

Application of Fuzzy-TOPSIS in Civil Engineering- A Review

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Abstract: *The real world presents numerous challenges that necessitate resolution, including decision-making processes. A fundamental initial step in addressing these issues is to identify the defining characteristics of the problems and acquire relevant measurements. This process is referred to as modelling. Fuzzy-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a prominent distance-based MCDM/MADM (multi-criteria or multi-attribute decision making) technique. Fuzzy-TOPSIS is a hybrid approach that leverages fuzzy logic to address real-world multi-criteria decision-making challenges. It enables decision-makers to conduct analysis, comparisons, and rankings of available alternatives when facing multiple, often conflicting, criteria. This paper will trace the origins and evolution of this technique, as well as its applications in various domains of civil engineering.*

Keywords: civil engineering

I. INTRODUCTION

The FUZZY-TOPSIS framework is a multi-criteria decision analysis approach that integrates the principles of fuzzy set theory and the Technique for Order of Preference by Similarity to Ideal Solution method to address decision problems characterized by uncertainty and imprecision. The TOPSIS concept is applicable in a fuzzy environment, where the ratings of alternatives and the weights of criteria are expressed using linguistic terms (Gitinavard et al., 2017). The FUZZY-TOPSIS method is designed to handle decision-making scenarios where the input data is uncertain or vague, which is a common occurrence in real-world situations. The method aims to identify the best alternative by finding the one that is closest to the positive ideal solution and farthest from the negative ideal solution.

Unlike the classic TOPSIS method, FUZZY-TOPSIS is capable of modeling qualitative and imprecise information, such as linguistic variables, through the use of fuzzy sets. This allows for a more accurate representation of the decision-makers' preferences and a more robust decision-making process. The FUZZY-TOPSIS method has been implemented and applied in various fields, such as supplier selection in the automotive industry (Lima & Carpinetti, 2015) and college rankings (Purnomo et al., 2022). The results have shown that FUZZY-TOPSIS is suitable for handling decision-making problems with uncertain and imprecise information, and it can provide more reliable and consistent rankings compared to the classic TOPSIS method.

Fuzzy-TOPSIS: Its Origin and Development in Multi-Criteria Decision Making

Fuzzy-TOPSIS is a widely-used multi-criteria decision-making method that has gained significant attention in the field of decision analysis. The Technique for Order Preference by Similarity to Ideal Solution method was first introduced by Yoon and Hwang, and it has since been expanded to incorporate fuzzy set theory to address the inherent uncertainty and imprecision in decision-making problems.

The TOPSIS concept can be applied in fuzzy environments, which are common in multi-criteria decision-making settings, where the performance of each alternative and the importance of each criterion are described using linguistic terms. Researchers have applied this method in various fields, recognizing its ability to handle both numerical data and linguistic variables, as well as bipolar information with positive and negative values.

One of the key advantages of Fuzzy-TOPSIS is its ability to distinguish between cost and benefit criteria, allowing for the selection of solutions that are closest to the positive ideal solution and farthest from the negative ideal solution. This approach has been particularly useful in supplier selection problems, where the decision-maker must weigh multiple, often conflicting, criteria.

The study examined supplier selection for a small-scale steel manufacturing unit, utilizing the Fuzzy-TOPSIS method to address the inherent uncertainty in the decision-making process (Yadav et al., 2018). The authors showcased the effectiveness of the method in identifying the most appropriate supplier, while also performing a sensitivity analysis to explore the impact of criteria weights on the final decision.

Additionally, the Fuzzy-TOPSIS method has been applied in college rankings, where the goal is to group and evaluate tertiary institutions based on multiple components. By utilizing this decision-making approach, the authors were able to identify the best alternative solution that balances the various criteria and provides a more comprehensive ranking of the institutions.

In conclusion, Fuzzy-TOPSIS has emerged as a powerful tool in multi-criteria decision-making, offering a robust and efficient approach to address the complexities and uncertainties inherent in real-world decision problems.

II. FUZZI-TOPSIS ALGORITHM

Steps involved in the Fuzzi-TOPSIS method

The Fuzzy-TOPSIS approach is a popular multi-criteria decision-making technique that blends the principles of traditional TOPSIS with fuzzy set theory to handle decision problems involving uncertain or imprecise data. This method aims to identify the best alternative solution, which is closest to the positive ideal solution and farthest from the negative ideal solution.

The algorithm involved in the Fuzzy-TOPSIS method can be summarized in the following steps:

1. Define the decision matrix and criteria weights: The decision matrix is constructed with the alternatives as rows and the criteria as columns. The weights of the criteria are also determined, either through expert judgment or using a separate weighting method.
2. Normalize the decision matrix: The decision matrix is normalized to eliminate the unit dependence of the criteria.
3. Construct the weighted normalized decision matrix: The normalized decision matrix is multiplied by the corresponding criteria weights to obtain the weighted normalized decision matrix.
4. Calculate the separation measures: The separation of each alternative from the PIS and NIS is calculated using the n-dimensional Euclidean distance.

Advantages and Limitations of the Fuzzy-TOPSIS Method

The Fuzzy-TOPSIS method is a widely recognized and extensively utilized decision-making approach that combines the principles of fuzzy set theory and the TOPSIS method. This technique is particularly useful in scenarios where decision-making involves multiple, often conflicting criteria, and the information available is imprecise or uncertain.

One of the primary advantages of the Fuzzy-TOPSIS method is its ability to handle linguistic variables and fuzzy information. This is particularly beneficial in situations where decision-makers need to express their preferences using subjective or qualitative terms, such as "good," "poor," or "average." The fuzzy set theory allows for the representation of these linguistic variables as fuzzy numbers, enabling a more realistic and nuanced analysis of the problem at hand.

Additionally, the Fuzzy-TOPSIS method has the ability to consider both positive and negative criteria, effectively modeling the bipolarity present in real-world decision-making problems. This is a significant advantage over traditional TOPSIS, which may struggle to handle such complex information.

Despite its many advantages, the Fuzzy-TOPSIS method also has some limitations. One such limitation is the potential for ranking reversal, where the ranking of alternatives may change when a new alternative is introduced or an existing one is removed. This can be a concern in certain decision-making scenarios, where the stability and consistency of the ranking are critical.

Moreover, the Fuzzy-TOPSIS method can be computationally intensive, particularly when dealing with a large number of alternatives and criteria. The process of calculating the separation measures from the positive and negative ideal solutions, as well as the final ranking of alternatives, can become time-consuming and complex as the problem size increases.

In conclusion, the Fuzzy-TOPSIS method offers a robust and flexible approach to decision-making in the face of imprecise or uncertain information. Its ability to handle linguistic variables, consider bipolarity, and incorporate decision-maker weights makes it a valuable tool in a variety of applications. However, researchers and practitioners should be aware of its limitations, such as the potential for ranking reversal and the computational complexity, and weigh these factors against the specific needs of their decision-making problem. (Sabaghi et al., 2015).

Application of Fuzzy-TOPSIS in Civil Engineering

Application of Fuzzy-TOPSIS Method in Structural Engineering

Structural engineering is a critical field that focuses on the design, analysis, and construction of buildings, bridges, and other infrastructure. In recent decades, researchers have demonstrated increasing interest in applying fuzzy logic-based techniques, such as the Fuzzy-TOPSIS method, to tackle the inherent challenges and complexities encountered in structural engineering.

The Fuzzy-TOPSIS methodology integrates the principles of fuzzy logic and the TOPSIS technique, thereby constituting a multi-criteria decision-making approach. This method allows for the incorporation of imprecise and qualitative information, making it particularly useful in situations where data is incomplete or uncertain.

One of the key applications of the Fuzzy-TOPSIS method in structural engineering is the assessment and evaluation of existing reinforced concrete structures. Factors such as the corrosion of steel reinforcement, concrete cracking, scaling, and spalling, as well as deflections, can be treated as fuzzy sets and analysed using the Fuzzy-TOPSIS method. This approach allows for a more comprehensive and accurate evaluation of the structural condition, which is essential for prioritizing maintenance and repair efforts.

The research conducted in this area has shown that the Fuzzy-TOPSIS method can effectively handle the inherent uncertainty and ambiguity present in structural engineering assessments. By incorporating expert knowledge and fuzzy logic, the Fuzzy-TOPSIS method provides a more robust and reliable decision-making framework, leading to improved outcomes in structural engineering applications.

Application of Fuzzy-TOPSIS Method in Geotechnical Engineering

The field of geotechnical engineering, which focuses on the study and application of soil and rock mechanics, often faces complex decision-making scenarios that require the consideration of multiple, sometimes conflicting, criteria. One method that has proven highly useful in such situations is the Fuzzy Technique for Order Preference by Similarity to Ideal Solution approach.

The Fuzzy-TOPSIS method is a multi-criteria decision-making tool that can effectively handle the uncertainty and imprecision inherent in geotechnical problems. This approach allows for the integration of both qualitative and quantitative factors, enabling decision-makers to consider a wide range of parameters, from soil properties to environmental impacts, when evaluating potential solutions (Hipel, 1982).

The application of Fuzzy-TOPSIS in geotechnical engineering has been explored in various contexts. For instance, it has been used in the selection of appropriate mining techniques for thin coal seam extraction, where the method's ability to handle multiple, often conflicting, criteria has proven invaluable. Similarly, the Fuzzy-TOPSIS approach has been applied to the evaluation of asteroid regulate and cobble simulants, where researchers have used the method to assess the fidelity of these materials in relation to their intended applications (Metzger et al., 2019).

One notable example of the Fuzzy-TOPSIS method's application in geotechnical engineering is its use in the selection of an appropriate mechanized mining technical process for thin coal seam mining (Wang & Tu, 2015). In this case, the method's ability to handle multiple criteria, such as technical, economic, and environmental factors, proved crucial in identifying the most suitable mining technique.

Applications of FUZZY-TOPSIS Method in Transportation Engineering

The transportation sector plays a crucial role in the economic and social development of a region, and the efficient management of transportation systems is a key concern for policymakers and transportation engineers. In recent years, the application of fuzzy logic techniques, such as the Fuzzy-TOPSIS method, has gained significant attention in the field of transportation engineering (Mehan & Sharma, 2011; Sarkar et al., 2012).

Fuzzy logic is a powerful tool for modelling and analysing complex systems characterized by uncertainty, ambiguity, and imprecision. This approach is particularly useful in transportation planning and management, where decision-making often involves subjective judgments and incomplete information. One of the prominent applications of the Fuzzy-TOPSIS method in transportation engineering is the development of traffic light control systems. Fuzzy logic-based traffic light control systems have been shown to outperform traditional control methods in reducing traffic congestion and improving the overall efficiency of the transportation network (Abiyev et al., 2017). The Fuzzy-TOPSIS method has also been employed in various other transportation-related applications, such as the assessment of transportation infrastructure projects, the evaluation of transportation modes, and the selection of optimal routes for freight and passenger transportation.

Applications of Fuzzy-TOPSIS Method in Construction Management

The construction industry, known for its complexity and dynamic nature, faces numerous challenges in decision-making processes, particularly when dealing with ambiguous and subjective information. One promising approach to address these challenges is the application of the Fuzzy-TOPSIS method, which combines the principles of fuzzy logic and the TOPSIS decision-making technique.

The application of Fuzzy-TOPSIS in construction management has been explored by various researchers. For example, one study utilized Fuzzy-TOPSIS to determine the critical path of a construction project by considering criteria such as time, cost, risk, quality, and safety, while accounting for the uncertainty of real-world projects (Dorfeshan & Mousavi, 2019). Another study applied Fuzzy-TOPSIS for supplier selection in the automotive industry, demonstrating the method's ability to model qualitative and imprecise information, as well as its advantage in avoiding ranking reversal issues (Lima & Carpinetti, 2015).

Additionally, Fuzzy-TOPSIS has been employed in the assessment of construction site risks. In this context, the method has been used to evaluate the safety risks associated with construction sites, incorporating various assessment indices and addressing the complex interdependencies between different hazards. Overall, the Fuzzy-TOPSIS method has proven to be a valuable tool in addressing the unique challenges faced by the construction industry.

By leveraging the strengths of fuzzy logic and the TOPSIS decision-making technique, Fuzzy-TOPSIS provides a robust and flexible framework for supporting decision-making in construction management, leading to improved project outcomes and enhanced overall performance.

Application of Fuzzy-TOPSIS in Environmental Engineering

Environmental engineering is a multifaceted field that involves the application of various techniques and methodologies to address complex environmental problems. One such approach is the use of Fuzzy-TOPSIS, a decision-making tool that can be employed in environmental engineering to aid in decision-making processes (Harremoës, 1997). The use of Fuzzy-TOPSIS in environmental engineering has demonstrated its effectiveness in addressing complex decision-making scenarios. For instance, it has been utilized in supplier selection for an automotive company, where it was found to be suitable for modeling qualitative and imprecise information, and did not suffer from ranking reversal issues. Furthermore, Fuzzy-TOPSIS has been applied in the selection of optimal waste-to-energy plant sites, where it has been integrated with other methods, such as TODIM and PROMETHEE, to considering economic, environmental, social, and technological factors (Wu et al., 2018).

Application of Fuzzy-TOPSIS in Water Resources Management

Water resources management is a critical aspect of environmental sustainability, as it involves the efficient and effective allocation and utilization of water resources to meet the diverse needs of various stakeholders, including

human populations, agricultural activities, industrial processes, and ecological systems. The inherent complexity and uncertainty associated with water resources systems, such as imprecision in data, subjectivity in decision-making, and the dynamic nature of environmental factors, have led to the exploration of advanced decision-making tools to support water resources management (Kambalimath & Deka, 2020).

Fuzzy logic-based approaches have gained significant attention in the domain of water resources management due to their ability to handle the inherent uncertainties and imprecisions that characterize these systems. Fuzzy rule-based systems and fuzzy optimization techniques have been widely employed to model and manage water resources under uncertain conditions (Mujumdar & Ghosh, 2008). Fuzzy logic-based approaches have been adopted to address uncertainty in water resource systems modeling, including fuzziness, subjectivity, imprecision, and lack of adequate data.

The application of Fuzzy-TOPSIS in water resources management can be particularly beneficial in situations where multiple criteria, such as water quality, water quantity, environmental impact, and economic considerations, need to be evaluated and balanced to make informed decisions (Moorthi et al., 2018).

The Fuzzy-TOPSIS method allows for the integration of expert knowledge and subjective judgments into the decision-making process, while also considering the relative importance of each criterion. By applying Fuzzy-TOPSIS, water resources managers can effectively assess and prioritize various management alternatives, taking into account the inherent uncertainties and complexities associated with water resources systems.

Comparison of Fuzzy-TOPSIS with other MCDM Methods

Multi-Criteria Decision-Making techniques have gained significant attention in various fields, as they provide a structured approach to address complex decision-making problems involving multiple, often conflicting criteria. In this research paper, we will focus on the comparison of Fuzzy-TOPSIS with other MCDM methods, highlighting the strengths, weaknesses, and areas of application of each approach.

The implementation of Fuzzy-TOPSIS and other MCDM methods in college rankings has been explored in the literature. The study found that the Fuzzy-TOPSIS approach can provide more accurate and reliable results by considering multiple criteria, such as faculty qualifications, research output, and student satisfaction, in the ranking process. Furthermore, researchers have highlighted the need for evaluating the trustworthiness of various MCDM methods, as the presence of numerous techniques can create uncertainty for decision-makers. Criteria for evaluating the performance of MCDM methods, such as logical consistency, mathematical soundness, and practical feasibility, have been proposed to guide the selection of the most appropriate method for a given decision-making problem.

When comparing Fuzzy-TOPSIS to other MCDM methods, studies have found that it offers several advantages, including its ability to handle both numerical and linguistic data, as well as its simplicity and efficiency in the calculation process. However, the effectiveness of Fuzzy-TOPSIS may be influenced by the choice of membership functions, the aggregation operators, and the weighting scheme used in the decision-making process.

In conclusion, the comparison of Fuzzy-TOPSIS with other MCDM methods highlights the importance of selecting the most appropriate technique for a given decision-making problem. Careful consideration of the problem structure, the decision-maker's preferences, and the trustworthiness of the MCDM methods is crucial in ensuring the reliability and validity of the decision-making process.

Current Limitations of Fuzzy-TOPSIS in Civil Engineering Applications

Fuzzy-TOPSIS has become a popular multi-criteria decision-making tool in various fields, including civil engineering. Fuzzy-TOPSIS extends the traditional TOPSIS method by incorporating fuzzy logic to handle the inherent uncertainty and ambiguity in decision-making processes. However, despite its widespread application, Fuzzy-TOPSIS faces several limitations in the context of civil engineering.

One significant limitation of Fuzzy-TOPSIS in civil engineering is the challenge of handling bipolar information. Civil engineering projects often involve both positive and negative criteria, such as cost and performance, which can affect the effectiveness and efficiency of decision-making. To address this, researchers have proposed the use of bipolar fuzzy sets, which can better capture the positive and negative aspects of decision-making criteria.

Another limitation of Fuzzy-TOPSIS in civil engineering applications is the dependence on the subjective judgments of decision-makers. To overcome this, some researchers have proposed the integration of Fuzzy-TOPSIS with other methods, such as the Complex Proportional Assessment method, to incorporate the opinions of multiple experts and reduce the impact of subjectivity (Dorfeshan & Mousavi, 2019).

This issue can significantly impact the reliability and credibility of the decision-making process in civil engineering, where the consequences of incorrect decisions can be severe. To address the rank reversal problem, researchers have proposed various modifications to the Fuzzy-TOPSIS method, such as introducing a new approach to avoid rank reversal cases. However, the solutions proposed so far have been limited to case studies, and there is a need for more comprehensive and generalizable approaches to address this issue.

Evaluation of FUZZY-TOPSIS Effectiveness in Civil Engineering Decision-Making

Civil engineering decision-making often involves complex and multifaceted problems that require the consideration of various criteria, some of which may be subjective or uncertain in nature. Fuzzy TOPSIS has emerged as a promising approach to address these challenges, as it integrates the principles of fuzzy set theory and the TOPSIS method to handle uncertainty and imprecision in the decision-making process (Kurniawan & Utama, 2021; Rastgoftar et al., 2012). The effectiveness of Fuzzy TOPSIS in civil engineering decision-making has been explored in various studies. One study compared the performance of TOPSIS and Fuzzy TOPSIS in supplier selection for an automotive company, finding that Fuzzy TOPSIS is better suited to model qualitative and imprecise information, while TOPSIS requires less effort for data collection and computer processing. Another study focused on the use of Pythagorean fuzzy sets in Fuzzy TOPSIS, which provide a larger space to represent agreement, disagreement, and hesitancy grades in decision-making, and applied it to the selection of critical path in a marble processing plants project.

The fuzzy TOPSIS method has also been widely applied in various civil engineering domains, such as infrastructure project selection, risk assessment, and sustainable materials evaluation. These studies have provided insights into the on-going trends, most popular approaches, and directions of study concerning the fuzzy TOPSIS method, highlighting its effectiveness in handling the inherent uncertainty and complexity in civil engineering decision-making.

III. CONCLUSION

The civil engineering field often faces complex decision-making scenarios that require balancing multiple, and sometimes conflicting, criteria. Fuzzy-TOPSIS has emerged as a promising approach for addressing this challenge, offering a systematic framework for evaluating alternatives under uncertainty. This paper provides a comprehensive summary of the effectiveness of Fuzzy-TOPSIS in civil engineering decision-making, drawing insights from recent literature.

Fuzzy-TOPSIS is a variant of the conventional TOPSIS approach, which seeks to identify the alternative that is both closest to the ideal solution and furthest from the negative-ideal solution. The incorporation of fuzzy logic permit for tackling linguistic variables and vague information, which is often prevalent in civil engineering decision-making contexts. Researchers have demonstrated the applicability of Fuzzy-TOPSIS in a variety of civil engineering domains, including water resource management, air quality assessment, and project value evaluation (Fisher, 2006; Mujumdar & Ghosh, 2008).

One of the key advantages of Fuzzy-TOPSIS is its ability to effectively incorporate both quantitative and qualitative criteria in the decision-making process. This is particularly useful in civil engineering, where decisions often involve a mix of technical, economic, environmental, and social considerations. Fuzzy-TOPSIS provides a structured approach to aggregate these diverse factors, allowing decision-makers to make informed choices that balance multiple objectives.

A study by (Sánchez et al., 2005) presented a fuzzy system for evaluating the value of construction projects in civil engineering, highlighting the effectiveness of Fuzzy-TOPSIS in this context. Another investigation explored the application of Fuzzy-TOPSIS to air quality management, demonstrating its potential to incorporate uncertainty and broader socio-economic factors into environmental decision-making. Furthermore, researchers have explored the integration of Fuzzy-TOPSIS with other decision-making techniques, such as multi-criteria analysis and fuzzy

optimization, to enhance its capabilities in water resource systems modeling. These hybrid approaches have shown promising results in improving the effectiveness and robustness of civil engineering decision-making.

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