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Analytic Hierarchy Process (AHP) Model in Determining Road Improvement Selection Strategies

[1]Galang Satrio
Universitas Negeri Semarang,
Sekaran, Kec. Gn. Pati, Kota Semarang, Jawa Tengah 50229 Indonesia

ABSTRACT
This study aims to determine the priority of road repair in Kudus Regency using the Analytic Hierarchy Process (AHP) method. Four main criteria, namely cost, technical, road conditions, and environment are used as the basis for the assessment, which are further broken down into several subcriteria. Data was obtained through a paired comparison questionnaire to experts, then processed using geometric averages and analyzed through a paired comparison matrix to obtain priority weights. The results showed that the environmental criteria had the highest weight (0.35), followed by technical (0.30), cost (0.25), and road condition (0.09). Based on the final value of the AHP, Jalan Kedungdowo-Garung Kidul is the first priority, followed by Jalan Kesambi-Jelak and Jalan Honggosoco-Margorejo. These findings provide a scientific basis for local governments to formulate road improvement strategies that are more effective, efficient, and sustainability-oriented.
KEYWORDS: *Analytic Hierarchy Process (AHP); road repair priorities; Multi-Criteria Decision Making (MCDM); Road Infrastructure; Weighting Criteria; Kudus Regency; Spatial Analysis; GIS.*

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I. INTRODUCTION

The repair and maintenance of the road network is one of the top priorities for local governments because it is directly related to community mobility, safety, and the smooth running of local economic activities. The quality of road infrastructure affects the distribution of goods and services as well as accessibility to social facilities—so the decision to allocate the budget for road improvements must be made in an integrated and priority-based manner to maximize socio-economic benefits with limited resources (Moazami, Behbahani and Muniandy, 2011).

In many regions, including districts in Indonesia, budget constraints and the number of roads that need improvement make the issue of prioritization a crucial managerial challenge. Traditional approaches that rely solely on road surface conditions or political pressure often result in less efficient decisions; therefore, a method is needed that is able to integrate technical (e.g., surface conditions, traffic), economic (cost, benefit), and social (accessibility, population density) criteria in a single decision-making framework (Ahmed, Vedagiri and Rao, 2017).

The Analytic Hierarchy Process (AHP) method developed by Saaty is one of the Multi-Criteria Decision Making (MCDM) techniques that is widely used to prioritize infrastructure problems because of its ability to combine qualitative and quantitative assessments systematically and provide reliable weight to each criterion. A systematic review of the application of AHP to transportation problems shows that AHP is effective in determining priority weights between criteria and is often combined with other techniques (e.g. Fuzzy-AHP, TOPSIS) to handle uncertainty and improve decision consistency. The use of AHP in road paving/maintenance cases has been reported in several international studies and developing country contexts (Alkharabsheh and Duleba, 2023).

However, local characteristics—such as traffic patterns, district road typology, soil geotechnical conditions, and regional development priorities—make the prioritization results location-specific. In Kudus Regency, which has a combination of small industrial centers, agricultural areas, and a dense district road network, research is needed that adapts the AHP framework with criteria and subcriteria relevant to the local context. Until now, the published literature that explicitly applies AHP for the priority of road repair on the scale of Kudus Regency is still limited, so this study fills this practical and academic gap.

The objectives of this study are (1) to formulate an AHP model that integrates technical, cost, safety, and socio-local criteria for determining the priorities of road repair in Kudus Regency; (2) determine the relative weight of the criteria and priority order of the sample road sections using expert assessments (related agencies, road engineers, community leaders); and (3) recommend budget allocation strategies and corrective actions based on the results of the prioritization. The research method will include identification of criteria through literature review and stakeholder consultation, preparation of AHP hierarchy, collection of pairwise comparisons from expert panels, weight calculation and consistency tests, as well as model application to selected road section datasets in Kudus Regency.

The expected contribution of this study is (a) the provision of a decision model that can be used by the Public Works Office and related agencies in Kudus Regency for a more transparent and evidence-based road repair budget allocation; (b) a priority list of concrete road sections as short- and medium-term planning materials; and (c) technical policy recommendations that consider the balance between cost efficiency and socio-economic impact. The results of the study can also be used as a reference for similar studies in other districts with comparable regional characteristics.

II. LITERATURE REVIEW

Multi-criteria in Prioritizing Road Maintenance

Road maintenance is a complex decision-making issue because it involves many technical, economic, social, and environmental criteria. In the transport and infrastructure management literature, the multi-criteria method (MCDM) is considered a very useful tool to help formulate road maintenance priorities. For example, (Hasan, Whyte and Aljassmi, 2024) proposed a multilevel MCDM framework to evaluate road transport system projects by involving stakeholders to weigh criteria flexibly.

In addition, (Kriswardhana *et al.*, 2025) discusses an in-depth review of the application of AHP in transportation decision-making, showing a trend that AHP is increasingly being used in the context of road infrastructure due to its ability to combine qualitative and quantitative assessments.

AHP in Prioritizing Road Maintenance

The Analytic Hierarchy Process (AHP) method has been widely applied to determine priorities in road maintenance. (Li *et al.*, 2018) uses AHP at the network-level to assign weights to factors such as pavement performance, under-road structure, traffic, road life, and road grade, and then uses those weights to determine road network maintenance priorities. Another study by (Nugraha, 1936) integrated AHP with Geographic Information Systems (GIS) to produce a spatial framework for road maintenance priorities. In the study, AHP was used to give weight to criteria such as traffic volume, road authority, strategic value, population density, type of handling, and environmental impact, then GIS visualized these priorities spatially.

Criteria for Determining Road Repair Priorities

To build a valid AHP model, the selection of criteria is essential. In a study in Padang City, (Kamil *et al.*, 2017) Identify 18 road maintenance criteria, including road conditions, types of maintenance, mobility, accessibility, road use benefits, population density, and accident rates. (Han *et al.*, 2020) In the study "Application of AHP to Road Selection" it was noted that AHP analysis can capture the structural characteristics of roads as well as contextual factors such as surrounding facilities (POI – Points of Interest) and relationships between road sections, which are very relevant when prioritizing road maintenance or rehabilitation.

Challenges and Advantages of AHP in Road Infrastructure

Although AHP is widely used, there are challenges such as inconsistencies in expert judgment and the subjectivity of paired comparisons. However, its advantages lie in its intuitive hierarchical structure and its ability to combine technical data and stakeholder opinions.(Baric and Zeljko, 2021) show in transport studies that AHP is well-suited for complex decisions because it can divide large problems into smaller components, perform pairwise comparisons, and then synthesize priority weights. Furthermore, the integration of AHP with GIS (Nugraha, 1936) offers advantages in spatial visualization and more informative and transparent resource allocation.

III. RESEARCH METHODOLOGY

Research Design

This study uses a quantitative approach with the Multi-Criteria Decision Making (MCDM) method, namely the Analytic Hierarchy Process (AHP). This approach was chosen because it is able to give priority weight to various assessment criteria, so that it can be used to determine a comprehensive road improvement strategy. The location of the study is Kudus Regency, which has a variety of road conditions and levels of density of economic activities, so it requires a systematic and objective prioritization method.

Identification of Criteria and Arrangement of AHP Hierarchy

The AHP model of this study consists of three main levels:

Level 1 – Objective: Determine the priorities of the road improvement strategy of Kudus Regency.

Level 2 – Criteria: Determined based on a literature review and consultation with experts, including:

i. Physical condition of the road (damage, IRI, cracking, rutting)
ii. Traffic volume (LHR)
iii. Repair costs
iv. Accessibility and mobility of the community
v. The strategic value of the road
vi. Population density
vii. Environmental impact

Level 3 – Alternative: Road sections that are the object of priority analysis.

These criteria and subcriteria are compiled based on the findings (Kamil *et al.*, 2017) with the adjustment of the local context of Kudus.

Data Collection

Data is obtained through:

i. Pairwise comparison questionnaire to experts, consisting of officials of the Kudus PUPR Office, road practitioners, and transportation analysts.
ii. Secondary data is in the form of data on road conditions, road classes, average daily traffic, road network maps, and socio-economic data per sub-district.

Respondents used the AHP scale (1-9) according to Saaty to assess the level of importance between the criteria.

Table 1. Paired Comparison Value Scale

Scale Values	Definition	Explanation
1	Equally important	Two equally important contributing activities
3	A little more important	Results and assessments are stronger than the other
5	More important	Results and ratings are stronger than the other
7	Very important	Stronger and dominating activity
9	Absolutely more important	The condition of one activity is highest than the other
2, 4, 6, 8	The value between two adjacent opinions	Conditions when compromise is required
Resiprocal	If activity i has the above value that is used to compare activity j, then j is a reciprocal value when compared to i	
Rational	Comparison of value increases from scale	If consistency is in the condition, it is forced to obtain a value n on the matrix

Data Analysis Using AHP

The stages of AHP analysis include:

i. Create a paired comparison matrix for all criteria.

$$Mark = \frac{Row\ Value}{the\ amount\ of\ each} \tag{1}$$

ii. Calculate the local priority weight using the eigenvector method.

$$X = \sqrt[n]{a1 + a2 + a3 + \cdots + an} \tag{2}$$

Calculate *the maximum* eigenvalue using

$$\lambda_{maks} = (w_1 x\ C_1) + (w_2 x\ C_2) + \ldots. + \quad (3) (w_n x\ C_n)$$

where =

w = *own vector*

C_1 = number of columns i–i of the comparison matrix,

n = number of elements

iii. Check the consistency of the matrix using the Consistency Ratio (CR), which should be less than 0.1.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

where =

CI = Consistency Index

λ_{max} = Greatest eigenvalue

n = Number of criteria

The results of the consistency index test are used to test the consistency ratio. Consistency ratio testing can be done using the equation:

$$CR = \frac{CI}{RI} \quad (5)$$

where, =

CR = *Consistency Ratio*

CI = *Consistency Index*

RI = *Rasio Index*

iv. Calculates the global weight of a combination of criteria and subcriteria weights.
v. Assess alternative road sections based on the weight of the criteria.
vi. Determine the final priority of the road section.

This approach follows the structure of the applied analysis (Li *et al.*, 2018) in the AHP study of infrastructure.

IV. RESULTS AND DISCUSSION

Based on the classification of road condition components, an assessment was carried out on 14 road sections whose results are described in this section. To make it easier for readers to understand, the discussion began with a visual presentation of each road section. Overall, the condition of the 14 road sections varies, ranging from the category of severely damaged to good condition. However, some road sections still require more intensive repair efforts to maintain or improve their quality to achieve optimal conditions.

In the early stages of the study, data was collected through the distribution of questionnaires to the respondents. After that, data processing was carried out using a geometric average assessment scale (geomean) to calculate the results of the assessment of 7 respondents on the main criteria and subcriteria determined. This calculation aims to obtain a score that represents each criterion based on the collective views of the respondents. The results of the geometric mean calculation are presented in full in Table 2, Table 3, Table 4, Table 5, and Table 6.

Table 2. Recapitulation of the Assessment of the Main Criteria

Criterion	Geomean	Criterion
Cost	1,38	Technical
Cost	0,24	Road Conditions
Cost	1,99	Milieu
Technical	0,37	Road Conditions
Technical	1,06	Milieu
Road Conditions	3,04	Milieu

Table 3. Recapitulation of the Assessment of Technical Criteria

Criterion	Geomean	Criterion
Flexible Pavement	0,22	Rigid Pavement

Table 4. Recapitulation of Cost Criteria Assessment

Criterion	Geomean	Criterion
Very Expensive	0,86	Expensive
Very Expensive	0,48	Keep
Very Expensive	0,40	Cheap
Expensive	0,75	Keep
Expensive	0,35	Cheap
Keep	0,64	Cheap

Table 5. Recapitulation of Environmental Criteria Assessment

Criterion	Geo mean	Criterion
Residential Areas	1,40	Industry
Residential Areas	1,60	Business/Trade
Residential Areas	5,23	Agriculture
Industry	0,91	Business/ Trade
Industry	1,83	Petanian
Business/Trade	3,50	Petanian

Table 6. Recapitulation of Road Condition Criteria Assessment

Criterion	Geomean	Criterion
Destroyed	1,90	Very Severe
Destroyed	0,96	Severe
Destroyed	1,81	Ugly
Destroyed	1,63	Keep
Destroyed	1,81	Good
Destroyed	1,48	Excellent
Very Severe	0,85	Severe
Very Severe	1,49	Ugly
Very Severe	1,34	Keep
Very Severe	1,81	Good
Very Severe	1,81	Excellent
Severe	0,96	Ugly
Severe	1,30	Keep
Severe	1,44	Good
Severe	2,43	Excellent
Ugly	1,46	Keep
Ugly	1,78	Good
Ugly	1,66	Excellent
Keep	1,83	Good
Moderate Conditions	1,38	Excellent
Good	1,18	Excellent

The analysis began by processing the data from the respondents' assessment of all the criteria that were the focus of the research. The weight of each criterion is determined through the preparation of a pairwise comparison matrix, where preferences between criteria are assessed based on the level of relative importance according to respondents. After that, the weights are calculated using the inverse method, which is a standard procedure in the Analytic Network Process to maintain logical consistency in the provision of comparative values. The results of the calculation are shown in Table 7.

Table 7. Key Criteria Matrix

	A	**B**	**C**	**D**
A	1	0,72	4,23	0,50
B	1,38	1	2,72	0,95
C	0,24	0,37	1	0,33
D	1,99	1,06	3,04	1
Sum	**4,61**	**3,15**	**10,99**	**2,78**

Furthermore, the calculation process for the subcriteria is carried out by following the same procedure as in the assessment of the main criteria. The next stage is the calculation of the priority vector or *eigen vector*, in which a paired comparison matrix is processed to obtain the priority vector value of each parameter. This priority vector value is then used in determining the maximum λ value. The procedure for calculating the priority vector is explained through equation (3), while the calculation results are presented in Table 8.

Table 8. Eigenvector value of makasimum and consistency of the main criteria

	A	B	C	D	Sum	E-Vector	Matrix x Priority	Consistency
A	0,22	0,23	0,38	0,18	1,01	0,25	1,05	4,14
B	0,30	0,32	0,25	0,34	1,21	0,30	1,24	4,11
C	0,05	0,12	0,09	0,12	0,38	0,09	0,38	4,03
D	0,43	0,34	0,28	0,36	1,41	0,35	1,46	4,16
							λ max =	**4,11**

The calculation of the maximum eigenvector value and the consistency test for the subcriteria was carried out by following the same steps as in the assessment of the main criteria. The maximum eigenvalue is obtained by multiplying the initial matrix by the priority vector (E-Vector) of each matrix, then adding the multiplication result. This process is shown in the following:

Consistency test

$$CI = \frac{4{,}11-4}{4-1} \tag{6}$$

= 0,037

Consistency ratio test

$$CR = \frac{0{,}037}{0{,}89} \tag{7}$$

$= 0.041 \leq 0.1$ ***(Consistent)***

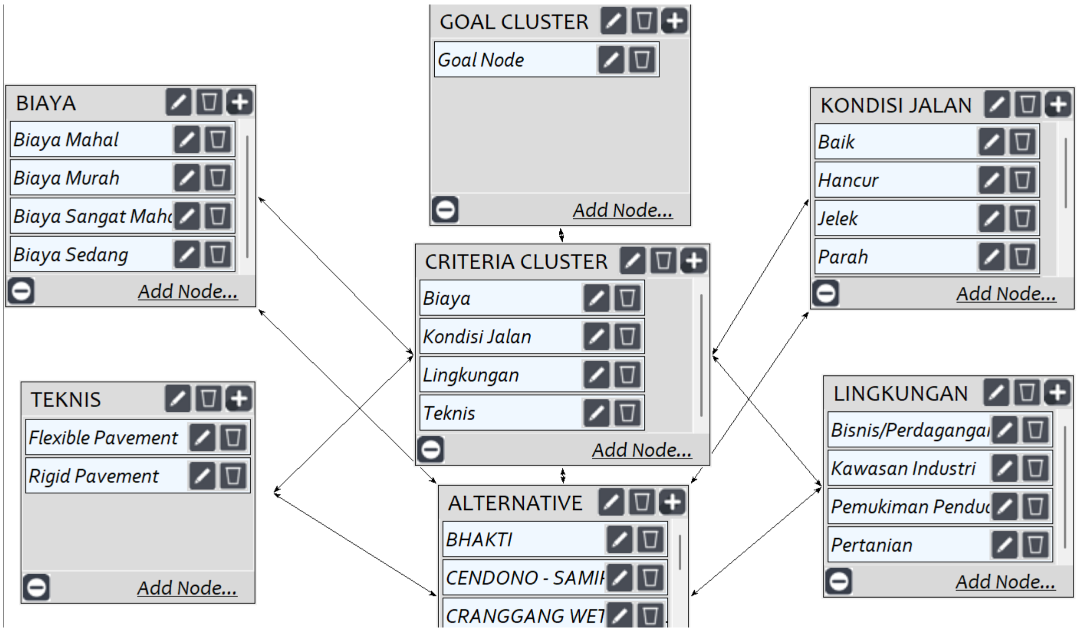
The weight of the criteria and subcriteria can then be summarized in Table 9.

Table 9. Priority Scale Hierarchy

Purpose	Main Criteria	Subkriteria
Priority	Cost (A) (0.25)	Very Expensive (a1) (0.37)
		Expensive (a2) (0.32)
		Medium (a3) (0.17)
		Cheap (a4) (0.13)
	Technical (B) (0.30)	Flexible Pavement (b1) (0,82)
		Rigid Pavement (b2) (0,18)
		Crushed (c1) (0.10)
		Very Severe (c2) (0.12)

	Road Condition (C) (0.09)	Severe (c3) (0.11)
		Ugly (c4) (0.13)
		Medium (c5) (0.15)
		Good (c6) (0.20)
		Excellent (c7) (0.21)
	Environment (D) (0.35)	Population Settlements (d1) (0.12)
		Industry (d2) (0.21)
		Business/Commerce (d3) (0.17)
		Agricultural Areas (d4) (0.51)

The Analytic Hierarchy Process (AHP) method used in this study is compiled based on four main criteria that are set as the basis for the decision-making process. The structure of the relationship between criteria, subcriteria, and alternatives is described through the AHP hierarchical model which shows the levels of analysis and systematic assessment flows. The hierarchical representation is generated using Super Decisions software to make it easier to structure and analyze pembobotan pada setiap elemen. Overall, the shape and arrangement of the AHP hierarchical model are shown in Figure 1.



Picture 1. AHP Network Model Dependencies

Berdasarkan hasil analisis menggunakan metode Analytic Hierarchy Process (AHP), diperoleh urutan prioritas perbaikan jalan pada setiap alternatif. Hasil tersebut ditampilkan secara rinci pada Tabel 10, yang menunjukkan bobot prioritas masing-masing alternatif berdasarkan perhitungan serta evaluasi terhadap kriteria dalam struktur hierarki.

Table 10. Priority Scale Order of Road Repair Using the ANP Method

No.	**Road Sections**	**Order of Priorials**	**AHP Score**
1	Jalan Kedungdowo - Garung Kidul	1	0,110
2	Jalan Kesambi - Jelak	2	0,094
3	Jalan Pohdengkol - Nosari	4	0,077
4	Jalan Honggosoco - Margorejo	3	0,079
5	Jalan Pelanggading - Rejosari	5	0,071
6	Jalan Cendono - Samirejo Kab. Kudus	12	0,060

7	Jalan Puyoh - Bonajar - Soco	7	0,069
8	Jalan Cranggang Wetan - Kuwukan	6	0,070
9	Jalan Mayor Kusmanto	8	0,064
10	Jalan Subchan Ze	11	0,062
11	Jalan Kandangmas - Cranggang Wetan	9	0,063
12	Jalan Bhakti	10	0,063
13	Jalan Gebog - Menawan	13	0,059
14	Jalan Umk - Gondangmanis	14	0,059

Based on the results of the analysis using the Analytic Hierarchy Process (AHP) method which involves four assessment functions in the priority formulation process, a sequence of recommendations for road sections that are the main priorities for improvement is obtained. The modeling results show that Jalan Kedungdowo – Garung Kidul ranks first, considering that the need for improvement on the section can be met with a relatively low budget allocation. In second position, Jalan Kesambi – Jelak also emerged as a priority with the category of cheap budget needs. Meanwhile, Jalan Honggosoco - Margorejo is ranked third, which is both included in the group of sections with low repair cost needs.

These findings show that the environmental aspect has the greatest influence on the process of weighting criteria compared to other parameters. With the highest weight obtained, environmental factors are seen as a strategic element in determining the level of urgency of road repairs, especially in relation to sustainability and efforts to reduce negative impacts on the surrounding area.

Overall, the ranking results for all 14 analyzed roads are presented in Table 10, which contains the distribution of improvement priorities based on the final value of the AHP method synthesis. The results of these priorities are expected to be a basis for consideration for local governments in formulating budget allocation policies that are more targeted and support the improvement of the quality of road infrastructure services.

V. CONCLUSION

This study confirms that the use of the Analytic Hierarchy Process (AHP) method is an effective approach in determining the priorities for road repair in Kudus Regency. The AHP method was chosen because it is able to simplify the decision-making process through weighting criteria in a structured and systematic manner. Meanwhile, integration with GIS provides spatial analysis capabilities that allow for more comprehensive and location-based mapping of road conditions.

The results of the analysis showed that the environmental criteria had the highest weight, which was 0.35, followed by the technical aspect of 0.30, cost of 0.25, and road condition of 0.09. The magnitude of the weight on environmental parameters indicates that any road improvement plan must consider its potential impact on the surrounding area, in line with the principles of sustainable infrastructure development. Based on the results of AHP's ranking of the 14 roads studied, Jalan Kedungdowo-Garung Kidul is a top priority, considering the condition of the sections that have suffered significant damage and relatively low budget needs. The next priority is Jalan Kesambi-Jelak and Jalan Honggosoco - Margorejo, which have similar characteristics to Jalan Kedungdowo-Garung Kidul, which require immediate repairs at a not large cost.

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