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Research Article

A Hybrid Approach Based on Factor Analysis and Fuzzy AHP Multi-criteria Decision-Making Model for Evaluating Pavement Maintenance Management Practices: The Case of Ethiopian Roads Authority

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Abstract

The construction industry has long been realized as one of the most important enablers for the social, economic, and political development of countries. Road pavement that has been constructed undergoes a process of deterioration and catastrophic failure after opening to traffic starts at a low rate and with time this rate increases because of aging, overuse, misuse, and mismanagement. Proper maintenance management practice helps to reduce the cost of maintenance and to make sure the pavement is in good condition with minimum maintenance. Thus, the study focuses on exploring the pavement maintenance management practice in the Ethiopian road authority. The method of data analysis for this study was carried out by using factor analysis and fuzzy AHP methods. Factor analysis provides as to reduce a data set to a more manageable size without much loss of the original information while fuzzy AHP is used to determine the preference weights of the variables. To achieve the objective, the data were collected from primary and secondary sources. SPSS software version 23, and Microsoft Excel were used as analysis tools. The study revealed that written maintenance management plans (0.072), maintenance staff training (0.071), maintenance management team leader (0.069), maintenance checklists (0.068), and periodic maintenance (0.063) were mostly practiced in the Ethiopian road authority. Finally, it can be recommended that the decision-makers conduct practical solutions to enhance, advance, and improve pavement maintenance management practices.

Keywords

Pavement, Maintenance Management, Factor Analysis, Fuzzy AHP

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1. Introduction

The construction industry is a sector of the economy that transforms various resources into constructed physical economic and social infrastructure necessary for socio-economic development. It embraces the process by which the said physical infrastructure is planned, designed, procured, constructed or produced, altered, repaired, maintained, and demolished [1]. The construction industry consists of various sectors. These are the building, transportation systems and facilities which are airports, harbors, highways, subways, bridges, and railroads. Roads and highways are a major part of the transportation infrastructure that play a substantial role in the local economy, community development, and, it provides a link between businesses, industries and consumers, it affects the development of economy and social activities for the country [2].

Efficient sustainable rural, urban and inter-urban transport infrastructure in combination with affordable transport services drive commerce, mobility and access to social services and underpin development in all countries. Roads, averaging 80% worldwide, dominate the transport sector in many countries and are principal means of passenger and freight movement [3]. The pavement maintenance management system is a set of tools that helps decision maker to determine optimum strategies for existing pavement condition by evaluation and maintenance of the pavement to reserve an acceptable serviceability for a desired period of time [1]. Poor pavement maintenance management practices lead the company to spend more money to maintain and repair the pavement [8].

The authors did not get any study that is the same as the current study while searching in the international journals as this study is almost unique of its kind and deals with pavement maintenance management practice in the Ethiopian road authority. The importance of road transport, it is important to identify maintenance of the pavement is important to make sure the traffic flows smoothly facilitate transport service, and reduce costs of travel and trade, enhancing accessibility to markets and services [4]. This study offers a prolonged support to earlier investigation on the concept of maintenance management of pavement through the development of an advanced method of factor analysis and Fuzzy AHP methodologies. The methodology provides as to consider the human assessment of qualitative attributes is always subjective and thus imprecise. Thus, to model this kind of uncertainty in human preference, fuzzy sets could be incorporated with the pairwise comparison as an extension of AHP. Furthermore, the study provides a reference guide for the company in general to know the pavement maintenance management practice. Moreover, this study provides a secondary source of data for future users, academicians and policymakers shall also use this study to make further investigation on the topic as required and also it serves as a basis for further studies. This study aimed to explore pavement maintenance management practices. To achieve this study, there is a need to explore pavement maintenance management practices in the recent literature. Nowadays, it is accepted that the study on pavement maintenance management systems was rarely practiced in the road networks of Ethiopia; even though the studies on pavement maintenance management practice are very limited.

The rest of the paper is structured as follows: Section 2 presents pavement maintenance management practice and Section 3 present how the integrated methodology of factor analysis and fuzzy AHP can be adopted. Section 4 shows numerical analysis and results of factor analysis and fuzzy AHP results along with some discussions related to pavement maintenance management. Section 5 presents a discussion of the findings. Finally, general conclusions and remarks are then presented in Section 6.

2. Pavement Maintenance Management Practices

Pavement management, in its broadest sense, encompasses all the activities involved in the planning, design, construction, maintenance, evaluation, and rehabilitation of the pavement portion of a public works program [6]. Pavement maintenance management practices identified in the literature can be defined as follows [8].

2.1. Maintenance Management Team

Maintenance management team provides the overall coordination of maintenance functions to meet the pavement maintenance requirement [6]. Maintenance management team members to make sure that all works are going in the direction of the implementation of the strategic plans drawn for the maintenance organization.

1. Cooperation and Coordination of Maintenance Team: Maintenance coordination is an attempt at reaching an agreement on sharing tasks and responsibilities in working together in maintenance, focusing on identifying complementarities and possible interactions [7].
2. Responsible Maintenance Management Team: responsible maintenance management team sets the framework for maintenance to improve its effectiveness and efficiency [7].
3. Maintenance Organization Management: is responsible for managing the operations and maintenance of all the pavement facilities of the organization [7].
4. Maintenance Management Team Leader: provides leadership and line management to the team, coordinating and overseeing [8].
5. A Commitment of Maintenance Management Team: The commitment of the maintenance team plays a vital role in organizations as they drive the direction of the organization [9].

6. Maintenance Leadership: is responsible for establishing the policies and expectations that serve to guide maintenance and the maintenance organization in supporting maintenance activities [10].
7. Maintenance Management Team Meeting: Maintenance management team meetings among a client, consultant, and contractor shall be organized at regular intervals on maintenance management approaches [11].
8. Private Contractor Participation for Maintenance: The involvement of a private contractor in the construction project has a significant role in some maintenance work especially through using specialized out-source contractors [12].
9. Staffing Skilled Manpower: Skilled manpower has well-defined job roles, knows what is expected of them, the skills and knowledge as well as the resources to perform, and rewards for good performance [13].
10. Maintenance management team capacity and capability: Maintenance management team's capacity and capability determine the required resources for maintenance [14].

2.2. Maintenance Management Plan

The pavement maintenance plan has been prepared to the framework of guidance, standards, and performance management incorporated in the national code of practice for maintenance [15].

1. Written Maintenance Management Plan: A written maintenance management plan including maintenance policy, standard procedures, and strategy helps to provide sufficient maintenance management [7].
2. Strategic Maintenance Management Plan: Strategic maintenance management is the integration of your maintenance program into the business plans of the company for the least amount of production disruption while maintaining the road pavement [16].
3. Staff Involvement in Developing the Maintenance Plan: The involvement of staff members in the maintenance plan provides to maximize individual contributions to improving the best value service delivery [17].
4. Maintenance Management Plan Revision: Maintenance plan revision provides to ensure the information that may be useful for roads wishing to pursue the maintenance plan [18].
5. Budget for Financing Maintenance Programs: The pavement maintenance program needs an adequate budget to provide the road components and services required to make road maintenance work [19].
6. Maintenance Planning and Scheduling: focuses on the planning and scheduling of the routine, day-in and day-out maintenance.

2.3. Maintenance Approaches

Maintenance activities were performed on the actual state of an asset and evaluated any changes in the parameters of the asset with time [20]. Based on their operational frequency maintenance activity is broadly categorized into two. These are Periodic and Routine maintenance. Periodic Maintenance: Periodic maintenance consists of the provision of a surfacing layer at regular intervals of time [21]. Routine Maintenance: This maintenance covers items such as repairing of cracks and patch work, filling of potholes, maintenance of carriageways, maintenance of road signs [21]. Based on their time of application maintenance is classified as Preventive Maintenance. Corrective Maintenance: Performed after a deficiency occurs in the pavement, such as loss of friction, moderate to severe rutting, or extensive cracking [22]. Emergency Maintenance: Performed during an emergency, such as a blowout or severe pothole that needs repair immediately [5].

2.4. Maintenance Information and Communication Management

Maintenance information and communication are the most important components of maintenance management that are required to make any justification and decision [23].

1. Maintenance Checklists: Maintenance checklist is typically a list of maintenance actions arranged systematically to organize information of maintenance and instructions are supplied for maintenance evaluation [24].
2. Maintenance Staff Training: Maintenance training means investing in competitiveness, profitability, quality, and growth [25].
3. Schedule Maintenance Work: Schedule maintenance work is the planned hours of work over some time and it can be repeated continuously, subject to change following collective agreement [24].
4. Documentation and Recordkeeping: Documentation and recordkeeping are, formal documents, reports, notes, and written files of the organization about the maintenance of a certain piece of resources [24].

2.5. Maintenance Identification and Assessment

A variety of assessment mechanisms were used to determine the requirement through a variety of techniques as follows.

1. Identify and Categorize Maintenance Problems: Maintenance work management process begins with work identification, which is identifying work that needs to be performed [26].
2. Inspection and Reporting of Faults: One of the important forms of maintenance is to inspect at the right time and duly record the data to produce an inspection report [8].
3. Maintenance Resources Allocation: The resources

needed for maintenance consist of human resources, capital, tools, and information and the quality of human resources will depend on the environment of the company [27].

4. Continuous Improvement: Continuous improvement is best described as constantly striving for better ways to do things and comparing one's operation to others to find better ways to the functional reliability of an item [28].
5. Maintenance Quality Supervision: Proper maintenance quality supervision provides recording data of executed maintenance works, availing all the necessary resources at the right time [20].
6. Measure maintenance performance: Maintenance performance can be properly managed in a well-planned manner effectively and efficiently to make the road safe, serviceable, and stable [29].

2.6. Maintenance Management Controlling

Maintenance controlling is defined as the performance measurement system with indicators that are able to measure important elements of maintenance functions performance [30].

1. Inventory Control: Maintenance inventory control is an important maintenance management practice used to show how much inventory you have at any one time and how to keep track of it in a maintenance organization [29].
2. Financial Control: Financial Control deals with the fiscal control procedures of the maintenance organization [26].
3. Maintenance Task Execution: Maintenance task execution ensures the scheduled activities are carried out within the allocated time and through the effective use of resources [31].

3. Study Methodology

The main purpose of this research is to construct an evaluation model for the pavement maintenance management practice in the Ethiopian road authority. The factor analysis and FAHP methods are used in a two-stage process. In the first stage: factor analysis was employed to reduce a huge number of inter-correlated measures to a few representative constructs [32]. In the second stage, the underlying structure of items in a data set was used as criteria weights in fuzzy AHP, and the fuzzy preference weights of the hierarchy were calculated using the matrix constructed by FAHP.

3.1. Data Collection

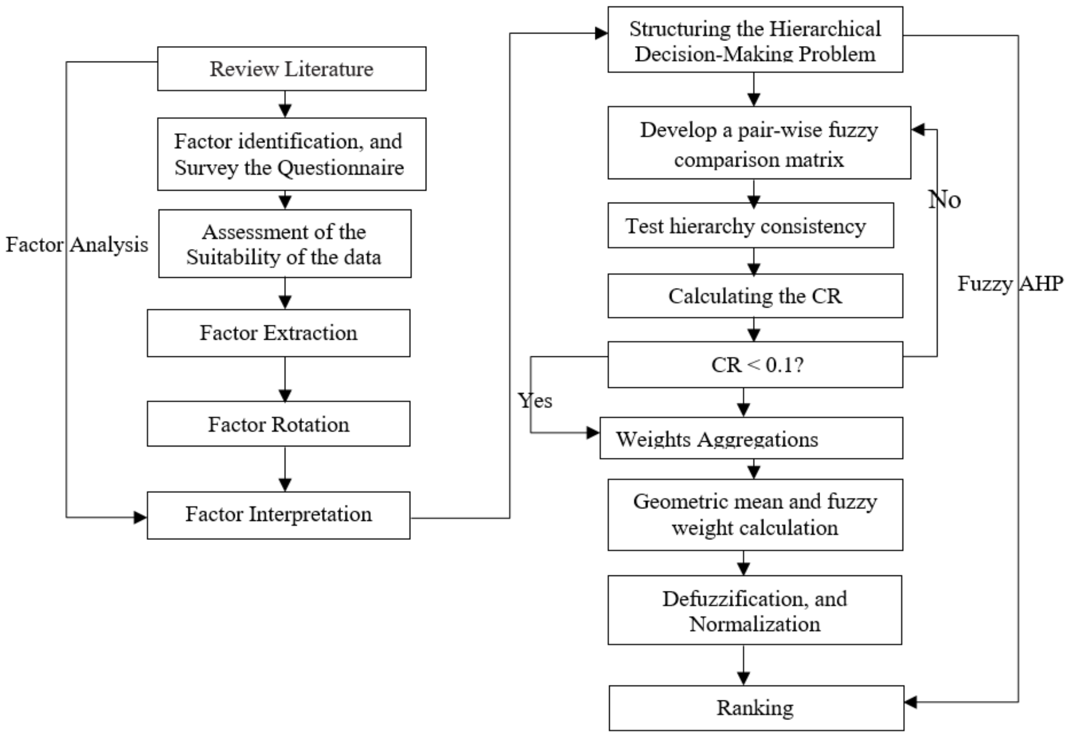

Figure 1. *The steps, and procedures conducted by the applied methodologies. Source: own work, 2023.*

The necessary data for this study was first obtained from the recent literature review regarding the concept of the pavement maintenance management practice. To reduce the number of items in a questionnaire for identifying the underlying structure of items in a data set factor analysis was performed and sixty-one questionnaires were distributed to the staff members of pavement maintenance management professionals and academicians in the Ethiopian road authority, and the number of valid questionnaires is sixty-one. In the case of fuzzy AHP, fifteen senior decision experts were selected from academicians and industrialists in the maintenance of roads. To measure the internal consistency or reliability of the questionnaire Cronbach's alpha, and consistency ratio methods were applied. The steps and procedures of the applied technique are presented in the following sub-sections.

3.2 Factor Analysis

Factor analysis can be applied to developing a questionnaire. In doing the analysis, irrelevant questions can be removed from the final questionnaire [33]. Factor Model with 'm' Common Factors Let $X = (X_1, X_2, \ldots X_p)'$ is a random vector with mean vector μ and covariance matrix Σ [34]. The factor analysis model assumes that $X = \mu + \lambda F + \varepsilon$, where, $\lambda = \{\lambda_{jk}\}_{n*m}$ the matrix of factor loadings; λ_{jk} is the loading of the j^{th} variable on the k^{th} common factor, F = tor, $F = (F_1, F_2, \ldots F_m)'$ denotes the vector of latent factor scores; F_k is the score on the k^{th} common factor and $\varepsilon = (\varepsilon_1, \varepsilon_2, \ldots \varepsilon_p)'$ denotes the vector of latent error terms; ε_j is the j^{th} specific factor [35].

There are three major steps involved in factor analysis: i) assessment of the suitability of the data, ii) factor extraction, and iii) factor rotation and interpretation. They are described as [36]:

3.2.1. Assessment of the Suitability of the Data

To determine the suitability of the data set for factor analysis, sample size and strength of the relationship among the items have to be considered [36]. Generally, a larger sample is recommended for factor analysis. Nevertheless, a smaller sample size can also be sufficient if solutions have several high-loading marker variables < 0.80 [35].

Determinant Score

The value of the determinant is an important test for multicollinearity or singularity. The determinant score of the correlation matrix should be > 0.00001 which specifies that there is an absence of multicollinearity.

1) Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy

The KMO test is a measure that has been intended to measure the suitability of data for factor analysis. The KMO measure of sampling adequacy is given by the formula [36]:

$$KMO_i = \frac{\sum_{i\neq j} R_{ij}^2}{\sum_{i\neq j} R_{ij}^2 + \sum_{i\neq j} U_{ij}^2} \quad (1)$$

2) Bartlett's Test of Sphericity

The significant value < 0.05 indicates that a factor analysis may be worthwhile for the data set. To measure the overall relation between the variables the determinant of the correlation matrix $|R|$ is calculated. Under H_0, $|R|$ =1; if the variables are highly correlated, then $|R| \approx 0$. The Bartlett's test of Sphericity is given by [36]:

$$x^2 = -\left(n - 1 - \frac{2p+5}{6}\right) * \ln|R| \quad (2)$$

Where, p= number of variables, n= total sample size and R= correlation matrix

3.2.2. Factor Extraction

Factor extraction encompasses determining the least number of factors that can be used to best represent the interrelationships among the set of variables [36]:

1) Kaiser's (Eigenvalue) Criterion

The eigenvalue of a factor represents the amount of the total variance explained by that factor. In factor analysis, the remarkable factors having eigenvalue greater than one are retained and considered to be significant [34].

2) Scree Test

A scree plot graphs eigenvalue magnitudes on the vertical access, with eigenvalue numbers constituting the horizontal axis [37].

3.2.3. Factor Rotation and Interpretation

There are two main approaches to factor rotation; orthogonal (uncorrelated) or oblique (correlated) factor solutions. In this study, orthogonal factor rotation is used because it results in solutions that are easier to interpret and report [36].

1) Orthogonal Factor Model Assumptions

The orthogonal factor analysis model assumes the form $X = \mu + \lambda F + \varepsilon$, and adds the assumption that $F \sim (0, 1_m)$ (i.e. the latent factors have mean zero, unit variance, and are uncorrelated, E ~ (0, Ψ) where $\Psi = \operatorname{diag}(\Psi_1, \Psi_2 \ldots, \Psi_n$ with Ψ_i denoting the j^{th} specific variance, ε_j, and F_k, are independent of one another for all pairs, j, k.

2) Variance Explained by Common Factors

The portion of the variance of the j^{th} the variable that is explained by the 'm' common factors is called the communality of the j^{th} variable: $\sigma_{jj} = h_j^2 + \Psi_j$ where, σ_{jj} is the variance of X_j (i.e. j^{th} diagonal of Σ). Communality is the sum of squared loadings for X_j and given by $h_j^2 = (\lambda\lambda')_{jj} = \lambda_{j1}^2 + \lambda_{j2}^2 + \ldots\ldots + \lambda_{jm}^2$ is the communality of X_j, and Ψ_j is the specific variance (or uniqueness) of X_j.

3.3. Fuzzy AHP and Fuzzy Set Theory

The Fuzzy AHP extends this framework by incorporating the use of fuzzy logic, which enables comparisons between elements that are not easily quantifiable [38]. Fuzzy Set Theory is used to model the subjective and uncertain aspects of the problem. These membership functions can be defined based on linguistic terms provided by decision-makers, such as "absolutely preferred " or " not preferred "[39]. A fuzzy set $A = \{(x, \mu A(x))/x \epsilon X\}$, is a set of ordered pairs and X is a subset of the real numbers R, where μA(x) is called the membership function which assigns to each object "x" a grade of membership ranging from zero to one [39]. If the membership value is 1, it is the full element of the set; if it is 0, it is not the element of the set. In contrast to classical sets, the membership degrees of the elements can vary in infinite numbers between the range of [0, 1] in fuzzy sets [40].

1) Membership Function

The membership function of Ã fuzzy set is shown by μÃ(x). Fuzzy sets described each object with the membership function having a degree of membership ranging between 0 and 1 [40]. If x element belongs to Ã fuzzy set, it is μÃ(x) =1; if it does not belong to, it is μÃ(x) =0 [40]. In the current study, the triangular membership function is used [41].

2) Verbal /linguistic variables

In fuzzy logic, verbal/linguistic variables are an important concept of fuzzy sets. Linguistic variables are used to express human feelings and decisions [42].

3) Fuzzy numbers

Fuzzy numbers are a fuzzy subset of real numbers. Fuzzy numbers are used to handle the indefinite numerical values such as around 7 or close to 10 [43]. The TFN is determined by three real numbers consisting of "M" = {l, m, u}. The parameters l, m, and u signify the smallest possible value, the most promising value, and the largest value of fuzzy event [44].

The membership function of a triangular fuzzy number (TFN) A, is a function $\mu A(x)$: R → [0, 1], defined as [45].

$$\mu\widetilde{A}(x) = \begin{cases} 0, x<l \\ x-l/m-l, l\le x\le m \\ u-x/u-m, m\le x\le u \\ 0, x>u \end{cases} \qquad (3)$$

Where, inequality $l \le m \le u$ holds, Variables l, m, and u are the lower, middle, and upper values, respectively, and when $l = m = u$, TFN becomes a crisp number.

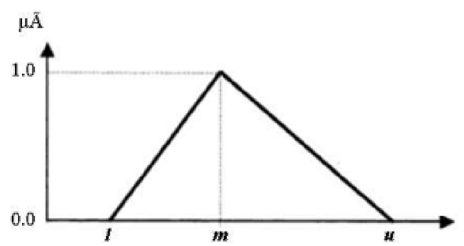

Figure 2. *The membership function of the triangular fuzzy number [46].*

The TFN can be denoted by $\widetilde{A} = (l, m, u)$. Assume two TFNs, $\widetilde{A}_1 = (l_1, m_1, u_1)$ and $\widetilde{A}_2 = (l_2, m_2, u_2)$ and scalar $k > 0$, $k \in$ R. The basic arithmetic operations are defined as follows [40].

Addition of the fuzzy number ⊕ [40].

$$\widetilde{A}_1 \oplus \widetilde{A}_2 = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2) \qquad (4)$$

Multiplication of the fuzzy number ⊗ [40].

$$\widetilde{A}_1 \otimes \widetilde{A}_2 = (l_1 * l_2, m_1 * m_2, u_1 * u_2), \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \qquad (5)$$

Subtraction of the fuzzy number ϴ [40].

$$\widetilde{A}_1 \ominus \widetilde{A}_2 = (l_1 - l_2,\ m_1 - m_2,\ u_1 - u_2) \qquad (6)$$

Division of a fuzzy number ∅ [40].

$$\widetilde{A}_1 \oslash \widetilde{A}_2 = (l_1 / m_2, m_1 / m_2, u_1 / l_2), \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \qquad (7)$$

Reciprocal of the fuzzy number [47].

$$\widetilde{A}^{-1} = (l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1), \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \qquad (8)$$

The following steps were used to implement the fuzzy AHP technique [42].

3.3.1. Structuring the Hierarchical Decision-making Problem

In the first step, the hierarchical decision-making problem is structured. The structures of the analytic hierarchy process were established by identifying six variable groups and their associated sub-criteria (a total of 30 variables).

3.3.2. Develop a Pair-wise Fuzzy Comparison Matrix

As in the conventional AHP, n(n-1)/2 K, experts (decision-makers) are required for each comparison group for a level to construct a positive fuzzy reciprocal comparison matrix $\check{A} = \{\tilde{a}_{ij}\}$. The matrix is expressed as follows [42].

$$\tilde{A} = \{\tilde{a}_{ij}\} = \begin{bmatrix} 1 & \tilde{a}_{12} \ldots. & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 \ldots. & \tilde{a}_{2n} \\ \tilde{a}_{31} & \tilde{a}_{32} \ldots. & a_{3n} \\ . & . & \cdots \\ . & . & \cdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} \ldots\ldots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12}.\ldots.. & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 \ldots\ldots & \tilde{a}_{2n} \\ 1/\tilde{a}_{13} & 1/\tilde{a}_{23} \cdots & \tilde{a}_{3n} \\ . & . & . \\ . & . & . \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} \ldots.. & 1 \end{bmatrix} \tag{9}$$

$$\text{Where, } \tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} \text{ The variable i is relative preferred to variable j} \\ 1\ \forall i = j \text{ Variable i is equally preferred to variable j} \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1} \text{ The variable i is relatively less preferred than variable j} \end{cases}$$

Table 1. *Linguistic terms and the corresponding triangular fuzzy numbers [48].*

Saaty scale	Linguistic Variable	Fuzzy Number	Triangular Fuzzy Scale	Reverse Triangular Fuzzy Number
1	Equally preferred (EP)	$\tilde{1}$	(1, 1, 3)	$\left(\frac{1}{3}, \frac{1}{1}, \frac{1}{1}\right)$
3	Moderate preferred (MP)	$\tilde{3}$	(1, 3, 5)	$\left(\frac{1}{5}, \frac{1}{3}, \frac{1}{1}\right)$
5	Strong preferred (SP)	$\tilde{5}$	(3, 5, 7)	$\left(\frac{1}{7}, \frac{1}{5}, \frac{1}{3}\right)$
7	Very strong preferred (VSP)	$\tilde{7}$	(5, 7, 9)	$\left(\frac{1}{9}, \frac{1}{7}, \frac{1}{5}\right)$
9	Absolute preferred (AP)	$\tilde{9}$	(7, 9, 9)	$\left(\frac{1}{9}, \frac{1}{9}, \frac{1}{7}\right)$
2, 4, 6, 8, are intermediate values between the two adjacent judgments				

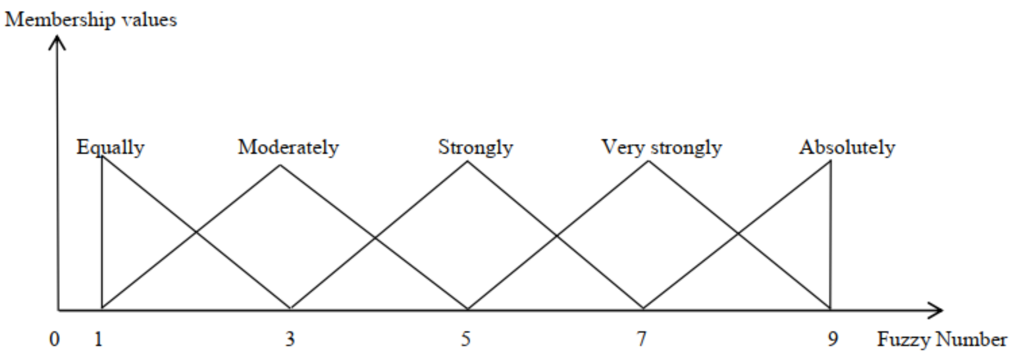

Figure 3. *Linguistic variables for the importance weight of each criterion [49].*

Once the number of the decision of the experts were determined and the experts were then asked to perform pair-wise comparisons between the dimension and the compared dimension [33].

Table 2. *Linguistic variables describing weights of the criteria and values of ratings [43].*

Linguistic Variable	Fuzzy numbers	Membership function	Domain	Triangular Fuzzy Scale (l, m, u)
Just equal	$\tilde{1}$	1	1	(1, 1, 1)
Equally preferred		μ(A)(x) = (3-x) / (3-1)	1 ≤ x ≤ 3	(1, 1, 3)

Linguistic Variable	Fuzzy numbers	Membership function	Domain	Triangular Fuzzy Scale (l, m, u)
Moderately preferred	$\tilde{3}$	μ(A)(x) = (x-1) / (3-1)	1 ≤ x ≤ 3	(1, 3, 5)
		μ(A)(x) = (5-x) / (5-3)	3 ≤ x ≤ 5	
Strongly preferred	$\tilde{5}$	μ(A)(x) = (x-3) / (5-3)	3 ≤ x ≤ 5	(3, 5, 7)
		μ(A)(x) = (7-x) / (7-5)	5 ≤ x ≤ 7	
Very strongly preferred	$\tilde{7}$	μ(A)(x) = (x-5) / (7-5)	5 ≤ x ≤ 7	(5, 7, 9)
		μ(A)(x) = (9-x) / (9-7)	7 ≤ x ≤ 9	
Absolutely preferred	$\tilde{9}$	μ(A)(x) = (x-7) / (9-7)	7 ≤ x ≤ 9	(7, 9, 9)

3.3.3. Test Hierarchy Consistency

AHP develops a consistency measure, by using a consistency ratio that is calculated using the consistency index, CI, and random index, RI [44].

$$CI = \frac{\lambda max - n}{(n-1)} \quad (10)$$

Where λmax the maximum eigenvalue and n is is the dimension of the judgment matrix.

RI is obtained by averaging the CI of a randomly generated reciprocal matrix, and N is the number of items compared.

Table 3. *Random consistency index [50].*

Matrix Dimension	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

If CR, the ratio of CI and RI is less than 10%, then the evaluations of the decision maker can be considered as having an acceptable consistency, the calculated consistency ration should be less than or equal to 0.1.

$$CR = \frac{CI}{RI} \quad (11)$$

Where CR is the consistency ratio RI is the random index.

3.3.4. Weights Aggregations

If there is more than one decision maker, the preferences of each decision maker of alternatives, and the final priorities of the alternatives can be obtained by aggregating the local priorities of elements of different levels, which are obtained in the above steps [49].

$$\tilde{a}_{ij} = (\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \tilde{a}_{ij}^3 \ldots \ldots \otimes \tilde{a}_{ij}^N)^{1/n} \quad (12)$$

Where, $\tilde{a}_{ij}$ - is the integrated triangle fuzzy number by N experts.

$\tilde{a}_{ij}^k$ - is the i-th to the j-th variable pair comparison by expert k.

⊗ - is the symbol of matrix multiplication.

3.3.5. Calculate Geometric Mean of Triangular Fuzzy Numbers

The geometric mean of the triangular fuzzy numbers values of each criterion is calculated as shown in Eq. (13). Here $\tilde{r}_i$ still represents triangular values [49].

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \tilde{a}_{i3} \otimes \ldots \otimes \tilde{a}_{in})^{1/n} \quad (13)$$

3.3.6. Calculate the Fuzzy Weight of Variables

To find the fuzzy weight of criterion i ($\tilde{w}_i$), multiply each $\tilde{r}_i$ with this reverse vector.

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \ldots \ldots \ldots \oplus \tilde{r}_n)^{-1} \quad (14)$$

Where $\tilde{a}_{in}$ is the fuzzy comparison value of variable i to variable n.

$\tilde{r}_i$ is the geometric mean of the fuzzy comparison value of variable i to each variable,

$\tilde{w}_i$ is the fuzzy weight of the i-th variables, which can be indicated by a triangular fuzzy number.

$\oplus$ is the symbol of matrix plus.

3.3.7. Defuzzification

The defuzzification phase starts with the weighted vector $\widetilde{w}_i$, since $\widetilde{w}_i$ are still fuzzy triangular numbers they need to be de-fuzzified to obtain the total integral value for the TFNs by the center of area method [50], via applying Eq. (15).

$$BNP_i = \frac{[(Uw_i - Lw_i) + (Mw_i - Lw_i)]}{3} + Lw_i \quad (15)$$

3.3.8. Normalize Weights to Make Sure the Sum of Weights Add-up to 1

Remember the sum of factors must add-up to one. In normalization, normalized vectors w_i for criteria are obtained [49].

$$BNPw1 = \frac{BNP1}{(BNP1 + BNP2 \ldots + BNPn)} \quad (16)$$

3.3.9. Ranking

The weights for each sub-criterion are obtained by multiplying the weights of the criteria and sub-criteria. Then, arranging the obtained weights, the sub-criteria ranking is received [45].

4. Data Analysis

4.1. Factor Analysis Results

In carrying the results, the data was analyzed by using the statistical software SPSS. This study has followed three major steps for factor analysis: a) assessment of the suitability of the data, b) factor extraction, and c) factor rotation and interpretation.

4.1.1. Step 1: Assessment of the Suitability of the Data

To analyze the pavement maintenance management practice, Kaiser-Meyer-Olkin is used to measure the suitability of data for factor analysis. The correlation matrix shows that there are a few items whose inter-correlations > 0.3 between the variables. The value for the determinant is an important test for multi-collinearity.

Table 4. *Factor Correlation Matrix. Source: own work, 2022.*

Component		**1**	**2**	**3**	**4**	**5**	**6**
Correlation	1	1.000					
	2	.125	1.000				
	3	-.003	.248	1.000			
	4	.180	.334	.125	1.000		
	5	.320	.368	.343	.156	1.000	
	6	.074	.383	.275	.171	.320	1.000

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

Table 5 illustrates the value of KMO statistics is equal to 0.709 > 0.6 which indicates that sampling is adequate. Bartlett's test of Sphericity is highly significant at $p < 0.001$ which shows that the correlation matrix has significant correlations among at least some of the variables.

Table 5. *Kaiser-Meyer-Olkin and Bartlett's Test of Sphericity.*

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.709
Bartlett's Test of Sphericity	Approx. Chi-Square	53.326
	Df	19

KMO and Bartlett's Test		
	Sig.	.000

4.1.2. Step 2: Factor Extraction

Table 6 demonstrates the eigenvalues and total variance explained. The result shows that 78.90% common variance shared by thirty variables can be accounted for by six variables.

Table 6. Eigenvalues (EV) and Total Variance Explained.

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%
1	7.890	26.299	26.299	7.890	26.299	26.299	5.045	16.816	16.816
2	4.938	16.459	42.759	4.938	16.459	42.759	4.226	14.086	30.902
3	3.270	10.900	53.658	3.270	10.900	53.658	4.066	13.554	44.455
4	2.605	8.682	62.341	2.605	8.682	62.341	3.467	11.558	56.013
5	2.101	7.004	69.344	2.101	7.004	69.344	3.125	10.418	66.431
6	1.802	6.007	75.352	1.802	6.007	75.352	2.676	8.921	75.352

Extraction Method: Principal Component Analysis.

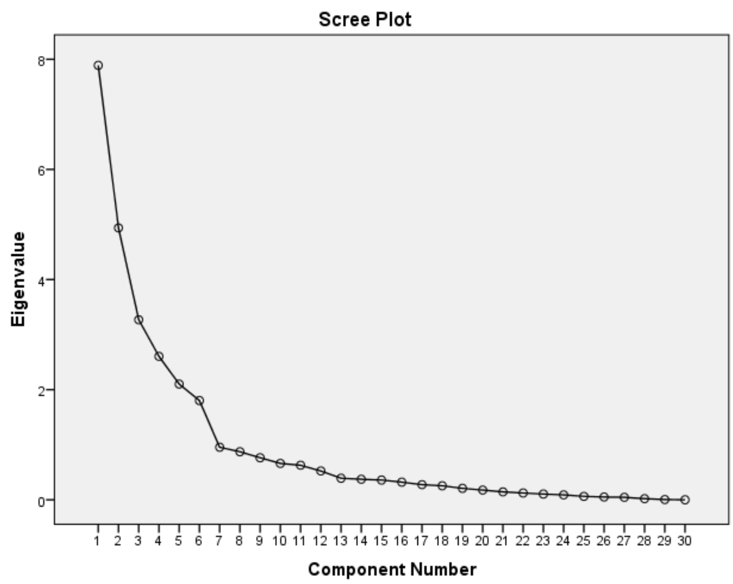

Figure 4. Scree Plot of Factor Analysis.

In Figure 4, for the Scree test, a graph is plotted with eigenvalues on the y-axis against the six component numbers in their order of extraction on the x-axis. The initial factors extracted are large factors with higher eigenvalues followed by smaller factors.

4.1.3. Step 3: Factor Rotation and Interpretation

The present study has executed the extraction method based on principal component analysis and the orthogonal rotation method based on varimax with Kaiser Normalization. The communalities reflect the common variance in the data structure after the extraction of factors/variables.

Table 7. *The items/factor structure of the pavement maintenance management practice in the Ethiopian roads authority after variable reduction procedures.*

Rotated Component Matrix						
	Component					
	1	**2**	**3**	**4**	**5**	**6**
Cooperation and coordination of the maintenance team	0.734					
Maintenance Management Team leader	0.827					
A commitment of the Maintenance Management Team	0.827					
Maintenance leadership	0.768					
Maintenance Management Team meetings	0.686					
Private Contractor Participation for Maintenance	0.786					
Staffing skilled manpower	0.796					
Maintenance Management Team Capacity and Capability	0.762					
Written Maintenance Management Plan				0.715		
Strategic Maintenance Plan				0.785		
Staff Involvement in Developing the Maintenance Plan				0.812		
Maintenance Management Plan Revision				0.799		
Budget for Financing Maintenance Programs				0.715		
Routine maintenance		0.818				
Periodic maintenance		0.879				
Emergency maintenance		0.826				
Preventive maintenance		0.932				
Corrective maintenance		0.904				
Maintenance checklists					0.662	
Maintenance Staff Training					0.945	
Schedule maintenance work					0.947	
Documentation and Recordkeeping					0.792	
Identify and categorize maintenance problems			0.77			
Inspection and reporting of faults			0.879			
Maintenance Resources allocation			0.846			
Quality supervision			0.879			
Measure maintenance performance			0.782			

Rotated Component Matrix						
	Component					
	1	2	3	4	5	6
Inventory Control						0.725
Financial Control						0.92
Maintenance Task Execution						0.907
Extraction Method: Principal Component Analysis.						
Rotation Method: Varimax with Kaiser Normalization.						
a. Rotation converged in 6 iterations.						

4.1.4. Reliability Analysis

The reliability of a questionnaire is examined with Cronbach's alpha. It provides a simple way to measure whether or not a score is reliable [48].

$$\alpha = \frac{n\bar{r}}{(1+\bar{r}(n-1))} \quad (17)$$

The Cronbach's alpha coefficient for the factors/variables with total scale reliability is 0.898 > 0.7. It shows that the variables exhibit a correlation with their component grouping and thus they are internally consistent.

Table 8. Reliability Results.

Constructs	Reliability (Cronbach's Alpha)	Number of items
Component 1	0.910	8
Component 2	0.868	5
Component 3	0.938	5
Component 4	0.881	4
Component 5	0.929	5
Component 6	0.882	3
Total scale reliability	0.898	30

4.2. Fuzzy Analytic Hierarchy Process Results

After conducting the factor analysis for identifying the underlying factors/variables, and the number of variables/ factors to retain in the factor loading matrix, it was further analyzed by using the FAHP methodologies for prioritizing, and ranking of the identified pavement maintenance management practice which was conducted in the Ethiopian road authority. The following steps were implemented for conducting the fuzzy AHP technique.

4.2.1. Structuring the Hierarchical Decision

In this study, a hierarchical structure was established in the e first step in the AHP and then the questionnaire was designed. There is a total of 30 evaluation criteria categorized into six main dimensions shown in Figure 5. The hierarchical structure presented in three levels in which the goal of the decision was presented in the top, the six variable groups and thirty criteria are located in the second and third levels, respectively in the form of a hierarchical diagram.

4.2.2. Develop a Pair-wise Fuzzy Comparison Matrix

The use of ratings enables DMs to analyze each criterion concerning other criteria for their subsequent ranking relative to each other. A decision matrix 'D' as shown in Table 9 may be constructed to measure the relative degree of importance for each success factor or criteria, based on the proposed methodology.

Table 9. *Fuzzy pairwise comparison matrix of criteria concerning the overall objective.*

D	C_1	C_2	C_3	C_4	C_5	C_6
C_1	(1,1,1)	(2,3,4)	(3,4,5)	(2,3,4)	(4,5,6)	(2,3,4)
C_2	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(1/5,1/4,1/3)	(2,3,4)	(3,4,5)
C_3	(1/5,1/4,1/3)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(3,4,5)	(1/3,1/2,1)
C_4	(1/4,1/3,1/2)	(3,4,5)	(1,2,3)	(1,1,1)	(4,5,6)	(2,3,4)
C_5	(1/6,1/5,4)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1,1,1)	(1/5,1/4,1/3)
C_6	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,2,3)	(1/4,1/3,1/2)	(3,4,5)	(1,1,1)

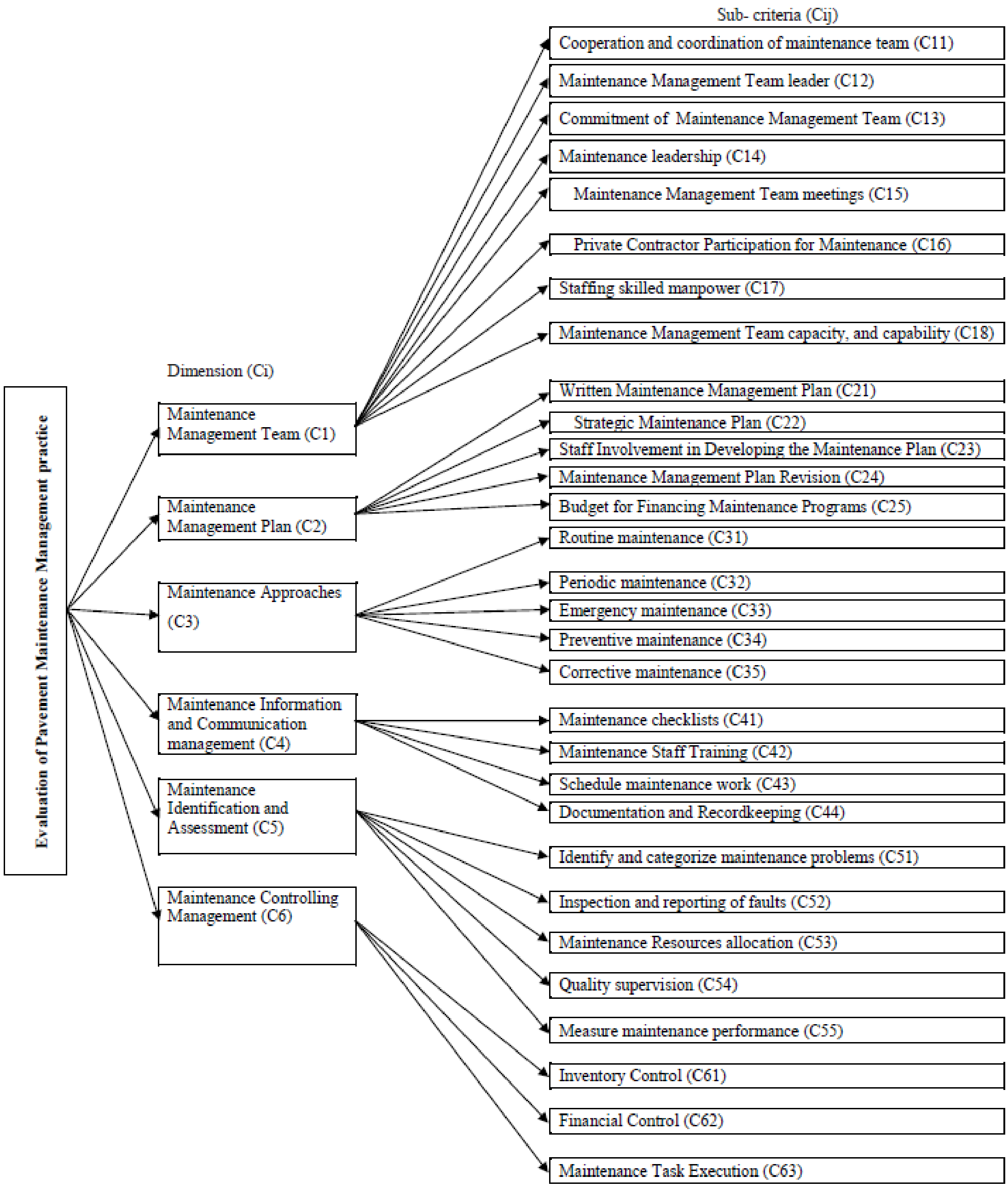

Figure 5. *The proposed multi-criteria decision-making model for pavement maintenance management practice.*

4.2.3. Test Hierarchy Consistency

The Eigenvalue method was suggested to perform the consistency check. The consistency ratio (CR) was defined as a ratio between the consistency of a given evaluation matrix and the consistency of a random matrix where RI is a random index that depends on n, as shown in Table 3. The Eigenvalue method was used to perform a consistency check by finding the value of λ_{max}. Then, the consistency index (CI) and consistency ratio (CR) can be done by using Eq. (10) and Eq. (11).

$$CI = \frac{\lambda_{max} - n}{(n-1)} = CI = \frac{6.091 - 6}{(6-1)} = 0.018$$

$$CI = 0.018, \lambda_{max} = 6.091, n = 6, RI_{(n=6)} = 1.24.$$

$$CR = \frac{0.018}{1.24} = 0.014 < 0.1$$

Therefore, the pairwise comparison matrix is acceptable. Similarly, the consistency ratios of all other conducted and the results are less than 10%. Thus, all the judgments are acceptable consistency.

4.2.4. Weights Aggregations

After checking the validation of the expert's opinion, the geometric mean method aggregates the preference of the overall decision experts in relation to the objective with a triangular fuzzy number by using Eq. (12).

$$\tilde{a}_{ij} = (\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \tilde{a}_{ij}^3 \ldots \ldots \otimes \tilde{a}_{ij}^N)^{1/15}$$

As a sample calculation, the aggregated fuzzy pairwise comparison values for the criteria with respect to the goal are shown in in Table 10.

Table 10. *The aggregated fuzzy pairwise comparison values for the criteria with respect to the goal.*

	V1	V2	V3	V4	V5	V6
V1	1.000, 1.000, 1.000	0.384, 1.103, 2.656	0.569, 1.179, 2.428	0.834, 1.534, 2.945	2.378, 3.965, 6.010	2.070, 3.415, 5.152
V2	0.376, 0.907, 2.605	1.000, 1.000, 1.000	0.681, 1.397, 2.789	0.999, 1.865, 3.317	1.858, 3.174, 5.052	1.513, 2.578, 4.179
V3	0.441, 0.883, 1.809	0.344, 0.658, 1.370	1.000, 1.000, 1.000	0.486, 1.297, 3.442	2.380, 4.407, 7.671	2.021, 3.837, 7.157
V4	0.340, 0.652, 1.199	0.286, 0.500, 0.897	0.291, 0.771, 2.059	1.000, 1.000, 1.000	1.661, 3.754, 7.834	1.780, 4.161, 9. 202
V5	0.166, 0.252, 0.420	0.198, 0.315, 0.538	0.130, 0.227, 0.420	0.125, 0.259, 0.578	1.000, 1.000, 1.000	1.446, 3.223, 6.820
V6	0.199, 0.296, 0.483	0.254, 0.404, 0.678	0.153, 0.279, 0.523	0.130, 0.272, 0.620	0.147, 0.310, 0.692	1.000, 1.000, 1.000

4.2.5. Geometric Mean Calculation of Triangular Fuzzy Numbers

The geometric mean of the fuzzy comparison values was found using the FAHP and Microsoft Excel for each criterion. Using Eq. (13), the geometric mean for criteria 1 was calculated as follows:

$\tilde{r}_1 = ((1 \otimes 0.384 \otimes 0.569 \otimes 0.834 \otimes 2.378 \otimes 2.070)^{1/6}, (1 \otimes 1.103 \otimes 1.179 \otimes 1.534 \otimes 3.965 \otimes 3.415)^{1/6}, (1 \otimes 2.656 \otimes 2.428 \otimes 2.945 \otimes 6.010 \otimes 5.152)^{1/6}$

$\tilde{r}_1 = (0.870, 1.412, 2.202)$

With similar steps, other calculations of the geometric means of fuzzy comparison values for each criterion are determined. It also includes the total values, the inverse values, and the values in increasing order.

$\tilde{r}_2 = (0.884, 1.399, 2.226)$

$\tilde{r}_3 = (0.748, 1.221, 2.007)$

$\tilde{r}_4 = (0.601, 0.990, 1.609)$

$\tilde{r}_5 = (0.285, 0.409, 0.617)$

$\tilde{r}_6 = (0.230, 0.376, 0.647)$

Fuzzy Weight Calculation

The fuzzy preference weights are calculated, and the results are presented below after fuzzy weights for each criterion were computed using Eq. (14) as follows:

$\tilde{w}_1 = \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5 \oplus \tilde{r}_6)^{-1}$

Where, $\tilde{r}_i$ was multiplied by the inverse of the summation vector in the form of increasing order.

$\tilde{w}_1 = (0.870, 1.412, 2.202) \otimes \left(\frac{1}{2.202+\cdots.+0.647}\right), \left(\frac{1}{1.412+\cdots+0.376}\right), \left(\frac{1}{0.870+\cdots.+0.230}\right)$

$\tilde{w}_1 = (0.093, 0.243, 0.609)$

Likewise, the residual fuzzy weights $\tilde{w}_i$ values are:

$\tilde{w}_2 = 0.095, 0.241, 0.615$

$\tilde{w}_3 = 0.080, 0.210, 0.555$

$\tilde{w}_4 = 0.065, 0.171, 0.445$

$\tilde{w}_5 = 0.031, 0.070, 0.170$

$\tilde{w}_6 = 0.025, 0.065, 0.179$

***Table 11**. The fuzzy weights of the variables.*

Decision Variables	**Fuzzy Weights($\tilde{w}_i$)**	**BNP**			**Normalized Local weights (BNPw)**	**Rank**
Fuzzy weights of the variable groups (Vi) with respect to the goal						
Maintenance Management Team	0.093	0.243	0.609	0.315	0.256	2
Maintenance Management Plan	0.095	0.241	0.615	0.317	0.258	1
Maintenance Approaches	0.08	0.21	0.555	0.282	0.229	3
Maintenance Information and Communication management	0.065	0.171	0.445	0.227	0.184	4
Maintenance Identification and Assessment	0.031	0.07	0.17	0.09	0.073	5
Maintenance Controlling Management	0.025	0.065	0.179	0.089	0.073	6
Fuzzy weights of the sub-criteria under C_1 (Cij): Maintenance Management Team						
Cooperation and coordination of the maintenance team	0.07	0.118	0.206	0.131	0.119	4
Maintenance Management Team leader	0.158	0.277	0.461	0.299	0.271	1
A commitment of the Maintenance Management Team	0.038	0.064	0.113	0.072	0.065	7
Maintenance leadership	0.073	0.125	0.215	0.138	0.125	3
Maintenance Management Team meetings	0.038	0.064	0.111	0.071	0.065	8
Private Contractor Participation for Maintenance	0.083	0.143	0.249	0.158	0.144	2
Staffing skilled manpower	0.059	0.102	0.176	0.112	0.102	6
Maintenance Management Team Capacity and Capability	0.063	0.108	0.187	0.119	0.109	5
Fuzzy weights of the sub-criteria under C_2 (Cij): Maintenance Management Plan						
Written Maintenance Management Plan	0.165	0.278	0.465	0.303	0.277	1
Strategic Maintenance Plan	0.125	0.212	0.36	0.232	0.212	3
Staff Involvement in Developing the Maintenance Plan	0.137	0.236	0.405	0.259	0.237	2
Maintenance Management Plan Revision	0.075	0.124	0.211	0.137	0.125	5
Budget for Financing Maintenance Programs	0.089	0.147	0.242	0.159	0.146	4
Fuzzy weights of the sub-criteria under C_3 (Cij): Maintenance Approaches						
Periodic maintenance	0.165	0.278	0.466	0.303	0.277	1
Preventive maintenance	0.125	0.212	0.36	0.233	0.213	3
Routine maintenance	0.138	0.237	0.405	0.26	0.238	2
Emergency maintenance	0.076	0.125	0.211	0.137	0.126	5
Corrective maintenance	0.089	0.148	0.242	0.16	0.146	4
Fuzzy weights of the sub-criteria under C_4 (Cij): Maintenance Information and Communication Management						
Maintenance checklists	0.25	0.368	0.545	0.388	0.37	2
Maintenance Staff Training	0.271	0.391	0.553	0.405	0.386	1
Schedule maintenance work	0.073	0.106	0.156	0.112	0.107	4
Documentation and Recordkeeping	0.093	0.134	0.202	0.143	0.137	3

Decision Variables	Fuzzy Weights($\tilde{w}_i$)	BNP			Normalized Local weights (BNPw)	Rank
Fuzzy weights of the sub-criteria under C_5 (Cij): Maintenance Identification and Assessment						
Identify and categorize maintenance problems	0.15	0.26	0.438	0.283	0.258	1
Inspection and reporting of faults	0.114	0.195	0.34	0.216	0.197	4
Maintenance Resources allocation	0.13	0.22	0.381	0.244	0.222	2
Quality supervision	0.129	0.221	0.372	0.241	0.219	3
Measure maintenance performance	0.064	0.103	0.172	0.113	0.103	5
Fuzzy weights of the sub-criteria under C_6 (Cij): Maintenance Controlling Management						
Inventory Control	0.522	0.639	0.779	0.647	0.638	1
Financial Control	0.127	0.158	0.2	0.162	0.16	3
Maintenance Task Execution	0.163	0.202	0.251	0.206	0.203	2

4.2.6. Defuzzification

The average of the fuzzy values for each criterion, which was based on Eq. (15), was used to determine the relative non-fuzzy weight or defuzzified weight of each criterion. The calculation of defuzzification was as follows.

$$BNP_i = \frac{[(Uw_i - Lw_i) + (Mw_i - Lw_i)]}{3} + Lw_i$$

$$BNPi = [(0.609 - 0.093) + (0.243 - 0.093)]/3 + 0.093$$

$$BNPi = 0.315$$

4.2.7. Normalizing the Defuzzified Weight of Criterion

Then, the defuzzified weights must be normalized using Eq. (16) along with the normalized weights for each criterion. Therefore, the normalization weight of C_1 can be calculated as follows:

$$BNPw1 = \frac{BNP1}{(BNP1 + BNP2 \ldots + BNPn)}$$

$$BNPw1 = 0.315/(0.315 + 0.317 + 0.282 + 0.227 + 0.090 + 0.089) = 0.256$$

Table 12. Weighted values and rankings considered by decision experts.

Dimension	Local Weight	Sub criteria (Cij)	Local Weights	Global Weights	Ranking by Category	Overall Ranking
Maintenance Management Team	0.256	Cooperation and coordination of the maintenance team	0.119	0.030	24	16
		Maintenance Management Team leader	0.271	0.069	6	3
		A commitment of the Maintenance Management Team	0.065	0.017	29	23
		Maintenance leadership	0.125	0.032	23	15
		Maintenance Management Team meetings	0.065	0.017	29	23
		Private Contractor Participation for Maintenance	0.144	0.037	19	12
		Staffing skilled manpower	0.102	0.026	28	19
		Maintenance Management Team Capacity and Capability	0.109	0.028	25	18

Dimension	Local Weight	Sub criteria (Cij)	Local Weights	Global Weights	Ranking by Category	Overall Ranking
Maintenance Management Plan	0.258	Written Maintenance Management Plan	0.278	0.072	4	1
		Strategic Maintenance Plan	0.213	0.055	13	7
		Staff Involvement in Developing the Maintenance Plan	0.238	0.061	9	6
		Maintenance Management Plan Revision	0.126	0.032	22	14
		Budget for Financing Maintenance Programs	0.146	0.038	17	11
Maintenance Approaches	0.229	Periodic maintenance	0.277	0.063	5	5
		Preventive maintenance	0.213	0.049	12	9
		Routine maintenance	0.238	0.055	8	8
		Emergency maintenance	0.126	0.029	21	17
		Corrective maintenance	0.146	0.033	18	13
Maintenance Information and Communication management	0.184	Maintenance checklists	0.370	0.068	3	4
		Maintenance Staff Training	0.386	0.071	2	2
		Schedule maintenance work	0.107	0.020	26	21
		Documentation and Recordkeeping	0.137	0.025	20	20
Economic condition	0.073	Identify and categorize maintenance problems	0.258	0.019	7	22
		Inspection and reporting of faults	0.197	0.014	15	28
		Maintenance Resources allocation	0.222	0.016	10	25
		Quality supervision	0.219	0.016	11	26
		Measure maintenance performance	0.103	0.008	27	30
Maintenance Identification and Assessment	0.073	Inventory Control	0.638	0.047	1	10
		Financial Control	0.160	0.012	16	29
		Maintenance Task Execution	0.203	0.015	14	27

Similarly, the BNP value of the remaining dimension and sub-criteria can be obtained in a similar computational procedure (see Table 11). The normalized weights of criteria placed at the third level in the hierarchy can be presented in Table 12.

5. Discussion of Research Results, and Implications

These studies evaluate the pavement maintenance management practice in the Ethiopian roads authority by integrating factor analysis and fuzzy AHP methods. As it was observed in Table 12, the decision experts compared local weights in each group variable and ranked maintenance management plan (0.258), and maintenance management team (0.256) as the first and second most maintenance management practice in the pavement. Thus, the decision experts believe that the maintenance management plan and maintenance management team have been exercised by the maintenance staff in their company. Maintenance Approaches (0.229) is the next maintenance management practice in the pavement identified by the decision experts followed by maintenance information and communication management (0.184), and Maintenance Identification and Assessment (0.073). Contrariwise, Maintenance Controlling Management (0.073) is poorly practiced in the management of pavement maintenance.

The results indicate that the decision experts are convinced that the maintenance practice like maintenance management plan and maintenance management team overshadow the practice in the Ethiopian Roads Authority. Hence, the maintenance staff in the Ethiopian Roads Authority should be taken into consideration and put in more effort and attention to improve those maintenance management practices.

Individually, further examining each sub-criteria under their dimension, the greatest weighted value under the maintenance management team category was Maintenance Management Team leader (0.299), Private Contractor Participation for Maintenance (0.158), Maintenance leadership (0.138), Cooperation and coordination of maintenance team (0.131), and Maintenance Management Team capacity and capability (0.119). On the contrary staffing skilled manpower (0.112), commitment of maintenance management team (0.072), and maintenance management team meetings (0.071).

Next, the Written Maintenance Management Plan (0.3033), Staff Involvement in Developing the Maintenance Plan (0.259), and Strategic Maintenance Plan (0.232) maintenance management practice, were identified as the most practiced by the Ethiopian roads authority. Contrariwise, the Budget for Financing Maintenance Programs (0.159), and Maintenance Management Plan Revision (0.137) were poorly practiced by the Ethiopian Roads Authority.

Furthermore, the highest most practiced sub-criteria under the maintenance approaches were Periodic maintenance (0.303), Routine maintenance (0.260), and Preventive maintenance (0.233). Contrariwise, Corrective maintenance (0.160), and Emergency maintenance (0.137) were poorly practiced management approaches in pavement maintenance.

This finding can be supported by [51], that periodic maintenance management was considered the best road maintenance management approach by the Ethiopian Roads Authority. The operation is occasionally required on a section of road after a period of a number of years. He also proved that periodic maintenance is based on a detailed inspection performed at certain time intervals such as seasonally or yearly depending on the type and kind of facilities.

Moreover, the maintenance management practice which is mostly practiced in the Ethiopian road authority under the maintenance information and communication management category were Maintenance Staff Training (0.405), Maintenance checklists (0.388), and Documentation and Record-keeping (0.143). Contrariwise, Schedule maintenance work (0.112) was poorly practiced pavement maintenance management practice.

Additionally, the greatest weighted values under the maintenance identification and assessment category were Identified and categorized as maintenance problems (0.283), Maintenance Resources allocation (0.244), and Quality supervision (0.241).

On the contrary, Inspection and reporting of faults (0.216) and Measure maintenance performance (0.113) were poorly practiced pavement maintenance management practices.

Finally, the results revealed that Inventory Control (0.647), and Maintenance Task Execution (0.206) were identified as the best pavement maintenance management practice under maintenance controlling management maintenance practice. Contrariwise, Financial Control (0.162) was identified as poorly practiced pavement maintenance management practices by the Ethiopian Roads Authority.

Overall, the sub-criteria with the highest-ranked final weights among global weights were written maintenance management plan (0.072), maintenance staff training (0.071), maintenance management team leader (0.069), maintenance checklists (0.068), and periodic maintenance (0.063).

The implication is that the level of awareness of the highest-ranked pavement maintenance management practice is good, thus, there is a need to upkeep those maintenance practices. So, it needs attention to advance those maintenance management practices in the Ethiopian roads authority to achieve the goal of the company.

On the contrary, quality supervision (0.016), maintenance task execution (0.015), inspection and reporting of faults (0.014), financial control (0.012), and measure maintenance performance (0.008) were identified as poorly practiced pavement management practice in the Ethiopian roads authority. Hence, the maintenance staff in the Ethiopian Roads Authority ought to take into consideration and put in more effort and attention to improve those maintenance management practices while handling managing maintenance.

The implication is that the level of awareness on the above-identified pavement maintenance management practice is poor, thus, there is a need to intensify those maintenance management practices in the Ethiopian roads authority. It also indicates that the maintenance practices were taking place when the staff failed to carry out the maintenance practices regularly based on the standards of the practice. Thus, the maintenance staff should consider those and put in more effort and attention to advance the maintenance management practices.

This study provides knowledgeable in view of the pavement maintenance management practice in the Ethiopian roads authority by integrating factor analysis and fuzzy AHP methods. It can also help us to comprehend how academicians carry out a study by using a comprehensive model. This study helps us important implications for the practitioners, and project managers to have a clear understanding of the pavement maintenance management practice that is improperly adopted on the roads. The findings of this study provide academia and practitioners with insightful information to enhance the current pavement maintenance management practice and help us to take proactive measures and get the optimum result for poorly practiced pavement maintenance.

6. Conclusions

Based on the findings and discussion of the study the following conclusions are suggested:

1. Pavement maintenance management practices were extracted through performing exploratory factor analysis on thirty items developed from a synthesis of the literature and perception of practitioners in the construction sector.

2. The extracted pavement maintenance management practice was further analyzed via the fuzzy AHP model to prioritize the newly developed questionnaires for the criteria by experts in terms of their relative impotence, subjectivity, and uncertainty of human assessment are taken into account fuzzy set theory in a fuzzy environment.
3. From the proposed method, fuzzy AHP helps to find out that the maintenance management plan and maintenance management teams are better practiced in the maintenance management of the Ethiopian Roads Authority as agreed by the decision experts followed by maintenance information and communication management under the main categories of dimension of pavement maintenance management practices. On the contrary, maintenance controlling management and maintenance identification and assessment were identified as rarely practiced Ethiopian Roads Authority.
4. The study also concluded that the top five pavement maintenance management practices mostly practiced in the Ethiopian roads authority were written maintenance management plan (0.072), maintenance staff training (0.071), maintenance management team leader (0.069), maintenance checklists (0.068), and periodic maintenance (0.063).
5. The finding of this study motivates the authors to formulate recommendations to advance the practice of managing pavement maintenance.
6. The authors recommended that the findings of the current study confirm that the fuzzy AHP technique is a powerful tool for evaluating MCDM regarding maintenance management practice.
7. The maintenance staff members of the Ethiopian Roads Authority should be taken into consideration and put in more effort and attention in maintenance identification, maintenance assessment, and control. The maintenance staff should properly organize the maintenance documents, and revise the maintenance plan and schedule for developing their understanding and awareness. The staff members in the maintenance district should be properly supervised and record-keeping on road maintenance activities.
8. The paper provides a supportive practical solution for decision-makers in pavement maintenance management practice to enhance and improve their maintenance practices in managing the maintenance of road construction.

Abbreviations

AHP	Analytical Hierarchy Process
BNP	Best Non-fuzzy Value
ERA	Ethiopian Roads Authority
KMO	Kaiser-meyer-olkin
CI	Consistency Index
CR	Consistency Ratio
DMP	Decision-making Problem
EV	Eigenvalues
MCDMM	Multi Criteria Decision Making Methods
RI	Random Index
TFN	Triangular Fuzzy Number

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Data Availability Statement

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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