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The Applicability of Multiple MCDM Techniques for Implementation in the Priority of Road Maintenance

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ABSTRACT

Priority of road maintenance can be viewed as a process influenced by decision-makers with varying decision-making power. Each decision-maker may have their view and judgment depending on their function and responsibilities. Therefore, determining the priority of road maintenance can be thought of as a process of MCDM. Regarding the priority of road maintenance, this is a difficult MCDM problem involving uncertainty, qualitative criteria, and possible causal relationships between choice criteria. This paper aims to examine the applicability of multiple MCDM techniques, which are used for assessing the priority of road maintenance, by adapting them to this sector. Priority of road maintenance problems subject to internal uncertainty caused by imprecise human judgments will be reviewed and investigated, as well as the most popular theories and methods in group MCDM for presenting uncertain information, creating weights for decision criteria, examining causal relationships, and ranking alternatives. The study concluded that through the strengths and weaknesses reached, fuzzy set theory is the most appropriate and best used in modeling uncertain information. In addition, the methods that are employed the most common in the literature that has been done to explore the correlations between decision criteria have been examined, and it is concluded that the fuzzy best-worst method may be utilized in this research. The Fuzzy VIKOR approach is most likely the best method for ranking the decision alternatives.

Keywords: MCDM, Priority, Maintenance, Uncertainty

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قابلية تطبيق تقنيات MCDM المتعددة للتنفيذ في أولوية صيانة الطرق

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الخلاصة

يمكن النظر إلى أولوية صيانة الطرق على أنها عملية تتأثر بصانعي القرار مع اختلاف سلطات اتخاذ القرار. اعتمادًا على وظيفته ومسؤولياته ، قد يكون لكل صانع قرار وجهة نظره وحكمه الخاص. لذلك ، يمكن اعتبار تحديد أولوية صيانة الطريق بمثابة عملية MCDM. فيما يتعلق بأولوية صيانة الطرق ، فهذه مشكلة صعبة في MCDM تنطوي على عدم اليقين والمعايير النوعية والعلاقات السببية المحتملة بين معايير الاختيار. الغرض من هذه الورقة هو فحص إمكانية تطبيق تقنيات MCDM ، والتي تستخدم لتقييم أولوية صيانة الطرق ، من خلال تكييفها مع هذا القطاع. ستتم مراجعة أولوية مشاكل صيانة الطرق الخاضعة لعدم اليقين الداخلي الناجم عن الأحكام البشرية غير الدقيقة والتحقيق فيها ، بالإضافة إلى النظريات والأساليب الأكثر شيوعًا في مجموعة MCDM لتقديم معلومات غير مؤكدة ، وإنشاء أوزان لمعايير القرار ، وفحص العلاقات السببية ، وترتيب البدائل . خلصت الدراسة إلى أنه من خلال نقاط القوة والضعف التي تم التوصل إليها ، فإن نظرية المجموعة الضبابية هي الأنسب والأفضل لاستخدامها في نمذجة المعلومات غير المؤكدة ، بالإضافة إلى أن الأساليب المستخدمة الأكثر شيوعًا في الأدبيات التي تم إجراؤها لفحص الارتباطات بين معايير القرار ، وتم الاستنتاج الى أن طريقة الأفضل والأسوأ الضبابية هي الطريقة التي يمكن استخدامها في هذا البحث. من المرجح أن يكون أسلوب Fuzzy VIKOR هو أفضل طريقة لتصنيف البدائل.

الكلمات المفتاحية: ادوات القرار المتعدد المعايير ، الأولوية ، الصيانة ، عدم اليقين

1. INTRODUCTION

Since human preference is clouded by uncertainty in most practical cases, decision-makers would find it impossible to directly give exact numerical values to the comparison judgments **(Zadeh, 1965)**. As a result, it is theoretically very challenging for the decision-maker to represent the degree of his preferences and level of confidence in terms of the AHP in pairwise comparison assessments. Thus, it has been argued that AHP is unsuccessful when applied to vaguely or ambiguous portrayed real-world problems that involve subjectivity and uncertainty **(Efstathiou, 1984; Deng, 1999)**. Probability and fuzzy set theories (FST) can handle imprecision, uncertainty, and subjectivity in decision-making processes **(Zadeh, 1965; Zimmermann, 2011)**. FST seeks to codify human behavior's subjective and imprecise aspects by expressing and quantifying hazy information through a membership grade function. Whereas probability focuses on the stochasticity of the decision-making process. As a result, a probabilistic theory is not an appropriate fit for the subjectivity and imprecision inherent in humans' decision-making process **(Efstathiou, 1984; Zimmermann, 2011; Kordi and Brandt, 2012)**.

This paper aims to determine the effectiveness and weakness of MCDM tools and theories for evaluating the priority of road maintenance. The decision-making tools used in other fields will be surveyed and studied to see their applicability in determining the priority of road maintenance. The Hierarchical analytical process (AHP) has been extensively utilized for the ranking and analysis of road pavement maintenance priority **(Agarwal et al., 2004; Farhan and Fwa, 2009)**. Priority-setting is straightforwardly affecting the adequacy of accessible assets, which are often the essential justice of the decision-maker. Priority ranking is determined by various factors, including environmental effects, pavement conditions, predicted execution, traffic volume, budgetary requirements, and execution standards **(Nodrat and Kang, 2018).** Determining road maintenance's priority involves more than one decision at a time. It seems reasonable for MCDM to determine the priority of road maintenance. MCDM can be defined as evaluating the alternatives for the goal of selection or ranking, utilizing a variety of qualitative and/or quantitative criteria that each have their own unique measurement units. This can be done to determine which alternative is superior to the others **(Özcan et al., 2011)**.

This paper aims to determine the effectiveness and weakness of MCDM tools and theories for evaluating the priority of road maintenance. The decision-making tools used in other fields will be surveyed and studied to see their applicability in determining the priority of road maintenance. The fuzzy-based pairwise comparison advantage is to make decision-makers judgments more flexible. This is accomplished through the various levels of fuzzification. Also, suppose the attitude toward risk needs to be taken into account. In that case, fuzzy set theory allows for overlapping criteria preferences if the expert isn't sure about the level of importance among a set of decisions. There's a way for an interval decision to be made, which is shown by a fuzzy membership function **(Kordi and Brandt, 2012)**. In decision problems in which the degrees of uncertainty are expected to increase or change over time, such as in pavement failure and deterioration, where different conditions are expected to change over time, but there is no predictive information on the future state, FST can also be considered useful. To account for the possibility of error in the heuristic and experienced judgments made by experts. **(Shah et al., 2014)**, used fuzzy pairwise comparison deduction technique combined with AHP to keep the subjectivity in judgment in ranking road maintenance factors based on the subjective rating. The normalized weights are used to rank the fuzzy AHP findings. However, decision-makers levels of confidence and risk-taking attitudes should be considered in real-world decisions.

The fuzzy technique known as the Technique for Order Preference by Ideal Situation (TOPSIS) operates on the principle that the most preferred decision alternative should not only be the closest to the positive ideal solution (PIS) but also be the farthest from a negative ideal solution (NIS). Thereby demonstrating its capability and efficiency in dealing with uncertainty **(Khalif, 2016)**. According to **(Durbach and Stewart, 2012)**, the TOPSIS method has two major drawbacks, which are as follows: (A) the use of Euclidean distance does not consider the correlation of the attributes, which is determined from PIS and NIS. (B) It is not easy to weigh and maintain consistency of judgment in this tool, especially with additional attributes. Analytical Hierarchical process (AHP) is one of the methods adopted in making decisions that adopt the Multi-Attribute Decision Method -MADM according to multiple criteria through which it is possible to describe the form of determining the basic criteria and the comparison between them as a multi-criteria decision-making problem **(Mahjoob et al., 2016)**. The AHP method, proposed by **(Thomas, 1980)**, helped capture decision objectivity by reducing the number of complex decisions and turning them into a series of pairwise comparisons and collecting results. It is also a useful technique for checking the consistency of results and reducing decision bias **(Khazael and Al-Bakri, 2021)**. This research intends to examine the applicability of multiple MCDM-based tools for prioritization road maintenance by reviewing theories and tools for representing uncertain information in group MCDM and the aggregation methods used to generate relative criteria weights, the methods used to prioritize criteria weights, and finally, the methods adopted for ranking decision alternatives.

2. UNCERTAINTY MODELING IN MCDM

The following section discusses the various modeling tools that can be used for modeling uncertainty in multi-criteria decision-making problems. Before continuing with the analysis, it is important first to discuss what is meant by the word "uncertainty." According to **(Stewart and Durbach, 2016)**, the definition of "uncertain" means "not known or decided for sure; open to doubt or questioning." **(Khalif, 2016)** provided the following definition of uncertainty for use in the context of multi-criteria decision-making applications: "The presence of uncertainty implies that in a given circumstance a person does not possess the quantitative and qualitative information necessary to describe, prescribe, or anticipate the behavior of a system or another characteristic in a deterministic and numerical manner. " Uncertainty can be divided into two types, according to **(Durbach and Stewart, 2012)**, which are referred to as "external" and "internal" uncertainties. Concerns about factors beyond the Decision-Maker's (DM) ability to influence are called external uncertainty. Internal uncertainty is a phenomenon related to problem structuring and analysis, as well as ignorance, information complexity, subjective evaluations, and imprecise human judgments. Internal uncertainty can also be caused by the fact that information is overly complex.
As indicated in the previous section, it is important to note that the uncertainty present in this investigation is an internal uncertainty brought about by imprecise human judgments. To put it another way, it is not uncommon for people to form subjective judgments while lacking the certainty of a hundred percent certainty. Therefore, the following section will analyze the tools available to model internal uncertainty.

2.1 The Uncertainty Modeling Methods

The following section summarizes and analyzes the methods used in uncertain information to represent it in decision-making, which is necessary because the Decision Maker's (DM) inability to make accurate evaluations consistently is the root cause of the group district road maintenance priority problem.

2.1.1 Probability Theories

This technique provides the most exhaustive mathematical description of uncertainty. Subsets of a universal sample space set measure uncertainty **(Wierman, 2010)**. The measure of the uncertainty function gives each particular subset of the general set or event a number between 0 and 1. This range of numbers is called the probability of the subset or action. If the event has a probability of 0, it is extremely unlikely that it will occur, while if the probability is 1, it will likely occur. In probability theories, the overall probability of space of an event is equal to one. To put this another way, the product of summing the probabilities for each event in space must match the space's overall probability. Uncertainty is measured by assigning each subset of the universal set or even a probability between 0 and 1; this value is known as the probability of the subset or action **(Kochenderfer, 2015)**.

To use notions related to probability, it would be essential to establish a multivariate probability distribution, Z(x), for each event, x. Probability distributions frequently referred to in this context as "lotteries," would then need to be compared before making a decision **(Stewart and Durbach, 2016)**. According to **(Diniz et al., 2012)**, the umbrella of probability theories encompasses two basic schools of thinking. These schools of thought are known as the Frequentists and Bayesian methods. The frequentist method includes a traditional form of statistical technique that can be utilized to define and estimate the probability. The probability is computed using these methods based on the ratio of how often an event has happened to how often it has been observed **(Vogelgesang and Scharkow, 2017)**. The Bayesian probability theory, on the other hand, uses the conventional approach form to the probability notion by defining probability as a quantity of present evidence-based belief. This is a form of the traditional approach to the probability concept. This theory is also known as subjective probability **(Galavotti, 2017)**. One of The theory's drawbacks is that uncertainty needs to be modeled in the MCDM model, which is based solely on expectations.

Additionally, an expectation model, such as the multi-attribute utility theory, must be applied to the results. However, not all potential outcomes are covered by these simple expectation models. The probability of an occurrence is defined by Bayesian theory, which means the belief degree that DM/s have in the potential of that event occurring based on the information that is now accessible **(Batanero et al., 2016)**. This constraint reflects how difficult it is for probability theories to express ignorance/insufficient facts, which can crop up in a decision-making problem. In other words, one criticism of probability theories is that they do not provide an explicit mechanism for dealing with ignorance **(Stewart and Durbach, 2016)**. The computation procedure is made more difficult by the high number of prior probabilities required by probability theories like the Bayesian approach. This is another disadvantage of these theories **(Suárez, 2020)**.

2.1.2 The Dempster-Shafer (D-S) Theory

This method was developed as a mathematical tool for reasoning with incomplete and uncertain information. This new method of coping with uncertainty is a result of two flaws that he observed in probability theory **(Yang et al., 2019)**:

1. The difficulty of expressing ignorance in terms of its lack of specificity.
2. the necessity for an individual's subjective belief in an event and the event's denial to add up to one. Dempster claimed that evidence supporting one hypothesis in many situations should not necessarily decrease the belief in all others **(Dempster, 1969).** According to the D-S theory, there is no necessity for a belief not committed to a specific proposition to be committed to the proposition's negation. This makes the total allocation of belief can vary to suit the extent of knowledge of the decision maker.

2.1.3 Rough Set Theory

The theory of rough sets is a new way to use math or simple tools to deal with fuzziness in knowledge-based systems, information systems, and data analysis. This theory can be applied to various fields, including process control, economics, engineering, social science, medical science, and many more **(El Safty et al., 2021).** Its method is to classify and analyze information and knowledge that is vague, uncertain, or incomplete. It is considered one of the first ways to look at data that isn't based on statistics **(Salama, 2011).**

Rough set theory is predicated on the idea that an individual's level of knowledge about the universe is directly proportional to their capacity to categorize the things that exist within it. A formal approximation of a crisp set, also known as a conventional set, can be stated in terms of a pair of sets that offer the original set's lower and higher approximations. This is what is meant by the term "rough set." The pair of crisp sets represent a rough set, also referred to as the lower and upper approximations of the original set. The lack of precision achieved with this method can be represented by a boundary region of a set **(Slim and Nadeau, 2020)**. The rough set theory attempts to convey uncertainty by focusing on the boundary region of a set. In contrast, fuzzy set theory uses fuzzy membership to deal with uncertainty. One of the problems with rough set theory is that it is based on data that isn't always complete **(Mohamed, 2011)**. However, in applications for real-world decision-making, there are frequent instances of data and knowledge that are either incomplete or missing **(Mohamed, 2011)**.

2.1.4 Fuzzy Set Theory (FST)

The concept of fuzzy sets is a different approach to resolving the issue of making imprecise judgments. Due to the lack of precise, crisp numbers to describe uncertainty, fuzzy set theory was offered to deal with uncertainty using natural words **(Zhu et al., 2021)**. The use of FST as a starting point makes the construction of conceptual frameworks much simpler. FST provides a framework analogous to the one used for ordinary sets, but it is more general and has the potential to have a much wider range of applications than ordinary sets, particularly in pattern classification and information processing. Imprecision is caused more by the lack of clearly defined criteria for class membership than by the presence of random variables, and this framework is a natural way to deal with such problems **(Zimmermann, 2010)**.
FST uses linguistic variables and membership functions with varying grades to model uncertainty inherent in natural language **(Mentes and Helvacioglu, 2011)**. First, FST is applied to a group of objects denoted by X. If M is a fuzzy subset of X. There is a function called M(x) that maps the elements of X into M using numbers between 0 and 1, depending on whether or not X is itself fuzzy. There are M elements in this set, and these numbers represent the degree to which each one belongs to the set. The elements of a fuzzy set (subset) have a degree of membership in the set, whereas the elements of a classical set (subset) have a degree of membership in the set **(Sivanandam et al., 2007).** Modeling uncertainty can be done in several different ways, two of which are the FST and the rough set theory.

2.2 Summary and Outcomes of the Uncertainty Information Modeling MCDM Tools

There are several tools for presenting and modeling internal uncertain Information, some of the most important described above. The tools discussed above were reviewed to bring out strengths and weaknesses depending on their applicability for modeling internal uncertain Information as follows:

2.2.1 Strengths

1. The previous tools review indicates that probability theories, the D-S theory, rough set theory, and FST are the most frequently used frameworks for handling information about internal uncertainty in decision-making.

2. For this study, FST offers great potential in modeling uncertainty in this study. Its advantage over these other theories is its ability to represent imprecise and incomplete judgments, a typical problem in evaluating a group district's road maintenance priority.
3. Due to the large number of studies published in the literature, FST is the best technique of these tools for uncertainty modeling.
4. FST consumes less time to calculate because many software programs can be used to analyze and design FST concepts.

2.2.2 Weaknesses

1. Using the tools of probability theories, the D-S theory, and the rough set theory in this research is hard because people's opinions are subjective, their assessments aren't complete, and the selected criteria are interrelated.
2. One of the major limitations of probability theories is the assumption that events are independent. When it comes to the process of group district road maintenance priority, which is highly interconnected and dependent on one another. So, for this limitation, it is not reasonable to use it in the evaluation process of the criteria used.
3. Probability theory takes a lot of time and effort from researchers because it requires them to know the probability of each situation in advance.
4. One of the problems with D-S theory is that it operates under the presumption that the various pieces of evidence are independent. However, it is not always reasonable to assume that evidence is independent.
5. If the combination rule isn't properly applied, the D-S theory's computational complexity could be a major source of criticism.
6. One of the problems with D-S theory is that it can only be applied to sets of exhaustive and exclusive hypotheses.
7. One of the problems with rough set theory is that it is based on data that isn't always complete. However, in applications for real-world decision-making, there are frequent instances of data and knowledge that are either absent entirely or only partially present.

3. PRIORITY DERIVATION

The process of deriving priorities is very important in solving any decision-making problem. In MCDM, the priorities represent the weights assigned to each decision element, which may be alternatives or criteria **(Jana et al., 2020)**. The opinions and judgments of the DM are reflected in the decision elements weights that are used in MCDM. These weights determine the relative importance of the various criteria **(Zhao et al., 2021)**.

It is well-known that the importance of each criterion is not always equal. Consequently, the weights that represent the significance of the selection criteria play a vital part in the analysis of the evaluation process used to determine the group district road maintenance priority. So, the next section will give an overview of the most common prioritization and weighting methods used in academic literature to derive the priorities and weights of the decision elements and the possibility of their application and limits. These methods will be discussed in relation to the elements of the decision that will be prioritized and the weights that will be assigned to them. After that, based on the features of these tools, a decision is made on the methodology that should be used for this paper.

4. APPROACHES OF THE GROUP AGGREGATION AND PRIORITIZATION

In each situation that requires a group to make a choice, two primary steps need to be taken into consideration: the first stage is aggregation, and the second is prioritization. According to what has been written about group decision-making, the two most common ways to handle the aggregation and prioritization phases depend on whether the group wants to act as a unit or as separate individuals and whether two aggregation approaches are specified: the consensus approach and the majority approach. The process of aggregating individual judgments is often known as "AIJ," or the process of aggregating individual priorities (AIP) **(Forman and Peniwati, 1998)**. The group aggregating and the prioritization phase are independent steps in both ways **(Joseph, 1999)**.

In the process of aggregating individual judgments, the decision makers' judgments are aggregated into a new set of aggregated group judgments for each set of PCJMs (pairwise comparison judgment matrix) that are considered. This is then converted as if it contains the judgments provided by a 'new individual,' and the group solution is derived from the preference of the priorities of this individual. This can be accomplished by employing an aggregation method, which combines the preferences and PCJMs of individuals into a single preference and PCJM for the entire group. After that, a suitable prioritization method should be utilized to get a single group priority vector **(Forman and Peniwati, 1998)**.

Utilizing an appropriate prioritizing technique that determines the number of individual priorities from a set of PCJMs supplied by a group of decision-makers is the best way to achieve prioritization when aggregating individual priorities. This is how prioritization is achieved (DMs). After that, an additional aggregation technique is employed to produce the group aggregation by combining the individual priorities into a group priority vector to build the group aggregation **(Forman and Peniwati, 1998)**.

In the literature that has been done on the topic, different aggregation methods have been proposed for use during the phase of group decision-making known as "aggregation." In AIJ and AIP, the weighted arithmetic mean and the geometric mean are utilized rather frequently to accomplish the goal of group aggregation. According to **(Aczél and Saaty, 1983)**, the geometric mean is more appropriate for AIJ since it preserves the reciprocal characteristics of the aggregated Pairwise Comparison Judgment Matrices. However, in AIP, either the geometric mean or the Weighted Arithmetic Mean is meaningful for aggregating the people's priorities. According to **(Forman and Peniwati, 1998),** the geometric mean should be utilized when dealing with AIJ. The Weighted Arithmetic Mean and geometric mean aggregation procedures were analyzed by **(Ramanathan and Ganesh, 1994)** using the axioms for group preference aggregation. They showed that the GM method, as an aggregation method, fails to satisfy the Pareto optimality axiom, which was described above. On the other hand, the Weighted Arithmetic Mean method did satisfy the Pareto optimality axiom. In this research, the Weighted Arithmetic Mean approach aggregates individual judgments within a group of decision-makers as necessary.

Using a suitable prioritizing approach is recommended to derive the group priorities and weights for decision elements from PCJMs. This is necessary to handle the prioritization phase. In this research, we handle the subjective uncertainty in decision-makers assessments related to group road maintenance priority evaluation by applying the FPP (Fuzzy Performance Programming) methods of deriving proprieties from fuzzy PCJMs.

5. MCDM TOOLS CONCERNING DEPENDENCY

All possible relationships and dependencies between the decision elements must be considered when making a decision. The goal of a good problem structure for MCDM is to investigate the dependencies between the elements of decision-making. In light of this, the next part offers an overview of new approaches in the field of MCDM that deal with the dependency between different decision factors. These new approaches were developed in response to recent advances in the field. Following an analysis of the dependency tools, this section aims to assist in choosing the appropriate method for studying dependency between criteria after examining the dependency tools.

5.1 Regression Analysis

This statistical process estimates the correlations between factors. Numerous methods for performing regression analysis exist, including linear regression, non-linear regression, and linear least squares. The regression analysis has been used in multicriteria decision-making to explore the relationship between the decision-making criteria **(Leskinen et al., 2003)**. Because this tool does not consider the current condition of the issue or the opinions/ judgments of experts, it cannot be utilized in every circumstance requiring a decision. In addition, one of the drawbacks of regression analysis is that it may conclude that a substantial relationship exists between two factors. The degree of effect of other, more important components is not measured **(Saaty, 1996)**. This is a significant limitation of the technique. Additionally, the problem of subjective uncertainty in decision-making problems is not addressed by regression analysis. These reasons need to motivate researchers to look for a better approach to analyzing the dependencies between the decision-making factors.

5.2 Analytic Network Process (ANP)

The Analytic Network Process is a relatively recent MCDM method presented by **(Saaty, 1996)**. It is capable of dealing with all different sorts of interactions systematically. By generating numerous weights by building a "super-matrix," the ANP technique can handle cases where several elements depend on one another **(Kandel, 1983)**. The ANP method has three basic principles, namely, Decomposition and comparative judgments, mean pairwise comparisons from responses to derive the local priorities of all elements in the cluster with respect to their parent, and finally, Synthesis, which is used to multiply the local priorities of elements in a cluster by the global priority of the parent element. The Analytic Network Process is a new theory that expands the AHP and generalizes the super-matrix method. In the ANP approach, networks replace hierarchies **(Saaty, 1996).** The ANP's most significant innovation is the presence of an influence network among clusters and elements. The network structure (feedback) lacks a hierarchy's linear top-to-bottom pattern characteristic. Numerous MCDM research studies have made substantial use of the ANP to examine the interdependence of decision elements **(Büyüközkan and Berkol, 2011)**.

5.3 Fuzzy ANP

As mentioned, human judgments concerning evaluations are frequently unclear and challenging to measure by exact or crisp numerical values; therefore, FST has once again been required to deal with uncertain problems characterized by imprecision and vagueness.

Within the framework of ANP, the concept of "fuzziness" in human judgment was developed due to human judgments' inherent subjectivity and uncertainty **(Mikhailov and Singh, 2003)**. To study and handle the dependency and relationships between criteria in any MCDM problem in uncertainty, the Fuzzy ANP has been widely employed **(Govindan et al., 2013)**.

5.4 DEMATEL

The DEMATEL method was developed by the Geneva Research Centre of the Battelle Memorial Institute between the years 1972 and 1976. It created an association between complex and intertwined problem groups **(Gabus and Fontela, 1973)**. Using matrices or digraphs, this method helps to visualize the structure of intricate causal relationships in a system. Because it is a form of the structural modeling approach, it is very helpful in studying the cause-and-effect relationships between the components of a system. The DEMATEL can confirm dependency among elements, aid in creating a map that reflects their relative relationships, and be used to investigate and solve complex and interconnected problems. With the assistance of impact relation diagrams, this technique uses matrices to turn interdependency relationships into a cause-and-effect group and identifies the crucial factors of complicated structural systems **(Zhou et al., 2011).**

5.5 Fuzzy DEMATEL

The DEMATEL method is used in this technique to analyze relationships or dependency multicriteria decision-making problems in fuzzy environments using the Fuzzy Set Theory **(Zadeh, 1965).** This method does this by using linguistic assessments rather than numerical values. The Fuzzy DEMATEL approach has seen widespread use in group decision-making. This method involves obtaining the opinions of a group to determine the relationships/dependencies between elements in MCDM problems **(Wang and Wu, 2016)**. The advantages of the Fuzzy DEMATEL approach are the same as those of the method of DEMATEL. The Fuzzy DEMATEL method considers that human judgments' subjectivity makes human evaluations and preferences typically ambiguous and challenging to quantify with precise numerical values.

5.6 Fuzzy Best Worst Technique (FBWM)

The best-worst technique is the most recent MCDM developed by **(Rezaei, 2015)**. Conceptually similar to the Analytical Hierarchy Process (AHP) and the Analytical Network Process (ANP), this technique uses pairwise comparisons to arrive at the weight of factors **(Saaty, 2004)**. Best-worst Method offers two distinct advantages over AHP and ANP: first, fewer pairwise comparisons, and second, a more consistent magnitude relation. The weights of criteria are established in BWM via determinative preference of the simplest criterion over diverse criteria and preference of all criteria on the worst criterion by assigning a scale between one and nine. The BWM approach, which requires fewer data and less pairwise comparison, can produce more consistent findings than the AHP method. This is because BWM requires less data. Rezaei expanded a linear mathematical model illustrating how to compute the weights of several criteria in the case of multi-optimality **(Rezaei, 2015)**. However, because there is a possible correlation between the criteria, the fuzzy worst-and-best method was used to give a solution to reduce many comparisons between the criteria.

Based on prior research, the fuzzy Best-worst method methodology implementation is the best MCDM tool for studying dependency.

Table 1 summarizes the MCDM tools discussed and reviewed above to highlight strengths and weaknesses depending on their decision-making type, methodology, usage areas, adaptability/flexibility, consistency measurement, weighting System, process, and conclusions based on the author's conclusion from previous MCDM tools.

Table 1. Analysis of MCDM methods for studying dependency

	Regression Analysis	ANP	FUZZY ANP	DEMATEL	FUZZY DEMATEL	FBWM
Decision Making	Individual	Individual and group	Individual and group	group	group	group
Methodology	Creating a graphical relationship among factors	Creating network structure and pairwise comparison matrix	Creating network structure and pairwise comparison matrix	Construct a network structure with interdependent relationships	Construct a network structure with interdependent relationships	Construct a hierarchical structure with interdependent relationships
Areas of Usage	To support decision-making to simplify	To support decision-making for complexity	To support decision-making for complexity	To support decision-making for complexity	To support decision-making for complexity	To support decision-making for complexity
Adaptability/ Flexibility	Uneasy to adapted	Easy to adapted	Easy to adapted	Easy to adapted	Easy to adapted	Easy to adjust and more accurate and consistent
Consistency Measurement	More consistency but between two factors	consistency but consume much time	consistency but consume much time	consistency but consume much time	consistency but consume much time	More consistency but consumes less time
Weighting System	Link correlation	Pairwise comparison	Pairwise comparison	Pairwise comparison	Pairwise comparison	Pairwise comparison
Process	It can give a strong link between two factors but not estimate the degree of influence of other factors.	Easy implementation and expressive power of modeling	Easy implementation and expressive power of modeling	High level of interaction with DMs	High level of interaction with DMs	High level of interaction with DMs
Conclusions	Linear, on-linear assessment	Several pairwise comparison equations, Complex survey process for non-expert participants	Several pairwise comparison equations, Complex survey process for non-expert participants	Examine a cause and effect among criteria, making a causal diagram.	Examine a cause and effect among criteria, making a causal diagram.	Give a more consistent magnitude relation.

6. MCDM TOOLS FOR DETERMINING THE RANKING OF ALTERNATIVES

Several methods have been employed in the literature to determine the ranking of alternatives.

6.1 Weighted sum model method (WSM)

Due to its intuitive process, the WSM is the simplest accessible method suitable to problems of a single dimension. The utility hypothesis is used in the background of this method, which states that the overall value of every alternative is equivalent to the alternative's total sum. When the ranges of the units being measured are the same across all criteria, WSM is an easy method to apply; however, when the ranges of the units being measured are different—for instance, when both qualitative and quantitative attributes are being measured—the problem becomes difficult to manage because the hypothesis mentioned above is being violated. As a result, normalization schemes need to be used. Due to its simplicity, it is standard practice to combine WSM with other methodologies, such as AHP. Eq. (1) determines the optimal solution to a problem with n criteria and m alternatives **(Kolios et al., 2016)**:

$$A^{*}_{WS} = max \sum_{i}^{m} a_{ij} w_j \quad (1)$$

where i =1..., m, A^{*}_{WS} represents the weighted sum score, a_{ij} is the score of the i-th alternative with respect to the j-th criterion and w_j is the weight of the j-th criterion.

6.2 Weighted Product Method (WPM)

The WPM is an alternative that can be used instead of the WSM. The WPM is quite similar to the WSM, with the primary distinction being that the procedure involves calculating a product rather than a sum. Through the process of multiplying ratios that are related to each and every criterion, each potential alternative is compared in relation to the others. Finally, WPM is seen as being appropriate for use in both single- and multi-dimensional scenarios. Eq. (2) compares two possible solutions: Ak and Al **(Kolios et al., 2016)**. In a pairwise comparison, the optimal solution is the one that is at least equal to the other options; specifically, to be more exact, the best solution is Ak when R ($\frac{Ak}{Aj}$) is greater than 1. (when considering a maximization problem).

$$\boldsymbol{R}\left(\frac{A_k}{A_l}\right) = \prod_{j=1}^{n}\left(\frac{a_{kj}}{a_{lj}}\right)^{w_j} \quad (2)$$

where, as previously stated, a_{lj} is the i-th alternative's score in relation to the j-th criterion, and w_j is the weight of the j-th criterion **(Kolios et al., 2016)**.
Using fuzzy numbers and the fuzzy set theory, **(Triantaphyllou and Lin, 1996)** expanded the WSM and WPM approaches to assess and rank finite alternatives in uncertain circumstances. They suggested using the Fuzzy WSM and the Fuzzy WPM for ranking alternatives. They presumed that the decision maker/decision-makers make use of fuzzy numbers to represent the weights of the relevance of the criteria (denoted as $\tilde{w}$=($\tilde{w}1$,$\tilde{w}2$,….,$\tilde{w}n$)T) and the performance value of the alternatives (denoted as a_{lj}) in the decision-making process.
On the other hand, fuzzy WSM and Fuzzy WPM are very simple ways to solve problems of single decision-making. These methods can't be used to solve problems by making decisions as a group **(Triantaphyllou and Lin, 1996)**.

6.3 The ELECTRE

The ELECTRE (Elimination and Choice Translating algorithm) family was introduced by Benayoun, Roy, and Sussman in 1968. The method was later developed by Bernard **(Roy, 1996)**. This tool usually consists of two major steps **(Roy, 1990)**. In the first stage, alternatives are compared pairwise to establish a relationship of outranking. The outranking relationship was employed in the second stage to make a recommendation to the decision-maker. The ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS, and ELECTRE TRI techniques are all members of this family. It would appear that all ELECTRE approaches have a similar way of articulating the concepts, but they are differentiated according to the kind of decision problem that is being handled. It has been demonstrated that ELECTRE I is the most appropriate method for selection problems, and ELECTRE TRI appears to be appropriate for assignment-type problems. The other ELECTRE methods are suitable for ranking problems. In particular, it has been demonstrated that ELECTRE III is more appropriate for ranking problems. It has been determined that ELECTRE III is helpful in various applications **(Marzouk, 2011)**. The most apparent weakness of these methods is that they yield an incomplete ranking system and only produce a core of leading alternatives **(Triantaphyllou, 2000)**. This indicates it follows that these methods are not always capable of locating the alternative that is chosen the most. Another drawback is that the ELECTRE family of approaches works best with choice problems that entail a small number of criteria but a huge number of potential alternatives **(Lootsma, 1990)**.

6.4 Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

This method does not presume the existence of an option that is incomparably superior to the others; instead, it considers the possibility that one alternative has some degree of superiority over the others and can help determine the option that is best suited **(Mikhailov and Singh, 2003)**. The PROMETHEE utilizes preference functions to rank alternatives in accordance with their net flows, hence eliminating the need for complex criterion measurements. The superiority of fuzzy set theory in MCDM issues guarantees that fuzzy and PROMETHEE are combined. The fuzzy-PROMETHEE coordinate can get the most out of the available information and come to an objective choice despite lacking much subjective data **(Tan et al., 2021)**.

6.5 Fuzzy Analytic Hierarchy Process (FAHP)

The Analytic Hierarchy Process, often known as AHP, is a technique that allows for the derivation of priority scales through the use of pairwise comparisons for the opinions of experts **(Sidney, 1957)**. It was considered one of the most extensively utilized methods for making multiple criterion decisions" **(Habibi et al., 2014)**. The Hierarchical analytical process is one of the methods adopted in making decisions that adopt the Multi-Attribute Decision Method -MADM according to multiple criteria. Through it, defining basic criteria and arbitrage can be described as a multi-criteria decision-making problem **(Mahjoob et al., 2016)**. The main stages of AHP include assigning the significant criteria, determining the relative significance of each used criterion, and making pairwise comparisons to assess the value of the consistency ratio. It is a simple and effective instrument; therefore, it is utilized by decision-makers and researchers **(Fakher et al., 2022)**. Thomas L. Saaty developed this method to define priorities and methodically facilitate complex decision-making **(Saaty, 2008)**. The AHP assists decision-makers in identifying and setting priorities depending on their objectives, expertise, and knowledge of each situation **(Alani and Mahjoob, 2021).** The AHP methodology's hierarchical structure makes it easy to merge the parts into a whole by measuring and synthesizing a range of factors of a complicated decision-making process in a hierarchical way. This is possible because the AHP methodology can hierarchically measure and synthesize these factors. According to bibliometric analysis, between 1992 and 2006, the number of articles discussing MCDM (Multicriteria Decision Making) and MAUT (Multiattribute Utility Theory) rose by 4.2. This tendency can be traced mainly to increased publications focusing on AHP and EMO-Evolutionary Multi-objective Optimization.

Consequently, the three fundamental roles of the AHP method are the structure of complexity, synthesis, and measurement **(Dalkey and Helmer, 1963).** Saaty maintains that to deal with the complexity of a decision-making process, there is a need to identify the numerous factors that influence the decision and organize them in a hierarchical structure of "homogenous clusters of components" **(Saaty, 2008).** To acquire the ratio scale measurement, the factors must be compared. A procedure in which each factor in the hierarchy is compared with its parent factor will be used to determine the relative weight of each factor in the hierarchy. The priorities (weights) for each level of the hierarchy are determined by multiplying the significance of an element at each level by the significance of the component to which it is related (parent element). AHP is so-called because it "measures and synthesizes the plethora of components in a hierarchy" **(Saaty, 2008)**. Despite having the term "analytic" in its name, this methodology's most important feature is its capacity to dissect an abstract entity into its pieces. To select the best alternative to a decision-making problem while considering the uncertainty inherent in the environment, the AHP has been developed to work in fuzzy environments. Therefore, incorporating fuzzy approaches into the AHP framework is feasible for handling expert evaluations (**Abdulkareem and Erzaij, 2022)**. In MCDM situations, fuzzy AHP methods have been employed extensively to rate the alternatives derived from the fuzzy pairwise comparison judgment matrix **(Ayağ and Özdemir, 2011).**

6.6 Fuzzy TOPSIS

Fuzzy TOPSIS is a frequently used technique for evaluating and ranking options developed by **(Tzeng and Huang, 2011)**. Fuzzy TOPSIS's main principle is to choose the alternative closest to the (PIS) and farthest from the (NIS). It is said that TOPSIS is one of the simplest methods and that it is ideal for big-scale problems with a large number of criteria and options. In addition, the Fuzzy TOPSIS technique has been employed in numerous MCDM applications for ranking alternatives under uncertainty **(Büyüközkan and Çifçi, 2012)**. MCDM in a fuzzy environment was first introduced by **(Bellman and Zadeh, 1970)**. The fuzzy set theory helps decision-makers address real-life problems more accurately by allowing confusing qualitative or quantitative information to be converted into computable equivalents **(Rezaei, 2015)**. The classic TOPSIS method has difficulties forming judgments because it only considers crisp values, rectified by the combination of fuzzy and TOPSIS, eliminating the defect caused by the old method **(Tan et al., 2021)**.

6.7 FVIKOR

The VIKOR method ranks alternatives by a similarity measure, much like TOPSIS, but it sometimes seems more effective. VIKOR method is further developed and used in various other forms like extended VIKOR, the extension of VIKOR method in intuitionistic fuzzy environment, with linguistic information and with hesitant fuzzy element, Induced aggregation operators in the VIKOR method, interval 2-tuple linguistic VIKOR method, extended VIKOR method based on prospect theory, etc. **(Devi, 2011)**. When a decision-maker seeks a workable solution that comes the closest to the ideal answer, and the alternatives can be evaluated in accordance with all defined criteria, the VIKOR is designed to resolve MCDM problems with conflicting and non-commensurate criteria.

Table 2 summarizes the MCDM tools discussed and reviewed above to bring out strengths and weaknesses depending on their decision-making type, areas of usage, inputs, outputs, the scale of ranking, best-selected alternatives, levels of consistency, and software application, which is based on the author conclusion from previous MCDM tools.

Table 2. Analysis of MCDM methods for ranking alternatives

	FWSM	FWPM	ELECTRE	PROMETHEE	AHP	FTOPSIS	FVIKOR
Decision - Making	Individual	Individual	group	group	Individual	group	group
Areas of Usage	To support decision-making for Choice problems or ranking problems	To support decision-making for Choice problems, ranking problems	To support decision-making for Choice problems or ranking problems	To support decision-making for Choice problems, ranking problems	To support decision-making for Choice problems or ranking problems	To support decision-making for Choice problems or ranking problems	To support decision-making for Choice problems or ranking problems
Inputs	Criteria weights of each alternative	Criteria weights of each alternative	Criteria weights of each alternative	Criteria weights of each alternative	Pairwise comparison on a ratio scale from 1 to 9	Ideal and anti-ideal option weights	The best and worst option weights
Outputs	Complete ranking with the highest overall performance score (Pi) value	Complete ranking with the highest overall performance score (Pi) value	Complete ranking based on indices	Complete ranking with the net outranking flow for each alternative	Complete ranking with scores	Complete ranking with closeness score to ideal and distance to anti-ideal	Complete ranking with a closeness score to the best option
Scale of Ranking	Positive values	Positive values	Between −1 to 1	Between −1 to 1	Between Zero to one	Between Zero to one	Positive values
Best selected alternative	alternative with Maximum Value	alternative with Maximum Value	alternative with Maximum Value	alternative with Maximum Value	alternative with Maximum Value	alternative with Maximum Value	alternative with minimum Value
levels of Consistency	Restrictions	Restrictions	Restrictions	Restrictions	No Restrictions	No Restrictions	No Restrictions
Software application	Micro Soft Excel, MATLAB	Micro Soft Excel, MATLAB	Micro Soft Excel, MATLAB	Micro Soft Excel, MATLAB	Micro Soft Excel, MATLAB	Micro Soft Excel, MATLAB	Micro Soft Excel, MATLAB

7. CONCLUSIONS

This paper pointed out the method and tools implemented in MCDM techniques that can be used in the decision of road maintenance priority. It reviews the literature regarding methods and tools in MCDM to deal with the aggregation, prioritization, and ranking stages in group decision-making problems in the presence of uncertainty and dependency. Reviewing the advantages and limitations of those methods and tools was very useful for investigating the proper techniques that should be adopted in this paper. Since the problem of road maintenance priority depends on the internal certainty of expert opinions. The literature that models uncertainty in the MCDM field has been reviewed and analyzed. Through the strengths and weaknesses reached it can be concluded that fuzzy set theory is the most appropriate and best to be used as a realistic way to tackle subjective uncertainty in DMs' judgments in this paper. Aggregation and prioritization methods for group decision-making were discussed. Among various prioritization methods, the WAM method is adopted for aggregating the judgments of the group of DMs. The methods concerning studying dependency among criteria and the most used methods in the literature were reviewed, and it is concluded that the Fuzzy Best Worst method can be adopted in this paper. Finally, different approaches for ranking alternatives were discussed and analyzed. It is concluded that the Fuzzy VIKOR method is likely the right choice for ranking alternatives in this paper.

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