the MOMP, a rational decision should rely on the most convenient solution based on the consideration of decision-makers.

Hwang and Masud [21] states that, based on the phase that decision-makers participate, the MOMP methods can be classified in three different categories: priori methods, activity methods and posteriori or generation methods. The decision makers express their preference before the solution process in priori methods. The criticisms of priori methods include the difficulty of decision makers to be precisely quantify by to evaluate problem and make appropriate preferences [20]. In interactive methods, the stages of discussion with decision-makers are adjusted in such a way that they are paralleled to stages of analysis and step patterns tend to converge after several iterations towards more suitable conclusion. The decision-makers accelerate the research on their answers and then move to a more appropriate solution. The obstacle is they never grasp the entire picture or a proximity to it. Therefore, only in the light of what their perception capability, the most preferred solution is chosen.

Mavrotas [20] argues that due to the computation effort of generation methods, they do not attract much interest; it is time consuming and difficult to estimate effective solutions due to a lack of readily available software. There are, however, some important advantages of generation methods. There are two separate phases to the solution process: first, generating effective solutions and then involving decision-makers when all information is available. It is thus favourable when the decision-makers have little or no time to be available and interaction with them is difficult, since they take part only in the second stage but with the knowledge of all possible outcomes. Furthermore, the fact that no alternative solutions have yet to be identified further strengthens confidence among decision makers.

The outranking methods evaluate alternatives based on outranking relations. The two main procedures of the methods are pairwise comparisons of the criteria to build outranking relations and utilization of these outranking relations to get the final decision [15].

According to Bufardi et al. [22], outranking methods are one of the major families of MCDM methods and the first introduces outranking method ELECTRE was introduced by Bernard Roy in 1968. From then on, various outranking methods have been developed such as ELECTRE family methods, PROMETHEE family of methods, ORESTE, MAPPAC, QUALIFLEX, PRAGMA, and TACTIC [14]. The outranking methods rely on the construction and application of an outranking relation [22].

Bernard Roy, a pioneer of outranking methods, introduced the concept of an outranking relationship. According to Roy [23], among various alternatives a binary relation called an outranking relationship is established. The preferences of decision makers for evaluation of alternatives and the nature of the problem are taken into consideration in this relationship.

Bufardi et al. [22] suggest that unlike other MCDM approaches, outranking methods has an exception that allows an incomparability of alternatives. It is an important characteristic in situations such as certain alternatives may not be compared due to any particular reason. Siskos [24] implies that incomparability between two options is likely to arise from the lack of information, or the failure of decision-makers to assess any alternative, or their refusal to consider it.

2.4 Fuzzy Extensions of ELECTRE Methods

ELECTRE is the first introduced outranking method and still the most powerful in representation [25]. It allows decision-makers to take the most advantageous action among others with maximum advantage and minimum conflict while considering various criteria [15]. There is more than one type of ELECTRE method in the literature designated for different decision problems. While ELECTRE I best suits selection problems, ELECTRE II, III, and IV are designed for ranking problems, and ELECTRE TRI for assignment problems [26].

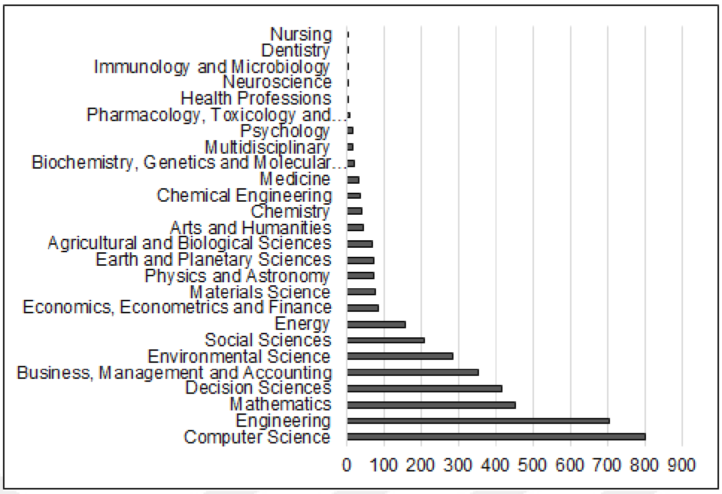

Figure 2.1 : Subject areas of the ELECTRE methods publications.

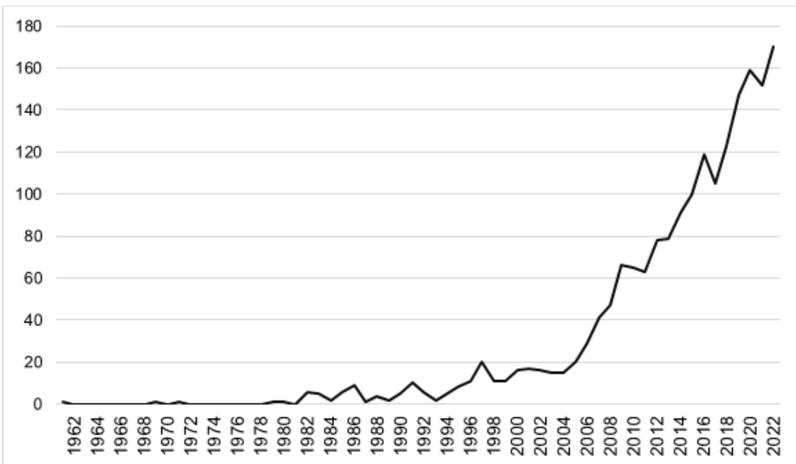

Figure 2.2 : Frequencies of the ELECTRE methods publications over years.

As the method is practical for more than one type of problem, the methods of the ELECTRE family are the most widely used outranking methods [27]. There are many studies in the literature that covers various subject areas. Some examples of recent studies are risk evaluation [28], prioritization of public transport systems [29], quality assessment [30], optimization of water supply systems [31], and sustainable supplier selection [32]. Figure 2.1 shows the distribution of subject areas of publications on the ELECTRE methods, while Figure 2.2 shows the frequencies over the years.

For most decision-making approaches, using crisp numbers for evaluation can be considered inefficient, especially when using linguistic assessment terms, as human thoughts can be imprecise. Zadeh [33] introduced the fuzzy set theory to the literature in 1965 to deal with such problems, and today there are more than 20 extensions of fuzzy sets [34]. According to the fuzzy set theory, an element can partially belong to a fuzzy set, while membership of an element is binary for crisp sets [33]. Thus, fuzzy sets provide a broader range of frames than classical sets, and they are convenient for projecting problems more realistically [35]. In the literature, there can be found many studies that combine different types of fuzzy sets with decision-making approaches. As ELECTRE is one of the methods that make use of linguistic evaluation terms, various fuzzy extensions of the method have been studied.

2.4.1 Ordinary fuzzy ELECTRE methods

The ordinary fuzzy ELLECTRE method is developed for dealing with the ambiguity and imprecision of decision-making, helping decision-makers during the assignment of weights to the criteria. As a result, DMs can deal with a broader range of perspectives on weights rather than assigning crisp numbers [35]. There exist numerous studies on extensions of ELECTRE based on ordinary fuzzy sets. For example, Sevkli [36] proposed the triangular fuzzy ELECTRE I method and its application to a supplier selection problem. In addition, Hatami-Marbini and Tavana [37] extended the ELECTRE I to trapezoidal fuzzy sets as a method for group decision-making. Mohamadghasemi et al. [38] developed a triangular fuzzy ELECTRE III group decision-making method integrated with the fuzzy weighted average approach. Noori et al. [31] proposed triangular fuzzy ELECTRE III to solve an optimization problem of water supply selection.

2.4.2 Type-2 fuzzy ELECTRE methods

Type-2 fuzzy sets differ from type-1 fuzzy sets in terms of their membership functions. The membership functions of type-2 fuzzy sets, namely the secondary membership function, are also fuzzy. This fact increases the fuzziness of the sets, giving more space for vagueness [27]. As the computational process of the IT2FS is more straightforward, there are extensions of the ELECTRE methods based on this type of type-2 fuzzy sets in the literature. Chen [27] introduced an ELECTRE-based outranking group decision-making method based on IT2FS. She developed signed distances in IT2FS and compared pairs of alternatives based on their signed distances. Finally, she applied the proposed method to a supplier selection problem and proved the method's effectiveness by a comparative analysis. Çelik et al. [39] extended the ELECTRE to IT2FS as a multi-criteria decision-making method. They apply the proposed method to a green logistic provider selection problem. Another extension is proposed by Zhong and Yao [40] as a multi-criteria group-decision methodology based on ELECTRE I and IT2FS. An application to a supplier selection problem is also provided. Selvaraj and Jeon [41] extended the ELECTRE III method to trapezoidal IT2FS. They used their method to evaluate OECD countries based on innovational capabilities. Ayyıldız et al. [42] used the trapezoidal IT2FS ELECTRE method with AHP (analytical hierarchy process) for individual credit ranking evaluation. They developed trapezoidal IT2FS AHP to evaluate criteria, then ranked the experts using trapezoidal IT2FS ELECTRE.

2.4.3 Intuitionistic fuzzy ELECTRE methods

The intuitionistic fuzzy ELECTRE (IF ELECTRE) is first developed by Wu and Chen [43]. They defined three types of concordance and discordance sets based on the accuracy function, score function, and intuitionistic index and developed concordance and discordance matrices using these sets. They introduced the procedures of the method in detail and illustrated two hypothetical examples. A new extension of the IF ELECTRE method is proposed by Vahdani et al. [44] as a multi-criteria group decision-making method. They defined a novel intuitionistic discordance index derived from fuzzy distance measure in their methodology. They applied the introduced method to the selection problem of flexible manufacturing systems for a company. They also provide a comparative analysis.

Another IF ELECTRE group decision-making method is introduced by Devi and Yadav [45] and applied to a plant location selection problem. Further, Xu and Shen [46] proposed an IF ELECTRE by developing a novel IF entropy measure. They provide an application example on supplier selection. Ebrahimnejad et al. [47] extended the IF ELECTRE by introducing novel indexes. Apply method to evaluation of outsourcing providers. There are many other studies to extend the methods on areas such as supplier risk assessment [48], site selection for offshore wind powers [49], job selection [50], carbon emission strategy selection [51], and evaluation of investments in green flight activities [52].

2.4.4 Pythagorean fuzzy ELECTRE methods

Akram et al. [53] presented a new ELECTRE method based on PFS, called Pythagorean fuzzy ELECTRE (PF ELECTRE). They mentioned that their motivation to extend the ELECTRE method on PFS arose from the fact that the representation space on PFS is greater than IFS and their more extensive capability of compensating uncertainty in decision-making problems. In the study, they developed a novel method, clarified the procedures, and provided two illustrative examples of health safety and environmental management. Other studies are extending ELECTRE methods on secondary products of PFS, such as interval-valued Pythagorean fuzzy sets [54] and hesitant Pythagorean fuzzy sets [55,56]. Furthermore, there are different application studies of the methods in different areas. Some examples are financial decision-making [54], risk evaluation [55], and selection of an e-waste disposal system [57].

2.4.5 Picture fuzzy ELECTRE methods

The PiFS were first used with the ELECTRE method by Liang et al. [58], not as a proposed PiF ELECTRE method, but as an integration of evaluation based on distance from average solution (EDAS) with the ELECTRE method. They extended this integrated method to PiFS as the sets contribute decision-making process by increasing the capability of representing uncertainty, as the sets are composed of three parameters. They applied the proposed integrated method to evaluate cleaner production levels. Further, Liang et al. [59] introduced an integrated TODIM and ELECTRE method to evaluate the performance of Green Mine in China. Kumar et al. [60] extended PiF sets by introducing a new picture fuzzy entropy measure and developed an integrated TODIM and ELECTRE method based on this novel extension. They also introduce an application for a supplier selection problem. There are only five publications referring PiF ELECTRE methods from 2018 to 2023.

2.4.6 Spherical fuzzy ELECTRE methods

The spherical fuzzy ELECTRE method was proposed by Menekşe and Camgöz Akdağ [61] in 2022. They propose two different approaches to extend the ELECTRE method on spherical fuzzy sets. In the first approach, they provided spherical fuzzy strong, weak, and moderate concordance and discordance sets, then compared concordance and discordance indexes of alternatives by the proposed formulation based on these sets. In the second approach, on the other hand, they used single types of concordance and discordance sets to compare alternatives. In their study, they also proposed an interval-valued spherical fuzzy ELECTRE method. They also illustrated the novel methods by applying the procedures on internal audit planning of an organization.

Furthermore, Menekşe and Camgöz Akdağ [62] proposed an integrated AHP ELECTRE method based on spherical fuzzy sets. As a first step, they used the AHP method to determine the weights of the criteria with linguistic terms that correspond to spherical fuzzy numbers. After alternatives were evaluated by decision-makers, they obtained a spherical fuzzy decision matrix. Then they applied the ELECTRE method to rank the alternatives based on obtained spherical fuzzy decision matrix. Finally, they apply their model to a higher education institution's IT management assessment.

Akram et al. [63] introduced another two approaches as integrated spherical fuzzy AHP ELECTRE method, focusing mainly on group decision-making processes. They briefly mentioned that the proposed SF ELECTRE method by Menekşe and Camgöz Akdağ [61] needs to be revised for group decision-making. In the study, they used AHP to decide criteria weights; then, they proposed SF ELECTRE I and SF ELECTRE II procedures by extending the used structure of spherical fuzzy sets on the ELECTRE method to handle the group decision-making process. Besides, they applied these two novel methods separately to a real case of the public transportation problem in Turkey.

2.4.7 Neutrosophic fuzzy ELECTRE methods

Ji et al. [64] introduced an integrated MABAC (multi-attribute border approximation area comparison) ELECTRE method that relies on neutrosophic fuzzy sets. They suggested that MABAC is based on the assumption that criteria are complementary; however, the integration of two methods allows the consideration of non-complementary criteria in their outsourcing provider selection problem. First, they used the MABAC method to obtain weighted decision and difference matrixes in a neutrosophic fuzzy decision environment. Then, after the steps of MABAC, they introduce the ELECTRE method to obtain neutrosophic fuzzy concordance and discordance matrices. Finally, they rank the alternatives according to alternatives based on these matrices. Ma et al. [65] proposed an interval neutrosophic fuzzy ELECTRE III method. They developed the novel method to evaluate cloud services based on their trustworthiness to recommend to small and medium-sized enterprises.

2.4.8 Q-rung orthopair fuzzy ELECTRE methods

Pınar and Boran [66] developed the q-rung orthopair fuzzy (q-ROF) ELECTRE method. They mentioned that q-ROF sets to increase the flexibility of the decision-making process in comparison to other fuzzy sets. They provide a new distance measure with q-ROF sets and integrate it into their novel ELECTRE method. Furthermore, they formulated strong, moderate, and weak concordance and discordance matrices to get the aggregate dominance matrix. They further suggest that if the ELECTRE can not eliminate all the alternatives, the q-ROF TOPSIS (technique for order preference by similarity to an ideal solution) method, also introduced in the same study, can be integrated to overcome the problem. The study aims to develop new methods for supplier selection problems, and they applied their novel method to a case of a selecting supplier for a construction company.

Bao and Shi [67] proposed a new linguistic q-ROF ELECTRE method to solve multi-attribute decision-making problems. First, they developed a new distance measure based on q-ROF numbers to evaluate the weights of attributes. Then apply q-ROF ELECTRE to the robot selection problem of an energy company. Narayanamoorthy et al. [68] introduce an interval-valued q-ROF ELECTRE III as a multi-attribute group decision-making method. They describe the procedure in detail and present the method as an efficient approach to solving solid waste management problems during an emergency, with the example of the COVID-19 pandemic.

2.4.9 T-spherical fuzzy ELECTRE methods

Only one study on T-spherical fuzzy (t-SF) sets with ELECTRE methods exists in the literature. Wang and Chen [69] proposed the t-SF ELECTRE method and claimed that this set is differentiated from other fuzzy sets in terms of the representation capability of uncertainty. They argued some recently developed T-SF distance measures and score functions for their effectiveness in the sphere of the ELECTRE method. They proposed the t-SF ELECTRE I method with the use of concordance, discordance, and prioritization Boolean matrices, and they evolved the method to a t-SF ELECTRE II with two novel t-SF Minkowski distance measures. Finally, they presented an application case for the investment evaluation of a company and a comparative analysis to show their method's validity.

2.4.10 Fermatean fuzzy ELECTRE methods

Fermatean fuzzy ELECTRE is first introduced by Zhou et al. [70]. They developed a new distance measure for fermatean fuzzy numbers relying on Jensen–Shannon divergence and three novel outranking relationship measures. Then, they introduced strong, medium, and weak concordance and discordance matrices based on the fermatean fuzzy sets. Next, they apply their method to a site selection problem considering a local type of mobile field hospital during the COVID-19 pandemic in Wuhan. Lastly, they proved their method's superiority over the fermatean fuzzy TOPSIS and MABAC methods in terms of maintaining vivid and optimal ranking orders.

Further, Kirişçi et al. [71] developed another fermatean fuzz ELECTRE I method to solve group decision-making problems. Based on the score and accuracy functions approach, they defined fermatean fuzzy strong, medium, and weak concordance and discordance sets. Finally, they obtained the dominant alternative by using their method on the biomedical material selection problem.

3. EXTENSIONS OF ORDINARY FUZZY SETS

3.1 Type-2 Fuzzy Sets

Type-2 fuzzy sets (T2FS) are the direct extensions of type-1 (ordinary) fuzzy sets whose membership functions are also fuzzy. This fact increases the fuzziness of the sets, giving more space for vagueness. They developed by Zadeh [72], architect of the fuzzy sets ideology.

Let $X \neq \emptyset$ be a given set. A T2FS U in X is defined as an object of the following form:

$$U = \{(x, \mu_U(x)|x \in X\} \tag{3.1}$$

where $\mu_U(x)$ is the membership function, which is also a fuzzy set in $[0,1]$. The membership function of the $\mu_U(x)$ called as secondary membership function of x in X.

3.2 Intuitionistic Fuzzy Sets

Intuitionistic fuzzy sets (IFS) were first introduced by Atanassov in 1986, and some of the operations of the sets are defined.

Let $X \neq \emptyset$ be a given set. According to Atanassov [73], an intuitionistic fuzzy set I in X is defined as an object having the form:

$$I = \{(x, \mu_I(x), \nu_I(x))|x \in X\} \tag{3.2}$$

where $\mu_I : X \to [0,1]$ and $\nu_I : X \to [0,1]$ are the membership and non-membership functions, respectively, and for every $x \in X$, it holds that:

$$0 \leq \mu_I(x) + \nu_I(x) \leq 1 \tag{3.3}$$

Sum of the membership and non-membership functions should not has to be equal to 1, opposed to ordinary fuzzy sets. Hence,

$$\pi_I(x) = 1 - \mu_I(x) - \nu_I(x) \tag{3.4}$$

is referred as the degree of hesitancy of the element x to set A. The degree of hesitancy improved the level of representation of vagueness.

If only one element exists in IFS, it is degraded to an intuitionistic fuzzy number (IFN), denoted as $A = (\mu_A, \nu_A)$.

3.2.1 Score function

Let $A = (\mu_A, \nu_A)$ is a IFN. The score function of A is defined as follows [74]:

$$S(A) = \mu_A - \nu_A \tag{3.5}$$

3.2.2 Accuracy function

Let $A = (\mu_A, \nu_A)$ is a IFN. The accuracy function of A is defined as follows [75]:

$$A(A) = \mu_A + \nu_A \tag{3.6}$$

3.2.3 Euclidean distance

Let $A = (\mu_A, \nu_A)$ and $B = (\mu_B, \nu_B)$ are two arbitrary IFNs. Euclidean distance between A and B is defined as follows [76]:

$$d_e(A,B) = \sqrt{(|\mu_A - \mu_B|^2 + |\nu_A - \nu_B|^2 + |\pi_A - \pi_B|^2)} \tag{3.7}$$

3.3 Pythagorean Fuzzy Sets

Pythagorean fuzzy sets (PFS) were proposed by Yager [77]. He defined PFS, which are extensions of IFS, developed operations within the sets, and compared the novel sets with intuitionistic fuzzy sets. He claimed that the PFS are more efficient in representing human thinking as their membership functions can represent a broader range of space.

Let $X \neq \emptyset$ be a given set. According to Yager's definition [77], a PFS P in X is defined as an object of the following form:

$$P = \{(x, \mu_P(x), \nu_P(x)) | x \in X\} \tag{3.8}$$

where $\mu_P : X \to [0,1]$ and $\nu_P : X \to [0,1]$ are the membership and non-membership functions, respectively, they satisfy the condition $0 \leq (\mu_P(x))^2 + (\nu_P(x))^2 \leq 1$ for every $x \in X$.

The hesitancy degree of the element is calculated by Eq. 3.9:

$$\pi_P(x) = \sqrt{1 - (\mu_P(x))^2 - (\nu_P(x))^2} \tag{3.9}$$

3.4 Picture Fuzzy Sets

Cuong [78] introduced Picture fuzzy sets (PiFS) in 2014. He described PiFS as direct extensions of the fuzzy sets and the intuitionistic fuzzy sets with three parameters. Let $X \neq \emptyset$ be a given set. A PiFS A in X is defined as an object of the following form:

$$A = \{(x, \mu_A(x), \eta_A(x), \nu_A(x)) | x \in X\} \tag{3.10}$$

where the function $\mu_A(x) : X \to [0,1]$ defines the positive membership degree, $\eta_A(x) : X \to [0,1]$ defines the neutral membership degree and $\nu_A(x) : X \to [0,1]$ defines the negative membership degree, and for every $x \in X$, they satisfying the following condition:

$$0 \leq \mu_A(x) + \eta_A(x) + \nu_A(x) \leq 1 \tag{3.11}$$

The degree of refusal membership is calculated as $\pi_A(x) = 1 - \mu_A(x) - \eta_A(x) - \nu_A(x)$.

3.4.1 Picture fuzzy sets operations

If only one element exists in a PiFS, it is degraded to a picture fuzzy number (PiFN), denoted as $A = (\mu_A, \eta_A, \nu_A)$.

3.4.1.1 Addition operation

Let $A = (\mu_A, \eta_A, \nu_A)$ and $B = (\mu_B, \eta_B, \nu_B)$ are two arbitrary PiFNs. The addition operation of A and B is executed as follows:

$$A \oplus B = (\mu_A + \mu_B - \mu_A \mu_B, \eta_A \eta_B, \nu_A \nu_B + \nu_A \eta_B + \nu_B \eta_A) \tag{3.12}$$

3.4.1.2 Multiplication operation

Let $A = (\mu_A, \eta_A, \nu_A)$ and $B = (\mu_B, \eta_B, \nu_B)$ are two arbitrary PiFNs. The multiplication operation of A and B is executed as follows:

$$A_1 \otimes B_1 = (\mu_A \mu_B + \mu_A \eta_B + \mu_B \eta_A, \eta_A \eta_B, \nu_A + \nu_B - \nu_A \nu_B) \tag{3.13}$$

3.4.1.3 Arithmetic operations

Let $A = (\mu_A, \eta_A, \nu_A)$ is a PiFN. The multiplication operation of A by a positive nonzero crisp value k is executed as follows:

$$k \cdot A = (1 - (1 - \mu_A)^k, (\eta_A)^k, (\eta_A + \nu_A)^k - (\eta_A)^k) \tag{3.14}$$

Let $A = (\mu_A, \eta_A, \nu_A)$ is a PiFN and k is a positive nonzero crisp value. The kth power of A can be found as follows:

$$A^k = ((\mu_A + \eta_A)^k - (\eta_A)^k, (\eta_A)^k, 1 - (1 - \nu_A)^k) \tag{3.15}$$

3.4.2 Score function

Let $A = (\mu_A, \eta_A, \nu_A)$ is a PiFN. The score function of A is defined as follows [79]:

$$S(A) = \mu_A - \nu_A \tag{3.16}$$

3.4.3 Accuracy function

Let $A = (\mu_A, \eta_A, \nu_A)$ is a PiFN. The accuracy function of A is defined as follows [79]:

$$A(A) = \mu_A + \eta_A + \nu_A \tag{3.17}$$

3.4.4 Comparison of two PiFNs

Let $A = (\mu_A, \eta_A, \nu_A)$ and $B = (\mu_B, \eta_B, \nu_B)$ are two arbitrary PiFNs. Comparison method between A and B is defined as follows [79]:

(1) if $S(A) > S(B)$, then $A \succ B$

(2) if $S(A) = S(B)$, then $\begin{cases} A(A) > A(B) \implies A \succ B \\ A(A) = A(B) \implies A \sim B \end{cases}$

3.4.5 Hamming distance

Let $A = (\mu_A, \eta_A, \nu_A)$ and $B = (\mu_B, \eta_B, \nu_B)$ are two arbitrary PiFNs. Hamming distance between A and B is defined as follows [80]:

$$d_h(A,B) = |\mu_A - \mu_B| + |\eta_A - \eta_B| + |\nu_A - \nu_B| + |\pi_A - \pi_B| \tag{3.18}$$

3.4.6 Euclidean distance

Let $A = (\mu_A, \eta_A, \nu_A)$ and $B = (\mu_B, \eta_B, \nu_B)$ are two arbitrary PiFNs. Euclidean distance between A and B is defined as follows:

$$d_e(A,B) = \sqrt{(|\mu_A - \mu_B|^2 + |\eta_A - \eta_B|^2 + |\nu_A - \nu_B|^2 + |\pi_A - \pi_B|^2)} \tag{3.19}$$

3.5 Spherical Fuzzy Sets

Kutlu Gündoğdu and Kahraman [81] defined spherical fuzzy sets (SFS) and basic arithmetic operations in addition to the defuzzification operation.

Let $X \neq \emptyset$ be a given set. An SFS S in X is defined as an object of the following form:

$$S = \{(x, \mu_s(x), \nu_s(x), \pi_s(x)) | x \in X\} \tag{3.20}$$

where the function $\mu_s(x) : X \to [0,1]$ defines the membership degree, $\nu_s(x) : X \to [0,1]$ defines the non-membership degree and $\pi_s(x) : X \to [0,1]$ defines the hesitancy degree independently from the membership and non-membership degrees, and for every $x \in X$, it holds that:

$$0 \leq \mu_s^2(x) + \nu_s^2(x) + \pi_s^2(x) \leq 1 \tag{3.21}$$

The refusal degree is equal to $\sqrt{1-(\mu_s(x))^2+(\nu_s(x))^2+(\pi_s(x))^2}$.

3.6 Neutrosophic Sets

Neutrosophic sets are defined by Smarandache [82]. Let $X \neq \emptyset$ be a given set. A neutrosophic set N in X is defined as an object of the following form:

$$N = \{(x, T_N(x), I_N(x), F_N(x)) | x \in X\} \tag{3.22}$$

where the function $T_N(x) : X \to [0,1]$ defines the truth-membership degree, $I_N(x) : X \to [0,1]$ defines the indeterminacy-membership degree and $F_N(x) : X \to [0,1]$ defines the falsity-membership degree, and for every $x \in X$, they satisfying the following condition:

$$0 \leq T_N(x) + I_N(x) + F_N(x) \leq 3 \tag{3.23}$$

3.7 Q-Rung Orthopair Fuzzy Sets

Yager [83] proposed q-rung orthopair fuzzy sets (q-ROFS) as a generalized class of PFS. Since the sum of qth power of membership and non-membership degrees are equal to or less than 1 for q-ROFS, he referred PFS as q-ROFS when q=2.

Let $X \neq \emptyset$ be a given set. A q-ROFS Q in X is defined as an object of the following form:

$$Q = \left\{(x, \mu_Q(x), \nu_Q(x), \pi_Q(x)) | x \in X\right\} \tag{3.24}$$

where $\mu_Q : X \to [0,1]$ and $\nu_Q : X \to [0,1]$ are the membership and non-membership functions, respectively, and for every $x \in X$, it holds that:

$$0 \leq (\mu_Q(x))^q + (\nu_Q(x))^q \leq 1 \tag{3.25}$$

The degree of hecitancy is equal to $\pi_Q(x) = \sqrt{1-(\mu_Q(x))^q - (\nu_Q(x))^q}$.

3.8 T-Spherical Fuzzy Sets

T-spherical fuzzy sets (t-SFS) are extensions of SFS and defined as generalized class of SFS.

Let $X \neq \emptyset$ be a given set. An t-SFS T in X is defined as an object of the following form:

$$T = \{(x, \mu_T(x), \nu_T(x), \pi_T(x)) | x \in X\} \tag{3.26}$$

where the function $\mu_T(x) : X \to [0,1]$ defines the membership degree, $\nu_T(x) : X \to [0,1]$ defines the non-membership degree and $\pi_T(x) : X \to [0,1]$ defines the hesitancy degree independently from the membership and non-membership degrees, and for every $x \in X$, it holds that:

$$0 \leq \mu_T^t(x) + \nu_T^t(x) + \pi_T^t(x) \leq 1 \tag{3.27}$$

The refusal degree can be given as $\sqrt{1-(\mu_T(x))^t+(\nu_T(x))^t+(\pi_T(x))^t}$.

3.9 Fermatean Fuzzy Sets

Senapati and Yager [84] introduced fermatean fuzzy sets (FFS) as special subsets of q-ROFS. They assumed q-ROFS as FFS if q equals 3.

Let $X \neq \emptyset$ be a given set. A FFS F in X is defined as an object of the following form:

$$F = \{(x, \mu_F(x), \nu_F(x), \pi_F(x)) | x \in X\} \tag{3.28}$$

where the function $\mu_F(x) : X \rightarrow [0,1]$ defines the membership degree, $\nu_F(x) : X \rightarrow [0,1]$ defines the non-membership degree and they satisfy the condition $0 \leq (\mu_F(x))^3 + (\nu_F(x))^3 \leq 1$ for every $x \in X$.

The hesitancy degree is equal to $\pi_F(x) = \sqrt{1-(\mu_F(x))^3-(\nu_F(x))^3}$.

4. METHODOLOGY

4.1 Single-Valued Intuitionistic Fuzzy ELECTRE

As mentioned in 2.4.3, Wu and Chen [43] proposed IF ELECTRE and explained the steps as follows:

Step 1: Constructing the decision matrix based on evaluations of alternatives. If the evaluation process is based on ordinal data, they can be directly used and expressed by applying equation 4.28.

$$M = \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array} \begin{bmatrix} X_{11} & \dots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \dots & X_{mn} \end{bmatrix} = \begin{bmatrix} (\mu_{11}, \nu_{11}) & \dots & (\mu_{1n}, \nu_{1n}) \\ \vdots & \ddots & \vdots \\ (\mu_{m1}, \nu_{m1}) & \dots & (\mu_{mn}, \nu_{mn}) \end{bmatrix} \tag{4.1}$$

where $X = \{x_1, x_2, ..., x_n\}$ denotes the set of criteria and $A = \{A_1, A_2, ..., A_m\}$ denotes the set of alternatives while $A_i = \{\langle x_j, X_{ij} \rangle | x_j \in X\}$ indicates the IFS A_i of ith alternative on X and $X_{ij} = (\mu_{ij}, \nu_{ij})$ indicates IF value of ith alternative with respect to jth criterion.

Simultaneously, the IFS of weights of the criteria $W = \{\langle x_j, w_j | x_j \in X \rangle\}$ should be constructed by decision makers where $0 \leq w_j \leq 1$ and $\sum_1^n w_j = 1$.

Step 2: Constructing the three types of concordance and discordance sets whose definitions are based on the concepts of score function, accuracy function and hesitancy degree. The concordance sets of A_k and A_l contains all the criteria that A_k is favorable than A_l. Their definitions are as follows:

$$C_{kl} = \{ j | \mu_{kj} \geq \mu_{lj}, \nu_{kj} < \nu_{lj} \text{ and } \pi_{kj} < \pi_{lj} \} \tag{4.2}$$

is defined as concordance set where $\mu_{kj} \geq \mu_{lj}$ and $\nu_{kj} < \nu_{lj}$ satisfy the conditions of a higher score function which denotes a higher IF value, and $\pi_{kj} < \pi_{lj}$ indicates a lower hesitancy degree referring a higher accuracy function.

$$C'_{kl} = \{j|\mu_{kj} \geq \mu_{lj}, \nu_{kj} < \nu_{lj} \text{ and } \pi_{kj} \geq \pi_{lj}\} \tag{4.3}$$

is defined as midrange concordance set. The difference is here that the accuracy function of alternative k is lower than alternative l as its hesitancy degree is greater.

$$C''_{kl} = \{j|\mu_{kj} \geq \mu_{lj} \text{ and } \nu_{kj} \geq \nu_{lj}\} \tag{4.4}$$

is defined as weak concordance set. Here the concordance of an alternative is only relying on the greater membership degree with a greater non-membership degree, simultaneously. According to their classification, Eq. 4.2 is more concordant then Eq. 4.3, and its more concordant then Eq. 4.4 .

The concordance sets of A_k and A_l contains all the criteria that A_k is not favorable than A_l. Their definitions are as follows:

$$D_{kl} = \{j|\mu_{kj} < \mu_{lj}, \nu_{kj} \geq \nu_{lj} \text{ and } \pi_{kj} \geq \pi_{lj}\} \tag{4.5}$$

is defined as discordance set where $\mu_{kj} < \mu_{lj}$ and $\nu_{kj} \geq \nu_{lj}$ satisfy the conditions of a lower score function which denotes a lower IF value, and $\pi_{kj} \geq \pi_{lj}$ indicates a higher hesitancy degree referring a lower accuracy function.

$$D'_{kl} = \{j|\mu_{kj} < \mu_{lj}, \nu_{kj} \geq \nu_{lj} \text{ and } \pi_{kj} < \pi_{lj}\} \tag{4.6}$$

is defined as midrange discordance set. The difference is here that the accuracy function of alternative k is higher than alternative l as its hesitancy degree is smaller.

$$D''_{kl} = \{j|\mu_{kj} < \mu_{lj} \text{ and } \nu_{kj} < \nu_{lj}\} \tag{4.7}$$

is defined as weak discordance set. Here the discordance of an alternative is only relying on the smaller membership degree with a smaller non-membership degree, simultaneously. According to their classification, Eq. 4.5 is more concordant then Eq. 4.6, and its more concordant then Eq. 4.7 .

Step 3: Calculating the concordance matrix as defined in Eq. 4.9. Concordance matrix is consist of concordance indexes of alternatives found by Eq. 4.8 which is defined in the paper. The concordance index implies the relative dominance of an alternative over its competitor based upon the relative weight of the consecutive decision criterion.

$$g_{kl} = w_C \times \sum_{j \in C_{kl}} w_j + w_{C'} \times \sum_{j \in C'_{kl}} w_j + w_{C''} \times \sum_{j \in C''_{kl}} w_j \tag{4.8}$$

$$G = \begin{bmatrix} - & g_{12} & \cdots & \cdots & g_{1m} \\ g_{21} & - & g_{23} & \cdots & g_{2m} \\ \cdots & \cdots & - & \cdots & \cdots \\ g_{(m-1)1)} & \cdots & \cdots & - & g_{(m-1)m)} \\ g_{m1} & g_{m2} & \cdots & g_{m(m-1))} & - \end{bmatrix} \tag{4.9}$$

where a higher value of g_{kl} denotes that alternative k is preferred over alternative l, and maximum value of g_{kl} indicates the positive ideal point.

Step 4: Calculating the discordance matrix as defined in Eq. 4.11. Discordance matrix is consist of discordance indexes of alternatives found by Eq. 4.10 which is defined in the paper. The discordance index implies that an alternative worse than its competitor based upon the relative weight of the consecutive decision criterion.

$$h_{kl} = \frac{\max_{j \in D_{kl}} w_D^* \times d_e(X_{kj}, X_{lj})}{\max_{j \in J} d_e(X_{kj}, X_{lj})} \tag{4.10}$$

where $d_e(X_{kj}, X_{lj})$ is the Euclidean distance which is defined in 3.2.3 and w_D^* is either w_D, $w_{D'}$ or $w_{D''}$.

$$H = \begin{bmatrix} - & h_{12} & ... & ... & h_{1m} \\ h_{21} & - & h_{23} & \cdots & h_{2m} \\ \cdots & \cdots & - & \cdots & \cdots \\ h_{(m-1)1} & \cdots & \cdots & - & h_{(m-1)m} \\ h_{m1} & h_{m2} & \cdots & h_{m(m-1))} & - \end{bmatrix} \tag{4.11}$$

where a higher value of h_{kl} denotes that alternative k is less preferable than l, and maximum value of h_{kl} indicates the negative ideal point.

Step 5: Constructing the concordance dominance matrix according to Eq. 4.12. The concept of the computational process in this step is that the preferred alternative should have minimum separation from the positive ideal solution, that is the minimum distance from the maximum index.

$$K = \begin{bmatrix} - & k_{12} & ... & ... & k_{1m} \\ k_{21} & - & k_{23} & \cdots & k_{2m} \\ \cdots & \cdots & - & \cdots & \cdots \\ k_{(m-1)1} & \cdots & \cdots & - & k_{(m-1)m} \\ k_{m1} & k_{m2} & \cdots & k_{m(m-1))} & - \end{bmatrix} \tag{4.12}$$

where

$$k_{kl} = g^* - g_{kl} \tag{4.13}$$

indicating that difference between each alternative and the positive ideal solution. A higher value of k_{kl} refers that alternative k is less preferable than alternative l.

Step 6: Constructing the discordance dominance matrix according to Eq. 4.14. The concept of the computational process in this step is that the preferred alternative should have maximum separation from the negative ideal solution, that is the maximum distance from the minimum index.

$$L = \begin{bmatrix} - & l_{12} & ... & ... & l_{1m} \\ l_{21} & - & l_{23} & \cdots & l_{2m} \\ \cdots & \cdots & - & \cdots & \cdots \\ l_{(m-1)1} & \cdots & \cdots & - & l_{(m-1)m} \\ l_{m1} & l_{m2} & \cdots & l_{m(m-1))} & - \end{bmatrix} \tag{4.14}$$

where

$$l_{kl} = h^* - h_{kl} \tag{4.15}$$

indicating that difference between each alternative and the negative ideal solution. A higher value of l_{kl} refers that alternative k is favorable to alternative l.

Step 7: Constructing the aggregate dominance matrix explained in Eq. 4.16. The operational result derives from the indices of concordance and discordance matrices.

$$R = \begin{bmatrix} - & r_{12} & ... & ... & r_{1m} \\ r_{21} & - & r_{23} & \cdots & r_{2m} \\ \cdots & \cdots & - & \cdots & \cdots \\ r_{(m-1)1)} & \cdots & \cdots & - & r_{(m-1)m)} \\ r_{m1} & r_{m2} & \cdots & r_{m(m-1))} & - \end{bmatrix} \tag{4.16}$$

is defined as aggregate dominance matrix where

$$r_{kl} = \frac{l_{kl}}{k_{kl} + l_{kl}} \tag{4.17}$$

referring to the relative closeness to ideal solution within the range of $[0,1]$. While the value of r_{kl} increases, the alternative getting closer to the positive ideal point and far from the negative ideal point at the same time, i.e., A_k is better alternative.

Step 8: Choosing the best alternative. This step is consisting of ranking the alternatives based on their final value in Eq. 4.18. The alternative with maximum grade of final value is the best among all.

$$\bar{T}_k = \frac{1}{m-1} \sum_{l=1, l \neq k}^{m} r_{kl}, k = 1, 2, ..., m \tag{4.18}$$

$$A^* = \max\{\bar{T}_k\} \tag{4.19}$$

4.2 Novel Single-Valued Picture Fuzzy ELECTRE

A novel single-valued PiF ELECTRE method is proposed in this section. The motivation of the research is the fact that PiFS can represent human thoughts and decision more efficiently than IFS as they composed of three parameters which is two in IFS. Decision makers can express their opinions in an environment that contains more answer type than IFS, hence, their decisions demonstrated more realistically.

4.2.1 Novel picture fuzzy concordance and discordance sets

Inspired by the study of Wu and Chen [43] explained in 4.1, new concordance and discordance sets are classified in PiF environment. As the PiFS comprises more types of membership, they allow to define more types of concordance and discordance sets.

For definition of concordance and discordance sets, the concepts of score function (3.4.2, accuracy function (3.4.3, and PiF membership degrees are utilized.

The strong concordance set is defined as follows:

$$SC_{kl} = \{j|\mu_{kj} \geq \mu_{lj}, \eta_{kj} < \eta_{lj}, \nu_{kj} < \nu_{lj} \text{ and } \pi_{kj} < \pi_{lj}\} \tag{4.20}$$

where $\mu_{kj} \geq \mu_{lj}$ and $\nu_{kj} < \nu_{lj}$ satisfy the conditions of a higher score function which denotes a higher PiF value, and $\pi_{kj} < \pi_{lj}$ indicates a lower refusal degree referring a higher accuracy function. Besides, $\eta_{kj} < \eta_{lj}$ condition forces A_k to have a greater positive membership degree for satisfying the condition of a higher accuracy function, i.e., here the higher accuracy function is ensured by a higher positive membership degree, which increases the importance of positive membership degree for concordance relation.

The concordance set is defined as follows:

$$C_{kl} = \{j|\mu_{kj} \geq \mu_{lj}, \eta_{kj} \geq \eta_{lj}, \nu_{kj} < \nu_{lj} \text{ and } \pi_{kj} < \pi_{lj}\} \tag{4.21}$$

where $\mu_{kj} \geq \mu_{lj}$ and $\nu_{kj} < \nu_{lj}$ satisfy the conditions of a higher score function and $\pi_{kj} < \pi_{lj}$ satisfies the condition of a higher accuracy function, respectively. Here the condition of forcing a greater positive membership degree is eliminated and the cases except from strong concordance relation is accepted. In other words, the set includes A_k if it has higher score and accuracy functions with a support of greater neutral membership degree for greater accuracy function. Thus, Eq. 4.20 is more concordant than Eq. 4.21.

The moderate concordance set is formulated as follows:

$$MC_{kl} = \{j|\mu_{kj} \geq \mu_{lj}, \nu_{kj} < \nu_{lj} \text{ and } \pi_{kj} \geq \pi_{lj}\} \tag{4.22}$$

where the $\mu_{kj} \geq \mu_{lj}$ and $\nu_{kj} < \nu_{lj}$ satisfy the conditions of a higher score function, but with a lower accuracy function that $\pi_{kj} \geq \pi_{lj}$ implies. The effect of neutral membership degree is disregarded in the moderate concordance relation. Hence, Eq. 4.21 is more concordant than Eq. 4.22.

The weak concordance set is defined as follows:

$$WC_{kl} = \{j|\mu_{kj} \geq \mu_{lj}, \eta_{kj} \geq \eta_{lj} \text{ and } \nu_{kj} \geq \nu_{lj}\} \tag{4.23}$$

where the conditions are that all the membership degrees of alternative k should be greater than the alternative l which indicates a higher accuracy function. Thus, Eq. 4.22 is more concordant than Eq. 4.23.

The strong discordance set is defined as follows:

$$SD_{kl} = \{j|\mu_{kj} < \mu_{lj}, \eta_{kj} \geq \eta_{lj}, \nu_{kj} \geq \nu_{lj} \text{ and } \pi_{kj} \geq \pi_{lj}\} \tag{4.24}$$

where $\mu_{kj} < \mu_{lj}$ and $\nu_{kj} \geq \nu_{lj}$ satisfy the conditions of a lower score function which denotes a lower PiF value, and $\pi_{kj} \geq \pi_{lj}$ indicates a higher refusal degree referring a lower accuracy function. Besides, $\eta_{kj} < \eta_{lj}$ condition supports A_k to have a greater negative membership degree while satisfying the condition of a lower accuracy function, i.e., here a higher negative membership degree is superior in importance while satisfying a lower score function. Thus, discordance relation is relying more on the value of negative membership degree.

The discordance set is defined as follows:

$$D_{kl} = \{j|\mu_{kj} < \mu_{lj}, \eta_{kj} < \eta_{lj}, \nu_{kj} \geq \nu_{lj} \text{ and } \pi_{kj} \geq \pi_{lj}\} \tag{4.25}$$

where $\mu_{kj} < \mu_{lj}$ and $\nu_{kj} \geq \nu_{lj}$ satisfy the conditions of a lower score function and $\pi_{kj} \geq \pi_{lj}$ satisfies the condition of a lower accuracy function, respectively. Here the support of a lower neutral membership degree is eliminated and the cases except from strong discordance relation is accepted. In other words, the set includes A_k if it has lower score and accuracy functions without considering a greater importance of a greater negative membership degree. Thus, Eq. 4.24 is more discordant than Eq. 4.25.

The moderate discordance set is formulated as follows:

$$MD_{kl} = \{j|\mu_{kj} < \mu_{lj}, \nu_{kj} \geq \nu_{lj} \text{ and } \pi_{kj} < \pi_{lj}\} \tag{4.26}$$

where the $\mu_{kj} < \mu_{lj}$ and $\nu_{kj} \geq \nu_{lj}$ satisfy the conditions of a lower score function, but with a higher accuracy function that $\pi_{kj} < \pi_{lj}$ implies. The effect of neutral membership degree is disregarded in the moderate discordance relation. Hence, Eq. 4.25 is more discordant than Eq. 4.26.

The weak discordance set is defined as follows:

$$WD_{kl} = \{j|\mu_{kj} < \mu_{lj}, \eta_{kj} < \eta_{lj} \text{ and } \nu_{kj} < \nu_{lj}\} \tag{4.27}$$

where the conditions are that all the membership degrees of alternative k should be lower than the alternative l which indicates a lower accuracy function. Thus, Eq. 4.26 is more discordant than Eq. 4.27.

4.2.2 Proposed algorithm

The proposed methodology is basically an extension of IF ELECTRE method that is proposed by Wu and Chen [43]. The new method is composed of novel PiF concordance and discordance measurements, and after constructing the

Step 1: Constructing the decision matrix based on evaluations of alternatives. If the evaluation process is based on ordinal data, they can be directly used and expressed by applying equation 4.28.

$$M = \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array} \begin{bmatrix} X_{11} & \dots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \dots & X_{mn} \end{bmatrix} = \begin{bmatrix} (\mu_{11}, \eta_{11}, \nu_{11}) & \dots & (\mu_{1n}, \eta_{1n}, \nu_{1n}) \\ \vdots & \ddots & \vdots \\ (\mu_{m1}, \eta_{m1}, \nu_{m1}) & \dots & (\mu_{mn}, \eta_{mn}, \nu_{mn}) \end{bmatrix} \tag{4.28}$$

where $X = \{x_1, x_2, ..., x_n\}$ denotes the set of criteria and $A = \{A_1, A_2, ..., A_m\}$ denotes the set of alternatives while $A_i = \{\langle x_j, X_{ij} \rangle | x_j \in X\}$ indicates the PiFS A_i of ith alternative on X and $X_{ij} = (\mu_{ij}, \eta_{ij}, \nu_{ij})$ indicates PiF value of ith alternative with respect to jth criterion.

Simultaneously, the set of weights of the criteria $W = \{\langle x_j, w_j | x_j \in X \rangle\}$ should be constructed by decision makers where $0 \leq w_j \leq 1$ and $\sum_1^n w_j = 1$.

Step 2: Constructing the PiF concordance and discordance sets explained in section 4.1. The concordance sets of A_k and A_l contains all the criteria that A_k is favorable than A_l.

Step 3: Calculating the concordance matrix as defined in Eq. 4.9. Concordance matrix is consist of concordance indexes of alternatives defined in Eq. 4.29. The concordance index implies the relative dominance of an alternative over its competitor based upon the relative weight of the consecutive decision criterion.

$$g_{kl} = w_{SC} \times \sum_{j \in SC_{kl}} w_j + w_C \times \sum_{j \in C_{kl}} w_j + w_{MC} \times \sum_{j \in MC_{kl}} w_j + w_{WC} \times \sum_{j \in WC_{kl}} w_j \tag{4.29}$$

Step 4: Calculating the discordance matrix as defined in Eq. 4.11. Discordance matrix is consist of discordance indexes of alternatives found by Eq. 4.30 which is defined in the paper. The discordance index implies that an alternative worse than its competitor based upon the relative weight of the consecutive decision criterion.

$$h_{kl} = \frac{\max_{j \in D_{kl}} w_D^* \times d_e(X_{kj}, X_{lj})}{\max_{j \in J} d_e(X_{kj}, X_{lj})} \tag{4.30}$$

where $d_e(X_{kj}, X_{lj})$ is the Euclidean distance which is defined in 3.4.6 and w_D^* is either w_{SD}, w_D, w_{MD} or w_{WD}.

Step 5: Constructing the concordance dominance matrix according to Eq. 4.12. The concept of the computational process in this step is that the preferred alternative should have minimum separation from the positive ideal solution, that is the minimum distance from the maximum index. The indices in the discordance dominance matrix (Eq. 4.13) indicating that difference between each alternative and the positive ideal solution. A higher value of the index refers that A_k is less preferable than A_l.

Step 6: Constructing the discordance dominance matrix according to Eq. 4.14. The concept of the computational process in this step is that the preferred alternative should have maximum separation from the negative ideal solution, that is the maximum distance from the minimum index. The indices in the discordance dominance matrix (Eq. 4.15) indicating the difference between each alternative and the negative ideal solution. A higher value of index refers that alternative k is favorable to alternative l.

Step 7: Constructing the aggregate dominance matrix explained in 4.16. The operational result derives from the indices of concordance and discordance matrices. The concordance dominance matrix is consist of indices that (Eq. 4.17) referring to the relative closeness to ideal solution within the range of $[0, 1]$. While the value of the index increases, the alternative getting closer to the positive ideal point and far from the negative ideal point at the same time, i.e., A_k is better alternative.

Step 8: Choosing the best alternative. This step is consisting of ranking the alternatives based on their final value in Eq. 4.18. The alternative with maximum grade of final value is the best among all according to Eq. 4.19.

5. APPLICATION:LONG-TERM SHELTER SITE SELECTION AFTER EARTHQUAKE DISASTER IN ANTAKYA (HATAY)

5.1 Problem Definition

Turkey experienced one of the most devastating earthquake disasters in its history on 6th of February, 2023. Two earthquakes of magnitudes M 7.7 and M 7.6 occurred on the same day, approximately 9 hours apart [85]. The region that mainly affected by the earthquakes is consist of 10 provinces, around 100 km2. The Turkish government announced the highest level of emergency for the region. According to authorities, more than 59,000 people were dead and 1,500,000 people left homeless.

Hatay is one of the provinces in the affected region. After 14 days from the above-mentioned earthquakes, on 20th of February, an earthquake magnitude of M 6.4 occurred [86] in Hatay. Antakya (the main district of Hatay), Kırıkhan and Hassa were declared as the most disrupted districts, with greatest number of destroyed buildings, respectively [87]. These earthquakes left tremendous damage on the province that the reconstruction process may take very long time.

Antakya has the greatest population among 15 districts in total and the most disrupted region. The population of Antakya is 399,045 according to 2022 data of Turkish Statistical Institution [88]. According to same data, the most crowded neighbourhood of Antakya is Akasya with a population of 30,371 people. Akasya is one of the central neighbourhoods of Antakya and faced enormous destruction caused by the earthquakes.

According to governmental research conducted in region only 393 among 1,740 building are recorded as “undamaged” or “slightly damaged”, rest are within the categories such as “severely damaged”, “completely destroyed”, “urgent need to be demolished”, “impenetrable”, which mean that 1,347 buildings may not be used by their residents anymore. Thus, it is reasonable to infer that this neighbourhood has the greatest number of affected people need for shelters.

The aim of this thesis is providing a suitable methodology for a long-term shelter site selection after the earthquake disaster. Hence, the people living in Akasya neighbourhood are considered in this research and limit the context of this study.

To decide the location for a long-term shelter, firstly the candidate alternatives are determined. The alternatives are decided based on suggestions of experts as in Table 5.1.

Table 5.1 : Location alternatives.

	Location Alternatives
A_1	North Side of the Asi River
A_2	South Side of the Asi River
A_3	West Side of the Asi River
A_4	East Side of the Asi River
A_5	East Hillside of Habibi Neccar Mountain
A_6	West Hillside of Habibi Neccar Mountain

5.2 Criteria Selection and Evaluation

The determination process of criteria has mostly relied on a literature review. The mainly used study for criteria selection is Soltani et al. [89], as they provide a comprehensive literature review on shelter cite selection criteria after earthquake. Further, Yazdani et al. [90] analyzed prevailing criteria for optimal location selection of temporary resettlement after an earthquake. Soltani et al. [91] proposed a criteria selection analysis on the same subject by using Delphi method. Besides, Kılıçoğlu [92] provides a multi-criteria decision analysis on permanent settlement areas. These studies were utilized during the criteria selection process of the study. However, the criteria were finally decided after preliminary interviews with experts who are also the decision makers of this research.

Location Size (C_1): This criterion refers to the size of the location with considering the population density. It indicates the fact that whether the size of the area of an alternative location is suitable to cover determined population.

Accessibility (C_2): It refers to the current transportation potential of the alternative location. The criterion of accessibility indicates the level of convenience for any genre of transportation, including whether there is a current ground structure that makes possible vehicle transportation, if not, easiness of maintaining, as well as the current public transportation opportunities.

Distance from Risky Areas (C_3): This criterion indicates the suitable distance from risky areas which refers to the region that affected from the earthquake, as well as the seismic active fault line, which do not have to be the same region with the originally damaged area.

Distance from Water Reserves (C_4): This criterion refers to the distance from dangerous water zones in terms of the possibility of landslide, floods after heavy rains ets. These water zones can be named as sea sides, riversides, and terraces.

Proximity to Service Units (C_5): This criterion is referring to a convenient distance from public service units such as medical centers, schools, governmental units, relief centers.

Distance from Industrial Zones (C_6): It indicates an appropriate distance from industrial zones for avoiding air pollution as well as the hazardous affects of chemical wastes.

Avoiding Usage of Agricultural Areas (C_7): It refers to the importance of preserving agricultural areas.

Land Slope (C_8): Land slope criterion refers to the geological risk that steeper slopes cause such as landslides, avalanche, and floods in case of heavy rains or slush.

Seasonal Temperature Variations (C_9): This criterion indicates the seasonal extreme changes on temperature and any related environmental effect.

Geological Soil-Structure Condition (C_{10}): This criterion refers to the geological condition of soil that affect the structure on it, in terms of interaction and eligibility to structure.

Access to Clean Water (C_{11}): This criterion indicates the availability of water supply in terms of drinking water, domestic water and emergency water (in case of fires). Water resources can be naturel resources, or if possible draw wells etc.

Infrastructure (C_{12}): This criterion indicates the infrastructural condition of the alternative area. It refers to the currently available infrastructure as well as the ease of building new one. The term of infrastructure includes electrical infrastructure, water supply, evacuation and drainage.

5.2.1 Criteria evaluation process

The criteria evaluation process is conducted with five decision makers. While finalizing the decision makers, it was taken into consideration that they were experts in different fields. Three of them are scholars in fields of geology, urban planning and architecture; while two of them are managers at Hatay Metropolitan Municipality Urban Planning Department.

The method of evaluation of criteria weights is based on SWARA method that is proposed by Chen and Luo [93]. According to method, the criteria are first ranked based on their importance. The descending order of the criteria that obtained by evaluation of decision makers is as in Table 5.2

Table 5.2 : Descending order of the criteria.

$$C_3 \succ C_8 \succ C_5 \succ C_2 \succ C_7 \succ C_{10} \succ C_6 \succ C_{12} \succ C_1 \succ C_{11} \succ C_4 \succ C_9$$

Table 5.3 : Linguistic terms and PiF scale for alternatives/criteria.

Linguistic terms	Picture fuzzy numbers
Absolutely High value/importance (AH)	(0.9,0,0.05)
Very High value/importance (VH)	(0.75,0.05,0.1)
High value/importance (H)	(0.6,0,0.3)
Medium value/importance (M)	(0.5,0.1,0.4)
Low value/importance (L)	(0.3,0,0.6)
Very low value/importance (VL)	(0.25,0.05,0.6)
Absolutely low value/importance (AL)	(0.1,0,0.85)

Then, decision makers evaluate consecutive criteria with using the linguistic scale in Table 5.3 to get comparative importance degree of criterion $C_{(j-1)}$ over $C_{(j)}$ [93]. Comparative importance assessment of criteria with linguistic scale is shown in Table 5.4, and its representation in PiFNs (β_j) is in Table 5.5. Then, by taking average of five evaluation, the comparative importance degree of each criterion is computed and shown in Table 5.6.

Table 5.4 : Comparative importance assessment of criteria with linguistic scale.

	C_3-C_8	C_8-C_5	C_5-C_2	C_2-C_7	C_7-C_{10}	$C_{10}-C_6$
DM_1	AH	M	H	AH	VL	VH
DM_2	M	M	AH	AH	M	AH
DM_3	H	M	VH	L	VL	VH
DM_4	AH	M	AH	L	AH	AH
DM_5	L	AH	VH	VL	AH	AH
	C_6-C_{12}	$C_{12}-C_1$	C_1-C_{11}	$C_{11}-C_4$	C_4-C_9	
DM_1	L	VL	VH	VH	VL	
DM_2	L	AH	L	M	VH	
DM_3	M	H	L	VH	L	
DM_4	H	VH	AH	VH	H	
DM_5	AH	H	H	L	AH	

Table 5.5 : Comparative importance assessment of criteria with PiFNs.

	C_3-C_8	C_8-C_5	C_5-C_2	C_2-C_7	C_7-C_{10}	$C_{10}-C_6$
DM_1	(0.9,0,0.05)	(0.5,0.1,0.4)	(0.6,0,0.3)	(0.9,0,0.05)	(0.25,0.05,0.6)	(0.75,0.05,0.1)
DM_2	(0.5,0.1,0.4)	(0.5,0.1,0.4)	(0.9,0,0.05)	(0.9,0,0.05)	(0.5,0.1,0.4)	(0.9,0,0.05)
DM_3	(0.6,0,0.3)	(0.5,0.1,0.4)	(0.75,0.05,0.1)	(0.3,0,0.6)	(0.25,0.05,0.6)	(0.75,0.05,0.1)
DM_4	(0.9,0,0.05)	(0.5,0.1,0.4)	(0.9,0,0.05)	(0.3,0,0.6)	(0.9,0,0.05)	(0.9,0,0.05)
DM_5	(0.3,0,0.6)	(0.9,0,0.05)	(0.75,0.05,0.1)	(0.25,0.05,0.6)	(0.9,0,0.05)	(0.9,0,0.05)
	C_6-C_{12}	$C_{12}-C_1$	C_1-C_{11}	$C_{11}-C_4$	C_4-C_9	
DM_1	(0.3,0,0.6)	(0.25,0.05,0.6)	(0.75,0.05,0.1)	(0.75,0.05,0.1)	(0.25,0.05,0.6)	
DM_2	(0.3,0,0.6)	(0.9,0,0.05)	(0.3,0,0.6)	(0.5,0.1,0.4)	(0.75,0.05,0.1)	
DM_3	(0.5,0.1,0.4)	(0.6,0,0.3)	(0.3,0,0.6)	(0.75,0.05,0.1)	(0.3,0,0.6)	
DM_4	(0.6,0,0.3)	(0.75,0.05,0.1)	(0.9,0,0.05)	(0.75,0.05,0.1)	(0.6,0,0.3)	
DM_5	(0.9,0,0.05)	(0.6,0,0.3)	(0.6,0,0.3)	(0.3,0,0.6)	(0.9,0,0.05)	

Table 5.6 : Comparative importance degree (β_j).

C_3	
C_8	0.73,0,0.18)
C_5	(0.64,0,0.31)
C_2	(0.82,0,0)
C_7	(0.67,0,0.23)
C_{10}	(0.69,0,0.22)
C_6	(0.84,0,0)
C_{12}	(0.6,0,0.31)
C_1	(0.69,0,0.21)
C_{11}	(0.65,0,0.24)
C_4	(0.65,0,0.25)
C_9	(0.65,0,0.25)

The comparative importance index p_j is calculated with Eq. 5.1, then the importance degree r_j of each criterion is calculated with Eq. 5.2 [93]. Lastly, the criteria weights (w_j) are computed with Eq. 5.3 [93]. The Table 5.7 shows values and weights of each criterion.

$$p_j = S(\beta_j)(j = 2,3,...,n) \tag{5.1}$$

$$r_j = \begin{cases} 1, & j = 1 \\ r_{j-1}/(p_j + 1), & 2,3,...,n \end{cases} \tag{5.2}$$

$$w_j = r_j / \sum_{j=1}^{n} r_j, (j = 1,2,...,n) \tag{5.3}$$

Table 5.7 : Criteria weights.

Comparative importance index (p_j)	Importance degree (r_j)	Weight (w_j)
-	1	0.3423
0.55	0.6452	0.2208
0.33	0.4851	0.1660
0.82	0.2665	0.0912
0.44	0.1851	0.0634
0.47	0.1259	0.0431
0.84	0.0684	0.0234
0.29	0.0530	0.0182
0.48	0.0358	0.0123
0.41	0.0254	0.0087
0.40	0.0182	0.0062
0.40	0.0130	0.0044

5.3 Numerical Application of the Method

The steps of the proposed method are applied to obtains solution for the predefined problem.

Step 1: For the first step, the decision matrix is constructed based on decisions of an expert of the region. The decision maker used the linguistic scale that provided in Table 5.3. The decision matrix is shown in Table 5.8. Further, the linguistic decision matrix is converted to PiF decision matrix by using the same scale as in Table 5.9.

Table 5.8 : Evaluation of alternatives based on linguistic scale.

	A_1	A_2	A_3	A_4	A_5	A_6
C_1	AH	H	VH	L	VL	AL
C_2	VH	VH	VH	VH	M	M
C_3	H	L	AL	L	AL	VL
C_4	M	M	VL	L	L	L
C_5	VL	VL	VL	L	H	VH
C_6	L	L	M	M	VL	VL
C_7	L	L	L	L	AL	VL
C_8	M	L	L	M	L	VL
C_9	M	M	M	M	H	H
C_{10}	AH	L	L	VH	AL	AL
C_{11}	AH	AH	AH	AH	L	L
C_{12}	AH	AH	AH	AH	L	L

Step 2: The PiF concordance and discordance sets are constructed as explained in detail in 4.1. The concordance sets are shown in Table 5.10, Table 5.11, Table 5.12, Table 5.13, while the discordance sets are shown in Table 5.14, Table 5.15, Table 5.16, Table 5.17.

Table 5.9 : PiF representation of assessment of alternatives.

	A_1	A_2	A_3	A_4	A_5	A_6
C_1	(0.9,0,0.05)	(0.6,0,0.3)	(0.75,0.05,0.1)	(0.3,0,0.6)	(0.25,0.05,0.6)	(0.1,0,0.85)
C_2	(0.75,0.05,0.1)	(0.75,0.05,0.1)	(0.75,0.05,0.1)	(0.75,0.05,0.1)	(0.5,0.1,0.4)	(0.5,0.1,0.4)
C_3	(0.6,0,0.3)	(0.3,0,0.6)	(0.1,0,0.85)	(0.3,0,0.6)	(0.1,0,0.85)	(0.25,0.05,0.6)
C_4	(0.5,0.1,0.4)	(0.5,0.1,0.4)	(0.25,0.05,0.6)	(0.3,0,0.6)	(0.3,0,0.6)	(0.3,0,0.6)
C_5	(0.25,0.05,0.6)	(0.25,0.05,0.6)	(0.25,0.05,0.6)	(0.3,0,0.6)	(0.6,0,0.3)	(0.75,0.05,0.1)
C_6	(0.3,0,0.6)	(0.3,0,0.6)	(0.5,0.1,0.4)	(0.5,0.1,0.4)	(0.25,0.05,0.6)	(0.25,0.05,0.6)
C_7	(0.3,0,0.6)	(0.3,0,0.6)	(0.3,0,0.6)	(0.3,0,0.6)	(0.1,0,0.85)	(0.25,0.05,0.6)
C_8	(0.5,0.1,0.4)	(0.3,0,0.6)	(0.3,0,0.6)	(0.5,0.1,0.4)	(0.3,0,0.6)	(0.25,0.05,0.6)
C_9	(0.5,0.1,0.4)	(0.5,0.1,0.4)	(0.5,0.1,0.4)	(0.5,0.1,0.4)	(0.6,0,0.3)	(0.6,0,0.3)
C_{10}	(0.9,0,0.05)	(0.3,0,0.6)	(0.3,0,0.6)	(0.75,0.05,0.1)	(0.1,0,0.85)	(0.1,0,0.85)
C_{11}	(0.9,0,0.05)	(0.9,0,0.05)	(0.9,0,0.05)	(0.9,0,0.05)	(0.3,0,0.6)	(0.3,0,0.6)
C_{12}	(0.9,0,0.05)	(0.9,0,0.05)	(0.9,0,0.05)	(0.9,0,0.05)	(0.3,0,0.6)	(0.3,0,0.6)

Table 5.10 : Strong concordance set (SC_{kl}).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	-	1	10	1	-
A_2	-	-	-	-	-	-
A_3	-	-	-	-	-	-
A_4	-	-	-	-	-	-
A_5	-	-	-	-	-	-
A_6	-	-	-	-	-	-

Table 5.11 : Concordance set (C_{kl}).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	1,8,10	4,8,10	1,4	4,8,10,11,12	1,4,8,10,11,12
A_2	-	-	4	4	4,11,12	4,11,12
A_3	6	-	-	-	-	-
A_4	6	6,8,10	8,10	-	6,8,11,12	6,8,11,12
A_5	-	-	-	-	-	-
A_6	5	5	5	5	5	-

Table 5.12 : Moderate concordance set (MC_{kl}).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	3	3	3	2,3,7	2,3
A_2	-	-	3	1	1,2,3,7,10	1,2,10
A_3	-	-	-	-	2,7,10	1,2,10
A_4	-	-	3	-	2,3,7,10	1,2,10
A_5	5,9	5,9	5,9	5,9	-	1
A_6	9	9	3,9	9	3,7	-

Table 5.13 : Weak concordance set (WC_{kl}).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	2,4,5,6,7,9,11,12	2,5,7,9,11,12	2,7,8,9,11,12	-	-
A_2	2,4,5,6,7,9,11,12	-	2,5,7,8,9,10,11,12	2,3,7,9,11,12	8	-
A_3	2,5,7,9,11,12	2,5,7,8,9,10,11,12	-	2,6,7,9,11,12	3,8	-
A_4	2,7,8,9,11,12	2,3,7,9,11,12	2,6,7,9,11,12	-	4	4
A_5	-	8	3,8	4	-	2,4,6,9,10,11,12
A_6	-	-	-	4	2,4,6,9,10,11,12	-

Table 5.14 : Strong discordance set (SD_{kl}).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	-	-	-	-	5
A_2	1,3,10	-	-	-	-	5
A_3	1,10	-	-	-	-	5
A_4	1,3,10	1	-	-	5	-
A_5	1,10,11,12	11,12	1,11,12	11,12	-	-
A_6	1,10,11,12	11,12	11,12	11,12	-	-

Table 5.15 : Discordance set (D_{kl}).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	-	6	6	-	-
A_2	8	-	1,6	6,8,10	-	-
A_3	4,8	4	-	8,10	-	-
A_4	4	4	1	-	-	5
A_5	4,8	4	6	6,8	-	5
A_6	4,8	4	6	6,8	-	-

Table 5.16 : Moderate discordance set (MD_{kl}).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	-	-	5	5,9	9
A_2	-	-	-	5	5,9	9
A_3	3	3	-	3,4,5	4,5,9	3,4,9
A_4	-	-	-	-	9	9
A_5	2,3,6,7	1,2,3,6,7,10	2,7,10	1,2,3,7,10	-	3,7
A_6	2,3,6,7	1,2,3,6,7,8,10	1,2,7,8,10	1,2,3,7,10	1,8	-

Table 5.17 : Weak discordance set (WD_{kl}).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	-	-	-	-	-
A_2	-	-	-	-	-	-
A_3	-	-	-	-	-	-
A_4	-	-	-	-	-	-
A_5	-	-	-	-	-	-
A_6	-	-	-	-	-	-

Step 3: The concordance matrix is constructed by using Eq. 4.9 and Eq. 4.29, as in Table 5.18.

Table 5.18 : Concordance matrix (G).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	0.2966	0.3014	0.1490	0.3095	0.2970
A_2	0.0382	-	0.1176	0.0593	0.1297	0.0468
A_3	0.0528	0.0616	-	0.0209	0.0860	0.0220
A_4	0.0582	0.2683	0.2702	-	0.2849	0.2259
A_5	0.0256	0.0477	0.0819	0.0262	-	0.0214
A_6	0.1252	0.1252	0.1765	0.1258	0.2049	-

Step 4: Discordance matrix is constructed by using Eq. 4.11 and Eq. 4.30, as in Table 5.19.

Table 5.19 : Discordance matrix (H).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	0	0.2908	0.2908	0.0615	0.6250
A_2	1	-	0.6994	0.7500	0.0853	0.8671
A_3	1	0.7500	-	0.7500	0.0853	0.7107
A_4	1	0.6290	0.7500	-	0.4264	0.5085
A_5	1	1	1	0.8196	-	0.6374
A_6	1	1	0.8196	0.8196	0.1500	-

Step 5: The concordance dominance matrix is constructed in this step, by using Eq. 4.12 and Eq. 4.13. The concordance dominance matrix is shown in Table 5.20.

Table 5.20 : Concordance dominance matrix (K).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	0.0129	0.0081	0.1606	0	0.0126
A_2	0.2714	-	0.1920	0.2502	0.1798	0.2627
A_3	0.2568	0.2480	-	0.2886	0.2236	0.2875
A_4	0.2513	0.0412	0.0393	-	0.0246	0.0836
A_5	0.2840	0.2619	0.2277	0.2833	-	0.2882
A_6	0.1843	0.1843	0.1330	0.1837	0.1046	-

Step 6: The discordance dominance matrix is constructed in this step, by using Eq. 4.14 and Eq. 4.15. The discordance dominance matrix is shown in Table 5.21.

Table 5.21 : Discordance dominance matrix (L).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	1	0.7092	0.7092	0.9385	0.3750
A_2	0	-	0.3006	0.2500	0.9147	0.1329
A_3	0	0.2500	-	0.2500	0.9147	0.2893
A_4	0	0.3710	0.2500	-	0.5736	0.4915
A_5	0	0	0	0.1804	-	0.3626
A_6	0	0	0.1804	0.1804	0.8500	-

Step 7: The aggregate dominance matrix is constructed by using Eq. 4.16 and Eq. 4.17. The aggregate dominance matrix is shown in Table 5.22.

Table 5.22 : Aggregate dominance matrix (R).

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	0.9873	0.9887	0.8154	1	0.9676
A_2	0	-	0.6103	0.4998	0.8357	0.3359
A_3	0	0.5021	-	0.4642	0.8036	0.5015
A_4	0	0.9000	0.8641	-	0.9589	0.8546
A_5	0	0	0	0.3890	-	0.5572
A_6	0	0	0.5756	0.4955	0.8904	-

Step 8: In the last step, the final values of alternatives are calculated as defined in Eq. 4.18 as shown in Table 5.23. According to Eq. 4.19, North Side of the Asi River is the best alternative, as A_1 has the maximum grade of final value of 0.9518. The ranking of alternatives is $A_1 \succ A_4 \succ A_2 \succ A_3 \succ A_6 \succ A_5$, with final values of 0.9518, 0.7155, 0.4563, 0.4543, 0.3923 and 0.1892, respectively. The A_2 and A_3 are proximate to each other concerning their final values, while the final values of the other alternatives can be regarded as distinctive enough.

Table 5.23 : Final assessment values (T).

T_1	0.9518
T_2	0.4563
T_3	0.4543
T_4	0.7155
T_5	0.1892
T_6	0.3923

5.4 Sensitivity Analysis

A sensitivity analysis is conducted by using different concordance and discordance sets weights. Also, Hamming distance measure is used to compare the results ranking in terms of variation. The results are shown in Table 5.24. The table shows that the solutions with different weights conclude with similar results, which illustrates that the method provides consistent solutions.

The results shows that the A_1 remains as the best alternative against weights and distance measure changes. Further, the worst alternative is as A_5 during the whole analysis. The second alternative also do not vary. Besides, the third, fourth and fifth orders of ranking is varying within A_2, A_3 and A_6. As their final values are close each other in all solutions, their variation can be regarded as acceptable.

Table 5.24 : Results of sensitivity analysis.

$(w_{SC}, w_C, w_{MC}, w_{WC}, w_{SD}, w_D, w_{MD}, w_{WD})$	T_1	T_2	T_3	T_4	T_5	T_6	Ranking of alternatives
(1,0.75,0.15,0.10,1,0.75,0.15,0.10)*	0.9518	0.4563	0.4543	0.7155	0.1892	0.3923	$A_1 \succ A_4 \succ A_2 \succ A_3 \succ A_6 \succ A_5$
(1,1,0.30,0.20,1,1,0.30,0.20)	0.9372	0.2564	0.2309	0.5008	0.1146	0.3430	$A_1 \succ A_4 \succ A_6 \succ A_2 \succ A_3 \succ A_5$
(1,1,0.75,0.50,1,1,0.75,0.50)	0.8978	0.2536	0.1963	0.4196	0.0858	0.2480	$A_1 \succ A_4 \succ A_2 \succ A_6 \succ A_3 \succ A_5$
(1,0.75,0.50,0.25,1,0.75,0.50,0.25)	0.9429	0.4381	0.3916	0.6448	0.1542	0.3306	$A_1 \succ A_4 \succ A_2 \succ A_3 \succ A_6 \succ A_5$
(1,1,1,1,1,1,1,1)	0.8145	0.2967	0.1793	0.3571	0	0	$A_1 \succ A_4 \succ A_2 \succ A_3 \succ A_5 = A_6$
Hamming distance with weight*	0.9475	0.4578	0.4613	0.7176	0.1990	0.4024	$A_1 \succ A_4 \succ A_3 \succ A_2 \succ A_6 \succ A_5$

5.5 Comparative Analysis

In order to compare solutions with different methods, a comparative analysis is conducted by using PiF TOPSIS method that is provided by Kahraman et al. [94] and PiF MAIRCA-ELECTRE methodology that is proposed by Chen and Luo [93].

Table 5.25 : Ranking orders and final grades of comparative study.

PiF ELECTRE	PiF TOPSIS	PiF MAIRCA-ELECTRE
$A_1 = 0.9518$	$A_3 = 0.5911$	$A_1 = 3.3595$
$A_4 = 0.7155$	$A_4 = 0.4992$	$A_4 = 1.0685$
$A_2 = 0.4563$	$A_1 = 0.4799$	$A_6 = 0.2292$
$A_3 = 0.4543$	$A_6 = 0.4461$	$A_2 = -0.3029$
$A_6 = 0.3923$	$A_2 = 0.4394$	$A_5 = -1.9033$
$A_5 = 0.1892$	$A_5 = 0.3912$	$A_3 = -2.4511$

The Table 5.25 illustrates the results of the study. According to results, the best alternative is the same with A_1 in both proposed PiF ELECTRE method and PiF MAIRCA-ELECTRE methodology. Some rankings are differentiate in these two approaches, but results are similar enough to be acceptable. However, the results pf PİF TOPSIS method differentiate them more. The ranking of TOPSIS shows some similiraties, but the difference should be considered.

6. CONCLUSIONS

Decision-making can sometimes converge to a complicated process considering the decision environment and complexity of the problem. Besides, many existent problem comprise vague and imprecise information to deal with during the process of decision-making. Hence, there are various decision-making methodologies derives from these reasons. Hence, fuzzy MCDM methods are empowered techniques to handle such decision-making problems.

Even though fuzzy sets are allowing to evaluation with linguistic terms, their capability of representation differs. Picture fuzzy sets are one powerful fuzzy sets in representing vagueness and ambiguities as they allow four types of representation in terms of membership function; namely positive, neutral and negative thoughts with refusal to consideration.

Among all outranking methodologies, the ELECTRE is the most commonly utilized one. The ELECTRE method is a qualified tool to use in MCDM problems, when the problem includes non-compensatory criteria. With the representation capacity of picture fuzzy sets, picture fuzzy ELECTRE method may accepted as an effective method to utilize.

In this study, first a novel picture fuzzy ELECTRE method is developed inspired by the existing intuitionistic fuzzy ELECTRE method. New concordance and discordance sets are proposed in picture fuzzy environment to allow outranking relations between alternatives considering non-compensatory criteria.

The proposed method then applied to long-term shelter area selection problem in Antakya after the earthquakes occurred in February, 2023. The analysis consist of 12 criteria that are mainly decided after a literature review. Then, criteria weights are assigned by experts that are scholars and professions in different areas related to subject. 6 alternative locations are determined and evaluated by a local expert to create initial decision matrix by using PiF linguistic scale. Then, these terms demonstrated by PiFNs by using the same scale.

The solutions indicates that the North Side of the Asi River is the best alternative among all with maximum final value. Then, a sensitivity analysis relying on different weights of concordance and discordance sets and different picture fuzzy distance measures is conducted. The results of the sensitivity analysis approves the consistency of method and the final result.

Finally, a comparative analysis is conducted by using PiF TOPSIS method and PiF MAIRCA-ELECTRE methodology. The results of proposed method and MAIRCA-ELECTRE are demonstrates similar rankings, but the TOPSIS method somehow differentiates.

For further researches, the method can be extended to different fuzzy sets to compare results. The comparison would be both in terms of efficiency and the final solutions.

Moreover, the problem can be analyzed further with different experts with different backgrounds. Expertise in different professions leads to consider problem with different perspective, and may change the final decision. This is understood from the criteria evaluation matrix that is constructed in the study. As our decision makers have different expertise, their judgment have varied noticeably.

Additionally, the problem may be studied with initial decision matrix based on measurable data rather than expert decisions in the future. This may assure to have more consistent and valid results.

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