Prioritizing Road Maintenance: A Framework integrating Fuzzy Best-Worst Method and VIKOR for Multi-Criteria Decision Making

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Received: 12 February 2024 | Revised: 4 March 2024 | Accepted: 18 March 2024

ABSTRACT

A nation's development depends on its transport networks, particularly the road network, which plays a crucial role in the country's economic and social advancement and well-being. However, roads are subject to deterioration due to weather conditions, traffic loading, and construction quality. If they are not maintained properly, they will quickly worsen over time, resulting in reduced mobility and accessibility. To develop and maintain a good road network, careful planning is needed, which covers all aspects of road maintenance, funding, construction, quality, and other criteria. However, due to limited budgets, not all roads can be maintained and rehabilitated at the same time. Road maintenance priority and optimal use of insufficient funding are the most challenging problems the authorities face. The development of a systematic approach is essential to formulate appropriate maintenance policies. This is why the concept of road maintenance prioritization is essential. Additionally, industry experts have also identified a lack of a Multi-Criteria Decision Making (MCDM) technique that can incorporate the views of all Decision Makers (DMs) in the road maintenance prioritization process. This study aims to propose a framework for prioritizing road maintenance using MCDM techniques in a fuzzy environment. A case study that considers 20 criteria was conducted. The study integrated two MCDM techniques, namely the Fuzzy Best-Worst Method (BWM) and VIKOR, to help DMs evaluate and rank the alternatives, on the basis of the selected maintenance criteria. The aim of this framework is to enhance the decision-making process with impartiality and reliability and to assist in reaching an optimal decision. By comparing the Q values for each alternative, A5 was revealed to have higher priority over the other roads in terms of maintenance and rehabilitation activities.

Keywords- MCDM; DMs; BWM; VIKOR; road management; road maintenance prioritization

I. INTRODUCTION

Road infrastructure is the system of roadways that allows people and goods to be transported across different places. It is necessary for the economic development, social harmony, and environmental conservation. The purpose of roadway pavement construction is to enable rapid, easy, and safe transportation. Pavements are functionally inadequate when these characteristics are absent [1]. However, road infrastructure can deteriorate and lose performance, safety, and durability over time. Road degradation can be caused by a variety of factors, including traffic volume, weather conditions, material aging, design flaws, construction flaws, and insufficient maintenance. Cracks, raveling, potholes, rutting, and edge breaks are all common symptoms of road degradation [2]. Preventing or reducing the negative effects of road degradation is one of the issues that owners and management face. To accomplish this, they must employ efficient and appropriate procedures for maintaining and restoring roadways. The technical, economic, social, and environmental factors of road infrastructure, as well as the resources and limitations available, must be taken into account. Some of the methods and tools that may aid in this task are models for forecasting pavement degradation, Pavement Management Systems (PMS) and Pavement Management and Maintenance Systems (PMMS), and criteria for ranking priorities [2, 3]. The state of road infrastructure has a significant impact on the functionality, efficacy, and longevity of road transport networks, making these issues crucial subjects for study and application. Numerous publications address these subjects. The former include planning, designing, building, operating, managing, modeling, analyzing, evaluating, and improving road infrastructure [2, 3]. Road maintenance is often hard to finance, especially for rural and low-traffic highways. This causes rural populations to face less access, higher transportation expenses, and worsening road conditions. Several reasons contribute to the financial shortfall for road repair, entailing: unreliable or inadequate revenue sources, inadequate use of funds, bad prioritization, etc. [4, 5].

Road maintenance priority is a Multi-Criteria Decision Making (MCDM) problem. One of the most distinguishing features of MCDM approaches is that they can handle both quantitative and qualitative data. The ultimate goal of the MCDM model structure is to give a mechanism for someone taking part in the decision procedure to create and change the choices or make a decision based on the purposes rather than the best solution to a problem [6]. The decision is the process of determining which roads need to be repaired or upgraded based on considerations, such as road condition, traffic volume, safety, and environmental effects. Decisions of road maintenance priority depend on expert's preferences for both criteria and alternatives. Authors in [7] proposed the Hygiene Approach for governmental projects priority ranking depending on fuzzified experts' opinions. Prioritizing road maintenance is critical for making the best use of limited resources and increasing the performance and sustainability of road networks [8, 9]. Various approaches, such as multi-criteria analysis, Markov models, and biologically inspired models, have been proposed to assist road agencies in determining the priority of road maintenance. These approaches and models take into consideration many elements and weights to rank the roads in order of priority and maintenance requirements [10-12]. Fuzzy MCDM is a method for dealing with hazy and imprecise information in road repair ranking that employs fuzzy logic and MCDM. Fuzzy logic enables the use of words and fuzzy numbers to represent the opinions and assessments of experts and Decision Makers (DMs). MCDM is a method that assesses and orders options according to many criteria [13]. Road network performance and efficiency can be increased by using fuzzy MCDM to assist managers in allocating their limited funds and resources to the most important road segments [14]. Mathematical methods known as fuzzy multi-criteria models can help in decision-making when there are several incompatible criteria. In real-world circumstances, criteria are often imprecise and ambiguous. Fuzzy logic allows for the articulation of these characteristics. Fuzzy Multi-Attribute Utility Theory (MAUT), Fuzzy Analytical Hierarchy Process (FAHP), and fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are a few instances of fuzzy multi-criteria models [15]. Considering aspects, like pavement condition, traffic volume, safety, cost, and environmental impact, road maintenance priority is the process of sorting road sections or segments by their maintenance or repair urgency [15]. Road maintenance prioritization can help allocate resources and budget for road management effectively, as well as enhance service quality and network performance. Fuzzy multi criteria models can deal with uncertainty and ambiguity in data and criteria, and include expert and stakeholder views and choices, which makes them suitable for road maintenance priority [14, 16]. To rank road maintenance, fuzzy MCDM techniques, namely fuzzy TOPSIS, fuzzy AHP, fuzzy MARCOS, and fuzzy SWARA [17] can be applied. Each technique has benefits and drawbacks, and the optimal technique is determined by the type and complexity of the problem, the quality and availability of the data, and the preferences of the DMs. Fuzzy SWARA combines the fuzzy Step-wise Weight Assessment Ratio Analysis (SWARA) approach with the fuzzy measurement alternatives and ranking based on the compromise solution (MARCOS) method. The IMF SWARA method can manage both qualitative and quantitative factors, and it can generate a more precise and reliable order of road segments than the conventional fuzzy SWARA technique [17]. The main contribution of this study is the proposal of a framework established on two MCDM methodologies, the Fuzzy VIKOR and Fuzzy BWM to help DMs select, evaluate, and rank criteria and alternatives.

II. MATERIALS AND METHODS

A. Road Maintenance Priority Criteria

Road maintenance prioritization is the process of ranking road sections according to their need for maintenance, predicated on various criteria. Numerous methods and models have been proposed to determine the optimal priority for road maintenance, such as cost-benefit analysis, cost-effectiveness analysis, MCDM, and biologically inspired models. Various sets of evaluation criteria have been employed, depending on the type, nature, and degradation of each road. The condition of the roads that needed to be maintained had an impact on the choice of sub-criteria as well. As a result, a consultation with a number of academic researchers and professionals in road project maintenance was performed to develop a list of sub-criteria for determining road maintenance priorities. Table I provides an overview of the considered sub-criteria.

TABLE I. MAIN ROAD MAINTENANCE SUB CRITERIA

Main criteria	Sub-Criteria	Reference(s)
Road Condition (RC)	Pothole (RC1)	[18-22]
	Cracking (RC2)	
	Transverse slope (RC3)	
	Shoving (RC4)	
	Depressions (RC5)	
	Bumps and sags (RC6)	
	Patching and utility cut patching (RC7)	
Traffic Volume (TV)	Light trucks (TV1)	[21, 23, 24]
	Buses (TV2)	
Economic (EC)	Cost (EC1)	[18]
	Cost/ Benefit (EC2)	
Land Used (LU)	School & residential (LU1)	[18, 22]
	Tourism (LU2)	
	Education (LU3)	
Urban (UR)	Adding and building new services (UR1)	[20]
	Increase in population density (UR2)	
Demography / Society (D/S)	Area width (D/S1)	[23]
	Proposed development work region unit (D/S2)	
Institutional Aspect (IA)	Inclusion of the road into the strategic planning (IA1)	[25]
	Proposed by the community (IA2)	

III. ADOPTED MCDM METHODS

A. The Fuzzy Best-Worst Method (BWM)

The BWM is one of the newest and most efficient MCDM techniques introduced in 2015 by Dr. Jafar Rezaei. In fuzzy BWM, the fuzzy sets are used to evaluate the variables or criteria [26]. This method is implemented to weight the decision criteria. Expert judgments of pairwise comparisons, on the other hand, are frequently subjective and imprecise [27]. Fewer numbers of pairwise comparisons and achieving more consistent pairwise comparisons are the advantages of this method over other multi-criteria techniques [26, 28]. The steps of fuzzy BWM are [29-31]:

1. The method begins with identifying n decision criteria that will be used to evaluate the alternatives.
2. Define the linguistic terms that will be utilized to assess the criteria.
3. Determine the best (most important) and worst (least important) criteria or sub-criteria.
4. Obtain the vector (BO). The fuzzy preferences of the best criteria/sub-criteria compared to the others are determined using triangular fuzzy numbers.
5. Obtain the vector (OW) of the DMs' fuzzy preferences of all criteria/sub-criteria compared to the worst sub-criteria is determined deploying triangular fuzzy numbers.
6. Determine optimal fuzzy weights.

The ideal weight coefficients for each criteria/sub-criteria are acquired by solving a linear programming model or applying a fuzzy additive BWM:

$$min\ \tilde{\xi}^*$$

$$s.t.\begin{cases} \frac{(l_B^w, m_B^w, u_B^w)}{(l_j^w, m_j^w, u_j^w)} - (l_{Bj}, m_{Bj}, u_{Bj}) \leq (k^*, k^*, k^*) \\ \frac{(l_j^w, m_j^w, u_j^w)}{(l_w^w, m_j^w, u_w^w)} - (l_{jw}^w, m_{jw}^w, u_{jw}^w) \leq (k^*, k^*, k^*) \\ \sum_{j=1}^{n} R(\tilde{w}_j) = 1 \\ l_j^w \leq m_{jw}^w \leq u_j^w \\ l_j^w \geq 0 \\ j = 1,2, \ldots\ldots, n \end{cases} \quad (1)$$

7. Check the consistency of the fuzzy preference degrees by employing a fuzzy consistency index or a Consistency Ratio CR= $\tilde{\xi}^*$ /CI. If the consistency is acceptable, rank the alternatives by utilizing the fuzzy weights and a suitable aggregation operator. Otherwise, revise the fuzzy preference degrees to improve the consistency.

B. The Fuzzy VIKOR Method

Fuzzy VIKOR method is a way of making decisions based on multiple criteria that can deal with uncertainty and ambiguity. This technique has the acronym VIKOR, which comes from a Serbian phrase meaning multi-criteria optimization and compromise solution [32]. The method was developed to find a solution that is near the best and satisfactory for the DMs. The technique implements triangular fuzzy numbers for the criteria values and weights, and determines the ranking scores of the choices based on the notions of group utility and individual opinions [31]. There are some extensions of the method putting into service different types of fuzzy sets, such as bipolar fuzzy sets and circular intuitionistic fuzzy sets. The main steps of the Fuzzy VIKOR method are:

1. Define the alternatives, criteria, and weights as triangular fuzzy numbers.
2. Formation of the decision matrix according to the evaluation of all alternatives for different criteria.
3. Normalize the fuzzy decision matrix using the vector normalization method.
4. Determine positive and negative ideal points.

For each criterion, we determine the best and worst among all options and call them $f_j^{\sim *} = (l_j^*, m_j^*, r_j^*)$ and $f_j^{\sim -} = (l_j^-, m_j^-, r_j^-)$, respectively. It is assumed here that f_j is of interest.

$$f_j^{\sim *} = max\, f_{ij}^{\sim} \ , f_j^{\sim -} = \text{min}\ f_{ij}^{\sim} \quad \text{for} \ \ j \in \text{B} \qquad (2)$$

$$f_j^{\sim *} = min\, f_{ij}^{\sim} \ , f_j^{\sim -} = \text{max}\ f_{ij}^{\sim} \quad \text{for} \ \ j \in \text{C} \qquad (3)$$

5. Calculate the separation measures $S_i^{\sim}$ and $R_i^{\sim}$ of each alternative from the positive ideal solution and the negative ideal solution using the Euclidean distance.

$$S_i^{\sim} = \sum_{j=1}^{n} \ w_j^{\sim} \left(f_j^{\sim *} - f_{ij}^{\sim} \right) / \left(f_j^{\sim *} - f_j^{\sim -} \right) \qquad (4)$$

$$R_i^{\sim} = max\left[\ w_j^{\sim} (f_j^{\sim *} - f_{ij}^{\sim}) / (f_j^{\sim *} - f_j^{\sim -}) \right] \qquad (5)$$

6. Compute the ranking index Q for each alternative utilizing a weight v that reflects the decision maker's preference.

$$Q = \frac{v(s_i - s^-)}{s^+ - s^-} + (1 - v)\frac{(R_i - R^-)}{R^+ - R^-} \qquad (6)$$

where s^+ is the max s_i, $s^-$is the min s_i, R^+ is the max R_i, $R^-$is the min R_i, v is the weight of the decision-making of all the criteria, and (1-v) is the weight of an individual criterion. The v value can take any value from 0 to 1. Generally, it is equal to 0.5.

7. Rank the alternatives in ascending order of Q and select the best one as the compromise solution.

IV. STUDY AREA

Wasit governorate center was selected as the study area of this research. This governorate includes a number of important district roads that lead to many places, such as schools, residential building, universities, markets, etc. Lack of funding to build new roads and maintain the existing ones leads to deterioration, so preservation is required to a large part of this road network. The fluctuation of funding also caused a shortage in the budget allocated for road maintenance. Because of these problems, only a small number of roads within the city were maintained for a long period of time while many of them were not given much attention leading to the problem of failure of most of the road network within the governorate.

A. Case Study

Any MCDM process includes questioning DMs about criteria and alternatives, and the process of determining road maintenance priorities is an example of it. A DM uses the minimum of two criteria in the MCDM selection process when faced with a set of countable, finite, or uncountable options [33]. To study the decision of ranking the priority of road maintenance, six main regional roads were chosen from the study area: Wasit University Road (1.365 km), Wasit's provincial council road (0.610 km), Kut dam corniche road (0.63 km), Alzeytoun road (0.58 km), Wasit governorment road (0.0.75 km), and Al-Hurriyah road (0.655 km).

This study selected 13 DMs based on their experiences, job positions, and their degree of influence. They were requested to rank the road maintenance criteria and alternatives. The DMs consisted of the Director and the Assistant Director of the Municipality, the Director of the Project Management Department in the Municipality, the Municipality Maintenance Department Manager, the Maintenance Engineer, the Director and the Assistant Director of the Planning Department in Wasit Governorate, the Director and the Assistant Director of the Project Management Department in Wasit Governorate, and the Director and Assistant Director of the Social Contribution Department in Wasit Governorate.

V. RESULTS

A. Determination of Criteria Weights

The proposed fuzzy BWM was applied to perform the comparison and preference process and find the weights of the main- and sub-criteria. A questionnaire survey that involved a pair-wise comparison among the criteria was designed. On the basis of this, an FBWM pair-wise comparison questionnaire was sent to the DMs to compare the criteria using Linguistic Terms as shown in Table II. In the FBWM pair-wise comparison questionnaire, the experts were asked to specify the priority of the most important criteria over the other criteria in a scale from 1 to 5, as illustrated in Table III, where 1 represents equal importance and 5 represents absolute importance.

TABLE II. LINGUISTIC TERMS FOR MAKING PAIR-WISE COMPARISON AMONG THE CRITERIA

No.	Abbreviation	Linguistic Variables	TFNS	CI
1	EI	Equally Important	[1,1,1]	3
2	WI	Weakly Important	[2/3,1,3/2]	3.8
3	FI	Fairly Important	[3/2, 2, 5/2]	5.29
4	VI	Very Important	[5/2,3,7/2]	6.69
5	AI	Absolutely Important	[7/2,4,9/2]	8.04

TABLE III. EXPERTS' FUZZY PREFERENCES

DM no.	Best /Worst	B/OW	RC	TV	EC	LU	UR	DS	IA
DM1	Best	RC	1	5	4	4	3	3	4
DM1	Worst	DS	3	5	3	4	4	1	4
DM2	Best	RC	1	4	4	4	4	3	4
DM2	Worst	DS	3	3	2	5	5	1	3
DM3	Best	RC	1	4	3	5	3	2	5
DM3	Worst	DS	2	3	4	4	4	1	3
DM4	Best	RC	1	4	4	5	3	4	3
DM4	Worst	DS	4	4	3	4	3	1	4
DM5	Best	RC	1	5	4	5	2	2	3
DM5	Worst	DS	2	4	3	4	4	1	4
DM6	Best	RC	1	4	4	5	4	4	3
DM6	Worst	DS	4	5	4	4	3	1	3
DM7	Best	RC	1	3	3	4	4	5	4
DM7	Worst	DS	2	5	4	4	4	1	4
DM8	Best	RC	1	4	4	4	4	4	3
DM8	Worst	DS	4	5	4	4	3	1	4
DM9	Best	RC	1	4	5	3	3	4	4
DM9	Worst	DS	4	5	5	4	2	1	3
DM10	Best	RC	1	4	3	4	4	5	5
DM10	Worst	DS	5	4	4	4	4	1	4
DM11	Best	RC	1	4	4	4	4	4	3
DM11	Worst	DS	4	4	5	5	5	1	5
DM12	Best	RC	1	5	5	5	5	5	4
DM12	Worst	DS	5	5	5	5	5	1	5
DM13	Best	RC	1	4	3	3	4	4	4
DM13	Worst	DS	4	4	4	4	4	1	4

The process of calculating the criteria weights passes through formulating the model as in (1). As an illustration, the calculation of the weights of the main criteria by DMs is described below.

Min 0^* such that:

$$\left|\frac{(l_1^w, m_1^w, u_1^w)}{(l_1^w, m_1^w, u_1^w)} - (l_{11}, m_{11}, u_{11})\right| \leq (0^*, 0^*, 0^*)$$

$$\left|\frac{(l_1^w, m_1^w, u_1^w)}{(l_2^w, m_2^w, u_2^w)} - (l_{12}, m_{12}, u_{12})\right| \leq (0^*, 0^*, 0^*)$$

$$\left|\frac{(l_1^w, m_1^w, u_1^w)}{(l_3^w, m_3^w, u_3^w)} - (l_{13}, m_{13}, u_{13})\right| \leq (0^*, 0^*, 0^*)$$

$$\left|\frac{(l_1^W,m_1^W,u_1^W)}{(l_4^W,m_4^W,u_4^W)} - (l_{14},m_{14},u_{14})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_1^W,m_1^W,u_1^W)}{(l_5^W,m_5^W,u_5^W)} - (l_{15},m_{15},u_{15})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_1^W,m_1^W,u_1^W)}{(l_6^W,m_6^W,u_6^W)} - (l_{16},m_{16},u_{16})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_1^W,m_1^W,u_1^W)}{(l_7^W,m_7^W,u_7^W)} - (l_{17},m_{17},u_{17})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_6^W,m_6^W,u_6^W)}{(l_1^W,m_1^W,u_1^W)} - (l_{61},m_{61},u_{61})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_6^W,m_6^W,u_6^W)}{(l_2^W,m_2^W,u_2^W)} - (l_{62},m_{62},u_{62})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_6^W,m_6^W,u_6^W)}{(l_3^W,m_3^W,u_3^W)} - (l_{63},m_{63},u_{63})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_6^W,m_6^W,u_6^W)}{(l_4^W,m_4^W,u_4^W)} - (l_{64},m_{64},u_{64})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_6^W,m_6^W,u_6^W)}{(l_5^W,m_5^W,u_5^W)} - (l_{65},m_{65},u_{65})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_6^W,m_6^W,u_6^W)}{(l_6^W,m_6^W,u_6^W)} - (l_{66},m_{66},u_{66})\right| \le (0^*,0^*,0^*)$$

$$\left|\frac{(l_6^W,m_6^W,u_6^W)}{(l_7^W,m_7^W,u_7^W)} - (l_{67},m_{67},u_{67})\right| \le (0^*,0^*,0^*)$$

$$\sum_j R(\widetilde{w_j}) = 1,\ l_j^w \le m_j^w \le u_j^w,\ l_j^w \ge 0$$

The 0^* and CRs of the main criteria are displayed in Table IV. The CR is calculated by: CR = $\xi^*/_{CI}$. The calculated value of CR is close to 0 and far from 1, so the overall comparisons are consistent.

TABLE IV. 0^* AND CR OF THE MAIN CRITERIA

0^*	CR	DMs
1	0.189	DM1
1	0.189	DM2
1	0.2632	DM3
1	0.1495	DM4
1	0.26316	DM5
1	0.14948	DM6
0.80742	0.10043	DM7
0.82119	0.12275	DM8
1	0.14948	DM9
1	0.12438	DM10
1	0.14948	DM11
1	0.12438	DM12
1	0.14948	DM13

Using the detailed method, Tables V and VI present the fuzzy local weights for the criteria and sub-criteria. The results show that D/S is the worst criterion and RC is the best. The results agree with the expert ranking, which confirms the accuracy of the model. Global weights are calculated by multiplying the local weight of each sub-criterion of the related main criterion. Table VII portrays the final ranking of the criteria. The first five sub-criteria that have the greatest impact on road maintenance priority are IA1, UR1, EC1, TV1, LU1 and the criteria that have the least impact on road maintenance priority are D/S2, LU2, and RC3.

TABLE V. FUZZY AND CRISP WEIGHTS FOR EACH MAIN-CRITERION

	Fuzzy Wj			
Criteria	**l**	**m**	**u**	**Crisp**
RC	0.22762	0.26429	0.26619	0.2527
TV	0.10195	0.12611	0.1439	0.12399
EC	0.11554	0.14609	0.15929	0.14031
LU	0.1025	0.12379	0.13645	0.12092
UR	0.11998	0.15089	0.16357	0.14481
DS	0.046955	0.053459	0.057387	0.052601
IA	0.12228	0.15364	0.16331	0.14641

TABLE VI. FUZZY AND CRISP WEIGHTS FOR EACH SUB-CRITERION

	Fuzzy *Wj*			
Sub-criteria	**l**	**m**	**u**	**Crisp**
RC1	0.21033	0.23641	0.24598	0.23091
RC2	0.093381	0.10992	0.12933	0.11088
RC3	0.066943	0.07864	0.085734	0.077108
RC4	0.10629	0.12783	0.14941	0.12784
RC5	0.15631	0.1791	0.19834	0.17791
RC6	0.11146	0.13536	0.16159	0.13614
RC7	0.11133	0.13556	0.16227	0.13639
TV1	0.66349	0.77465	0.78694	0.74169
TV2	0.21591	0.24547	0.25318	0.23819
EC1	0.65792	0.77112	0.7834	0.73748
EC2	0.21888	0.24952	0.25724	0.24188
LU1	0.57291	0.60837	0.61128	0.59752
LU2	0.13214	0.14778	0.1613	0.14707
LU3	0.20505	0.2497	0.29393	0.24956
UR1	0.67003	0.78833	0.78833	0.7489
UR2	0.2053	0.2366	0.2366	0.22617
DS1	0.67559	0.79186	0.79192	0.75312
DS2	0.20233	0.23255	0.23255	0.22247
IA1	0.69786	0.80602	0.80602	0.76997
IA2	0.19041	0.21633	0.21633	0.20769

TABLE VII. RANKING OF THE ROAD MAINTENANCE CRITERIA

Main criteria	Sub-criteria	Local weight	Global weight	Global rank
RC: 0.2527	RC1	0.23091	0.05835	6
	RC2	0.11088	0.028019	17
	RC3	0.077108	0.019485	18
	RC4	0.12784	0.032306	13
	RC5	0.17791	0.044959	7
	RC6	0.13614	0.034401	10
	RC7	0.13639	0.034465	9
TV: 0.12399	TV1	0.74169	0.09196	4
	TV2	0.23819	0.029532	16
EC: 0.14031	EC1	0.73748	0.10347	3
	EC2	0.24188	0.033938	11
LU: 0.12092	LU1	0.59752	0.07225	5
	LU2	0.14707	0.017784	19
	LU3	0.24956	0.030176	15
UR: 0.14481	UR1	0.7489	0.10845	2
	UR2	0.22617	0.032752	12
DS: 0.052601	DS1	0.75312	0.039615	8
	DS2	0.22247	0.011702	20
IA 0.14641	IA1	0.76997	0.11273	1
	IA2	0.20769	0.030407	14

B. Ranking of Road Alternatives with Fuzzy VIKOR

The fuzzy linguistic variables listed in Table VIII are employed for this evaluation.

TABLE VIII. FUZZY LINGUISTIC TERMS USED IN RATING ALTERNATIVES

N	Linguistic Variables	TFNs
9	Extremely more important	[8, 9, 10]
8	Intermediate	[7, 8, 9]
7	Very strongly more important	[6, 7, 8]
6	Intermediate	[5, 6, 7]
5	Strongly more important	[4, 5, 6]
4	Intermediate	[3, 4, 5]
3	Moderately more important	[2, 3, 4]
2	Intermediate	[1, 2, 3]
1	Equally important	[1, 1, 1]

The DMs were asked to rank each road project in the ranking questionnaire in relation to each criterion. Table IX provides an example of DM1's evaluation of the six alternatives in accordance with all the criteria. The creation of the fuzzy decision matrix was a part of the fuzzy VIKOR. The six road projects are rated by DMs using the language terms in Table VIII. These linguistic convey DM opinions in rating the six road projects (Table X). The alternatives' assumed ratings are calculated by the graded mean integration method and are displayed in Table XII.

TABLE IX. RATINGS OF THE SIX ALTERNATIVES BY DM1 UNDER 20 CRITERIA

Criteria	A1	A2	A3	A4	A5	A6
c1	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c2	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c3	[5, 6, 7]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c4	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c5	[4, 5, 6]	[4, 5, 6]	[6, 7, 8]	[5, 6, 7]	[6, 7, 8]	[6, 7, 8]
c6	[4, 5, 6]	[4, 5, 6]	[6, 7, 8]	[5, 6, 7]	[6, 7, 8]	[6, 7, 8]
c7	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c8	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c9	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c10	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c11	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c12	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c13	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c14	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c15	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c16	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c17	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c18	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c19	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]
c20	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]	[6, 7, 8]

TABLE X. AGGREGATED FUZZY DECISION MATRIX

Criteria	Weight	A1	A2	A3	A4	A5	A6
c1	[0.047,0.062,0.065]	[4,6.35,8]	[4,6.35,8]	[6,7,8]	[5,6.45,8]	[5,6.3,8]	[4,6.05,8]
c2	[0.021,0.029,0.034]	[4,6.15,8]	[4,6.15,8]	[4,6.8,8]	[4,6.35,8]	[4,6.55,9]	[4,6.35,8]
c3	[0.015,0.02,0.022]	[4,6.35,8]	[4,6.5,8]	[5,6.9,8]	[4,6.5,8]	[5,6.65,9]	[4,6.3,8]
c4	[0.024,0.033,0.039]	[5,6.55,8]	[5,6.6,8]	[6,7,8]	[4,6.5,8]	[5,6.4,9]	[4,6.1,8]
c5	[0.035,0.047,0.052]	[4,6.25,8]	[4,6.3,8]	[4,6.9,8]	[4,6.3,8]	[4,6.35,9]	[4,6.1,8]
c6	[0.025,0.035,0.043]	[4,6.15,8]	[4,6.2,8]	[4,6.8,8]	[4,6.3,8]	[4,6.55,9]	[4,6.2,8]
c7	[0.025,0.035,0.043]	[5,6.5,8]	[5,6.6,8]	[6,7,8]	[4,6.4,8]	[5,6.5,9]	[4,6.2,8]
c8	[0.067,0.097,0.11]	[5,6.4,8]	[5,6.55,8]	[6,7,8]	[4,6.35,8]	[5,6.5,9]	[4,6.25,8]
c9	[0.022,0.03,0.036]	[4,6.4,8]	[4,6.45,8]	[4,6.85,8]	[4,6.4,8]	[4,6.45,9]	[4,6.15,8]
c10	[0.076,0.11,0.12]	[4,6.45,8]	[4,6.5,8]	[6,7,8]	[4,6.45,8]	[5,6.4,9]	[4,6.1,8]
c11	[0.025,0.036,0.04]	[4,6.3,8]	[4,6.35,8]	[5,6.95,8]	[4,6.35,8]	[5,6.55,9]	[4,6.35,8]
c12	[0.058,0.075,0.083]	[4,6.35,8]	[4,6.5,8]	[5,6.9,8]	[4,6.5,8]	[5,6.65,9]	[4,6.3,8]
c13	[0.013,0.018,0.022]	[4,6.5,8]	[4,6.5,8]	[5,6.95,8]	[5,6.55,8]	[5,6.35,9]	[4,6,8]
c14	[0.021,0.03,0.04]	[4,6.3158,8]	[4,6.3158,8]	[6,7,8]	[5,6.4211,8]	[5,6.2632,8]	[4,6,8]
c15	[0.08,0.11,0.12]	[4,6.1053,8]	[4,6.1053,8]	[4,6.7895,8]	[4,6.3158,8]	[4,6.5263,9]	[4,6.3158,8]
c16	[0.024,0.035,0.038]	[4,6.3684,8]	[4,6.4737,8]	[5,6.8947,8]	[4,6.4737,8]	[5,6.6316,9]	[4,6.2632,8]
c17	[0.031,0.042,0.045]	[5,6.5263,8]	[5,6.5789,8]	[6,7,8]	[4,6.4737,8]	[5,6.3684,9]	[4,6.0526,8]
c18	[0.009,0.012,0.013]	[4,6.3158,8]	[4,6.3684,8]	[4,6.8947,8]	[4,6.3158,8]	[4,6.3158,9]	[4,6.0526,8]
c19	[0.085,0.12,0.13]	[4,6.2105,8]	[4,6.2632,8]	[4,6.7895,8]	[4,6.3158,8]	[4,6.5263,9]	[4,6.1579,8]
c20	[0.023,0.033,0.035]	[5,6.4737,8]	[5,6.5789,8]	[6,7,8]	[4,6.3684,8]	[5,6.4737,9]	[4,6.1579,8]

TABLE XI. DE-FUZZIFYING SJ , RJ AND QJ AND RANKING O THE SIX ROAD PROJECTS

Parameter	A1	A2	A3	A4	A5	A6
S_j	[0.1254,0.12077,0.205]	[0.1254,0.10814,0.205]	[0,0,0.205]	[0.1398,0.1076,0.205]	[0.0662,0.091413,0]	[0.1594,0.15132,0.205]
R_j	[0.0304,0.015052,0.026]	[0.0304,0.015052,0.026]	[0,0,0.026]	[0.0304,0.01261,0.026]	[0.0152,0.0132,0]	[0.0304,0.0198,0.026]
Q_j	[0.89047,0.58403,1]	[0.89047,0.55322,1]	[0,0,1]	[0.92559,0.50495,1]	[0.45377,0.47681,0]	[0.9734,0.74985,1]
S	0.15039	0.14618	0.068333	0.1508	0.052538	0.17191
Rank	4	3	2	5	1	6
R	0.023817	0.023817	0.0086667	0.023003	0.0094667	0.0254
Rank	4	5	1	3	2	6
Q	0.82483	0.81456	0.33333	0.81018	0.31019	0.90775
Rank	5	4	2	3	1	6

The fuzzy best and worst values of alternative A_j were employed to calculate the separation measures of S_j, R_j and Q_j, followed by the normalized fuzzy difference. Table XI depicts the results of de-fuzzifying S_j, R_j, and Q_j and ranking the six road projects. The crisp value of Q for each alternative is utilized to determine the final ranking, which is obtained by applying the Fuzzy VIKOR that sorts the alternatives from the lowest to the highest value.

VI. CONCLUSION

This paper proposes a Multi-Criteria Decision Making framework that integrates Best-Worst and VIKOR methods in a fuzzy environment. The criteria chosen to determine the optimal decision to maintain alternatives for road projects depend on the preferences of the DMs. The final criteria list was acquired from collecting the opinions of various road maintenance specialists for this study, and were used as the basis for ranking road alternatives. However, this framework will work similarly for optimal decision making. A road network consisting of six roadways was considered in this research to compute, develop and verify the proposed framework.

The Fuzzy Best and Worst and the fuzzy VIKOR method were adopted to determine criteria weights and the ranking of the alternatives, respectively. The goal of the proposed framework was to help decision makers' work in a complex and uncertain environment by allowing them to collaborate and make decisions collaboratively and easily. The results disclose that by comparing the Q values for each alternative, A5 was revealed to have higher priority over the other roads in terms of maintenance and rehabilitation activities.

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