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An Analytical Hierarchy Process (AHP) Approach to Road Maintenance Prioritization: A Case Study in Shan State, Myanmar

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Abtract: Maintaining rural roads plays an important role in the development of society and economy in Shan State, Myanmar. This study aims to prioritize road maintenance by employing the Analytical Hierarchy Process (AHP). There are four types of pavement distress: roughness, raveling, potholes, edge failure, and bleeding. Data collection was conducted and analyzed in ten rural roads by using an Excel-based tool to evaluate the AHP analysis. The findings significantly discussed awareness of road conditions and pavement maintenance requirements, and R4 had the highest level of priority to maintain. The study also compared the Pavement Condition Index (PCI) method with AHP results, highlighting acceptance and differences. Significant differences were noted for others due to the comprehensive nature of AHP when both methods ranked R5 and R6 typically within the top three. This research provides a systematic and transparent approach for prioritizing road maintenance, enhancing resource optimization and decision-making. Both AHP and PCI methods are integrated, and a comprehensive way is recommended to ensure thorough assessment and optimal use of resources to plan road maintenance. The study also contributes to improving the sustainability and performance of the rural road network, supporting broader economic and social goals in Shan State, Myanmar.

Keywords: Road maintenance; Analytical Hierarchy Process; Pavement Condition Index; Rural roads; Pavement management

1. Introduction

The maintenance of rural roads is a critical aspect of infrastructure management, particularly in developing regions where road networks are essential for economic and social development. In Myanmar, rural roads serve as vital links between remote areas and urban centers, facilitating the movement of goods, services, and people. However, the maintenance of these roads presents significant challenges due to limited resources and the diverse types of distress that can affect road quality [1]. Therefore, effective

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prioritization of road maintenance is crucial to ensure the optimal use of available resources and to maximize the lifespan and functionality of the road network.

The primary problem addressed in this research is the need for a systematic and objective method to prioritize road maintenance activities. Traditional approaches to road maintenance often rely on subjective judgment or simplistic criteria, which can lead to inefficient allocation of resources and suboptimal maintenance outcomes [2]. This study seeks to address this issue by employing the Analytical Hierarchy Process (AHP), known as a structured decision-making framework that allows for the evaluation and prioritization of multiple criteria. The specific criteria considered in this study include various types of pavement distress, such as potholes, reveling, bleeding, edge failure, and roughness, each of which has different implications for road performance and maintenance needs.

The literature on road maintenance prioritization is extensive, with numerous studies highlighting the importance of using multi-criteria decision-making (MCDM) methods like AHP [3], [4], [5]. For instance, previous research has demonstrated the effectiveness of AHP in various infrastructure management contexts, from urban road maintenance to bridge management [6], [7]. These studies underscore the value of AHP in incorporating both quantitative and qualitative factors, thus providing a comprehensive assessment of maintenance needs. However, there is a gap in the application of AHP specifically to rural road networks in developing countries, where pavement conditions and maintenance challenges can differ significantly from those in urban or more developed areas [8], [9], [10], [11].

This study proposes an innovative approach by applying the AHP method to the prioritization of rural road maintenance in Shan State, Myanmar. Using data collected from ten rural roads, this research employs an Excel-based tool to facilitate the AHP analysis, making this process accessible and practical for local infrastructure managers [3]. While previous studies have highlighted the importance of multi-criteria decision-making (MCDM) methods like AHP in infrastructure management, there remains a significant gap in their application to rural road networks in developing countries, where unique pavement conditions and maintenance challenges prevail. This gap emphasizes the need for a tailored approach to effectively address the specific demands of rural road maintenance in Myanmar. The novelty of this research lies in its combination of a well-established decision-making framework with a user-friendly implementation tool tailored to the specific context of rural Myanmar. The new value of this research is to provides a replicable and scalable method for prioritizing road maintenance that can be adapted to other rural contexts; to offer a clear and transparent decision-making process that can enhance the accountability and effectiveness of maintenance planning; and to contribute to the knowledge on the application of AHP in infrastructure management, particularly in developing regions. This study aims to improve the road network's sustainability and performance by addressing the specific challenges of rural road maintenance in Myanmar, thereby supporting the development of the economy and the connection of society in rural areas.

2. Methods

This study follows a structured approach to prioritize road maintenance for rural roads in Shan State, Myanmar, using the Analytical Hierarchy Process (AHP). The design comprises several key stages that are data collection, criteria identification, AHP model construction, and priority calculation. It is necessary to evaluate the efficacy of this approach in comparison to the existing method. For the study of pavement evaluation, the condition of the pavement Index (PCI) method is used as the most accurate indexing method that integrates data on different types of discomfort as well as their severity and quantity [4]. As part of the LTPP experimental program of Myanmar, there is an assessment tool for evaluating the visual condition of pavements. The method helps to identify maintenance and rehabilitation requirements and assists in prioritizing projects using a decision support system. A Visual condition Index (PCI) has been established specifically to evaluate the condition of pavement in rural areas of Myanmar. Hence, the PCI approach serves as a reference in this study.

2.1 Study area

The study focuses on ten rural roads in Shan State, Myanmar. This research has received formal approval from the Department of Rural Road Development, as confirmed under letter number DRRD/2024/001. The data collection process adhered to all relevant guidelines and standards. These roads are managed by the Department of Rural Road Development (DRRD). All selected roads are flexible pavement and each road section is divided into twenty 25-meter-long subsections, resulting in a total of 200 subsections. This sampling ensures a comprehensive analysis of the road network's condition and maintenance needs.

2.2 Data collection

Data collection is a critical component of the research design, involving the gathering of the Pavement Condition Index (PCI) data, the International Roughness Index (IRI) measurements.

2.2.1 Pavement Condition Indek (PCI) data

In this study, pavement condition data collected conducted for each road subsection to identify and record the pavement different types of distresses. The selected sections indicated various surface distresses, such as potholes, raveling, and edge failures. These distresses are considered as the key variables in this study.

2.2.2 International Roughness Indek (IRI) measurements

The IRI for each subsection is measured using the Road Lab Pro tool, which provides an objective assessment of road roughness. Measurements are taken multiple times to ensure accuracy and averaged for consistency. IRI is used to assess the condition of road networks and to prioritize maintenance activities. The index is measured in meters per kilometer (m/km) or millimeters per meter (mm/m), with lower values suggesting smoother roads and larger values indicating rougher surfaces [12].

2.3 Calculation of Pavement Condition Index (PCI)

The main aim of the analysis was to determine the Pavement Condition Index (PCI), which is used to determine the general condition of the pavement. PCI was calculated in accordance with the guideline using Equations 1-3.

$$PCI = 100(1 - C\ \Sigma_{i=1}^{n} Fi) \tag{1}$$

$$Fi = Di \times Ei \times Wi \tag{2}$$

$$C = 1\ C \div \Sigma_{i=1}^{n} Fi(max) \tag{3}$$

where PCI is the Pavement Condition Index; i is the visual assessment item number; n is the number of items; Di is the degree rating; Ei is the extent rating; and Wi is the weight for the defects [13].

Each type of distress was ranked 1 to 5 values of degree and 1 to 5 values of extent. Degree is shown as the level to which the pavement is impacted and Extent is illustrated that the frequency of a distress was occurred. The degree and extent values were assigned for each section based on the field visual measurements and identified the distress by using the detailed description shown in table 1.

Table 1: Detailed descriptions of degree and extent [4], [14]

Degree (D) or Extent (E)	Description for Degree (D)	Description for Extent (E)
1	Distress size - • very small • Less significance and difficult to produce the weakness No need to maintain.	Occurrences - • Very few matched < 5% (of the affected pavement)

Degree (D) or Extent (E)	Description for Degree (D)	Description for Extent (E)
2	Distress size - • small • Less significant and easy to produce the weak spots. No need to maintain immediately.	Occurrences - • Discontinuous 5% to 15% (of the affected pavement)
3	Distress size - • Moderate • Significant and noticeable the distress. Need to maintain.	Occurrences - • Regular occurrences 15% to 30% (of the affected pavement)
4	Distress size - • severe • Significant and undesirable amounts of distress. Need to maintain regularly.	Occurrences - • Extensive regular 30% to 60% (of the affected pavement)
5	Distress size - • very severe • Insignificant and unacceptable amounts of distress. Need to maintain immediately.	Occurrences - • Throughout, extensive regular occurrences > 60% (of the affected pavement)

2.4 Prioritization of pavement maintenance using AHP technique

The Analytic Hierarchy Process (AHP) is a method applying in making decision procedure. AHP is a useful technique for decision makers to predict, prioritize and make ranking among several options, and both individual preferences and measurable outcomes are based to make AHP method process. Firstly, the problem and criteria of this study are defined, and the priority of pavement maintenance is determined as a goal based on various criteria. There are 5 criteria and 15 sub-criteria in this framework, which implements the prioritization of pavement maintenance. This framework is illustrated in figure 1. And then, 5 criteria are raveling, bleeding, pothole, edge drop, and IRI, and 15 sub-criteria are low, medium and high for each distress described in this framework [4].

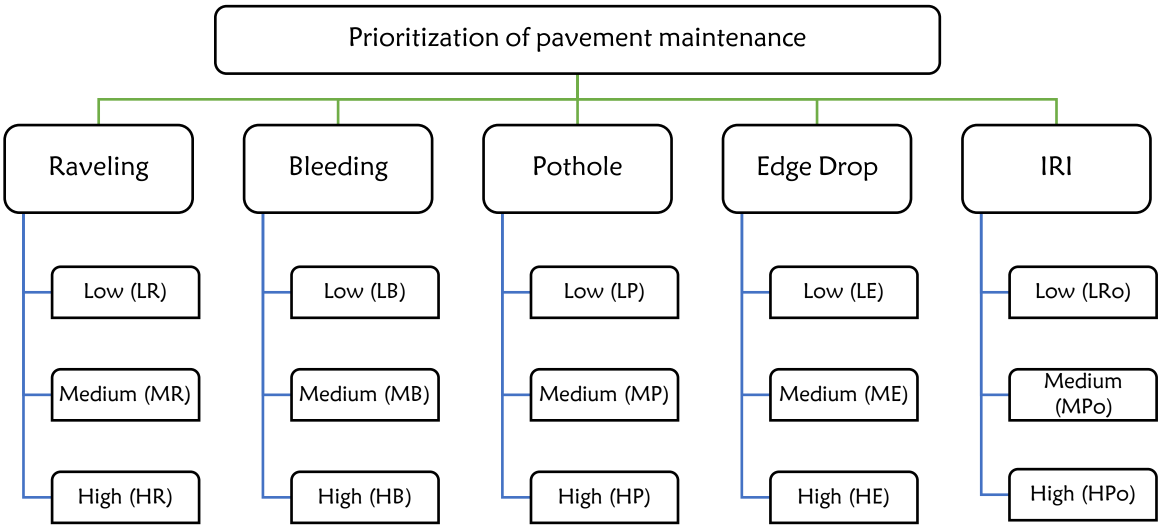

Figure 1: Framework of AHP to pavement maintenance prioritization [4]

In order to describe the contribution and influence of each component, a pairwise comparison matrix is created [14]. This matrix is important to describe the relationship between different options, and to show the difference in importance between factors. To perform pairwise comparison matrix, a scale is used and shown in table 2.

Table 2: Scale for comparison matrix [10]

Importance	Definition for each scale
1	Equally significant to others
3	Slightly more significant than others
5	Moderate
7	Very strong important over others
9	Extremely important over others
2, 4, 6, 8	Intermediate value

In order to normalize, the comparison matrix is divided by the total of the importance of each column. And then, the values in each row, are averaged to conduct priority vector, which gives the corresponding rating. The consistency ratio is calculated and checked with the limitation of CR $\leqslant$ 0.1. Following the equation 4 and 5, the consistency ratio (CR) is defined as the proportion of the consistency index (CI) and the random Index (RI), which is used to evaluate the whole matrix and is shown in table 3. The matrix is considered only when CR $\leqslant$ 0.1. Finally, the weighted average rating for the alternative of each decision is calculated and the highest one is chosen [15].

$$CR = CI/RI \tag{4}$$

$$CI = (\lambda max - n) \div (n-1) \tag{5}$$

Table 3: Random Index for AHP

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

3. Results and discussion

In this study, the degree and extent values were specified for each segment, and the calculation for Fi (max) of the individual section were conducted using equation 2 and 3. Further, pavement condition index (PCI) values for each road were computed using equation 1, and the PCI values are shown in Table 4.

Table 4: Calculated PCI value

Road ID	PCI value
R1	57.58
R2	86.97
R3	86.66
R4	87.15
R5	54.01
R6	62.35
R7	89.72
R8	84.42
R9	87.84
R10	87.31

To prioritize pavement maintenance, a hierarchy technique is established by considering various parameters at different levels of the structure. Pavement distress and roughness are determined as criteria and sub criteria of the modeling parameters. Using scale (table 2) and criteria, the pairwise comparison matrix is generated. The severity levels of different types of pavement distress are defined based on the scales (table 2) and the assigned values for each level of each distress are shown in table 5.

Table 5: Severity levels of each distress

	Distress type		Intensity level	Assigned value
		1	Low	3
1	Raveling	2	Medium	5
		3	High	7
		4	Low	3
2	Bleeding	5	Medium	3
		6	High	5

Distress type		Intensity level		Assigned value
		7	Low	5
3	Potholes	8	Medium	7
		9	High	9
		10	Very Low	1
4	Edge Failure	11	Low	3
		12	Medium	5
		13	Low	3
5	Roughness	14	Medium	5
		15	High	7

Initiated assessments of pairwise comparisons, between criteria A – raveling, B – bleeding, C – pothole, D – edge drop, and E – roughness, is shown in table 6.

Table 6: Pairwise comparison matrix

Criteria	A	B	C	D	E
A	1	2	0.2	2	1
B	0.5	1	0.25	2	0.5
C	5	4	1	4	3
D	0.5	0.5	0.5	1	0.5
E	1	2	0.33333	2	1
Sum	**8**	**9.5**	**2.28333**	**11**	**6**

Normalize the Matrix, the Weighted Sum, the Consistency Vector and λ max are described in the table 7.

Table 7: Normalization, the weighted sum, consistency vector, λ max of the matrix

Criteria	A	B	C	D	E	Priority vector	Weighted sum	Consistency vector
A	0.13	0.21	0.09	0.18	0.17	0.15	0.83	5.41
B	0.06	0.11	0.11	0.18	0.08	0.11	0.59	5.43
C	0.63	0.42	0.44	0.36	0.50	0.47	2.58	5.49
D	0.06	0.05	0.22	0.09	0.08	0.10	0.55	5.42
E	0.13	0.21	0.15	0.18	0.17	0.17	0.90	5.40
							λ Max	**5.43**

The consistency value is calculated in equation 4 and 5. The calculation procedure is in the following:

For the consistency index with the matrix size (n = 5),

$$\begin{aligned} CI &= (\lambda\ Max - n)/(n-1) \\ &= (5.43 - 5)/\ (5-1) \\ &= 0.107 \end{aligned}$$

For the consistency ratio with the random index at N5 in table 3,

$$\begin{aligned} CR &= CI / RI \\ &= 0.107 / 1.12 \\ &= 0.096 < 0.1 \end{aligned}$$

The final result of the consistency ratio is 0.096 that is less than 0.1. Therefore, the result is available to be considered. Finally, according to the AHP technique, the weighted average rating and the highest to the lowest rank are described in table 8.

Table 8: AHP weight and ranking

Road ID	Weight sum	Priority weight	Priority percentage	Rank
R1	6.29	0.10	10.21	4
R2	6.05	0.10	9.82	5
R3	3.96	0.06	6.42	10
R4	13.74	0.22	22.30	1
R5	7.62	0.12	12.36	2
R6	6.39	0.10	10.38	3
R7	4.04	0.07	6.55	9
R8	4.41	0.07	7.16	7
R9	4.21	0.07	6.83	8
R10	4.91	0.08	7.97	6

The results indicate that Road No. R4 has the highest priority rank to maintain with a priority weight of 0.22 and a priority percentage of 22.30 %. This suggests that R4 has the most critical distresses and needs immediately to take attention. As the second highest priority rank, Road No. R5 is following Road No. R4 with a priority weight of 0.12 and a priority percentage of 12.36 %. This indicates that R5 has the significant distress and is less severe than R4. Road R6, R1 and R2 is following closely with the same priority weight of 0.1 and the priority percentage of 10.38 %, 10.21% and 9.82% respectively. These road conditions are slightly better than R4 and R5. Therefore, these roads should be considered to maintain, following R4 and R5. A comparison was conducted between rank based on PCI values and the priority rank based on AHP technique and is shown in Table 9.

Table 9: Comparison of Ranking of Road Stretches Based on AHP and PCI

Road ID	PCI value	PCI based Rank	Priority weight	AHP based Rank
R1	57.58	2	0.10	4
R2	86.97	6	0.10	5
R3	86.66	5	0.06	10
R4	87.15	7	0.22	1
R5	54.01	1	0.12	2
R6	62.35	3	0.10	3
R7	89.72	10	0.07	9
R8	84.42	4	0.07	7
R9	87.84	9	0.07	8
R10	87.31	8	0.08	6

The results of the AHP-based prioritization demonstrate significant differences compared to the rankings based on the Pavement Condition Index (PCI). For instance, Road R4, which ranked seventh in PCI, emerged as the top priority in the AHP analysis due to severe potholes and edge failures that the PCI method does not fully capture. This divergence highlights the strength of the AHP method in incorporating multiple distress types and providing a more comprehensive evaluation framework. By comparing the PCI values and AHP rankings, it was found that five roads had similar rankings in both methods, while others showed significant differences. Roads R5 and R6 ranked within the top three in both methods, and R7, R8, and R9 were consistently ranked lower, indicating that both methods align in some cases. However, the AHP method provides a broader perspective by including numerous distress types and their impacts, whereas the PCI method primarily focuses on surface conditions and pavement quality measurements.

These findings align with previous studies that emphasize the value of multi-criteria decision-making methods, like AHP, in infrastructure management contexts. AHP is effectively used in urban road and bridge management [6], [7]. The results of this study also show that AHP is effective for rural roads in developing countries such as Myanmar. The AHP method's inclusion of subjective judgment in assigning weights and priorities, which PCI measurements do not consider, leads to differences in prioritization, especially for roads like R4 and R10. The AHP method is significantly influenced by potholes, edge failures, and functional distress, which the PCI method may overlook. This underscores the limitations of traditional PCI-based methods and reinforces the need for a holistic approach to ensure sustainable and effective road maintenance strategies.

In terms of sustainability, the integration of AHP into road maintenance decision-making supports better resource allocation by prioritizing roads that require urgent attention, extending the lifespan of the pavement network, and reducing long-term maintenance costs. This is particularly important for rural road networks in developing countries, where financial and technical resources are often limited. The integration of both methods provides a more comprehensive evaluation framework, with the PCI method offering a direct and objective assessment of pavement condition, while the AHP method identifies critical issues that require urgent attention based on multiple distress criteria. Overall, this study's approach adds value to the existing literature by applying AHP to rural road networks in a developing country context, demonstrating its potential to improve the sustainability and performance of the road network.

4. Conclusion

The aim of this study is to conduct the prioritization of road maintenance for rural roads in Shan State, Myanmar by utilizing an Analytical Hierarchy Process (AHP) approach. The findings show significant views into the road condition and maintenance needs, and highlight both agreements and differences between these two methods. The AHP method considers various issues based on multiple distress criteria, such as potholes, edge failures, and roughness and provides a comprehensive evaluation. However, the PCI method mainly highlights only on surface condition. The results demonstrate that roads like R4 and R10, which were ranked lower in PCI due to their surface condition, emerged as higher priorities in AHP due to severe distresses. Conversely, roads like R5 and R6 ranked similarly in both methods, showing that the AHP and PCI methods can align in some cases. This reinforces the importance of using a multi-criteria approach like AHP, which effectively identifies urgent maintenance needs by considering a broader range of factors.

Therefore, integrating both AHP and PCI methods is recommended to conduct the effective road maintenance planning. This approach ensures a thorough assessment of road conditions. If PCI assessments are regularly conducted and AHP evaluations are periodically implemented, road conditions can be continuously monitored and maintenance priorities can be accordingly adjusted. Clarifying AHP criteria should align with PCI ratings to enhance the coherence of the prioritization strategy. Future research should additionally consider other factors such as traffic volume and economic impacts to create a more detailed prioritization framework. Implementing these recommendations, the Department of Rural Road Development (DRRD) can improve the durability and safety of rural roads; enhance transportation infrastructure; and encouraging economic development in Shan State, Myanmar.

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Declarations

Author contribution

Nandar Tun: Conceptualization, methodology of the study, formal analysis, software and writing – original draft. Kyaing and Moe Thet Thet Aye: Methodology, supervision, review and editing.

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Conflict of interest

The authors declare no conflict of interest in this research and publication.

Ethical Clearance

This research does not involve human subjects.

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