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Cost Estimation for Road Preservation Based on AHP-Derived Priority Rankings: A Case Study of the Arjosari–Purwantoro Road Section (Central Java Provincial Border), Pacitan, Indonesia

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Abstract

Road preservation plays a critical role in maintaining pavement performance, extending service life, and optimizing the allocation of limited maintenance budgets. However, establishing preservation priorities requires a comprehensive assessment of pavement conditions and multiple decision-making criteria. This study aimed to determine road preservation priorities by integrating the Provincial/Regency Road Management System (Provincial/Kabupaten Road Management System, PKRMS) with the Analytic Hierarchy Process (AHP) and to estimate preservation costs for the Arjosari–Purwantoro road section in Pacitan Regency, Indonesia. PKRMS data were used to assess pavement conditions based on technical indicators, while AHP was applied to prioritize preservation alternatives through pairwise comparisons of decision criteria. The resulting priority rankings were subsequently integrated with cost estimates for the recommended preservation treatments. The findings identified preventive periodic maintenance as the highest-priority strategy, followed by routine maintenance and minor rehabilitation. The estimated costs were IDR 26,112,043,423 for preventive periodic maintenance, IDR 10,675,512,257 for routine maintenance, and IDR 2,852,344,312 for minor rehabilitation, resulting in a total estimated preservation cost of IDR 39,639,899,992 (approximately IDR 39.64 billion). Preventive periodic maintenance accounted for the largest share of the total estimated cost because it covered the greatest treatment length and area. The integration of PKRMS and AHP provided a systematic and transparent framework for prioritizing road preservation interventions and aligning treatment priorities with budget planning. These findings demonstrated the potential of the integrated approach to support evidence-based decision-making and more efficient road asset management under budget constraints.

INTRODUCTION

Road infrastructure plays a fundamental role in supporting regional connectivity, economic growth, and access to public services. As an essential transportation asset, road networks facilitate the movement of people and goods, improve accessibility to education, healthcare, commercial activities, and government services, and contribute to regional economic development. Well-maintained roads can reduce travel time, lower vehicle operating costs, improve traffic safety, and enhance logistics efficiency. Conversely, deteriorating road

conditions increase transportation expenses, restrict mobility, accelerate vehicle wear, and adversely affect economic productivity, particularly in regions that depend heavily on road transportation (Republik Indonesia, 2004; Riduan et al., 2026).

Road pavement deterioration results from cumulative traffic loading, environmental exposure, material aging, inadequate drainage, subgrade deficiencies, and construction-related factors (Brenes-Calderon et al., 2025). Pavement distresses, including longitudinal cracking, raveling, and rutting, may progressively worsen and contribute to more severe structural deterioration if appropriate maintenance interventions are delayed. Consequently, preventive pavement preservation is generally considered more cost-effective than extensive rehabilitation or reconstruction because timely interventions can extend pavement service life, maintain acceptable performance, and reduce long-term maintenance expenditures (Direktorat Jenderal Bina Marga, 2021; Menteri Pekerjaan Umum Republik Indonesia, 2011).

Road preservation has therefore become an integral component of infrastructure asset management. Beyond repairing existing pavement damage, preservation involves systematic maintenance planning to sustain pavement serviceability and optimize performance throughout its life cycle. However, local governments frequently face budgetary constraints when managing extensive road networks with varying pavement conditions and maintenance requirements. Because available funding may be insufficient to address all preservation needs simultaneously, transportation agencies must establish priorities for maintenance and rehabilitation interventions. Ineffective prioritization can result in inefficient public expenditure, delayed maintenance, and accelerated pavement deterioration, potentially increasing future rehabilitation costs (Masagung et al., 2023).

To support systematic road infrastructure management, Indonesia's Ministry of Public Works and Housing introduced the Provincial/Kabupaten Road Management System (PKRMS), which facilitates road inventory management, pavement condition assessment, and preservation planning. The system incorporates technical information concerning pavement distress, road roughness, shoulder conditions, drainage, and geometric characteristics to support the identification of maintenance requirements and appropriate treatment alternatives. Although PKRMS provides a structured basis for assessing road conditions and planning preservation activities, additional decision-making criteria may be necessary to establish priorities under budget constraints. Such criteria may include traffic volume, road network function, socioeconomic importance, and financial feasibility (Menteri Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia, 2023).

The need to integrate technical pavement assessments with financial planning has become increasingly important in road preservation management. Although PKRMS provides standardized information on road conditions, preservation prioritization may require additional consideration of technical, economic, and socioeconomic factors. The Analytic Hierarchy Process (AHP) offers a structured multicriteria decision-making approach that enables decision-makers to evaluate the relative importance of competing criteria through pairwise comparisons (Saaty, 2008). However, the application of an integrated PKRMS–AHP framework that explicitly connects preservation priority rankings with treatment cost estimation remains insufficiently documented in the literature examined. Addressing this issue could strengthen the relationship between technical assessments, priority determination, and financial resource allocation.

Previous studies have examined pavement condition assessment, maintenance strategy selection, and infrastructure prioritization using multicriteria decision-making methods (Liu et al., 2024; Nautiyal & Sharma, 2022; Tun et al., 2024). Some studies have employed AHP to determine infrastructure investment priorities (Kresnanto, 2022; Nababan, 2014; Nugraha et al., 2025; Pamungkas et al., 2017; Prahastyo et al., 2019; Sitanggang et al., 2022; Togelang et al., 2021), while others have applied road management systems to assess pavement performance and identify maintenance requirements (Arifin et al., 2025a, 2025b; Farida et al., 2025; Halich et al., 2023; Sari et al., 2026). Nevertheless, limited attention has been given to integrating PKRMS-generated technical indicators with AHP-derived criterion weights and translating the resulting preservation priorities into estimated financial requirements. Consequently, preservation planning approaches that focus exclusively on priority rankings may provide insufficient information for budget preparation, whereas cost estimation approaches that do not incorporate systematic prioritization may inadequately reflect competing maintenance needs. This limitation highlights the importance of integrating technical evaluation, multicriteria prioritization, and cost estimation within a unified road preservation planning framework (Armayadi et al., 2023).

The Arjosari–Purwantoro road section, located near the Central Java provincial border in Pacitan Regency, Indonesia, serves as an interregional transportation corridor supporting mobility and economic activities. PKRMS survey data identified several pavement distresses along the road section, including longitudinal cracking, alligator cracking, surface raveling, and localized pavement deterioration. Variations in pavement conditions across individual segments indicated the need for differentiated preservation treatments. Given the road's transportation function and the presence of multiple pavement distress types, preservation planning required an integrated assessment of technical conditions, treatment priorities, and associated financial requirements to support efficient resource allocation.

This study aimed to develop an integrated road preservation planning framework by combining PKRMS pavement condition data with the Analytic Hierarchy Process (AHP) to determine preservation priorities and estimate the associated costs for the Arjosari–Purwantoro road section. Technical indicators obtained from PKRMS were used to characterize pavement conditions and identify appropriate preservation treatments, while AHP was employed to determine the relative importance of decision criteria and establish priority rankings. These rankings were subsequently linked to treatment quantities and cost estimates to determine the financial requirements of the proposed preservation program.

The study contributed to road asset management by integrating standardized pavement condition assessments with multicriteria decision-making and preservation cost estimation. This approach provided a structured basis for establishing maintenance priorities and estimating the financial resources required for recommended interventions. Furthermore, the integration of PKRMS and AHP offered a transparent decision-support framework for local governments seeking to align pavement preservation needs with available infrastructure budgets. The findings were expected to support more systematic maintenance planning, improve the allocation of limited financial resources, and contribute to sustainable road infrastructure management in regional transportation networks.

METHODS

This study employed a quantitative approach to estimate road preservation costs based on priority rankings derived from the Analytic Hierarchy Process (AHP). The research was conducted on the Arjosari–Purwantoro road section near the Central Java provincial border in Pacitan Regency, Indonesia. The methodology comprised four stages: data collection, pavement condition assessment using the Provincial/Kabupaten Road Management System (PKRMS), preservation prioritization using AHP, and cost estimation for the recommended treatments.

Primary and secondary data were used in this study. Primary data were collected through pairwise comparison questionnaires administered to experts in road planning, maintenance, engineering, and infrastructure financing. Respondents included road maintenance personnel, technical engineers, infrastructure financing analysts, and planning consultants. Expert judgments were obtained using Saaty's nine-point fundamental scale and subsequently processed to determine the relative weights of the preservation decision criteria.

Secondary data were obtained from the PKRMS database and supporting documents provided by relevant government agencies. The data included pavement condition indicators, such as the International Roughness Index (IRI), Surface Distress Index (SDI), pavement distress characteristics, and road condition classifications. Additional information comprised road inventory records, average daily traffic (ADT), road functional classifications, geometric characteristics, and unit prices derived from the Indonesian Unit Price Analysis (Analisis Harga Satuan Pekerjaan, AHSP).

Pavement conditions were assessed using PKRMS data, including the Treatment Trigger Index (TTI), Surface Distress Index (SDI), and Road Condition Index (Indeks Kondisi Jalan, IKJ). Based on the applicable assessment criteria, road segments were classified as being in good, fair, lightly damaged, or heavily damaged condition. The assessment results were used to identify preservation needs and determine appropriate treatment alternatives for subsequent prioritization.

The Analytic Hierarchy Process (AHP) was applied to rank preservation alternatives based on four criteria: pavement condition, average daily traffic, preservation cost, and socioeconomic impact. The evaluated alternatives comprised routine maintenance, periodic maintenance, and rehabilitation. Pairwise comparison matrices were constructed from expert judgments, and criterion weights were calculated through matrix normalization and priority vector estimation. Judgment consistency was assessed using the consistency ratio (CR), and only matrices meeting the specified consistency threshold were included in the analysis. The resulting criterion weights were combined with the alternative assessments to establish the final preservation priority rankings.

Preservation costs were estimated based on the recommended treatments for the prioritized road segments. Treatment quantities were calculated using the required intervention lengths and widths, while unit costs were obtained from the applicable AHSP data. The estimated cost of each treatment was calculated by multiplying the relevant work quantities by their corresponding unit prices. The total preservation budget was then determined by aggregating the estimated costs of all recommended treatments.

The analysis integrated PKRMS pavement condition data, AHP-derived priority rankings, and treatment cost estimates to establish the financial requirements of the proposed

preservation program. The resulting estimates provided a basis for comparing preservation priorities and supporting budget allocation decisions for the Arjosari–Purwantoro road section.

RESULTS AND DISCUSSION

Integration of PKRMS Analysis and AHP Priority Rankings

The integration of the Provincial/Kabupaten Road Management System (PKRMS) and the Analytical Hierarchy Process (AHP) was performed to combine the technical road condition assessment obtained from PKRMS with the priority rankings of preservation alternatives generated by AHP. PKRMS was used to identify pavement conditions based on the Treatment Trigger Index (TTI) and Surface Distress Index (SDI), whereas AHP was employed to determine the priority ranking of preservation alternatives by considering pavement condition, traffic volume, preservation cost, and socio-economic impact. Consequently, preservation decisions were based not only on the physical condition of the pavement but also on the relative importance of multiple decision criteria.

Based on the PKRMS survey, the Arjosari–Purwantoro Road Section has a total length of 46.39 km, consisting of 13.29 km in good condition, 19.80 km in fair condition, 12.90 km in lightly damaged condition, and 0.40 km in heavily damaged condition. These results indicate that although most road segments remain serviceable, preventive preservation measures are required to prevent further deterioration.

Table 1. Integration of PKRMS Road Condition Assessment and AHP Preservation Priorities

Road Condition (PKRMS)	Length (km)	Initial PKRMS Recommendation	Corresponding AHP Alternative	AHP Score	Integrated Decision
Good	13.29	Routine maintenance	A1 – Routine Maintenance	0.198	Maintain pavement condition through routine maintenance
Fair	19.80	Periodic maintenance	A2 – Preventive Periodic Maintenance	0.523	Highest preservation priority
Lightly damaged	12.90	Periodic maintenance or minor rehabilitation	A2 – Preventive Periodic Maintenance	0.523	Prioritized to prevent further deterioration
Heavily damaged	0.40	Rehabilitation	A3 – Minor Rehabilitation	0.280	Localized (spot) rehabilitation

Source: Author's Analysis

Based on Table 1, preventive periodic maintenance was identified as the dominant preservation strategy. This result is supported by two considerations. First, road segments classified as fair and lightly damaged represent the largest proportion of the road network, totaling 32.70 km. Second, preventive periodic maintenance achieved the highest AHP priority score (0.523), indicating that it is the most appropriate preservation alternative for maintaining pavement performance before severe deterioration occurs.

Routine maintenance remains necessary for road segments in good condition to preserve pavement quality and extend service life. Conversely, minor rehabilitation is recommended only for localized heavily damaged sections totaling 0.40 km. This integrated

approach ensures that each preservation treatment is applied according to the actual pavement condition while simultaneously reflecting expert judgment regarding preservation priorities.

Table 2. Summary of PKRMS Results Integrated with AHP Priority Rankings

Preservation Alternative	Target Road Condition	Treatment Length (km)	AHP Score	Priority Rank
A2 – Preventive Periodic Maintenance	Fair and lightly damaged	32.70	0.523	1
A3 – Minor Rehabilitation	Heavily damaged	0.40	0.280	2
A1 – Routine Maintenance	Good	13.29	0.198	3

Source: Author's Analysis

As shown in Table 2, preventive periodic maintenance ranked first because it obtained the highest AHP score while covering the largest treatment length. Minor rehabilitation ranked second because it is required only for isolated heavily damaged segments, whereas routine maintenance ranked third since its objective is to preserve roads that remain in good condition rather than address significant deterioration.

The integration of PKRMS and AHP demonstrates that the two approaches complement each other effectively. PKRMS provides objective technical information regarding pavement conditions, while AHP determines the relative priority of preservation alternatives based on multiple engineering and socio-economic criteria. The integrated analysis indicates that preventive periodic maintenance should be prioritized, supported by localized minor rehabilitation and routine maintenance according to pavement condition.

Road Preservation Cost Estimation

Road preservation costs were estimated based on the priority rankings obtained from the integrated PKRMS–AHP analysis. Since preventive periodic maintenance was identified as the highest-priority preservation strategy, cost estimation primarily focused on road segments classified as fair and lightly damaged. The preservation cost was calculated using the following equations:

$$\text{Total Cost} = \text{Treatment Area} \times \text{Unit Ptice} \quad (1)$$

$$\text{Treatment Area} = \text{Road Length} \times \text{Road Width} \quad (2)$$

Table 3. Estimated Preservation Area and Cost Based on Priority Ranking

No	Preservation Alternative	Target Condition	Treatment Length (km)	Road Width (m)	Estimated Area (m²)	Unit Price (Million IDR/m²)	Estimated Cost (Million IDR)
1	Preventive Periodic Maintenance	Fair and lightly damaged	32.70	5.14	168,078.00	0.1553567	26,112.04
2	Minor Rehabilitation	Heavily damaged	0.40	5.14	2,056.00	1.387327	2,852.34
3	Routine Maintenance	Good	13.29	5.14	68,310.60	0.156279	10,675.51

Source: Author's Analysis

As presented in Table 3, preventive periodic maintenance requires the largest preservation budget, amounting to approximately IDR 26.11 billion. This cost is primarily attributed to the extensive treatment area (168,078.00 m²) corresponding to road segments classified as fair and lightly damaged.

Minor rehabilitation requires an estimated budget of approximately IDR 2.85 billion. Although this alternative has the highest unit cost, the total expenditure remains relatively low because only 0.40 km of the road section requires rehabilitation.

Routine maintenance is estimated to require approximately IDR 10.68 billion, covering 68,310.60 m² of pavement in good condition. The primary objective of this treatment is to maintain pavement performance and prevent premature deterioration.

The total estimated preservation cost for implementing all three preservation alternatives is approximately IDR 39.64 billion. These findings indicate that the largest proportion of the preservation budget should be allocated to preventive periodic maintenance, consistent with the priority ranking generated through the integrated PKRMS–AHP analysis.

The analysis indicates that pavement condition is the most influential criterion in determining preservation priorities, accounting for 49.84% of the total decision weight. This finding demonstrates that technical pavement condition remains the primary consideration in selecting appropriate preservation strategies. Road segments classified as fair and lightly damaged require timely intervention to prevent further deterioration and avoid more costly rehabilitation in the future.

Average Daily Traffic (ADT) ranked second with a weight of 24.08%, indicating that traffic demand significantly influences preservation decisions. The socio-economic impact criterion ranked third (16.81%), highlighting the importance of maintaining road accessibility for regional mobility and economic activities. In contrast, preservation cost received the lowest weight (9.27%), suggesting that respondents prioritized technical necessity and service performance over financial considerations alone.

Among the evaluated preservation alternatives, preventive periodic maintenance achieved the highest priority score (52.26%), followed by minor rehabilitation (27.98%) and routine maintenance (19.75%). The estimated preservation costs further support these priorities, with preventive periodic maintenance requiring the largest investment due to the extensive area requiring treatment.

Overall, integrating PKRMS with AHP provides a comprehensive decision-support framework by combining objective pavement condition assessment with multi-criteria decision analysis. The resulting preservation priorities are technically appropriate, economically feasible, and capable of supporting more efficient allocation of road maintenance budgets.

CONCLUSION

The road preservation cost estimates based on the AHP-derived priority rankings indicated that preventive periodic maintenance required an estimated budget of IDR 26,112,043,423, followed by routine maintenance at IDR 10,675,512,257 and minor rehabilitation at IDR 2,852,344,312. Accordingly, the total estimated preservation cost for the Arjosari–Purwantoro road section was IDR 39,639,899,992 (approximately IDR 39.64 billion). Preventive periodic maintenance accounted for the largest share of the total estimated budget because it covered the greatest road length and treatment area, making it the principal cost component of the proposed road preservation program.

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