

# Integrated decision-making strategies for expressway maintenance prioritization: Data-driven scoring, rule-based, and AHP approach

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**Abstract:** Effective expressway maintenance is crucial for enhancing safety and optimizing resource utilization. The interplay of safety risks, pavement deterioration, and constrained budgets underscores the necessity for a robust decision-making framework. This study introduces an integrated approach combining a data-driven scoring method, an Analytic Hierarchy Process (AHP), and a rule-based strategy to prioritize maintenance activities systematically. The scoring method evaluates critical factors, including Pavement Condition Rating (PCR), Accident Density (AD), Weighted Accident Severity Index (WASI), critical horizontal curves, projected traffic volumes, village access points, and annual rainfall. A rule-based strategy identifies high-priority segments using cumulative ratings derived from the Pavement Condition Index (PCI), International Roughness Index (IRI), Present Serviceability Index (PSI), and Present Serviceability Rating (PSR). AHP further refines prioritization by assigning weights to pavement distress types based on regression analyses. When applied to eight expressway sections, the framework identified Yangon-Phyu and Phyu-Naypyitaw as critical due to elevated safety risks and significant pavement deterioration. The most deteriorated units received top priority among the 130 pavement sample units analyzed. This research underscores the importance of data-driven maintenance strategies to prolong pavement lifespan, reduce accident rates, and enhance operational efficiency, providing actionable insights for engineers and policymakers engaged in sustainable expressway infrastructure management.

**Keywords:** Robust decision-making; Expressway maintenance; Integrated scoring; Rule-based approach; Analytic hierarchy process

## 1. Introduction

Pavement maintenance prioritization is fundamental to transportation infrastructure management, particularly for high-traffic corridors such as the Yangon-Mandalay Expressway. Ensuring road safety, extending pavement life, and optimizing limited resources require effective, data-driven maintenance strategies. However, traditional approaches to maintenance prioritization often focus narrowly on physical pavement conditions, relying primarily on metrics like the Pavement Condition Index (PCI) or the International Roughness Index (IRI). These methods fail to account for broader factors such as safety, accessibility, environmental conditions, and operational demands, which are equally critical for ensuring the functional longevity of high-speed expressways. This lack of a holistic approach limits the effectiveness of maintenance strategies and compromises the safety and efficiency of critical road networks.

To address this gap, this research introduces a novel multi-method framework for pavement maintenance prioritization that integrates quantitative scoring, rule-based techniques, and the Analytic

Hierarchy Process (AHP). The framework represents a significant advancement in transportation infrastructure management by providing a comprehensive and adaptable tool for decision-making. The integrated scoring method evaluates multiple parameters, including the Pavement Condition Index (PCI) rating, Accident Density (AD), Weighted Accident Severity Index (WASI), critical horizontal curves, projected traffic, village accessibility, and annual rainfall. This multi-criteria evaluation enables the framework to address structural and contextual challenges, ensuring that safety and accessibility considerations are embedded in maintenance decisions.

The innovative use of a rule-based system further enhances the prioritization process by aggregating key pavement performance indicators—Pavement Condition Index (PCI), International Roughness Index (IRI), Present Serviceability Rating (PSR), and Present Serviceability Index (PSI). This component identifies critical sections within the same maintenance category, offering a nuanced approach to resource allocation. Additionally, the AHP method prioritizes maintenance interventions by categorizing pavement surface types, such as Asphalt Concrete (AC) overlay and concrete pavements, and assessing distresses unique to each surface type based on ASTM D 6433 standard. By weighting distress factors based on their significance, the framework ensures precise prioritization and optimal resource distribution.

The benefits of this research extend beyond the Yangon-Mandalay Expressway. Globally, transportation engineers and decision-makers can apply this approach to improve road safety, optimize resource allocation, extend pavement lifespan, and reduce life cycle costs. Integrating safety factors into maintenance prioritization is essential, as research indicates that deteriorated pavement conditions elevate crash risks by compromising vehicle stability and increasing the likelihood of skidding or hydroplaning [1], [2]. For instance, maintaining good pavement conditions can reduce fatal and injury crashes by 26% compared to deficient pavements, even if it does not directly impact overall crash frequency. Although pavement condition alone may not be the primary factor in accidents, maintaining high-quality pavements can reduce accident rates. However, some argue that poor pavement conditions might make drivers more cautious and reduce speeds, potentially lowering crash rates. A complex interplay of human factors, vehicle issues, environmental conditions, roadway geometry, traffic volume, and pavement conditions also influences accident rates [3]. Therefore, integrating multi-method analysis and context-specific factors represents a significant innovation, enabling a deeper understanding of the interplay between pavement conditions, safety, and operational efficiency.

The primary aim of this research is to develop a multi-method framework for prioritizing expressway maintenance by integrating quantitative scoring, a rule-based system, and the Analytic Hierarchy Process (AHP). This framework is intended to enhance maintenance decision-making by providing a comprehensive, data-driven approach that considers diverse factors affecting pavement conditions and safety, optimizing resource allocation for effective infrastructure management. The specific objectives are:

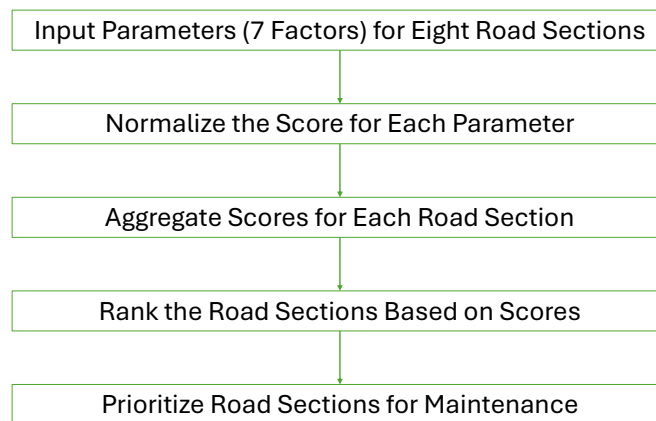
1. To establish a quantitative scoring system that evaluates pavement maintenance needs based on critical parameters, including Pavement Condition Index (PCI), Accident Density (AD), Weighted Accident Severity Index (WASI), critical horizontal curves, projected traffic volumes, village accessibility, and annual rainfall.
2. To develop a rule-based system that uses four primary pavement performance indicators—Pavement Condition Index (PCI), International Roughness Index (IRI), Present Serviceability Index (PSI), and Present Serviceability Rating (PSR)—to classify maintenance strategies and assign cumulative ratings to pavement units, enabling prioritization based on overall pavement condition.

3. To incorporate the Analytic Hierarchy Process (AHP) for prioritizing maintenance needs by categorizing pavement units according to surface types, specifically Asphalt Concrete (AC) overlay and concrete pavement distresses, in alignment with ASTM D 6433 standard.
4. To integrate these methodologies into a unified, adaptable framework that allows transportation engineers to make informed, precise, and resource-efficient maintenance decisions, tailored to the unique characteristics and challenges of the expressway.

In addition to its practical applications, this research contributes to scientific and technological advancements in transportation infrastructure management. The proposed framework offers a replicable model for strategic expressway maintenance planning, addressing the multifaceted challenges of modern roadway management and supporting the sustainable development of transportation infrastructure worldwide.

## 2. Material and methods

To prioritize pavement maintenance on the Yangon-Mandalay Expressway, an integrated scoring method was applied across eight key road sections, accounting for seven critical parameters: normalized average Pavement Condition Index (PCI) rating, average Accident Density (AD) per mile, average Weighted Accident Severity Index (WASI) per mile, number of critical horizontal curves, projected future traffic, number of accessible villages, and annual rainfall. Each parameter was normalized to a scale from 0 to 1, where higher values indicate greater need. These normalized scores were then aggregated to compute a total score for each section, reflecting its relative maintenance priority. Higher PCI, AD, and WASI scores indicated poorer conditions and higher safety risks, while sections with more critical curves [4], projected traffic, village access points, and rainfall received higher scores due to their operational and environmental demands. This multi-criteria approach ensures a balanced, data-driven prioritization that captures both structural and functional needs, making it highly effective and interpretable for maintenance decision-making. The following flowchart illustrates the integrated scoring method for prioritizing expressway maintenance on the Yangon-Mandalay Expressway.



**Figure 1.** Schematic representation of the integrated scoring method

A rule-based system was developed to determine optimal maintenance strategies for pavement units based on four key performance indicators: Pavement Condition Index (PCI) [5], [6], International Roughness Index (IRI), Present Serviceability Rating (PSR), and Present Serviceability Index (PSI) [3]. Each pavement unit was initially evaluated according to a set of predefined maintenance rules, which classify units into distinct maintenance strategies—ranging from Routine Maintenance to

Reconstruction—depending on the severity ratings of these indicators. The rule-based criteria specify that a maintenance rule is applied to a unit if at least two of the four performance indicators align with the defined rating threshold for that rule. This flexibility allows the system to capture units with varying degrees of distress while ensuring that they meet a minimum threshold for a recommended maintenance action. Once each unit was categorized into a maintenance strategy, it was observed that multiple units often fell under the same category, such as Minor Rehabilitation or Major Rehabilitation. To further prioritize units within each maintenance category, the sum of the ratings for all four indicators was calculated for each unit. This cumulative sum provided an additional layer of prioritization, where units with higher aggregate values indicated a greater urgency for maintenance intervention. By ranking units based on these summed values within each maintenance category, the rule-based system not only identifies the appropriate maintenance strategy but also effectively prioritizes units based on the severity of overall pavement conditions. This structured approach integrates both condition-based categorization and quantitative prioritization, enabling a comprehensive and data-driven framework for road maintenance decision-making.

The Analytic Hierarchy Process (AHP) was employed to prioritize pavement maintenance sections on the Yangon-Mandalay Expressway by systematically evaluating pavement distress data relevant to maintenance needs. The process began by defining the prioritization objective and structuring pavement distress types into a hierarchical model specific to Asphalt Concrete (AC) overlay and concrete pavements. Pairwise comparison matrices were constructed to assess the relative importance of each distress type, with weighted values derived from the significant values identified through multiple linear regression analysis of pavement distress and Pavement Condition Index (PCI) values [3]. These matrices were normalized, and priority weights were calculated to reflect the influence of each distress type. Consistency tests ensured logical coherence, with acceptable consistency ratios maintained throughout. Finally, the weighted scores for each distress type were aggregated to rank the road sections, with higher scores indicating sections that require immediate maintenance intervention. This structured approach integrates transportation engineer judgment with empirical data, providing a robust, data-driven framework for prioritizing pavement maintenance based on distress-specific needs.

## 2.1 Study area

The Yangon-Mandalay Expressway (YME) is a four-lane divided expressway connecting the cities of Yangon and Mandalay, spanning from 0/0 miles to 365 miles and 3 furlongs. It has been managed by the Department of Highways under the Ministry of Construction; this expressway comprises both concrete pavement and Asphalt Concrete (AC) overlay sections. As one of Myanmar's most important transportation corridors, the YME plays a vital role in supporting national mobility and economic activities. The Yangon-Mandalay Expressway (YME), Myanmar's first expressway opened in 2010, has now surpassed 14 years of continuous operation. Given its age and high usage, the expressway requires systematic maintenance to ensure safety, functionality, and longevity. A strategic, data-driven approach focusing on pavement conditions, traffic loads, and prioritized maintenance is essential to preserve YME as a reliable infrastructure asset.

## 2.2 Integrated data-driven scoring approach of expressway maintenance

Table 1. outlines the key factors considered for prioritizing road maintenance on the Yangon-Mandalay Expressway (YME) using an integrated scoring method, along with the rationale behind selecting this method due to its simplicity and interpretability for practical application by engineers. The average PCI rate was calculated and based on a practical survey and ASTM D 6433 standard [3]. Accident Density (AD) and Weighted Accident Severity Index (WASI) were calculated according to the accident

historical records from 2021 to 2023 along both ways of the road. The data for critical horizontal curves and village access points were obtained from the Department of Highways (DOH), Ministry of Construction (MOC), Myanmar. Projected future traffic volumes were sourced from the Myanmar Central Backbone Expressway Basic Design Project by KOICA (2020) (Bank, 2016). Annual rainfall data was referenced from the Myanmar Statistical Yearbook (2022).

**Table 1.** Factors consideration for prioritization of expressway maintenance

Factors to consider for prioritization	Description
Average PCI rate	Represents the pavement condition index, with a higher value of PCI rate indicating poor pavement condition.
Average AD/mile	Average number of total accidents per one mile.
Average WASI/mile	Average Weighted Accident Severity Index per one mile.
Critical Horizontal Curves	The number of critical horizontal curves for each road section that might affect road safety.
Projected Traffic (AADT)	Anticipated traffic volume (AADT) for each road section.
Number of Villages (Accessibility)	The number of villages along the road section provides access to the expressway.
Annual Rainfall (mm)	Represents potential weather-related impact on each road section.

### 2.3 Rule-based system of pavement maintenance approach

To determine optimal maintenance strategies for pavement units, a rule-based system was developed based on predefined thresholds for four key performance indicators—Pavement Condition Index (PCI), International Roughness Index (IRI), Present Serviceability Rating (PSR), and Present Serviceability Index (PSI). Especially, these six optimal pavement maintenance rules are considered for developing countries. By applying these canonical rules, each pavement unit is assigned a specific maintenance strategy according to its condition ratings, with at least two indicators matching the criteria for each rule.

- Rule 1 - If PCI (1, Good) and IRI (1, Very Good) or PSR (1, Very Good) or PSI (1, Very Good) then the pavement section should be Routine Maintenance.
- Rule 2- If PCI (1, Good or 2, Satisfactory) and IRI (2, Good) or PSR (2, Good) or PSI (2, Good) then the pavement section should be Preventive Maintenance.
- Rule 3 - If PCI (3, Fair or 4, Poor) and IRI (3, Fair or 4, Poor) or PSR (3, Fair or 4, Poor) or PSI (3, Fair or 4, Poor) then the pavement section should be Minor Rehabilitation.
- Rule 4 - If PCI (5, Very Poor or 6, Serious) and IRI (4, Poor) or PSR (4, Poor) or PSI (4, Poor) then the pavement section should be Major Rehabilitation (Initial Stage).
- Rule 5 - If PCI (5, Very Poor or 6, Serious or 7, Failed) and IRI (5, Very Poor) or PSR (5, Very Poor) or PSI (5, Very Poor) then the pavement section should be Major Rehabilitation (Heavy Stage).
- Rule 6 – If PCI (7, Failed) and IRI (6, Serious) and PSR (6, Serious) and PSI (6, Serious) then the pavement section should be Reconstruction [3]

After categorizing each unit according to a maintenance strategy, it became evident that several units frequently aligned within the same category, such as Minor Rehabilitation or Major Rehabilitation. To refine the prioritization within each maintenance category, a cumulative score was derived by summing the ratings of all four indicators for each unit.

## 2.4 Analytical Hierarchy Process (AHP) for prioritization of road maintenance

This research also employs the Analytic Hierarchy Process (AHP) to prioritize pavement maintenance sections on the Yangon-Mandalay Expressway (YME) by systematically evaluating both the Pavement Condition Index (PCI) and significant pavement distress identified through multiple regression analysis [3]. AHP utilizes Saaty's nine-point scale to assign relative importance to each distress type, where lower significance values from the regression analysis indicate higher priority in the maintenance decision hierarchy. This structured approach allows critical factors, such as high-impact distress types, to receive greater weight, ensuring that the most influential elements are prioritized for intervention. To verify the consistency of these assessments, Random Index (RI) values are employed, maintaining a consistency ratio below the acceptable threshold and thus validating the reliability of the prioritization. By balancing quantitative analysis with expert judgment, the AHP methodology provides a robust framework that enables transportation engineers to allocate resources effectively, focusing on sections that require urgent maintenance and supporting the long-term sustainability of critical infrastructure.

## 2.5 Pavement Condition Index (PCI)

Pavement Condition Index (PCI) is a system for assessing pavement conditions by type, and the level of damage that occurs and can be used as a reference in the maintenance plan. Standard practice for roads and parking lots pavement condition index surveys is issued under the fixed designation D-6433. The PCI method provides information on pavement conditions only at the time of the survey, but cannot provide a predictive picture in the future. However, by periodically conducting condition surveys, information on pavement conditions can be useful for predicting future performance, as well as being able to be used as a more detailed measurement input [7], [8], [9], [10]. The severity levels used in calculating PCI are low severity level (L), medium severity level (M), and high severity level (H). The steps of evaluation of the Pavement Condition Index (PCI) are as follows.

- Add up the total quantity of each distress type at each severity level, and record them.
- Divide the total quantity of each distress type at each severity level by the total area of the sample unit and multiply by 100 to obtain the percent density of each distress type and severity.
- Determine the deduct value (DV) for each distress type and severity level combination from the distress deduct value curves.
- Calculate the corrected deduct values (CDV) according to standard procedure.
- Determine the maximum corrected deduct value (CDV).
- Calculate the PCI by subtracting the maximum CDV from 100:  $PCI = 100 - \max CDV$  [5], [11]

## 2.6 International Roughness Index (IRI)

The International Roughness Index (IRI) was developed by the World Bank in the 1980s. IRI is used to define a characteristic of the longitudinal profile of a traveled wheel track and constitutes a standardized roughness measurement. The commonly recommended units are meters per kilometer (m/km) or millimeters per meter (mm/m). The IRI was defined as a mathematical property of a two-dimensional road profile (a longitudinal slice of the road showing elevation as it varies with longitudinal distance along a traveled track on the road). As such, it can be calculated from profiles obtained with any valid measurement method, ranging from static rods and level surveying equipment to high-speed inertial profiling systems [11], [12], [13], [14].

## 2.7 Present Serviceability Rating (PSR) and Present Serviceability Index (PSI)

One of the earliest pavement condition indices was the Present Serviceability Rating (PSR) developed at the AASHTO Road Test. The PSR was developed at the AASHTO Road Test by having raters riding in an automobile assign a pavement condition value that indicated the level of service the pavement provided. Researchers wanted, however, to measure this index objectively. Therefore, a relationship was developed between the mean PSR assigned by the panel, and some objective measurements such as roughness, rutting, and cracking. The new index, which was based on the values of pavement smoothness, rutting cracking, and patching was called the Present Serviceability Index (PSI) [15], [16].

## 2.8 Accident Density Method (AD)

The Accident Density Method involves calculating the density of accidents over a given length of roadway or within a defined area. This method helps to identify locations with higher accident concentrations, indicating potential safety issues that need to be addressed. This approach is often used for linear segments of roadways, such as highways or arterial roads [17].

$$\text{Accident Density, AD} = \frac{\text{Total Number of Accidents}}{\text{Length of Roadway Segment}} \quad (1)$$

Where: Total Number of Accidents is the total number of reported accidents within the specified roadway segment during the study period. Length of Roadway Segment is the length of the roadway segment in kilometers or miles.

## 2.9 Weighted Accident Severity Index Method (WASI)

The Weighted Accident Severity Index (WASI) Method is utilized in this research to provide a nuanced assessment of accident severity across the Yangon-Mandalay Expressway, incorporating a weighted approach to quantify the impact of different types of accidents. This method assigns specific weights to fatal, heavy impact injury, moderate impact injury, and light impact injury accidents, allowing for a single, composite index that reflects the overall severity profile of accidents on this expressway. For this study, the weighting values are defined as follows: fatal accidents are assigned a weight of 10 ( $W_f = 10$ ), heavy impact injury accidents a weight of 5 ( $W_h = 5$ ), moderate impact injury accidents a weight of 3 ( $W_m = 3$ ), and light impact injury accidents a weight of 1 ( $W_l = 1$ ). These weights emphasize the relative impact of each accident type on road safety, with fatal and severe injury accidents given greater importance due to their higher societal and economic costs.

Specifically, accidents are categorized based on the number of injuries sustained per accident: heavy impact injury accidents involve more than six injuries per accident, moderate impact injury accidents involve three to six injuries, and light impact injury accidents involve fewer than three injuries. This classification allows for a differentiated understanding of accident severity, which is essential for targeted safety interventions.

$$\begin{aligned} \text{WASI} = & \text{Number of Fatal Accidents} \times W_f + \text{Number of Heavy Impact Injury} \\ & \text{Accidents} \times W_h + \text{Number of Moderate Impact Injury Accidents} \times W_m + \\ & \text{Number of Light Impact Injury Accidents} \times W_l \end{aligned} \quad (1)$$

### 3. Results and discussion

This section presents the prioritized maintenance needs of the Yangon-Mandalay Expressway, derived from a combined approach of integrated scoring, rule-based analysis, and AHP approach. Results highlight priority areas requiring immediate intervention to enhance road safety and longevity. The findings underscore the value of a multi-method framework in systematically addressing critical maintenance requirements.

#### 3.1 Prioritization of expressway maintenance sections with integrated scoring approach

Table 2 presents the integrated characteristics of specific road sections on the Yangon-Mandalay Expressway (YME), illustrating the prioritization criteria used to assess maintenance needs. Seven normalized factors are considered: average rating of the Pavement Condition Index (PCI), average Accident Density (AD) per one mile, average Weighted Accident Severity Index (WASI) per one mile, number of critical horizontal curves, projected future traffic volume, village accessibility, and annual rainfall. Each factor is normalized on a scale from 0 to 1 for each way, where higher values indicate greater relative need or impact. The total score is derived by aggregating the normalized values for each factor, which provides a comprehensive assessment of each road section's overall maintenance priority.

**Table 2.** Prioritization of road sections with integrated scoring method

No	Road sections	Nor: PCI rate	Nor: AD/mile	Nor: WASI/mile	Nor: Critical curves	Nor: Future Traffic	Nor: No. of Villages	Nor: Annual Rainfall	Total Score	Priority Ranking
1	Ygn-Phyu	1	0.821	1.000	1	1	1.000	0.897	0.960	1
2	Phyu-Npt	0.8	0.772	0.893	0.2	0.75	0.776	1.000	0.742	3
3	Npt-Mtl	0.4	0.707	0.782	0.2	0.25	0.653	0.389	0.483	5
4	Mtl-Mdy	0.6	0.537	0.534	0.2	0.5	0.367	0.279	0.431	7
5	Phyu-Ygn	0.6	1.000	0.930	1	1	0.265	0.897	0.813	2
6	Npt-Phyu	0.8	0.472	0.447	0.2	0.75	0.388	1.000	0.580	4
7	Mtl-Npt	0.6	0.618	0.684	0.2	0.25	0.306	0.389	0.435	6
8	Mdy-Mtl	0.6	0.301	0.323	0.2	0.5	0.429	0.279	0.376	8

According to the ranking results, the Yangon-Phyu section ranks as the highest priority (Total Score: 0.960) due to its high scores across most indicators, reflecting significant demands on safety and maintenance. This section's high values in PCI rate, AD, WASI, critical curves, and traffic volume underscore the urgency of maintenance intervention. Phyu-Yangon follows closely as the second priority (Total Score: 0.813), also showing elevated values in PCI rate, AD, ASI, critical curves, and traffic, which suggests similar maintenance needs to its opposite direction.

Notably, factors such as future traffic volumes and village accessibility play a significant role in distinguishing the maintenance priorities between sections. The highest values in future traffic are allocated to sections expected to experience increased traffic demand, ensuring that the prioritization framework addresses not only current conditions but also anticipated operational demands. Additionally, annual rainfall data is integrated to capture potential weather-related impacts on pavement conditions, with higher rainfall values suggesting an increased risk of pavement deterioration. This multi-criteria prioritization approach, which combines physical condition indices with traffic, safety, and environmental factors, enables a holistic evaluation of maintenance needs on YME. By systematically prioritizing road sections based on these aggregated scores, this framework facilitates targeted and data-driven maintenance planning, enhancing the expressway's safety and

longevity. This method proves to be both adaptable and effective, providing a replicable framework for other high-traffic corridors with similar needs for sustainable and optimized infrastructure management.

### 3.2 Prioritization of pavement maintenance units by rule-based system

The application of fuzzy logic models in pavement condition evaluation has gained significant attention due to their ability to incorporate diverse input variables and account for uncertainties. The used of the densities of pavement distresses at various severity levels as inputs for a fuzzy logic-based model [18]. The model generated outputs such as the Pavement Condition Index (PCI), analyzed using Micro-Paver 5.2 software, and maintenance strategy recommendations derived from expert opinions. This approach underscores fuzzy logic's flexibility in integrating quantitative data and qualitative insights to inform maintenance strategies [18]. In assessing the pavement condition of the Kalumata Highway in South Ternate, applied the Pavement Condition Index (PCI) as a primary evaluation tool [14]. Their study demonstrated how visual surveys, coupled with the calculation of damage dimensions and severity, can yield a robust PCI score that aids in determining overall road health. This method provides a detailed and quantitative approach to identifying pavement deterioration, making it a valuable asset in maintenance planning and prioritization [14], [19].

This study integrates four critical pavement performance indicators—the pavement Condition Index (PCI) for structural failure, the International Roughness Index (IRI) for surface roughness, the Present Serviceability Rating (PSR) reflecting human perception, and the Present Serviceability Index (PSI) based on the AASHTO-developed method. These indicators collectively assess current pavement quality and guide the formulation of an optimal maintenance strategy. According to Table 3, pavement performance indicators rating of PCI, IRI, PSR, and PSI are categorized into groups 1, 2, 3, 4, 5, 6, and 7 for very good, good, fair, poor, very poor, serious, and failed condition respectively. The numerical values of these indices with their respective condition rating and category groups are shown in Table 3.

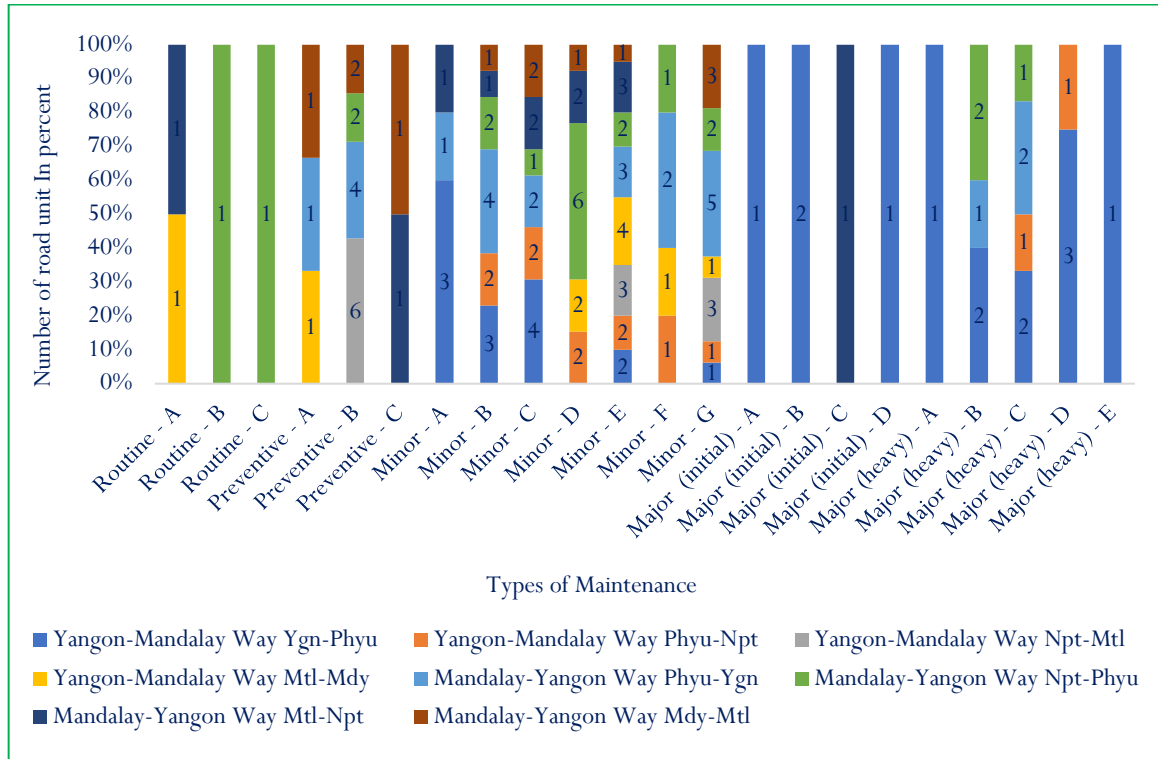
**Table 3.** Pavement performance indicators rating with category group

Category Group	Pavement Rating	PCI (ASTM D6433)	IRI (DOH, Myanmar)	PSR (Raters)	PSI (Objective Index)
1	Very Good	86-100	< , = 2	> , = 4.1	> , = 4.1
2	Good	71-85	2-4	3.6-4.0	3.6-4.0
3	Fair	56-70	4-8	3.1-3.5	3.1-3.5
4	Poor	41-55	8-12	2.6-3.0	2.6-3.0
5	Very Poor	26-40	12-16	2.1-2.5	2.1-2.5
6	Serious	11 - 25	>16	< , = 2	< , = 2
7	Failed	0 - 10			

To determine optimal maintenance strategies for pavement units, a rule-based system was developed based on predefined thresholds for four key performance indicators—Pavement Condition Index (PCI), International Roughness Index (IRI), Present Serviceability Rating (PSR), and Present Serviceability Index (PSI). By applying these canonical rules, each pavement unit is assigned a specific maintenance strategy according to its condition ratings, with at least two indicators matching the criteria for each rule as discussed in section 4.2.

After categorizing each unit according to a maintenance strategy, it became evident that several units frequently aligned within the same category, such as Minor Rehabilitation or Major Rehabilitation. To refine the prioritization within each maintenance category, a cumulative score was derived by summing

the ratings of all four indicators for each unit. Figure 2 illustrates the distribution of maintenance types across different road units along various sections of the Yangon-Mandalay Expressway (YME). The maintenance types are categorized into Routine, Preventive, Minor, and Major interventions, with each type further subdivided (e.g., Routine A, Routine B, Minor A, Minor B) to indicate the specific intensity and scope of maintenance required from category A to B. The percentage values on the y-axis represent the proportion of road units in each maintenance category, offering a comparative view of maintenance demands across the expressway's sections.



**Figure 2.** Prioritization of pavement maintenance units by maintenance strategies

### 3.3 Prioritization of pavement maintenance units by AHP approach

This research also employs the Analytic Hierarchy Process (AHP) to prioritize pavement maintenance sections on the Yangon-Mandalay Expressway (YME) by systematically evaluating both the Pavement Condition Index (PCI) and significant pavement distress identified through multiple regression analysis. Developed a PCI model using pavement distress survey data from video footage and photographs of road sections. The model was validated with Pavement Service Rating (PSR) data collected through driver behavior surveys and complemented by IRI data gathered via the TotalPave smartphone app [9].

In this research, PCI values of AC overlay and concrete pavement distresses were evaluated by ASTM D 6433 standard, and the most significant distresses were identified under regression analysis. Then, AHP utilizes Saaty's nine-point scale to assign relative importance to each distress type, where lower significance values from the regression analysis indicate higher priority in the maintenance decision hierarchy [3], [20]. This structured approach allows critical factors, such as high-impact distress types, to receive greater weight, ensuring that the most influential elements are prioritized for intervention. To verify the consistency of these assessments, Random Index (RI) values are employed, maintaining a consistency ratio below the acceptable threshold and thus validating the reliability of the prioritization [21].

**Table 4.** AHP weighted criteria value of each pavement distress for AC overlay

No.	AC overlay Pavement Distress	Abbreviation	Sig. Value	Weighted Criteria Value
1	Weathering -H	WT-H	0	0.247
2	Potholes-L	Pohl-L	0	0.247
3	Potholes-H	Pohl-H	0.001	0.167
4	Patching & Util Cut Patching-M	Pat-M	0.006	0.116
5	Potholes-M	Pohl-M	0.013	0.081
6	Weathering-M	WT-M	0.02	0.056
7	Joint Reflection Cracking-M	JRC-M	0.022	0.039
8	Lane/Shoulder Drop Off-H	L/S-H	0.035	0.027
9	Joint Reflection Cracking-H	JRC-H	0.037	0.020

Table 4. presents the Analytic Hierarchy Process (AHP) weighted criteria for Asphalt Concrete (AC) overlay pavement distresses, incorporating Pavement Condition Index (PCI) values. The distresses are categorized by severity—low (L), medium (M), and high (H)—and are ranked based on their statistical significance (Sig. Value) and assigned weighted criteria values. The lower the significance value, the higher the priority assigned to that distress type for maintenance, with a significance threshold of 0.05, indicating a 95% confidence level for prioritization decisions. Distress with Sig. Values below this threshold are considered more critical and prioritized accordingly.

**Table 5.** Consistency test of AHP approach for AC overlay

$\lambda$ (x)	9.342578806	
Consistency Index, CI	0.042822351	
Consistency Ratio, CR	0.029532656	< 0.1 Acceptable

Among the distress types, Weathering-H and Potholes-L are identified as the most significant, each with a significance value of 0 and the highest weighted criteria values of 0.247. These findings indicate that high-severity weathering and low-severity potholes have a substantial impact on PCI values and thus require immediate attention in the maintenance prioritization process. Potholes-H and Patching & Utility Cut Patching-M follow, with significance values of 0.001 and 0.006, respectively, reflecting moderate priority due to their slightly lower weighted criteria values of 0.167 and 0.116. Conversely, distresses such as Joint Reflection Cracking-H and Lane/Shoulder Drop-Off-H have higher Sig. Values (e.g., 0.037 and 0.035), resulting in lower weighted criteria and lower prioritization.

The consistency ratio (CR) for this AHP analysis is calculated to be 0.0295 as shown in Table 5, which is well within the acceptable threshold of 0.1, indicating that the prioritization process is reliable and consistent. This low CR confirms that the pairwise comparisons used to determine weighted values were logical and coherent, ensuring that the prioritization accurately reflects the impact of each distress type on pavement condition. By assigning higher weights to distress types with lower significance values, this AHP-based framework enables a structured and quantitative approach to prioritizing maintenance needs. The prioritization of high-severity and statistically significant distresses supports targeted resource allocation, thereby optimizing pavement management practices. This methodology underscores the importance of both distress severity and statistical significance in maintenance decision-making, contributing to a robust framework for the effective management of AC overlay pavement sections.

Higher AHP values indicate sections with more significant pavement deterioration, prioritizing them for maintenance interventions. Thus, out of a total of 130 sample units, sample units 84, 101, and 65 exhibit the highest weighted AHP scores (493.934, 479.18, and 425.042, respectively), highlighting

them as critical areas in need of immediate attention. Conversely, several units, such as 53, 94, and 96, have an AHP score of 0, indicating minimal or no immediate maintenance needs.

**Table 6.** AHP weighted criteria value of each pavement distress for concrete pavement

No.	Concrete pavement distress	Abbreviation	Sig. Value	Weighted criteria value
1	Scaling- H	SC-H	0	0.102
2	Linear Cracking - L	LC-L	0	0.102
3	Linear Cracking - M	LC-M	0	0.102
4	Linear Cracking - H	LC-H	0	0.102
5	Lane/Shoulder Drop Off - H	L/S-H	0	0.102
6	Spalling Joint - H	SPJ-H	0	0.102
7	Durability Cracking - H	DC-H	0	0.102
8	Pumping	Pumping	0.001	0.059
9	Faulting-H	F-H	0.001	0.059
10	Divided Slab-M	DS-M	0.001	0.059
11	Scaling-M	SC-M	0.002	0.039
12	Faulting-L	F-L	0.004	0.027
13	Joint Seal Failure-M	JS-M	0.01	0.020
14	Lane/Shoulder Drop Off-M	L/S-M	0.03	0.015
15	Shrinkage-H	S-H	0.032	0.012

Table 6 presents the Analytic Hierarchy Process (AHP) weighted criteria for concrete pavement distresses, calibrated with Pavement Condition Index (PCI) values to prioritize maintenance efforts. This table categorizes various distress types by their statistical significance (Sig. Value) and corresponding weighted criteria, indicating the relative importance of each distress type in influencing pavement conditions. Distresses are classified by severity level—low (L), medium (M), and high (H)—to provide a structured approach for prioritization. Among the distress types, those with a Sig. Value of 0 (Scaling-H, Linear Cracking-L/M/H, Lane/Shoulder Drop-Off-H, Spalling Joint-H, and Durability Cracking-H) are assigned the highest weighted criteria value of 0.102, emphasizing their significant impact on PCI values. This prioritization implies that these high-severity distresses are critical factors in pavement degradation and should be prioritized for intervention to maintain structural integrity and road safety. Other distress, such as Pumping and Faulting-H, have slightly lower significance (Sig. Value = 0.001) and a weighted criteria value of 0.059, indicating moderate priority in the maintenance hierarchy. Distress with higher Sig. Values, such as Shrinkage-H (Sig. Value = 0.032, Weighted Criteria = 0.012), are assigned lower weights, reflecting a relatively reduced impact on PCI and thus a lower urgency for immediate maintenance.

**Table 7.** Consistency test of AHP approach for concrete pavement

$\lambda$ (x)	16.388	
Consistency Index, CI	0.099141388	
Consistency Ratio, CR	0.062747714	< 0.1 Acceptable

According to Table 7, the Consistency Ratio (CR) of 0.0627 in this AHP analysis is below the acceptable threshold of 0.1, confirming that the pairwise comparisons and weighted prioritizations are reliable and consistent. The low CR reinforces the robustness of the AHP model, ensuring that the judgments are logical and coherent across distress types. This validated consistency enhances confidence in using this prioritization framework to guide maintenance decisions. By focusing on distress types with the most substantial impact on pavement conditions, this AHP-based approach enables a data-driven prioritization for resource allocation, ensuring that critical distresses are addressed first. The methodology's systematic weighting of distress types based on their statistical significance within the PCI framework provides a replicable model for effective pavement

management, allowing for informed, targeted maintenance strategies that optimize road longevity and serviceability for concrete pavements. Among 130 units, sample units 87 and 9 have the highest AHP weights of 2.689 and 2.22, respectively, suggesting that these sections exhibit severe distress and should be prioritized for maintenance. Conversely, units like 118 and 112 display the lowest AHP values of 0, indicating minimal deterioration and, thus, a lower immediate need for maintenance resources. This distribution allows for an efficient allocation of resources, ensuring that the most deteriorated sections are addressed first while deferring sections with minimal deterioration.

#### 4. Conclusion

This research presents an adaptable and integrated data-driven approach for prioritizing road maintenance on expressways. By combining a quantitative data-driven scoring method, a rule-based system, and the Analytic Hierarchy Process (AHP), the framework allows transportation engineers to identify and prioritize road sections with critical maintenance needs. The scoring method provides a balanced evaluation of key factors, including the Pavement Condition Index (PCI), Weighted Accident Severity Index (WASI), Accident density (AD), critical horizontal curves, projected traffic, village accessibility, and annual rainfall. The rule-based approach adds a layer of prioritization, distinguishing units within each maintenance category and enabling resource allocation according to overall ratings of current pavement. AHP, with its rigorously derived weighted criteria for various pavement distress types, particularly Asphalt Concrete (AC) overlay and concrete pavements, further refines the prioritization, ensuring targeted and effective maintenance interventions based on distress-specific needs.

The findings demonstrate the framework's practical applicability and adaptability for managing expressway maintenance in resource-constrained settings. By systematically addressing the most deteriorated units and considering future operational demands, this framework not only enhances road safety and infrastructure longevity but also supports proactive, cost-effective decision-making. This methodology has potential application for similar high-traffic corridors, where integrating structured, multi-criteria analysis can drive sustainable infrastructure management. Future research could focus on incorporating real-time data and monitoring capabilities to optimize maintenance planning further, offering an evolving solution for dynamic infrastructure needs.

#### Author's declaration

#### Author contribution

**Nan Htike Yee Mon** : Conceptualization, Methodology, Data Collection, Data Analysis, Writing-Original Draft, Visualization. **Kyaing** : Supervision, Writing – Review , and Methodological Guidance. **Moe Thet Thet Aye** : Supervision, Writing – Review.

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### Conflict of interest

The authors declare that they are NOT affiliated with or involved in any organization or entity with a financial or non-financial interest in the subject matter or materials discussed in this manuscript.

### Ethical clearance

This research does not involve humans as subjects.

### AI statements

The authors have manually rechecked the accuracy and correctness of all content to ensure it aligns with the data and topic of this study. The authors take full responsibility for the content, accuracy, and language used in this article. None of the AI-generated sentences, figures, or tables are included without thorough review and verification.

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