Soft Computing with Neutrosophic and fractional order frameworks: A state-of-the-Art review

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Abstract

This study reviews a comprehensive mathematical framework known as neutrosophic soft sets, which combines neutrosophic theory with the soft set theory. Also, we review neutrosophic fractional order functions. For decision making, this framework effectively conveys ambiguity and uncertainty. The developments in soft set theory and neutrosophic set theory are thoroughly examined in this article. We review the advancements of both theories in general. We examine the qualities, applications, and theoretical underpinnings of both theories. We study the combination of neutrosophic soft set theory and logic. The study talks about important new developments and techniques that make neutrosophic soft suites better at solving difficult real-world problems that aren't always clear. To promote the advancement of the discipline, we also provide a comprehensive overview of the theories derived from literature methodologies, and propose potential avenues for future research. This review serves as an important resource for researchers and practitioners wishing to utilize neutrophil suites in their work. It provides a deeper understanding of the potential effects and applications. This review also addresses a discussion on fractional order neutrosophic sets (FONS). The fractional order component offers an additional degree of freedom, enhancing the adaptability of neutrosophic sets for many applications.

Keywords: Neutrosophic sets; Soft sets; Neutrosophic fractional order functions; Decision making; Fuzzy logic

1 Introduction

The concepts of uncertainty and ambiguity in real-world problems have long been a focus in mathematical modeling. However, classical set theory still struggles to address these uncertainties. In 1965, Lotfi Zadeh developed fuzzy set theory as a solution to the problems of conventional set theory's uncertainty.[1] Fuzzy sets allow partial membership. Small and fuzzy groups also face challenges in capturing deeper levels of uncertainty.[2,3] This need has stimulated the development of more complex theories. Simple fuzzy sets, vague sets, and rough sets add a layer to address imprecision, ambiguity, and incompleteness. To enhance the modeling of uncertainty, Florentin Smarandache introduced the Neutro philosophical sets in 1999.[4] The Neutro philosophy set allows a more flexible approach to dealing with uncertainty by combining three criteria. Together, truth,

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uncertainty, and falsehood distinguish themselves from fuzzy sets that are vaguely intuitive. The Neutro philosophical series has a richer mathematical structure.[5,6] Truth supports false and uncertain elements separately. Each element ranges from 0 to 1. This triad helps neutrophils deal with complex and conflicting information. Sometimes, it is the case in real-world applications where complete data is not available.[7,8]
An element's membership in a neutrophil group can demonstrate more than just truth or falsity. However, it can also represent uncertainties. Specifically, each element in the neutrophil group has three levels associated with it: truth (T), uncertainty (I), and the falsehood (F). You can alter these values independently, ensuring resilience. This allows for the modeling of situations where some information may be true, some false, or some indeterminate. This structure makes neutrophil groups especially useful in areas where data are unclear or incomplete.We can manage uncertainty without imposing extra limitations like membership or probability functions. Molodtsov introduced soft set theory in 1999.[9] A soft set is defined as a family of parameterized sets, where each element is linked to a specific criterion. Therefore, modeling the setup. Ambiguity and uncertainty A subset of the universe of parameters is relevant. It provides a flexible structure for representing ambiguous data.[10] Soft groups offer unique advantages by avoiding strict requirements such as predefined membership functions or probability distribution.[11,12] This makes them attractive in applications such as flexible decision-making, where parameters can represent a variety of criteria that are often subjective or ambiguous. By adjusting the parameters and settings accordingly, they become more attractive. You can adapt the soft suite to any type of problem, from decision analysis to medical diagnosis. This implies that it is an effective tool for dealing with uncertainty in a straightforward manner.[13,14]
Although there are individual strengths, both neophilosophical and soft groups struggle to fully address the various types of uncertainty inherent in complex systems. This is especially true when the real problem of decision-making and data analysis often has an element of uncertainty, inaccuracy, and personal preferences. By combining the parameterized structure of soft clusters with the three-dimensional real framework of neutrophilic clusters, this hybrid approach gives us a structured but flexible way to deal with uncertainty. Soft neutrosophic groups are an extension that combines neutrosophic and soft group theories. It is defined as a parametrized Neutrosophic family. In this case, each criterion is associated with a Neutrosophic family. The model does not specify the true value, allowing false values to fluctuate independently. This structure allows the model to express a degree of uncertainty and ambiguity at the parameter and component level. It is a comprehensive method for capturing complex real-world situations with high levels of uncertainty.
Neutrosophic soft groups inherit the properties of both Neutrosophic and soft groups, including their parametrization. True-indeterminacy-false triples. They possess the capability to handle uncertainty on their own. Neutrosophic soft groups can implement common operations like links, splits, extensions, and products to manage data flexibly. Neutrosophic groups implement these common operations to bolster their three-valued structure. The model's accuracy in capturing the complexity of uncertainty is crucial. The soft neutrophil group's integrated framework has proven to greatly benefit applications that require complex management of uncertainty like processing images, clinical diagnosis, and making decisions. and artificial intelligence Uncertain parameters can accomplish this. The model of neutrosophic soft sets facilitates a more comprehensive comprehension of preferences and ambiguity in data. Neutrosophic soft groups represent a powerful combination of neutrosophic and soft group theories. This offers a comprehensive paradigm for addressing uncertainty in complex systems. The flexibility and adaptability of soft clusters render them optimal for nascent domains necessitating a sophisticated approach to uncertainty, including data processing and learning. knowledge of machinery. It will customize and expand functions. It will accelerate calculations and simplify the development of algorithms for soft-set neutrophilic operations in decision support systems. We anticipate that its widespread adoption across various fields will strengthen their role. They will be better equipped to tackle real-world challenges with complex and uncertain data.

2 Literature Review

Fuzzy sets serve as an appropriate mathematical method for characterizing imprecision and ambiguity. Vagueness typically denotes the challenge of acquiring precise assertions about a specific domain. Conversely, in fuzzy set theory, the binary yes-no alternative can be infinitely extended. Consequently, fuzzy set theory addresses both ambiguity and vagueness, while also embodying a notion of nuanced reasoning. An extension of conventional set theory, fuzzy sets were first proposed by Zadeh in 1965[1] and provide a mathematical framework for capturing ambiguity in everyday life.[15–17]

There is nothing complicated or out of the ordinary about fuzzy sets. Imagine that you are approaching a red light and you are tasked with advising a learner driver on when they should apply the brakes. Does the

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phrase "Begin braking 74 feet from the crosswalk" sound familiar to you? The first instruction is too specific and cannot be implemented effectively. Instead, it is suggested to apply the brakes promptly.

The text shows that while vague instructions can be correctly understood and carried out, detailed instructions can be ineffectual. This kind of ambiguity is not influenced by coincidence; in other words, it is not probabilistic.[18,19] The flipping of coins is a good example of a circumstance that plainly involves an element of randomness or chance. There are many additional situations as well. Consequently, computational models of actual systems must include the capability to identify, represent, manage, comprehend, and utilize both fuzzy and statistical uncertainty.[20–22] This is because both types of uncertainties are unpredictable. A natural and straightforward method of problem-solving, fuzzy interpretations of data structures offer a solution to a variety of problems. Traditional sets, also known as crisp sets, are comprised of objects that fulfill specific criteria that are necessary for membership.

Each element is given a membership degree according to fuzzy set theory, and non-membership is determined by subtracting membership from 1. The notion of intuitionistic fuzzy sets, on the other hand, was first presented by Atanassov.[23–25] This approach recognizes that the degree of non-membership may involve some hesitation and is not necessarily equivalent to 1 minus membership. This method aids in comprehending the dynamics of fuzzy sets. A generalization of fuzzy set theory, Sambuc's[26] interval-valued fuzzy set idea assigns a membership degree to each element, whereas the non-membership degree is determined by subtracting membership from membership. Some people might not, however, state the corresponding level of non-membership. Expanding on this finding, Atanassov's intuitionistic fuzzy set acknowledges that non-membership degree may include reluctance and not be equivalent to membership degree.[27–29] The fuzzy set extension that is utilized the most frequently in the body of research is known as intuitionistic fuzzy sets used by many researchers.[30–32]

This is an extension of fuzzy sets in which decision makers define the degree to which elements in the set are members of the set as well as the degree to which they are not members of the set.[33,34] Hesitancy is frequently a part of the decision-making process for elements in a collection. Different intuitionistic fuzzy sets as well as linear continuous intuitionistic fuzzy sets are used in research literature.

One technique for choosing the best option from a variety of options is the MCGDM method. In the course of our daily lives, we are confronted with a variety of decision-making (DM) issues. For this reason, we forecast decisions in order to find solutions to problems of this nature. The DM technique involves explicit and concise information; yet, complexity significantly influences several practical DM challenges, resulting in information that may not be presented as a coherent set. As a result, Zadeh[1] came up with the fuzzy set (FS) idea to comprehend these issues. This concept is distinguished by a membership degree (MD) that is associated with the closed interval [0, 1].[35,36]

Khan et al.[37] addressed Multi-Cluster Decision Making (MCDM) problems in the PF framework by proposing prioritized aggregation techniques for Pythagorean fuzzy information and developing operators employing Einstein T-norm and T-conorm. Interval-valued Pythagorean fuzzy Choquet integral operators were also created by them.[38,39] Nevertheless, the PFN's information range is constrained. They used the Pythagorean hesitant fuzzy TOPSIS approach[40] and the Pythagorean hesitant fuzzy Choquet integral[41] to tackle MCGDM problems by introducing Pythagorean hesitant fuzzy sets and decision-making processes. Garg and Rani[42] offered a novel decision-making method based on uncertainty-filled fuzzy sets and a multi-criteria decision making (MCDM) technique for fog-haze factor assessment in a Pythagorean probabilistic imperfect fuzzy environment was described by Batool et al.[43] Garg and Rani[44] used TOPSIS and maximizing deviation to create a MADM approach in a simplified neutrosophic hesitant fuzzy environment. Khan et al.[45] proposed a novel graphical ranking method and created a new ranking strategy for q-Rung Orthopair fuzzy values. For decision-making problems, Khan et al.[46] created fuzzy sets based on the q-Rung Orthopair. Mahmood[47] introduced the "T-bipolar soft set," which is more in line with the concept of bipolarity than earlier methods, and Lee[48] introduced bipolar-value fuzzy sets in 2000. In 2000, Lee extended Lee's generalization of fuzzy sets even further. The "T-bipolar soft set," a recent study by Mahmood, provides more evidence of the benefits of these theories for making decisions.

The models in question are incapable of taking into consideration the partial effect of the data. Uncertainty and ambiguity, which frequently accompany data changes, are characteristics of complex data sets. To overcome these difficulties, Romot et al.[49] introduced the idea of a complex fuzzy set (CFS), which is a complex-valued membership degree in a complex plane accompanied by a codomain unit disc. Several scholars[50–52] have carried out studies in the field of chronic fatigue syndrome (CFS). However, CFS only represents

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the elements in every set that are in agreement with one another; it does not discuss the elements that are in dispute. A CIFS was introduced by Alkouri and Salleh[53] to solve multi-criteria decision-making problems. They created a distance metric, looked at[30] connection, projection, and composition among CIFSs, and suggested further operational principles. To address multi-criteria decision-making independently, Rani and Garg[54,55] created T-norm and T-conorm-based generalized averaging operators, power operators, and distance measures.

As compared to the classical fuzzy sets, neutrosophic sets (NS) offer a more comprehensive understanding of uncertainty.[56,57] The incorporation of IDM enhances the framework's capacity to deal with uncertainty through the utilization of indeterminate membership, which offers a more adaptable and efficient method of expressing complex information in comparison to the conventional fuzzy sets. In a variety of domains, such as artificial intelligence and data miming, neutrosophic sets are ideally suited to successfully address the uncertainties that are present in practical scenarios. The use of Neutrosophic Sets (NSs) has been recommended by a multitude of specialists in a variety of different ways.[58] Azim et al.[59] made a significant contribution by employing the q-spherical fuzzy rough analytic hierarchy method to prioritize projects associated with Industry 4.0 technology. The intricate concepts of fuzzy sets presented herein offer resilient frameworks applicable to navigating challenging situations, particularly in decision-making across several industry sectors.
Below is the comprehensive review of the Neutrosophic sets and soft sets

Authors with year	**Major Findings**
Kraipeerapun, Pawalai, Chun Che Fung, and Warick Brown (2005)[60]	This study addresses uncertainty in mineral deposit forecasts by combining interval neutrosophic sets with contemporary soft computing approaches.
Broumi, Said, and Florentin Smarandache (2014)[61]	The idea of single valued neutrosophic soft expert sets (SVNSESs), which blend neutrosophic and soft expert sets, is presented in this paper. It looks at properties for proofs and fundamental operations such as AND, OR, intersection, complement, and union. This idea is extended to fuzzy and intuitionistic fuzzy soft expert sets. In order to illustrate the usefulness of SVNSESs, the paper looks at how they are applied to MCDM challenges.
Jha, Sudan, et al. (2019)[62]	The authors of this research highlight a significant problem with the stock market's trending trade scenarios, which include a lack of data exactness, data expression accuracy, and value uncertainty (the day's closing point). Using real data from the previous seven years, neutrophilic soft sets (NSS) are used to provide precise stock value predictions. The "open," "high," "low," and "adjacent close" variables are used in the approach to calculate the stock price. To ensure precise data conditions, the highest score number from the score function determines which beginning and high price have an impact on the closing price.
Peng, Xindong, and Chong Liu (2017)[63]	Three novel single-valued neutrosophic soft set (SVNSS) methods are presented in this study. To minimize information loss and preserve original material, the authors present a new axiomatic definition of the SVNN. Composite weights are developed to display both objective and subjective data, and objective weights for parameters are determined using grey system theory. A numerical example illustrates the feasibility and effectiveness of three proposed methods for single-valued neutrosophic soft decision making situations.
Karaaslan, Faruk (2017)[64]	The idea of a possible neutrosophic soft set is presented in this book along with related ideas such as universal set, null set, and subset. Union, intersection, and complement are examples of set-theoretical operations that are described using n-norm and n-conorm. Along with introducing AND-product and OR-product operations between two sets, the authors also suggest a method for making decisions that addresses uncertainty-based decision-making problems: the potential neutrosophic soft decision-making method.
Deli, Irfan (2017)[65]	Neutroposophic sets and soft sets are combined in this work to create interval valued neutrosophic soft sets, or ivn-soft sets. It develops a strategy and provides an illustrative instance to demonstrate how to use ivn-soft sets to make decisions through level soft sets. The concepts of intuitionistic fuzzy sets, fuzzy sets, interval-valued fuzzy sets, neutrosophic soft sets, and soft sets are also examined in this book.

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Abu Qamar, Majdoleen, and Nasruddin Hassan (2019)[66]	The authors of this work go over a few Q-neutrosophic soft set operations, including intersection, union, equality, complement, subset, AND operation, and OR operation. Additionally, they specify a Q-neutrosophic soft set's need and possibility operations. There is discussion of a number of properties and examples.
Ali, Mumtaz, et al. (2017)[67]	By combining bipolar neutrosophic soft sets with soft sets, the authors present a notation for them. Within these sets, they study intersection, complement, and union operations. Additionally, they create an aggregation operator and a decision-making process for these sets, illustrating their viability and efficiency using numerical examples.
Deli, Irfan, and Said Broumi (2015)[68]	In order to address contradictory information in belief systems, the study reinterprets the idea of a neutrosophic soft set. For theoretical research and applications, it provides definitions for neutrosophic soft matrices and related functional operators. The matrix can be used to hold a useful neutrosophic soft set in computer memory. Additionally, the authors create NSM-decision making, a decision-making procedure based on neutrosophic soft sets.
Dalkiliç, Orhan (2021)[69]	Using Deli and Broumi's concept of neutrosophic soft sets, this work investigates neutrosophic soft relations, composition, and the inverse of these connections., and a few associated properties and theorems are then presented by the authors. Furthermore, certain characteristics of soft relations are examined, and their equivalence classes and relations are illustrated with examples from real-world scenarios. Finally, leveraging the established soft relationship, they provide an algorithm to depict the correspondence between items in addressing ambiguity issues.
Bui, Quang-Thinh, et al. (2022)[70]	The sequence of NS-sets (NSS-sequence) is a novel idea based on NS-sets that is defined in this study. Reasonable, compelling, and proven attributes are employed to ascertain their inclusions, specific categories, operations, and distances. In a useful medical diagnostics experiment, the authors present an algorithm for NS-sequence decision-making.
Kraipeerapun, Pawalai, et al. (2006)[71]	The study quantifies the related uncertainty and offers a technique for forecasting the favorability of gold deposits. The integration of ensemble neural networks and interval neutrosophic sets is facilitated through the application of geographic information systems (GIS) data, utilizing three distinct neural network architectures. This study investigates the use of truth, indeterminacy, and false membership values to predict and estimate deposits and non-deposits. For every architecture, two different networks that reflect the levels of favorability for deposits and non-deposits are created. Uncertainty is estimated using both fake and true membership values.
Yan-Qing, Haibin Wang, Florentin Smarandache, and Zhang Rajshekhar Sunderraman. (2005)[72]	An essential component of neutrosophy is a neutrosophic set, which studies the genesis, character, and extent of neutralities as well as how they interact with other spectrum. Although it needs technical specifications, it is a universal formal framework. In this study, a single valued neutrosophic set (SVNS) is described in depth, including its properties and SVNS-related operations.
Smarandache, Florentin, Dmitri Rabounski, and Larissa Borissova (2005)[73]	The authors employ Neutrosophic Logic concepts within the framework of the General Theory of Relativity to generalise Einstein's four-dimensional pseudo-Riemannian differentiable manifold through Smarandache Geometry (Smarandache manifolds), leading to the development of new classes of relativistic particles and non-quantum teleportation. The essential characteristics of Neutrosophic Logic include its rejection of the Law of Excluded Middle and the allowance for open (or estimated) degrees of truth, falsity, and indeterminacy. Neutrosophic Logic and Smarandache Geometry were both conceived several years ago by one of the authors, F. Smarandache. The implementation of these purely mathematical theories in General Relativity uncovers hitherto unrecognised potentials for Einstein's theory. The extent to which the new theoretical possibilities correspond to actual occurrences, as well as the feasibility of the four-dimensional space-time continuum as a fundamental model of Nature, must be investigated through experimentation.

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Arora, Meena, and Ranjit Biswas (2010)[74]	Given that inconsistencies are unavoidable in web mining, its goal is to enhance the extraction of insightful information from diverse web data. The method works especially well in bioinformatics. However, this data may be inadequate, vague, and inconsistent. One could not arbitrarily discard one dataset in favour of another. Our sophisticated soft-computing technology will assist users in formulating and discovering answers to their enquiries without the need for iterative refinement through trial and error. The significant matter of proximity cannot be resolved with precise mathematics. By incorporating Neutrosophic search techniques into commercial query languages for imprecise inquiries, the study presents Neutrosophic tools, such as NRDM and Rank Sets, to enhance the user experience for non-experts.
Rajpal, Smita, M. N. Doja, and Ranjit Biswas (2008)[75]	The authors of this work suggest a novel intelligent search technique termed neutrophilic search, which finds the best match for the predicates to respond to any vague inquiry that database users may pose. In order to better serve lay users, it should be noted that the Neutrosophic-search approach might be readily integrated into the current commercial query languages of DBMS. The authors propose Neutrosophic-equality Search, a novel approach to relational database queries based on ranks.
Ju, Wen, and H. D. Cheng (2008)[76]	By combining a restructured SVM with a neutronsophic set for SVM inputs, the study lessens the impact of outliers using a weighting function. The research examines the capacity to differentiate outer membrane proteins (OMPs) from globular proteins and alpha-helical membrane proteins by employing amino acid composition and residue pair data. The experimental findings demonstrate that the suggested technique exceeds the conventional SVM regarding classification accuracy and MCC.
Kraipeerapun, Pawalai, and Chun Che Fung (2008)[77]	The study contrasts suggested classifier, which makes use of neural networks and interval neutrosophic sets, with the classification outcomes of SVM and NN approaches. Although they take classification process uncertainty into consideration, the results demonstrate efficacy that is comparable to that of current classifiers. Benchmark problems from the UCI machine learning repository are used in the analysis.
Banerjee, Goutam (2008)[78]	Within knowledge-based organisations, this research explores self-adaptive Fuzzy Cognitive Maps' feasibility. An illustration of encoding elucidates how the amalgamation of preliminary subjective knowledge with empirical data can assist a knowledge organisation in navigating its strategic decisions. The neutrosophic generalisation of FCM provides enhanced practical applications within the problem domain.
Maji, Pabitra Kumar (2012)[79]	In recent years, decision-making issues in imprecise environments have gained significant attention. The authors' method is based on a multiobserver input parameter data set and investigates object recognition in imperfect situations.
Ansari, Abdul Quaiyum, Ranjit Biswas, and Swati Aggarwal (2011)[80]	An enriching field that aids in encoding the imprecision and uncertainty present in the real world is soft computing. By incorporating soft computing methods into the systems, the current systems get an edge that enables them to solve issues that would otherwise be impossible. In the medical field, fuzzy architecture has been studied and used extensively.
Smarandache, Florentin, and Mumtaz Ali (2011)[81]	The reduction of data corruption brought on by flaws like inference, noisy channels, crosstalk, and packet loss is significantly aided by algebraic codes. The authors of this study use soft sets, which are approximate collections of codes, to introduce soft codes (soft linear codes). The writers also go over a variety of soft code kinds, including complete soft codes and type-1 soft codes.

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Pramanik, Surapati, and Dulal Mukhopadhyaya (2011)[82]	The goal of this research is to create an intuitionistic fuzzy multi-criteria group decision-making process for choosing college instructors. Individual evaluations are combined into a single judgment using gray relational analysis. Academic success, instructional skills, research experience, leadership qualities, personality traits, managerial talents, and core values are among the eight criteria that are based on expert assessments. Decision-makers are given weights that are seen as equal, indicating consistent importance. A linguistic variable that can be constructed using intuitionistic fuzzy sets is used to represent the evaluation of alternatives. Candidates are ranked and chosen using grey relational analysis. To illustrate the efficacy of the suggested method, the study tackles pedagogical issues pertaining to teacher selection.
Arora, Meena, and Ranjit Biswas (2011)[83]	This paper presents a novel soft-computing method for neutrosophic search. By obtaining inaccurate information from the internet, the model produces more insightful results. Although there are many data sources in bioinformatics, they may be inconsistent, imprecise, and incomplete. The goal of the project is to overcome the difficulty of eliminating inappropriate datasets by representing and extracting useful information from various data sources. Consequently, it constitutes an intelligent search for matches to address the vague inquiries of non-expert consumers. Our technology, as an intelligent soft-computing approach, will assist users in formulating and discovering answers to their inquiries without the need for iterative refinement through trial and error. The significant matter of proximity cannot be resolved with precise mathematics. To improve database management system user experience, the authors employ neosophic technologies.
Arora, Meena, and Ranjit Biswas (2011)[84]	A comprehensive description of a real system necessitates data that exceeds the capacity of human recognition and simultaneous processing. Consequently, one of the significant paradigmatic changes in science and mathematics over the last century has been the emergence of the concept of neutrosophy. It is essential to develop a system capable of responding to user queries presented in natural language, minimizing user effort. This paper proposes a novel search technique utilizing neutrosophic theory to address predicates presented in natural language, thereby facilitating responses to users' imprecise queries. It represents an intelligent search for matches to address the imprecise queries of non-expert users. This study proposes a novel searching technique utilizing neutrosophic theory to address predicates presented in natural language, thereby facilitating responses to users' imprecise queries. It represents an intelligent search for matches to address the imprecise queries of lay users.
Ansari, Abdul Quaiyum, Ranjit Biswas (2013)[85]	Fuzzy logic simulates real-world issues, but it requires a great deal of expertise because its inputs are frequently ambiguous and incomplete. A thorough framework for evaluating information's truth, indeterminacy, and untruth is provided by neosophic logic. It provides a fair evaluation of the dependability of the information by accurately representing characteristics like ambiguity, incompleteness, and inaccuracy. In order to help humans make well-informed decisions when data is ambiguous or partial, this research suggests improving fuzzy representation and reasoning systems by integrating neutrophilic data representation and reasoning systems.
Sahin, Ridvan, and Ahmet Küçük (2014)[86]	The study explores the basic workings of the neutrosophic soft set notion, which was first proposed by Molodtsov in 1999. After that, it discusses uncertainty in mathematical tools by applying the generalized neutrosophic soft set.
Sahin, Ridvan, and Ahmet Küçük (2014)[87]	The notion of neutrosophic soft sets, which integrate the ideas of soft sets and neutrosophic sets, is presented in this study. It defines several distance metrics for these sets, analyzes algebraic features of these sets, and gives an axiomatic definition of neutrosophic entropy associated with these sets. They suggest a methodology utilizing similarity measurements to ascertain the most appropriate choices from the available options. As a result, they can assess all possible choices.

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Broumi, Said, Ridvan Sahin, and Florentin Smarandache (2014)[88]	This paper presents the idea of generalized interval neutrosophic soft sets, examines how they work, and shows how they might be applied to decision-making situations.
Broumi, Said, Irfan Deli, and Florentin Smarandache (2014)[89]	Numerous soft connections, such as fuzzy, intuitionistic, and neutrosophic soft relations, are generalized by IVNSS relations. The article describes basic operations and examines properties of IVNSS relations such as transitivity, symmetry, and reflexivity
Mukherjee, Anjan, and Sadhan Sarkar (2014)[90]	This paper uses a set-theoretic approach to introduce similarity metrics between two neutrosophic soft sets. It examines key features and calculates the distance between these sets. The similarity measure is used to construct a decision-making technique that focuses on medical diagnosis concerns. The essential operations are outlined, and an analysis of qualities like reflexivity, symmetry, and transitivity in IVNSS relations is performed.
Peng, Juan-juan, et al. (2014)[91]	A new outranking technique for multi-criteria decision-making utilizing a simplified neutrosophic framework is presented in this research. Outranking relations are established for simplified neutrosophic numbers using the ELECTRE approach, which includes a thorough examination of their inherent characteristics. Additionally, a ranking methodology is established to tackle MCDM issues, guided by the outranking relationships of SNNs. Two real-world examples and a comparison analysis using the same example are used to illustrate the proposed methodology.
Deli, Irfan, and Said Broumi (2015)[92]	This paper presents a novel tool for processing uncertain data, referred to as neutrosophic sets. A method for analyzing uncertainty in large-scale data sets, the neutrosophic set measures the similarity and distance between sets. It is essential for identifying the parts of a data collection that interact. To quantify uncertainty in neutrosophic collections, the idea of entropy is presented. A hybrid framework that blends neutrosophic sets and soft sets is called interval valued neutrosophic sets. This document outlines the essential features of these sets in relation to various algebraic operations.
Maji, Pabitra Kumar (2015)[93]	In order to solve a multicriteria decision-making problem in imprecise contexts, the study investigates the usage of weighted neutrosophic soft sets, a combination of neutrosophic and soft sets with weighted parameters.
Dey, Partha Pratim, Surapati Pramanik, and Bibhas C (2016)[94]	Grey relational analysis is used in this study to present neutrosophic soft multi-attribute group decision-making with numerous decision-makers. By combining neutrosophic and soft sets, neutrosophic soft sets are produced. Using evaluators' choice parameters, the AND operator combines viewpoints into a single, cohesive viewpoint. The weights of the selection factors are established using the information entropy approach. Using gray relational analysis, the researchers rank the possibilities and select the best one. The efficiency of the strategy is illustrated using a numerical example.
Peng, Juan-juan, et al. (2016)[95]	Problems involving particular numbers are addressed by the introduction of simplified neutrosophic sets (SNSs). Nonetheless, there are problems with the way social networking sites are now run, as well as with their comparison techniques and aggregate operators. In addition to presenting a comparison framework based on intuitionistic fuzzy numbers, this paper investigates the novel functions of SNNs. Additionally, it examines a methodology for multi-criteria group decision-making (MCGDM) problems and presents a number of SNN aggregation operations. Along with comparisons to other tactics, an example is given.
Al-Quran, Ashraf, and Nasruddin Hassan (2016)[96]	The paper presents the idea of fuzzy parameterized neutrosophic soft expert sets, giving each member a degree of importance and describing key operations such as AND, OR, intersection, complement, subset, and union with examples. This concept is illustrated by its essential characteristics and relevant laws, including De Morgan's laws. A comparative analysis of our proposed method against alternative ways is performed to illustrate its advantages and its capacity to resolve issues of imprecision, indeterminacy, and inconsistent data.

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Authors	Major Findings
Deli, Irfan (2016)[97]	The ideas of refined neutrosophic sets (RNS) and refined neutrosophic soft sets (RNSS) are examined in this research. A formal framework for capturing uncertainty, imprecision, incompleteness, inaccuracy, and inconsistency in real-world information is provided by extending many notions. An application of RNS in medical diagnostics, pattern recognition, and RNSS in decision-making is presented, along with basic definitions and an efficient technique for both.
Abu Qamar, Majdoleen, and Nasruddin Hassan (2018)[98]	In this work, two-dimensional membership functions that convey uncertainty, indeterminacy, and falsehoods are introduced and analyzed as Q-neutrosophic soft sets. When dealing with two-dimensional, imprecise, uncertain, and inconsistent information in real-world problems, they are helpful. In a Cartesian product of universes, a subset of the Cartesian product of Q-neutrosophic soft sets is called a Q-neutrosophic soft relation. The paper outlines reflexivity, symmetry, transitivity, equivalence relations, and equivalence classes and uses real-world examples to validate their qualities. Using Q-neutrosophic soft relations, an algorithm is created to solve decision-making issues.
Deli, Irfan, Selim Eraslan, and Naim Çagman (2018)[99]	A novel notion of soft sets, known as interval-valued neutrosophic parameterized interval-valued neutrosophic soft sets, is presented in this study. These soft sets comprise fuzzy, intuitionistic, and neutrosophic sets, among others. Additionally, ivnpivn-soft matrices were introduced by the authors to represent these sets. They created a method for making decisions based on ivnpivn-soft sets and ivnpivn-soft matrices, and they included a numerical example to show how successful it is.
Uluçay, Vakkas, Memet Sahin, and Nasruddin Hassan (2018)[100]	Smarandache established a neutrosophic set to address issues related to incompleteness, indeterminacy, and the recognition of inconsistent information, subsequently advancing it to neutrosophic soft expert sets. The authors define the features and functions of the generalized neutrosophic soft expert set (GNSES). They use a GNSES-aggregation operator to develop an algorithm for a more effective decision-making process. The algorithm's effectiveness and applicability are demonstrated by testing in a decision-making situation, and it is compared to other approaches.
Akram, Muhammad, Sundas Shahzadi, and Florentin Smarandache (2018)[101]	In this paper, two hybrid models for soft computing are presented: neutrosophic soft rough sets (NSRSs) and soft rough neutrosophic sets (SRNSs). It offers an effective way to address these difficulties and suggests a mathematical solution for NSRS-related decision-making problems.

3 Fractional Order Neutrosophic set

A Fractional order neutrosophic set (FONS) is an advanced mathematical framework with fractional calculus to model uncertainty, vagueness, and imprecision. The fractional order introduces the notion of fractional calculus, allowing the modeling of relationships and dynamics with fractional (non-integer) dimensions or orders. By applying this to neutrosophic sets, it enables a more flexible and accurate representation of real-world problems where data and relationships exhibit memory, hereditary properties, or anomalous behaviors. FONS is particularly effective in fields like decision-making, control systems, image processing, and many other fields, where complex systems require robust tools to manage imprecise and partially known information. The fractional order component provides an additional degree of freedom, enhancing the adaptability of neutrosophic sets to diverse applications. By integrating fractional calculus, FONS enriches the capability of neutrosophic logic, offering a sophisticated approach for modeling and solving problems under uncertain and complex conditions.

Khan et al.[102] applied fractional order derivative and neutrosophic fuzzy theory to analyze changes in capital and population growth. Son et al. investigated control problems utilizing fractional differential equations in neutrosophic and granular computing. Moges and Wordofa used single-valued trapezoidal numbers to describe a multi-level, multi-objective linear fractional optimization problem. Several researchers have investigated FONS, including Son et al.,[103] Moges and Wordofa[104] discusses the problem related to fractional

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solid transportation problem. In this problem, they utilized the neutrosophic Goal Programming to manage conflicting objectives. Qassim et al.[105] solved the fractional partial differential equation with neutrosophic features information. Khalifa and Kumar[106] created an interval-valued linear fractional programming model with neutrosophic trapezoidal fuzzy numbers for coefficients. Verma and Singh[107] investigated an approach for solving a neutrosophic linear fractional optimization problem, with neutrosophic numbers representing the costs of objective functions and resources. A new computational method addressing neutrosophic uncertainty is shown in,[108] along with a novel tuning of the PI-PD controller based on the neutrosophic approach in.[109] The optimal solution for neutrosophic linear fractional programming problems with mixed constraints, as presented in[110] and,[111] involves addressing a multiobjective fractional transportation issue through the neutrosophic goal programming method. Joshi et al.[112] addressed the multi-objective linear fractional transportation issue inside a neutrosophic framework.

4 Basic Definitions

4.1 Fuzzy set:

In 1965, Lotfi A. Zadeh and Dieter Klaua presented fuzzy sets, which are comparable to sets with a degree of elemental membership and are an extension of the traditional set notion.

Definition 4.1. A fuzzy set[1] is a pair,

$$(\H{U}, m)\text{where}\H{U}$$

is a set (typically required to be non-empty) and $m : \H{U} \to [0,1]$ is a membership function. According to another definition, the universe of discourse is the reference set Ű often designated by Ω' or Y, and the grade of membership of y in $(\H{U}, m)$ is the value $m(y)$ for each $y \in \H{U}$.

Definition 4.2. The membership function of the fuzzy set $A' = \left(\H{U}, m\right)$ is the function $m = \acute{\mu}_{A'}$. The fuzzy set $\left(\H{U}, m\right)$ is frequently denoted by for $\{m(y_1)/y_1, m(y_2)/y_2, m(y_3)/y_3, ..., m(y_n)/y_n\}$ a finite collection $\H{U} = \{y_1, y_2, y_3, ..., y_n\}$.
Let $y \in \H{U}$. Then y is called
If $m(y) = 0$ (no member), it is not included in the fuzzy set $\left(\H{U}, m\right)$.
If $m(y) = 1$ (full membe), it is entirely included.
If $0 < m(y) < 1$, it is partially included (fuzzy members).

Example 4.3. Let A be a fuzzy number that is extremely close to zero. The element's membership value will drastically decrease as its value deviates from zero.

$$\mu_{A'(x)} = \tfrac{1}{(1+x^2)^2}$$

Here

$$\begin{aligned} \mu_{A'}(0) &= 1 \\ \mu_{A'}(1) &= 0.25 \\ \mu_{A'}(2) &= 0 \end{aligned}$$

Reducing the span of Gaussian functions by taking the cube of the numerator allows one to depict a fuzzy set real number that is very near to zero. As a result fuzzy is a highly natural approach to express objects where partial membership with variable degree is desired.

Definition 4.4. Two fuzzy sets "A' and B'"are equal $(A' = B')$ if and only if

$$\forall y \in \H{U} : \mu_{\text{A'}}(y) = \alpha_{B'}(y)$$

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Definition 4.5. A fuzzy set A=$\left(\text{Ű},\text{m}\right)$ will be empty $(A' = \Phi)$ iff

$$\forall y \in \text{Ű} : \mu_{A'}(y) = m(y) = 0$$

Definition 4.6. A fuzzy set A$'$ is included in fuzzy set B$'$ $(A' \subseteq B')$ if and only if

$$\forall y \in \text{Ű} : \mu_{A'}(y) \leq \mu_{B'}(y)$$

Definition 4.7. For a fuzzy set A' and $\alpha \in [0, 1]$,

$$A'^{[\alpha]} = \left\{y \in \text{Ű} | \mu_{A'}(y) = \alpha\right\}$$

is called a level of A' which is non empty.

Definition 4.8. The image of $\mu_{A'}$ represents the level set of A$'$, which is the set of all levels $\alpha \in [0, 1]$ that represent unique cuts:

$$\bigwedge_{A'} = \{\alpha \in [0, 1], A'^{[\alpha]} \neq \Phi\}$$
$$= \{\alpha \in [0, 1], \exists y \in \text{Ű}(\mu_{A'}(y) = \alpha)\}$$
$$= \mu_{A'}(\text{Ű}).$$

Definition 4.9. A fuzzy set A' $\left(\text{Ű} \subseteq \acute{R}\right)$ will be convex if and only if

$$\forall x, y \in \text{Ű}, \lambda' \in [0, 1]$$
$$\mu_{A'}(\lambda' x + (1 - \lambda')y) \geq \min(\mu_{A'}(x), \mu_{A'}(y))$$

Different features of convex fuzzy sets are described by Chang, Lowen, and Katsaras and Liu. We are unaware of more thorough analysis on strongly convex fuzzy sets, though.

Definition 4.10. Characteristic functions are generalized in fuzzy set theory to take values inside $[0, 1]$, or more broadly, in some algebra or structure (usually required to be at least a poset or lattice). The characteristic function $\mu_{A'} : F \to [0, 1]$ defined by

$$\mu_A = \begin{cases} 1 & y \in A' \\ 0 & otherwise \end{cases}$$

Definition 4.11. Crisp set: Countability and finiteness are the collection of a crisp set and they are equivalent qualities. The group of elements is present over the universal set Ű defined as Y. In this scenario, a random element exist that may or may not be a part of Y, implying that the set can be defined in two ways. These are the first elements that will either come from Y or will not come from set Y.

4.2 Fuzzy set connected to a crisp set:

Definition 4.12. For $\alpha \in [0, 1]$ and for any fuzzy set $A' = \left(\text{Ű},\text{m}\right)$ the crisp sets are given by
$A'^{\geq[\alpha]} = A'^{\alpha} = \{y \in \text{Ű— m}(y) \geq \alpha\}$, is known as $\alpha - \textbf{cut}$.
$\alpha - cut$ is a useful method for converting a fuzzy membership function into a simple belief assignment, and it serves as a link between fuzzy set theory and DST (Dempster-Shafer evidence theory). The $\alpha - cut$ method is a common way to execute simple arithmetic operations.

Definition 4.13. $A'^{>[\alpha]} = A''_{\alpha} = \left\{y \in \text{Ű— m}\,(y) > \alpha\right\}$, is known as strong $\alpha - \textbf{cut}$.
An approach based on a strong $\alpha - cut$ is described for selecting acceptable fuzzy logic relationship that are important in assessing time series trends. In addition to obtain crisp variation, a new defuzzification strategy based on weights is proposed.

Definition 4.14. $S\,(A') = Supp\,(A')$ =A$'^{>[0]}$ $= \left\{y \in \text{Ű— m}\,(y) > 0\right\}$, is known as support. The crisp subset of Y whose elements all have non-zero membership grade is the support of a fuzzy set A $'$.

Definition 4.15. C$(A') = Copre\,(A') = A'^{[1]} = \left\{y \in \text{Ű—m}\,(y) = 1\right\}$, is known as its core or kernel $(Kern\,(A'))$.

A crisp subset of Y containing all elements with membership grades of 1 is the core or kernel of a fuzzy set A$'$.

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4.3 Fuzzy set operations:

Definition 4.16. There is much uncertainty over the other basic operations, such as union and interaction, even though the complement of a fuzzy set has a single most widely accepted description.

Definition 4.17. Let A$'$ be a given fuzzy set, its complement A$'^{c}$ defined by the following membership function $\forall y \in$ Ű, $\mu_{A'^{c}}(y) = 1 - \mu_{A'}(y)$

Definition 4.18. Assume that t is a t-norm and s is a matching s-norm. There intersection A$' \cap B'$ of a pair of fuzzy set A$', B'$ is defined by :

$$\forall y \in \text{Ű} : \mu_{A'\cap B'}(y) = t\left(\mu_{A'}(y), \mu_{B'}(y)\right),$$

and union A$' \cup B'$ is defined by:

$$\forall y \in \text{Ű} : \mu_{A'\cup B'}(y) = s\left(\mu_{A'}(y), \mu_{B'}(y)\right)$$

Under the t-norm particularization, the union and intersection include a dual zero and an identity element and are commutative, monotonous, and associative. These are Φ for the intersection and Ű for the union, respectively. But a fuzzy set may not yield the empty set when it intersects with its complement, and the entire universe may not give Ű when it unites with it. Repetitively constructing the intersection and union of a finite family of fuzzy sets is a logical choice since intersection and union are associative.

Definition 4.19. For two fuzzy sets A$', B'$, the fuzzy set difference denoted by A$'\backslash B'$ or A$' - B'$ is given by the membership function:

$$\forall y \in \text{Ű} : \mu_{A'\backslash B'}(y) = t\left(\mu_{A'}(y), n\left(\mu_{B'}(y)\right)\right)$$

so, A$'\backslash B' =$ A$' \cap B'^{c} \forall y \in$Ű:

$$\mu_{A'\backslash B'}(y) = \min\left(\mu_{A'}(y), 1 - \mu_{B'}(y)\right)$$

By another representation of set difference:

$$\forall y \in \text{Ű} : \mu_{A'-B'}(y) = \mu_{A'}(y), t\left(\mu_{A'}(y), \mu_{B'}(y)\right)$$

4.4 Intuitionistic fuzzy sets:

Definition 4.20. Atanassove has provided an expansion of fuzzy sets. Two functions characterized as intuitionistic fuzzy set:
1. $\mu_{A'}(y)$ $-$degree of membership of y.
2. $\nu_{A'}(y)$ $-$degree of non-membership of y.
with these functions $\mu_{A'}, \nu_{A'}$:Ű$\rightarrow [0, 1]$ with $\forall y \in$Ű: $\mu_{A'}(y) + \mu_{B'}(y) \leq 1$.

Explanation: It is comparable to a scenario in which an individual is demonstrated by y voting

For this approach A $'$: $\left(\mu_{A'}(y) = 1, \nu_{A'}(y) = 0\right)$,
Opposite to it A $'$: $\left(\mu_{A'}(y) = 0, \nu_{A'}(y) = 1\right)$,
Or don't vote at all: $\left(\mu_{A'}(y) = \nu_{A'}(y) = 0\right)$.
We do have a proportion of approvals, rejections and abstentions, after all. Special intuitive fuzzy negators, t and s-norms, can be defined for this scenario. This situation mirrors a certain form of L-fuzzy sets when employing D'=$\left\{\left(\bar{\alpha}, \bar{\beta}\right) \in [0, 1]\,.^{2} : \bar{\alpha} + \bar{\beta} = 1\right\}$ and merging both functions into $(\mu_{A'}, \nu_{A'})$:Ű$\rightarrow D'$. This has been further extended by defining the image fuzzy set as follows. The following three functions transfer Ű to $[0, 1]$: $\mu_{A'}, \eta_{A'}, u_{A'}$ represent a PFS's degree of positive membership, degree of neutral membership, and degree of negative membership, respectively, as well as an extra requirement $\forall y \in$Ű: $\mu_{A'}(y) + \eta_{A'}(y) + \nu_{A'}(y) \leq 1$. This adds the possibility of "refusal of voting" to the voting sample above. This resembles with D'=$\left\{\left(\bar{\alpha}, \bar{\beta}, \bar{\gamma}\right) \in [0, 1]^{3} : \bar{\alpha} + \bar{\beta} + \bar{\gamma} = 1\right\}$ and special "picture fuzzy" negator, t-and s-norms.

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5 Research Methodology

In this section, we will look at the technique or approach for making multi-criteria group decisions using the fuzzy TOPSIS method.

5.1 Multi Criterion Group Decision Making:

Group choice making, additionally referred to as mutual or collective decision making, is the process by which individuals make decisions based on possibilities offered to them. In this case, the decision can no longer be attributed to a specific group member. This is because the action of each individual and social groups, such social influence can contribute to the result. Individual choice and group decisions are often made in different ways. Collaborating decision making is the most effective way to seek cooperation from other stakeholder's, build consensus and foster creativity in a professional context. The concept of harmony is that the decisions of a group are often more successful than the decision of an individual. In this regard some cooperative arguments may be able to produce more net performance results than individual working alone. Mutual collaboration or group decision making is often preferred when there is time for proper deliberation, discussion and dialogue, and it will yield more benefits than decision making alone in normal everyday situations. Committee's, teams, organizations, partnerships or other cooperative social processes can be used to accomplish this.
However this approach can sometimes have disadvantages. Other decision making methods may be preferred in extreme emergencies or crises, as emergency measures may need to be performed more quickly with less time for consideration. On the other hand, additional factors must be taken into account when evaluating the appropriateness of the decision making framework.

5.2 Fuzzy Topsis

A multi-criteria decision-making technique called fuzzy topsis ranks and chooses options according to how close they are to the best answer. By adding fuzzy logic to accommodate ambiguous or inaccurate data, it is an expansion of the traditional TOPSIS approach. It is frequently applied in decision-making procedures where several factors must be taken into account. The solution that performs the poorest is the worst; the solution that best meets the requirements is the ideal one. By permitting incremental element membership, encouraging flexibility in expressing preferences, and capturing uncertainty in the process, fuzzy TOPSIS introduces fuzzy sets to reflect ambiguity in decision-making. In this context, the membership values of criteria and alternatives are represented as linguistic variables or fuzzy numbers.

Fuzzy Topsis is a decision-making technique that provides a more nuanced depiction of uncertainty and imprecision by representing choice criteria and options using fuzzy sets. Elements in fuzzy sets are assigned degrees of membership, signifying their affiliation with a specific set. This makes it possible for decision-makers to precisely record and examine personal preferences and judgments. Fuzzy TOPSIS uses aggregated criteria values to determine how similar each alternative is to the ideal solution and the negative ideal solution. This thorough and methodical approach aids decision-makers in handling intricate issues with several criteria and unknowns. It allows for the consideration of imprecise, vague, or incomplete information, facilitating more realistic and robust decision-making processes.

6 Algorithm For Multiple Decision Making

There are some standard steps for Topsis

Step 1 We fix the decisions values of Decision maker's parameters.

Step 2 Replacing the values with Numerical terms

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Step 3 We have to compute Combined Decision Matrix

Step 4 We Compute Normalized Fuzzy decision Matrix.

$r_{ij} = (\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*})andc_j^* = max(c_{ij})$ [Benefits Criteria].

$r_{ij} = (\frac{\overline{a_j}}{c_{ij}}, \frac{\overline{a_j}}{b_{ij}}, \frac{\overline{a_j}}{a_{ij}})and\overline{a}_j = min(a_{ij})$ [CostCriteria].

Step 5 Compute Weighted Normalized Fuzzy decision Matrix along with assigning the Beneficial AND Non-Beneficial Criteria as
$\widetilde{v_{ij}} = \widetilde{r_{ij}} \times w_j$.

Step 6 Compute Fuzzy Positive Ideal solution (FPIS) Fuzzy Negative Ideal Solution (FNIS) Compute Fuzzy Positive Ideal solution (FPIS).
$A^+ = (v_1^+, v_2^+, v_3^+, ..., v_n^+)$ Where $v = max\{v_{ij3}\}$
Fuzzy Negative Ideal solution (FNIS)
$A^- = (v_1^-, v_2^-, v_3^-, ..., v_n^-)$ Where $v = min\{v_{ij1}\}$

Step 7 Compute the distance of each sample to the FPIS AND FNIS.

$$d(x, y) = \sqrt{\frac{1}{3}(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2}$$

$$d_i^+ = \sum_{j=1}^{n} d(v_{ij,} v_j^+)$$

$$d_i^- = \sum_{j=1}^{n} d(v_{ij,} v_j^-)$$

Step 8 Compute the closeness coefficient CC$_i$

$$CCi = \frac{d_i^-}{d_i^- + d_i^+}$$

7 Conclusion

The fuzzy sets theory addresses uncertainty and incomplete knowledge, offers numerous advantages. By expressing levels of satisfaction and discontent using the appropriate and erroneous membership functions, respectively, the theory of fuzzy sets enables decision-makers to employ more adaptable methods to replicate the challenges of real-world choices. This study offers a comprehensive review of the real-life applications solved with the neutrosophic set, soft set, and fractional functions. A neutrosophic set utilizes three membership functions—truth, indeterminacy, and falsity—for each element, which allow an independent range within [0,1] to handle uncertainty, inconsistency, and incompleteness effectively. However, a neutrosophic soft set extends this concept by incorporating parameterization, where each parameter maps to subsets of a universal set, enabling context-dependent representation of uncertain information. In contrast, a fractional order neutrosophic set incorporates fractional calculus into the membership functions, introducing a temporal or memory dimension to model systems where past states influence current conditions. These frameworks progressively enhance the ability to address complex, dynamic, and parameterized uncertainty in applications like decision-making, dynamic systems, and data analysis. We also solve the example using the TOPSIS method to show how fuzzy numbers can capture the uncertainties in data. The suggested approach to handling uncertainty outperforms more established ones. We classify each attribute substitute using neutrosophic numbers, which can have multiple values. The assessment process also includes the weight of each criterion as a linguistic variable. This review provides a comprehensive summary of the literature on a single page, demonstrating the superiority of neutrosophic decision logic over other fuzzy logic. This work allows readers to find numerous applications and their summaries in one convenient location and then extend their knowledge by modifying the more generalizing work.

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conflicts of interest

There are no conflicts of interest disclosed by the authors.

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