Multi-criteria evaluation of pavement quality based on the fuzzy AHP methodology: an integrated approach for optimizing road performance

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Abstract:

Introduction/purpose: In this paper, a multi-criteria evaluation framework for pavement condition assessment using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is proposed, integrating technical, economic, and environmental considerations. Road infrastructure is a key component of transportation systems, and its sustainability depends on effective management and maintenance. This study aims to provide a scientific basis for optimizing road maintenance planning by identifying and prioritizing the key factors affecting pavement quality. The framework considers technical, *economic, and environmental dimensions to ensure a comprehensive evaluation.*

Methods: A hierarchical structure of evaluation criteria was developed, including technical sub-criteria such as surface roughness, bearing capacity, traffic characteristics, and environmental conditions, alongside economic and material-related factors. Weights were assigned using the Fuzzy AHP method, with consistency checks validating the reliability of the results. A case study was applied to National Road RN101, linking Sidi Bel Abbès to Aïn Témouchent.

Results: The analysis revealed significant deficiencies in certain segments, including excessive roughness and insufficient structural strength. Sections subject to high traffic loads and severe environmental conditions showed the most deterioration. Technical aspects, particularly bearing capacity and material quality, were found to exert the strongest influence on pavement performance and durability.

Conclusion: The findings demonstrate the relevance and applicability of the proposed Fuzzy AHP-based evaluation model in supporting decision-making for road maintenance prioritization. The methodology can be extended to other road networks requiring a structured, reliable approach to pavement quality assessment.

Key words: pavement quality, fuzzy analytical hierarchy process (FAHP), maintenance strategy, multi-criteria management.

Introduction

Road infrastructure, particularly pavements, constitutes a fundamental component of modern transport systems. It facilitates the movement of people and goods while playing a crucial role in economic growth (Simões et al., 2017). By providing effective connections between urban, industrial and rural areas, these infrastructures facilitate trade, reduce travel time, and increase the efficiency of supply chains (Yang et al., 2014). Pavement quality directly influences user comfort and security, as well as economic drivers like fuel consumption and vehicle deterioration (Pérez-Acebo et al., 2020). For this reason, road infrastructure is a strategic economic and territorial resource (Taylor and Philp, 2015; Oulha and Derras, 2023).

In order to guarantee pavement lifespan and minimize maintenance expenses, optimized management is unavoidable (Gong et al., 2022). Subject to permanent stress from heavy traffic and climatic changes, pavements need intensive condition surveys and selective preventive treatments (Titus-Glover, 2019). Proactive management not only minimizes the cost of long-term repairs but also ensures continuous service (Derras et al., 2022). In this context, multi-criteria decision-making methods, such as Fuzzy AHP, have been increasingly applied in infrastructure management. Recent applications include: the assessment of unmanned maintenance strategies using a hybrid fuzzy-AHP evaluation framework (Hu et al., 2024), benefit-cost analyses integrating fuzzy concepts for pavement testing track planning (Fosu-Saah et al., 2023), and expressway renewal prioritization through a fuzzy Delphi–Fuzzy AHP–TOPSIS model (Zhu et al., 2023). These studies underscore Fuzzy AHP's strength in handling uncertainty and integrating technical, economic, and environmental criteria. Building on this foundation, the present study develops an integrated framework for pavement condition assessment and applies it to a real case study, thereby contributing to both methodological advancement and decision-support practice.

Road infrastructure managers are faced with paramount challenges in terms of pavement quality and lifespan. The rapid deterioration of such pavements, which is driven by the increasing movement of heavy freight, is a major constraint. Heavy vehicles exert repetitive loads that accelerate the wear of infrastructure, leading to cracking, rutting, and reducing the load-carrying capacity (Gong et al., 2022). Additionally, extreme climatic conditions such as heavy rainfall, freeze-thaw, and high temperatures subject pavements to additional stress, contributing to increased material degradation and higher erosion and cracking hazards (Titus-Glover, 2019).

In this context, a case study was conducted on the national road between Sidi Bel Abbès and Aïn Témouchent. This regional strategic corridor is particularly susceptible to accelerated degradation due to high transport flows and harsh environmental conditions. The study identified the most significant issues, such as a high percentage of cracks and high roughness on certain sections. Based on the Fuzzy AHP approach, priority was assigned to critical sections for urgent intervention, which made possible the optimal resource allocation.

To this end, a systematic and uniform evaluation of pavement condition is required to develop optimal maintenance plans. A correct evaluation system enables managers to choose interventions based on specific needs, levels of deterioration, and available resources. The integration of tools such as Fuzzy AHP enables the development of a multi-criteria hierarchy taking into account technical, economic, and environmental factors, thereby enabling optimal maintenance decisions. Through the identification of the most significant causes of pavement deterioration, such evaluations ensure preventive maintenance, conserving long-term costs in the form of avoiding more expensive reactive actions.

Enhancing pavement management practices is therefore critical in upholding the integrity and safety of road infrastructure. The current paper suggests providing a robust scientific foundation for optimizing pavement management practice through the identification of the most vital criteria for the durability of the latter. Close scrutiny of those criteria will avail a well-defined hierarchy such that decision-making and targeted intervention can be conducted (Titus-Glover, 2019).

The new contribution of the study is the step-by-step prioritization of factors influencing pavement life and quality and the establishment of priorities for efficient road management. Utilizing an integrated framework based on Fuzzy AHP, this study intends to provide enhanced knowledge of the significant factors in pavement maintenance, thereby driving road management policy (Gong et al., 2022, 2024; Galdiani et al., 2022). The findings claim not only to extend existing scientific evidence but also to provide road infrastructure managers with valuable resources with which to optimize their actions and maximize pavement lifespan.

Methodology

This study applies Fuzzy AHP to quantify the pavement's condition through hierarchical ranking of contributing factors by pair-wise comparison and multi-factor weightings.

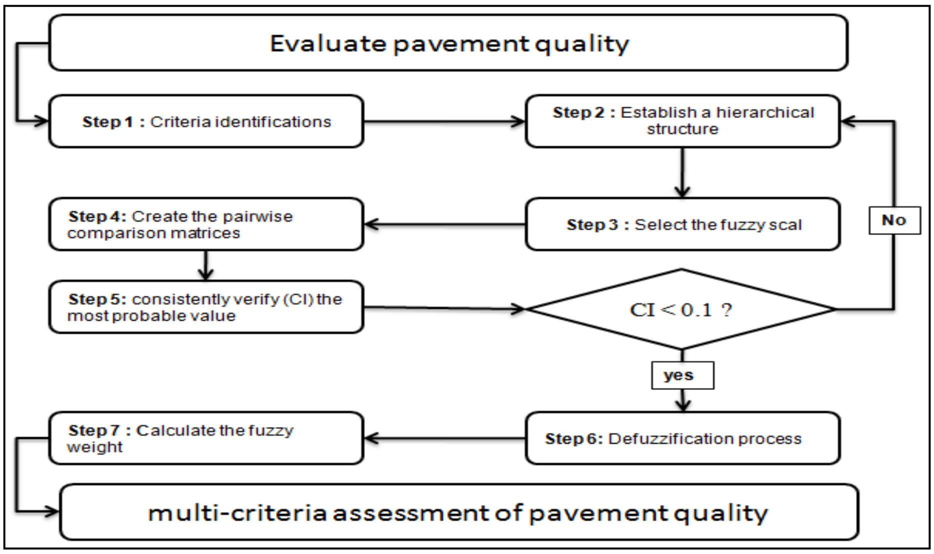

Figure 1 – The methodology used to evaluate pavement quality

The technique supplies a systematic weighing of factors amenable to influence in dealing with the attendant uncertainties of vague human judgment in qualitative rankings. The most important steps are the determination of the most significant factors that affect pavement quality, structuring the hierarchy of the criteria and sub-criteria, and application of the fuzzy analytic hierarchy process to make the prioritization more accurate at different levels of criteria (Figure 1).

Identification and pair-wise criteria comparison

The first step of this study is to identify the criteria affecting pavement quality. The criteria and sub-criteria for assessing the performance of pavements are based on the study of Sirin et al. (2019) and the various cited studies therein. This synthesis identifies 29 factors influencing pavement performance that are grouped into six general categories: surface conditions, infrastructure design, asphalt mixture properties, construction and maintenance quality, traffic loading, and environmental conditions. Every category is supported by research that demonstrates the noteworthy contribution of these criteria to pavement deterioration and optimization.

In the literature examined, there are some studies that bring out the immediate impact of surface conditions — roughness, cracking, and rutting — on the safety and comfort of users. For instance, Zhang et al. (2015) and Wang et al. (2016) present longitudinal and transverse cracks as having an exponential cost of maintenance if not taken care of in a timely manner. Also, Wayne Lee et al. (2017) cite rut depth as a major degradation indicator due to repeated heavy loading.

Asphalt mix properties and construction quality are also recognized as determining criteria. Behl et al. (2013) discuss the effect of additives in asphalt mixtures for enhancing thermal resistance and freeze-thaw cycle resistance, while Haiyan et al. (2017) discuss the effect of initial compaction on pavement life. These findings justify the inclusion of sub-criteria related to materials and processes, such as asphalt content, aggregate quality, and compaction procedures.

Traffic loads, particularly the heaviness of heavy traffic, become a recurring deterioration factor. Studies by Chen and Bai (2018) indicate that heavy vehicle traffic severity encourages cracking and rutting and is thus relevant as a technical sub-criterion.

Finally, the environmental factors, as considered by Tawalare and Raju (2016) and Wayne Lee et al. (2017), emphasize the significance of severe climatic conditions such as freeze-thaw cycles and excessive temperature variations in the rapid deterioration of materials.

A hierarchical structure

A hierarchical model has been established to categorize the criteria and sub-criteria that affect pavement quality. This model is comprised of a number of levels (see Figure 2). The first level consists of the three broad categories that have a considerable effect on pavement quality: technical, economic, and environmental. Each category is then subdivided into particular sub-criteria (level 2), which are recognized as key factors for pavement performance. The bottom of the hierarchy is the sub-sub-criteria, breaking the evaluation factors down into detailed specifics. The hierarchical structure facilitates multi-criteria analysis by establishing the different levels of factors and their interrelations.

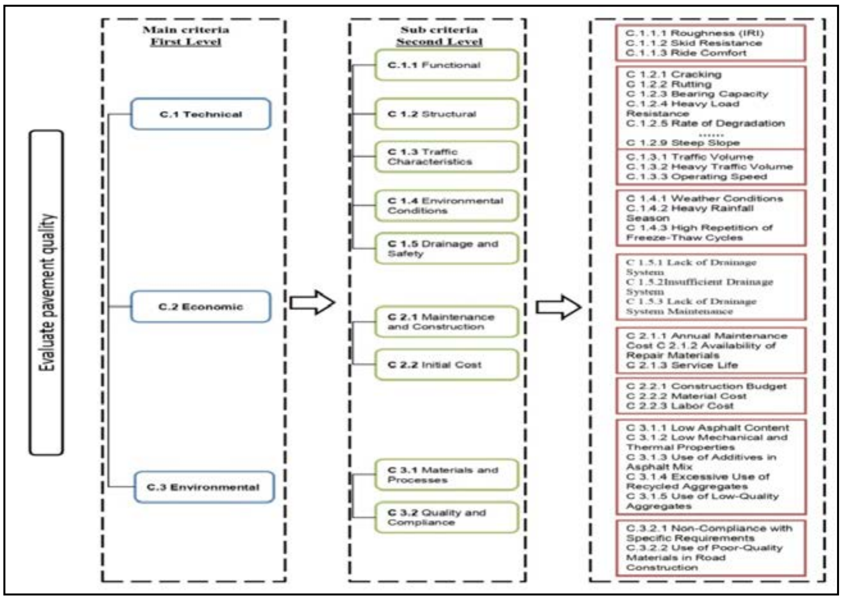

Figure 2 – Hierarchical structure (Source: authors)

For this analysis, the Triangular Fuzzy Number (TFN) is preferred for its simplicity and efficiency. A triangular fuzzy number $\breve{A} = (l\ \ , m\ \ , u\ \ )$ is defined by a triplet of values: l (the minimum value), m (the most likely value), and u (the maximum value), with a membership function $\mu_A(x)$ given by equation (1):

$$\mu_A(x) = \begin{cases} 0 \text{ for } x < 1 \\ \dfrac{x-l}{m-l} \text{ for } l \leq x \leq m \\ \dfrac{u-x}{u-m} \text{ for } m \leq x \leq u \\ 0 \text{ for } x > u \end{cases} \quad (1)$$

The algebraic operations between two triangular fuzzy numbers, denoted as $\breve{A}_1 = (l_1, m_1, u_1)\breve{A}_2 = (l_2, m_2, u_2)$, are formalized as follows:

Addition : $\breve{A}_1 + \breve{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$ (2)

Subtraction: $\breve{A}_1 - \breve{A}_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2)$ (3)

Multiplication : $\breve{A}_1 \times \breve{A}_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)$ (4)

Division : $\breve{A}_1 \div \breve{A}_2 = (l_1 \div l_2, m_1 \div m_2, u_1 \div u_2)$ (5)

Reciprocal: $\breve{A}_1^{-1} = (\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1})$ (6)

In this study, the computational approach relies on the use of fuzzy numbers, with specific values presented in Table 1.

Table 1 – The scale for evaluation of criteria using fuzzy AHP

Linguistic	The scale of fuzzy number	Inverse expression
Equally important	(1, 1,1)	(1, 1,1)
Intermediate preference	(1, 2,3)	(1/3.1/2.1)
Moderately more important	(2, 3,4)	(1/4.1/3.1/2)
Intermediate preference	(3, 4,5)	(1/5.1/4.1/3)
Strongly more important	(4, 5,6)	(1/6.1/5.1/4)
Intermediate preference	(5, 6,7)	(1/7.1/6.1/5)
Very Strong more important	(6, 7,8)	(1/8.1/7.1/6)
Intermediate preference	(7, 8,9)	(1/9.1/8.1/7)
Extremely more important	(8, 9,9)	(1/9.1/9.1/8)

Source: (Buckley, 1985)

Pair-wise comparison matrices are constructed by comparing the relative importance of the criteria at the same level in the hierarchy using the pairwise comparison method (Appendix 1).

$$[\breve{A}] = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (\frac{1}{u_{12}}, \frac{1}{m_{12}}, \frac{1}{l_{12}}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ (\frac{1}{u_{1n}}, \frac{1}{m_{1n}}, \frac{1}{l_{1n}}) & (\frac{1}{u_{2n}}, \frac{1}{m_{2n}}, \frac{1}{l_{2n}}) & \cdots & (1,1,1) \end{bmatrix} \quad (7)$$

The consistency of each comparison matrix is then verified by calculating the consistency index (CI) and the consistency ratio (CR), according to the following formulas:

$$IC = \frac{\lambda_{max} - n}{n - 1} \quad (8)$$

$$CR = \frac{IC}{RI} \quad (9)$$

where λ_{max} is the largest eigenvalue of the matrix, n is the dimension of the matrix, and RI represents the random consistency index, with its values provided in Table 2 (Galdiani et al., 2022).

Table 2 – Random consistency index value

N	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0.53	0.88	1.11	1.25	1.34	1.41	1.45

If the consistency ratio (CR) is less than 10% (CR < 10%), the matrix is considered consistent; conversely, a CR greater than 10% indicates inconsistency, requiring a reassessment of the judgments in the comparison matrix. The final weights are determined by the fuzzy averaging method, which involves calculating the fuzzy geometric mean of the TFN values for each factor (Equation 10). The obtained fuzzy weights are then calculated using the formula in Equation 11 (Gherbi et al., 2024):

$$\breve{r}_i = \left(\prod_{j=1}^{n} \breve{a}_{ij}\right)^{1/n}, \; i = 1,2,3, \dots, n \quad (10)$$

$$w_i = \breve{r}_i \otimes (\breve{r}_1 \oplus \breve{r}_2 \oplus \dots \dots \breve{r}_n)^{-1} \quad (11)$$

The fuzzy weights are then defuzzified using the center of area method, as shown in Equation 12. Subsequently, they are normalized to obtain interpretable values, as demonstrated in Equation 13:

$$w_i = \frac{l+m+u}{3} \quad (12)$$

$$nw_i = \frac{w_i}{\sum_{i=1}^{n} w_i}, \ i = 1,2,\ldots,n \quad (13)$$

Pavement degradation classification

In this study, a widely used assessment system to score pavement conditions has been employed to classify the level of road infrastructure deterioration. The Pavement Condition Index (PCI), which has been widely reported in the literature, is an index that measures pavement deterioration on a scale ranging from 0 (critical) to 100 (excellent).

Table 3 shows the structural and functional classification of pavement condition based on the dominant factors of cracking, rutting, potholes, and drainage efficiency. This follows from the systems that have been utilised by civil engineering structures in the past for scoring purposes in evaluating their structure, e.g., the French IQOA (quality assessment of engineering structures) scoring system (Orcesi et al., 2011).

Table 3 – Pavement condition classification based on degradation levels

Class	Pavement Condition	PCI Range (0-100)	Observed Distress Types
Excellent	Pavement in perfect condition	85 - 100	Smooth surface, minimal or no cracks, effective drainage
Good	Minor surface deterioration	70 – 85	Hairline cracks, slight surface wear, good drainage
Fair	Moderate deterioration	50 – 70	Medium cracks, slight rutting, early-stage ravelling
Poor	Advanced deterioration	25 - 50	Potholes, severe cracks, localized subsidence
Very Poor	Severely deteriorated pavement	0 – 25	Extensive deformation, weakened structure, severe drainage issues

Results and discussion

Analysis of final criterion weights

The decomposition of the results highlights the predominance of the technical criterion for pavement quality assessment, occupying 72.4% of the total weight (Figure 3). This predominance is caused by the technical parameters' immediate effect on road infrastructure lifespan, according to Garraín and Lechón (2019). In particular, properties such as bearing capacity and roughness play a crucial role in affecting pavement performance and its mechanical resistance to stress, as well as traffic load-carrying capacity. Therefore, the best practice and materials come as a strategic approach to increasing these inherent attributes, reducing costly maintenance procedures, and obtaining the maximum road structure durability.

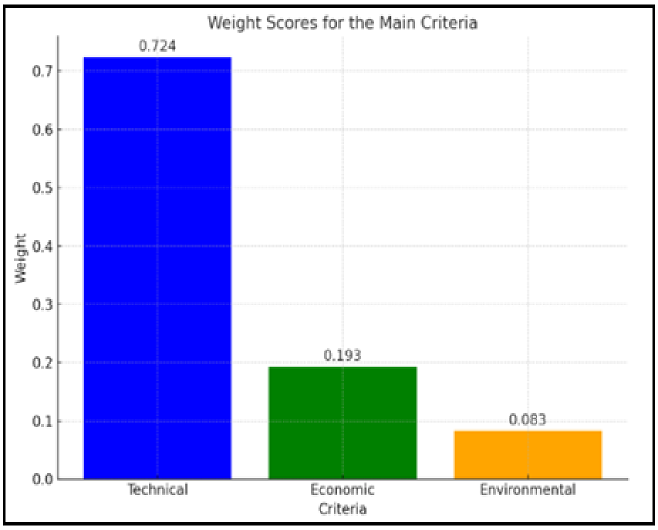

Figure 3 – Weight scores for the main criteria

The most significant of the technical criteria analysis (Table 4) are the functional sub-criteria, which have a combined weight of 48.1%. This preeminence is an indication of the central role played by surface condition attributes in optimizing the performance and life expectancy of road infrastructures. Of these, roughness, with a weight of 0.634, is the most critical factor because it has a direct impact on user comfort and pavement resistance, as seen from Saeed et al. (2017). Maintaining a correct surface condition minimizes premature degradation and enhances maintenance efficiency strategies.

Table 4 – Weight scores for the technical sub-criteria

Level 1		Level 2		Level 3	
Criteria	Weight (%)		Weight (%)		Weight (%)
C.1 Technical	72.4	C.1.1 Functional	48.1	C.1.1.1 Roughness (IRI)	63.4
				C.1.1.2 Skid Resistance	26
				C.1.1.3 Ride Comfort	10.6
		C 1.2 Structural	25.8	C.1.2.1 Cracking	30.23
				C 1.2.2 Rutting	21.63
				C 1.2.3 Bearing Capacity	10.58
				C 1.2.4 Heavy Load Resistance	6.21
				C 1.2.5 Rate of Degradation	6.82
				C 1.2.6 Weather Resistance	11.17
				C 1.2.7 Thin Asphalt Layers	7.54
				C 1.2.8 Extremely Rough Road	3.72
				C 1.2.9 Steep Slope	2.1
		C 1.3 Traffic Characteristics	11.6	C 1.3.1 Traffic Volume	62.3
				C 1.3.2 Heavy Traffic Volume	24
				C 1.3.3 Operating Speed	13.7
		C 1.4 Environmental Conditions	7.8	C 1.4.1 Weather Conditions	63.3
				C 1.4.2 Heavy Rainfall Season	25.9
				C 1.4.3 High Repetition of Freeze-Thaw Cycles	10.8
		C 1.5 Drainage and Safety	6.7	C 1.5.1 Lack of Drainage System	55.7
				C 1.5.2 Insufficient Drainage System	32,4
				C 1.5.3 Lack of Drainage System Maintenance	11.9

As far as structural sub-criteria are concerned, they also have a considerable impact, with a weighting of 25.8%. Cracking and rutting are some of the parameters that act as important indicators of pavement deterioration, which calls for serious consideration in infrastructural design and maintenance. The determinants of paramount importance in this context are bearing capacity and resistance to heavy loads, which verify that dynamic stresses, particularly those due to heavy transport traffic, significantly accelerate structural layer degradation (Yang et al., 2016). Optimized sub-grade design and high-performance materials are thus a necessity in order to reduce the number of interventions and enhance the service life of road infrastructures.

Traffic conditions, although less important than functional and structural issues (11.6%), also contribute significantly towards pavement degradation. Traffic volume (62.3%) and heavy traffic (24%), in specific terms, subject the pavement surface to repetitive loading, accelerating its deterioration. These findings are in agreement with the research of Meegoda and Gao (2015), in which the authors note that pavements should be designed to withstand anticipated load limitations to prevent premature deterioration.

Concerning environmental conditions (7.8% weight), the results indicate that meteorological conditions (63.3%) are the dominant influence, surpassing other influences such as the rainy season (25.9%) and freeze-thaw (10.8%). Climatic conditions' influence has been corroborated by Tawalare and Raju (2016) and Premkumar and Vavrik (2016), who state that severe thermal fluctuations expedite material degradation and compromise its mechanical strength. Furthermore, Zhang et al. (2018) demonstrated that long-term thermal exposure, with traffic loading, accelerates premature cracking and, thus, reduces pavement service life. While less important, the rainy season with high rainfall is nonetheless a major degradation factor as stated by Brown and Tawalare (2016). Heavy volumes of precipitation can cause settlement and erosion of the surface, especially in the absence of good drainage systems. Finally, the recurrence of freeze-thaw cycles (10.8%) calls for investment in thermally fluctuation-resistant materials to prevent cracking and loss of load-carrying ability (Tian et al., 2017).

The drainage sub-criterion (6.7%) once more indicates the major function of water management in ensuring pavement durability. No adequate drainage system is found to be the most important consideration in this category, carrying a weight of 55.7%. This is attested by Premkumar and Vavrik (2016), who state that water pooling on the surface accelerates degradation, particularly in asphalt pavements, which are most susceptible to water penetration. Inadequate drainage, with a weighting of 32.4%, can result in localized settlements as well as structural distortions, a fact reported by Yang et al. (2016) and Wayne Lee et al. (2017), who discovered rutting issues due to inadequate water runoff. Finally, poor maintenance of drainage networks (11.9%) is also a significant aggravating factor that increases the susceptibility of pavement erosion. It has been stated by Haiyan et al. (2017) that proper maintenance of drainage infrastructure is very important in order to attain long-term efficiency and prevent structural damage caused by water accumulation.

Economic factors (Table 5), contributing a combined weight of 19.3%, highlight the significance of embracing an optimized budget control method in road infrastructure maintenance strategies. Here, the maintenance and construction cost criterion as a sub-criterion is the leading determinant, having a weight of 0.751, highlighting the powerful impact of budgetary decisions on pavement lifespan. More importantly, the yearly maintenance cost, weighted at 0.685, is a determining factor in infrastructure durability. The findings are in agreement with the principles proposed by Tawalare and Raju (2016), who advocate for prioritizing preventive maintenance approaches to minimize reactive interventions, which tend to be more expensive and less efficient in the long run.

Table 5 – Weight scores for the economic sub-criteria

Level 1		**Level 2**		**Level 3**	
Criteria	**Weight (%)**		**Weight (%)**		**Weigh t (%)**
C.2 Economic	19.3	C.2.1 Maintenance and Construction	75.1	C.2.1.1 Annual Maintenance Cost	68.5
				C.2.1.2 Availability of Repair Materials	21.8
				C.2.1.3 Service Life	9.7
				C.2.2.2 Material Cost	24.9

Furthermore, although the initial cost has a lesser effect, with a weight of 0.249, it is nonetheless an important variable in the economic viability of road works. The high influence put on the construction budget (0.75) emphasizes the necessity for adequate allocation of funds between initial and recurring maintenance costs. This result concurs with the results of Abtahi et al. (2011), who stress the importance of proper budgeting to provide maximum lifespan with the least overall lifecycle cost of pavements.

Environmental conditions account for 8.3% of the overall evaluation (Table 6), which indicates their contributory role towards road infrastructure longevity. Construction materials and practices are examples of such factors, particularly in climates with high variations. Specifically, low asphalt content and material thermal properties have a direct bearing on pavement resilience to unfavorable environmental conditions (Tawalare and Raju, 2016; Onoyan-Usina et al., 2013). Therefore, selecting materials that have high thermal change resistance and severe climatic cycles is essential to counteract early degradation.

Whereas concerns over compliance standards, although low in weight of 0.0249 and moderately low, have to do with non-compliance with standards, rigorous monitoring of compliance during construction is therefore invaluable in the avoidance of early deterioration of pavements. Herein, the provision of high-standard materials is elementary in the elimination of remedial actions and assuring infrastructure stability for the long run.

These findings corroborate the imperative of pre-emptive technical parameter control to restrain premature aging of pavements. The prevalence of bearing capacity and roughness emphasizes the key function of pre-emptive action to achieve optimum infrastructure lifecycle performance. Through restraining maintenance operation frequency and expenses, this practice supports the research findings of Derras et al. (2022) and Oulha and Derras (2023), who propose active maintenance techniques. Thus, adopting an active pavement management approach is the best solution to optimize resources and achieve the longest life for the infrastructure.

Table 6 – Weight scores for the environmental sub-criteria

Level 1		Level 2		Level 3	
Criteria	**Weight** (%)		**Weight** (%)		**Weight** (%)
C.3 Environmental	8.3	**C.3.1**Materials and Processes	75.1	**C.3.1.1** Low Asphalt Content	48.3
				C.3.1.2 Poor Mechanical and Thermal Properties	26.5
				C.3.1.3 Use of Additives in Asphalt Mixtures	14.4
				C.3.1.4 Use of Low-Quality Aggregates	10.8
		C.3.2 Quality and Compliance	24.9	**C.3.2.1** Non-Compliance with Specific Requirements	75.1
				C.3.2.2 Use of Poor-Quality Materials in Constructed Roads	24.9

Table 7 provides a comprehensive summary of the final weight results, detailing the local and global weight distributions assigned to the criteria, sub-criteria, and sub-sub-criteria. The analysis of these tables reveals significant variations in weight values, demonstrating the distinct influence of each factor on pavement quality. These discrepancies underscore the relative importance of the evaluated parameters, enabling the identification of the most critical elements for the assessment and optimization of road maintenance strategies.

Table 7 – Summary of final weights for criteria, sub-criteria, and sub-sub-criteria in pavement quality assessment

Level 1		Level 2			Level 3		
Criteria	**Weight** (%)		**Weight** (%)	**Wi**		**Weight** (%)	**Wi**
C.1	72.4	**C.1.1**	48.1	0.3482	**C.1.1.1**	63.4	0.2208
					C.1.1.2	26	0.0705
					C.1.1.3	10.6	0.0369
		C 1.2	25.8	0.1816	**C.1.2.1**	30.23	0.0565
					C 1.2.2	21.63	0.0404
					C 1.2.3	10.58	0.0198
					C 1.2.4	6.21	0.0115
					C 1.2.5	6.82	0.0127
					C 1.2.6	11.17	0.0209
					C 1.2.7	7.54	0.0140
					C 1.2.8	3.72	0.0069
					C 1.2.9	2.1	0.0039
		C 1.3	11.6	0.0840	**C 1.3.1**	62.3	0.0523
					C 1.3.2	24	0.0202
					C 1.3.3	13.7	0.0115
		C 1.4	7.8	0.0565	**C 1.4.1**	63.3	0.0357
					C 1.4.2	25.9	0.0146
					C 1.4.3	10.8	0.0061
		C 1.5	6.7	0.0486	**C 1.5.1**	55.7	0.0270
					C 1.5.2	32,4	0.0157
					C 1.5.3	11.9	0.0058
C.2	19.3	**C.2.1**	75.1	0.1449	**C.2.1.1**	68.5	0.0992
					C.2.1.2	21.8	0.0316
					C.2.1.3	9.7	0.0141
		C.2.2	24.9	0.0481	**C.2.2.1**	75.1	0.0361
					C.2.2.2	24.9	0.0120
C.3	8.3	**C.3.1**	75.1	0.0623	**C.3.1.1**	48.3	0.0301
					C.3.1.2	26.5	0.0165
					C.3.1.3	14.4	0.0090
					C.3.1.4	10.8	0.0073
		C.3.2	24.9	0.0207	**C.3.2.1**	75.1	0.0155
					C.3.2.2	24.9	0.0051

Application of the methodology to a case study

The present case study focuses on National Road No. 101 (RN101), which connects Sidi Bel Abbès to Aïn Témouchent. This road represents a strategic component of the national highway network, serving as a major corridor between the inland areas and the Témouchent coastal region, and thus plays a vital role in regional mobility and economic exchanges. The average daily traffic volume is estimated at 24,508 vehicles/day, indicating a considerable loading on the pavement. Traffic pressure is further intensified during the summer season due to the touristic attractiveness of the coastal zone and the strategic position of Sidi Bel Abbès as a regional crossroads in Western Algeria. These characteristics place RN101 among the most heavily trafficked routes, making it particularly vulnerable to the combined effects of high traffic loads and local climatic conditions.

In terms of traffic composition, the road supports a medium level of heavy vehicle traffic, estimated between 500 and 1000 trucks/day, which significantly contributes to the structural deterioration of the pavement. The operating speed ranges from 70 to 90 km/h, reflecting fluid traffic conditions along most sections. However, the climatic conditions are characterized by an alternation of dry and humid seasons, which exacerbates pavement distress mechanisms such as cracking and rutting. Furthermore, the drainage system is limited, with recurrent stagnation zones and an irregular maintenance regime, leading to water infiltration and weakening of the pavement layers. From a structural standpoint, the bearing capacity measured by FWD testing indicates a deflection between 0.4 and 0.6 mm, which corresponds to a medium level of performance in terms of load-carrying capacity.

The pavement assessment reveals a Condition Score (CS) of 5.0081 (PCI range: 50–70), classifying the road in the "Fair" category with moderate deterioration, characterized by medium cracks, slight rutting, and early-stage ravelling (see Table 8 and Figures 4 and 5). The primary contributing factors to this condition include pavement roughness (0.6624), annual maintenance cost (0.7944), and the availability of repair materials (0.2844), highlighting significant maintenance and material management issues.

Structural criteria indicate a high vulnerability to traffic loads and climatic conditions, particularly cracking (0.1695), rutting (0.202), and the impact of heavy rainfall (0.1022). Furthermore, climatic conditions significantly influence pavement degradation, as evidenced by "Weather Conditions" (C.1.4.1) with a score of 0.1785 and "Heavy Rainfall Season" (C.1.4.2) at 0.1022, suggesting that adverse weather accelerates pavement distress. Additionally, the lack of an adequate drainage system (C.1.5.1) with a weight of 0.135 is a critical issue, exacerbating crack propagation and structural weakening due to moisture infiltration.

Figure 4 – Longitudinal and transverse medium cracking observed on the pavement surface

Figure 5 – Slight rutting indicating initial surface deformation

To enhance the condition of this road linking Sidi Bel Abbès to Aïn Témouchent, a major rehabilitation strategy is required, combining structural reinforcement and the implementation of an appropriate overlay system. The choice of this treatment is supported by the Fuzzy AHP results, which emphasized structural weaknesses and environmental stresses as the primary causes of deterioration. In this context, structural reinforcement involves strengthening the existing pavement layers through the use of high-performance bituminous mixtures with superior rutting resistance and durability under freeze–thaw cycles. The overlay system refers to the application of an additional asphalt layer that restores surface quality, increases load-bearing capacity, and prolongs service life. Considering the high traffic volume on RN101 (24,508 vehicles/day) and its exposure to seasonal rainfall and thermal variations, such measures are necessary to ensure the long-term durability of the pavement. Furthermore, optimizing the drainage system remains essential to limit water infiltration, reduce crack propagation, and maintain structural integrity over time.

Table 8 – Final weighting and condition score calculation for the case study pavement (Sidi Bel Abbès – Aïn Témouchent)

	Factor	Score (ASC_i)	overall weight (Wi)	PCI = ASCi × W_i
1	C.1.1.1	3	0.2208	0.6624
2	C.1.1.2	5	0.0705	0.3525
3	C.1.1.3	3	0.0369	0.1107
4	C.1.2.1	3	0.0565	0.1695

5	C 1.2.2	5	0.0404	0.202
	Factor	Score (ASC_i)	overall weight (Wi)	PCI = ASCi × W_i
6	C 1.2.3	5	0.0198	0.099
7	C 1.2.4	5	0.0115	0.0575
8	C 1.2.5	3	0.0127	0.0381
9	C 1.2.6	3	0.0209	0.0627
10	C 1.2.7	3	0.0140	0.042
11	C 1.2.8	5	0.0069	0.0207
12	C 1.2.9	5	0.0039	0.0195
13	C 1.3.1	5	0.0523	0.2615
14	C 1.3.2	5	0.0202	0.101
15	C 1.3.3	7	0.0115	0.0805
16	C 1.4.1	5	0.0357	0.1785
17	C 1.4.2	7	0.0146	0.1022
18	C 1.4.3	9	0.0061	0.0549
19	C 1.5.1	5	0.0270	0.135
20	C 1.5.2	3	0.0157	0.0471
21	C 1.5.3	5	0.0058	0.029
22	C.2.1.1	7	0.0992	0.7944
23	C.2.1.2	9	0.0316	0.2844
24	C.2.1.3	5	0.0141	0.0705
25	**C.2.2.1**	3	0.0361	0.1083
26	C.2.2.2	3	0.0120	0.036
27	C.3.1.1	5	0.0301	0.1505
28	C.3.1.2	5	0.0165	0.0825
29	C.3.1.3	7	0.0090	0.511
30	C.3.1.4	7	0.0073	0.1085
31	C.3.2.1	5	0.0155	0.0357
32	C.3.2.2	3	0.0051	0.6624

$cs = \sum_{i=1}^{26} W_i \times ASC_i = 5.0081$, Class Fair, Moderate deterioration, Medium cracks, slight rutting, early-stage ravelling

Conclusion

This study set out to explore the potential of a structured multi-criteria decision-making approach to assess pavement quality more objectively and comprehensively. By applying the Analytic Hierarchy Process (AHP) enhanced with expert judgment, the complexity of pavement degradation was captured through a hierarchical model encompassing technical, economic, and environmental factors.

The evaluation framework proved effective in identifying the most critical elements influencing road performance, such as surface roughness, maintenance costs, and the availability of repair materials. These findings reflect the challenges faced in real-world pavement management, where degradation often results from a combination of insufficient maintenance, environmental exposure, and traffic-related stresses.

Applied to a real case study on the Sidi Bel Abbès – Témouchent road segment, the method delivered a clear diagnosis of the pavement's condition, which was classified as fair and in need of major rehabilitation. This practical outcome illustrates the value of the approach not only as an academic tool but also as a decision-support system for infrastructure managers and engineers.

Ultimately, this methodology contributes to more transparent and evidence-based maintenance planning. Further refinement of the model, such as the integration of GIS data or real-time monitoring, could expand its applicability and precision in future assessments.

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Višekriterijumska procena kvaliteta kolovoza zasnovana na fazi AHP metodologiji: integrisani pristup za optimizaciju performansi puteva

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OBLAST: građevinarstvo, nauke o odlučivanju

KATEGORIJA (TIP) ČLANKA: originalni naučni rad

Sažetak:

Uvod/cilj: U radu se predlaže višekriterijumski okvir za procenu stanja kolovoza primenom fazi analitičkog hijerarhijskog procesa (eng. Fuzzy AHP) koji objedinjuje tehničke, ekonomske i ekološke aspekte. Putna infrastruktura predstavlja ključnu komponentu transportnih sistema, a njena održivost zavisi od efikasnog upravljanja i održavanja. Cilj ovog istraživanja je da pruži naučne osnove za optimizaciju planiranja održavanja puteva kroz prepoznavanje i rangiranje ključnih faktora koji utiču na kvalitet kolovoza. Okvir uzima u obzir tehničke, ekonomske i ekološke dimenzije kako bi se obezbedila sveobuhvatna procena.

Metode: Razvijena je hijerarhijska struktura kriterijuma za evaluaciju koja obuhvata tehničke podkriterijume kao što su hrapavost površine, nosivost, *karakteristike saobraćaja i uslovi životne sredine, kao i ekonomske faktore i faktore povezane sa materijalima. Težinski koeficijenti su određeni primenom metode fazi analitičkog hijerarhijskog procesa, uz proveru konzistentnosti radi potvrđivanja pouzdanosti rezultata. Studija slučaja primenjena je na državni put RN101 koji povezuje Sidi Bel Abes i Ajn Temušent.*

Rezultati: Analiza je pokazala značajne nedostatke na određenim deonicama, uključujući prekomernu hrapavost i nedovoljnu konstruktivnu čvrstoću. Deonice izložene visokim saobraćajnim opterećenjima i nepovoljnim uslovima životne sredine pokazale su najveći stepen degradacije. Utvrđeno je da tehnički aspekti, pogotovo nosivost i kvalitet materijala, najviše utiču na performanse i dugovečnost kolovoza.

Zaključak: Rezultati pokazuju relevantnost i primenljivost predloženog evaluacionog modela zasnovanog na metodi fazi analitičkog hijerarhijskog procesa pri određivanju prioriteta u procesu održavanja puteva. Metodologija se može proširiti na druge putne mreže koje zahtevaju strukturisan i pouzdan pristup proceni kvaliteta kolovoza.

Ključne reči: kvalitet kolovoza, fazi analitički hijerarhijski proces (FAHP), strategija održavanja, višekriterijumsko upravljanje.

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