Prioritizing Provincial Road Maintenance in Bali Using a Combination of PKRMS and AHP

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ABSTRACT

Budget constraints in Bali Province prevent the accommodation of all road maintenance needs in the annual program. While the Provincial/Kabupaten Road Management System (PKRMS) is commonly used, it lacks systematic integration of non-technical criteria. Conversely, the Analytical Hierarchy Process (AHP) relies heavily on expert judgment. The novelty of this study lies in the development of an integrated prioritization model that combines technical indicators from the PKRMS application with non-technical strategic criteria derived from the AHP method within a unified decision-making framework. This study aims to develop a hierarchical structure, determine criteria weights, establish a prioritization model, and compare priority rankings generated by the AHP method, the PKRMS application, the combination of PKRMS and AHP, and the 2025 maintenance program realization. The study was conducted on 101 provincial road sections in Bali Province involving 24 expert respondents. The analysis integrated technical and non-technical criteria obtained from AHP with the Triggered Priority Index (TPI) values generated by PKRMS. The results showed that non-technical criteria were more dominant (71%) than technical criteria (29%). The mathematical model obtained was Y = 22A1 + 7A2 + 23B1 + 10B2 + 21B3 + 17B4, where A1 represented road condition, A2 traffic volume, B1 connectivity, B2 zone development, B3 primary road network, and B4 social services accessibility. Comparison with the 2025 program showed that the combination of PKRMS and AHP achieved the highest conformity (75.00%). Therefore, this model is considered more objective and representative in supporting road maintenance priority determination.

Keywords: maintenance, priority, PKRMS, TPI, AHP.

INTRODUCTION

Provincial roads play a strategic role in supporting community mobility, logistics distribution, and interregional connectivity within Bali Province. Road maintenance programming involves the formulation of maintenance, rehabilitation, and improvement plans aligned with infrastructure performance targets and available fiscal capacity [11]. These programs should ideally be implemented based on asset preservation principles to maintain service levels throughout the infrastructure life cycle [5]. However, budget limitations remain a persistent challenge in road infrastructure management, often resulting in the inability to fully accommodate maintenance needs within annual programs [2]. Consequently, an objective, systematic, and measurable prioritization system is required to ensure that limited regional budgets are allocated effectively and efficiently.

Previous studies have applied various approaches in determining road maintenance priorities. Several researchers have implemented the Analytical Hierarchy Process (AHP) method to support decision-making involving multiple criteria and expert judgment. This approach can structure complex decision problems, however the resulting weights are still influenced by respondent subjectivity [13]. Other studies have utilized the Provincial/Kabupaten Road Management System (PKRMS) application to evaluate road conditions and determine maintenance priorities based on the Triggered Priority Index (TPI), which is derived from technical road performance indicators [3]. In addition, conventional prioritization strategies such as the worst-first approach have also been widely applied in road maintenance planning. Although this approach prioritizes road sections with the highest level of deterioration, it is often considered less efficient for long-term asset preservation

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compared with preventive maintenance strategies [4]. In practice, the implementation of PKRMS in Bali Province has predominantly focused on road asset inventory and technical condition evaluation, while non-technical strategic factors have not been systematically incorporated.

Based on these conditions, this study addresses the existing gap by integrating technical and non-technical criteria in road maintenance prioritization through a combination of the PKRMS application and the AHP method. The novelty of this study lies in the development of an integrated prioritization model that combines PKRMS based technical indicators with AHP derived non-technical strategic criteria through the adjustment of Multi Criteria Analysis (MCA) weights. This integration enables the prioritization process to not only reflect physical road conditions but also represent connectivity, zone development, primary road network, and social service accessibility [7]. Therefore, this study aims to: (1) develop a hierarchical decision structure for road maintenance prioritization; (2) determine the weight of each criterion using the AHP method; (3) formulate a mathematical prioritization model through the combination of PKRMS and AHP; (4) establish a maintenance priority scale; and (5) compare the prioritization results obtained from the AHP method, PKRMS application, the combination of PKRMS and AHP model, and the realization of the 2025 road maintenance program. The results of this study are expected to provide a more objective, transparent, and effective decision-making framework for road infrastructure management in Bali Province.

RESEARCH METHODS

Materials

This study was conducted on the provincial road network in Bali Province, which consists of nine regencies and cities. The research scope comprised 101 road sections with a total cumulative length of 805.35 km [9].



Figure 1. Provincial Road Network Map in Bali Province [10]

The study utilized both primary and secondary data. Primary data consisted of pairwise comparisons regarding the relative importance of criteria and subcriteria, obtained through structured interviews based on experts' judgment. Using a purposive sampling method, 24 expert respondents were selected based on their professional expertise and direct experience in road infrastructure. The respondent panel comprised representatives from local government, legislative bodies, regional planners, consultants, contractors, and road users. Complementary secondary data were gathered from authorized institutions, specifically regarding the Bali Province road network data, spatial planning maps, road condition reports, the Treatment Trigger Index (TTI), and Average Daily Traffic (ADT) data. The systematic research workflow is illustrated in Figure 2.

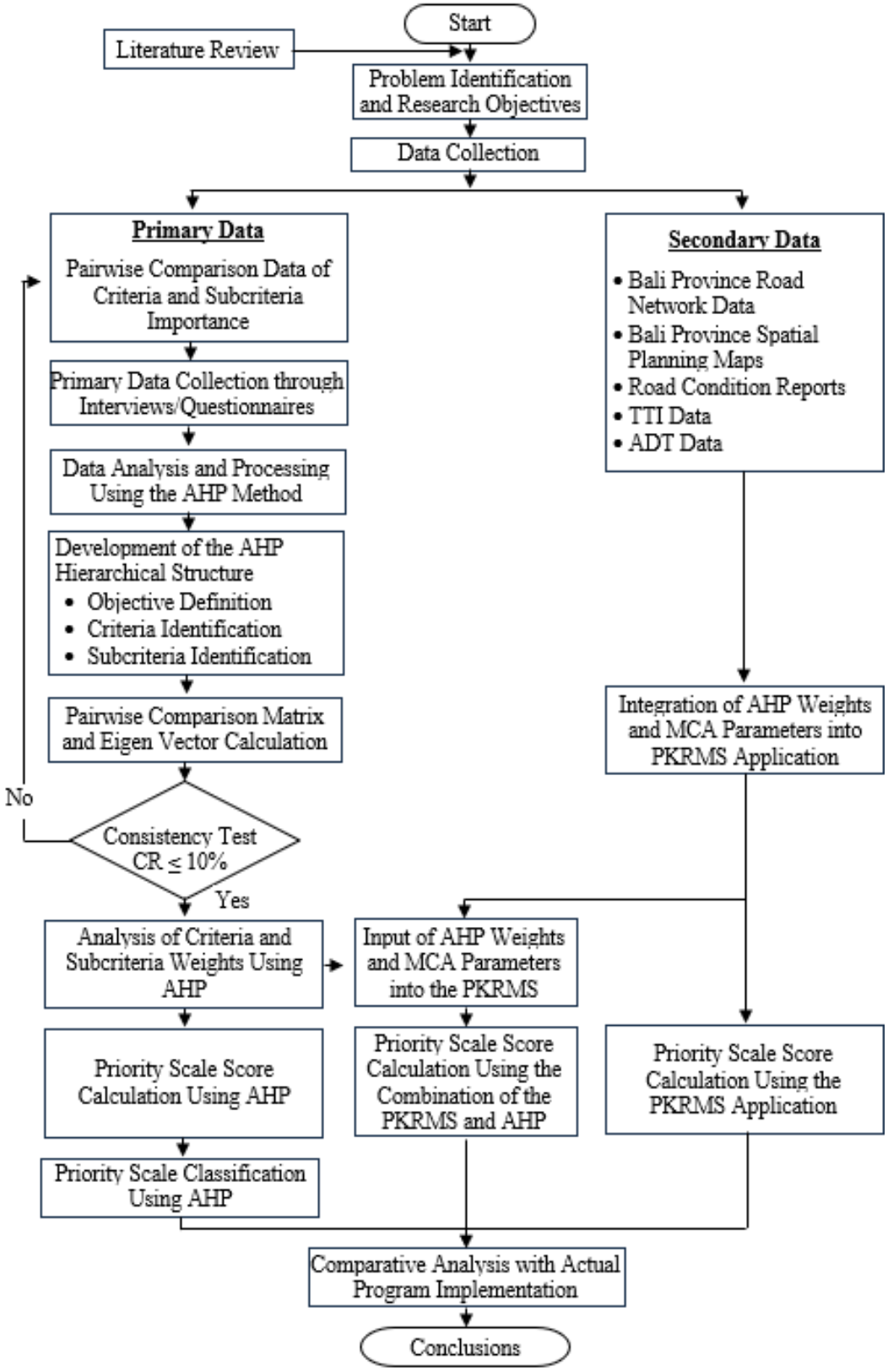


Figure 2. Flow chart

Methods

This study employed three analytical approaches, namely the AHP method, the PKRMS application, and the combination of PKRMS and AHP, to determine maintenance priorities for provincial road sections in Bali.

1. AHP Analysis
   The AHP method was utilized to determine the relative weight of each criterion and subcriterion based on expert judgment [13]. The analysis was executed through the following systematic stages:
   a. Development of the Hierarchical Structure
      The initial stage involved constructing a decision hierarchy derived from a comprehensive literature review and field observations. The structure was organized into three distinct levels:

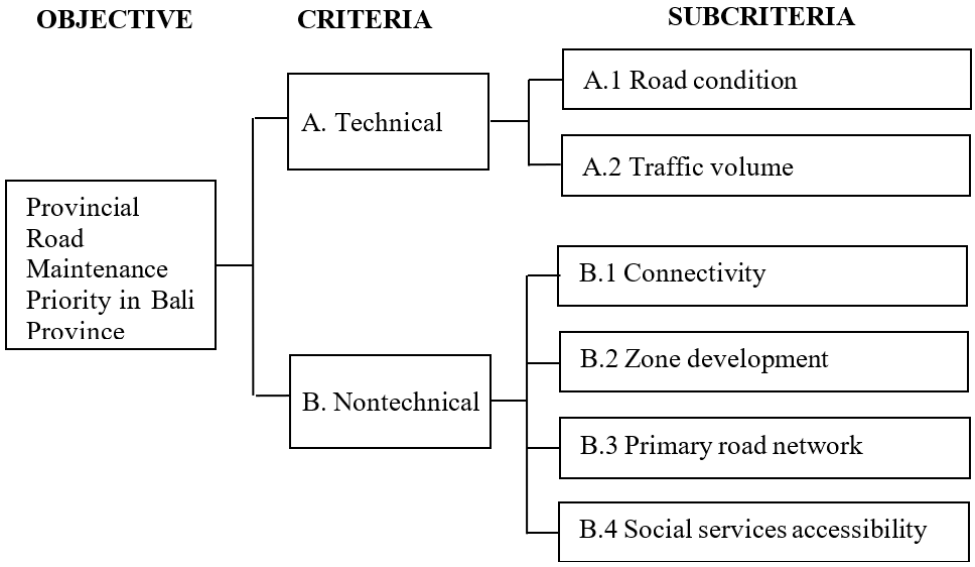


Figure 3. AHP Hierarchical Structure

Road maintenance priorities are determined based on technical and non-technical criteria. The technical criteria encompass road condition, which assesses the severity of pavement deterioration, and traffic volume, which reflects usage intensity based on Average Daily Traffic (ADT). The non-technical criteria include connectivity, which reflects the linkage of road sections to transportation nodes [8], regional development, which describes the role of roads in supporting strategic areas in accordance with spatial planning policies [10], primary road network, which indicates the function of road sections as connecting corridors between activity centers [12], and social services accessibility, which represents accessibility to public service facilities.

   b. Pairwise comparison matrix development
      Pairwise comparisons between criteria were conducted using Saaty's fundamental scale, ranging from 1 (equal importance) to 9 (extreme importance) [13]. This process quantifies the relative weight of each element within the decision hierarchy.
   c. Aggregation of expert judgments
      Given the involvement of multiple expert respondents, individual judgments were consolidated into a single representative value using the Geometric Mean (GM) method [6]. This method is preferred in AHP to maintain the reciprocity of the comparison matrix. The Geometric Mean is calculated as follows:

$$GM = \sqrt[n]{\prod_{i=1}^{n} Xi} \quad (1)$$

where:
GM : Geometric mean
Xi : Judgment of the i-th respondent
n : Number of respondents

d. Priority weight calculation (eigen vector)
Priority weights were determined using the geometric mean method to establish raw weights for each element [13]:

$$Wi = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \quad (2)$$

The priority weights were then normalized to obtain the final relative importance (Xi):

$$Xi = \frac{W_i}{\sum W_i} \quad (3)$$

where:
Wi : Geometric value of the i-th element
a_{ij} : Comparison matrix element (row i, column j)
n : Number of compared elements
Xi : Normalized priority weight of the i-th element

e. Maximum eigen value calculation
The maximum eigen value (λmax) was calculated to assess the consistency of the comparison matrix [13]:
λmax = Σ aij.Xj (4)

f. Consistency test
To ensure the reliability of the expert judgments, the Consistency Index (CI) was calculated [13]:

$$CI = \frac{\lambda maks - n}{n - 1} \quad (5)$$

The Consistency Ratio (CR) was then determined by comparing the Consistency Index (CI) with a Random Index (RI):

$$CR = \frac{CI}{RI} \leq 0.1\ (OK) \quad (6)$$

The comparison matrix was considered valid and consistent if the CR ≤ 0.10.

g. Determination of road maintenance priority scale
The priority value of each road section was calculated using the following mathematical model [1]:

$$Y = A(a_1 \times w_{a1} + \cdots + a_i \times w_{ai}) + \cdots + D(d_1 \times w_{d1} + \cdots + d_i \times w_{di}) \quad (7)$$

where:
Y : Priority scale of the evaluated road maintenance
A to D : Criteria weights derived from expert judgment analysis
$a_1, a_2, \ldots a_i$: Subcriteria weights derived from expert judgment analysis
$w_{a1}, w_{a2}, \ldots .. w_{a3}$: Alternative weights (based on data analysis)

2. PKRMS Analysis
The initial analysis using the PKRMS application was conducted based on technical parameters, including road condition and traffic volume. In this stage, data was processed within the PKRMS framework without incorporating Multi Criteria Analysis (MCA) adjustments. The primary output was the Triggered Priority Index (TPI), where a higher TPI value signifies a higher urgency for road maintenance [3].

3. Combination of PKRMS and AHP Analysis
The combination of PKRMS and AHP analysis was conducted by integrating technical parameters from the PKRMS with non-technical parameters obtained from the AHP weighting results. The AHP derived weights for criteria and subcriteria were systematically embedded into

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the MCA module of the PKRMS application [7]. This integration generated a comprehensive TPI value that balances technical data with regional development needs and social connectivity, resulting in a more comprehensive priority ranking [3].

Data Analysis

The results of the road section maintenance priority analysis obtained from the AHP method, the PKRMS application, and the combination of PKRMS and AHP analysis were subsequently compared with the realization of the provincial road maintenance program in Bali Province for the 2025 fiscal year. The analysis was conducted by evaluating the level of conformity between the priority ranking generated by each method and the actual program implementation in the field, thereby identifying the most representative approach in supporting decision-making for road maintenance.

RESULT AND DISCUSSION

The prioritization of provincial road maintenance in Bali was established through an AHP hierarchical structure comprising the primary objective, two main criteria, and six subcriteria. The weighted distribution of these elements is summarized in Table 1. The results of the aggregated pairwise comparison matrix indicate that non-technical criteria exert a more dominant influence on the model, accounting for 71% of the total weight, while technical criteria contribute 29%. Among the specific subcriteria, connectivity achieved the highest relative weight at 23%, followed closely by road condition 22% and the primary road network 21%. Other factors, such as social services accessibility 17%, zone development 10%, and traffic volume 7%, played a comparatively smaller yet significant role in the overall prioritization framework.

Table 1. Weighting Distribution of Road Maintenance Criteria and Subcriteria

Code	Criteria Description	Criteria Weight (%)	Subcriteria Code	Subcriteria Description	Subcriteria Weight (%)
A	Technical	29	A1	Road condition	22
			A2	Traffic volume	7
B	Non-technical	71	B1	Connectivity	23
			B2	Zone development	10
			B3	Primary road network	21
			B4	Social services accessibility	17
	Total	100			100

The consistency test yielded a Consistency Ratio (CR) of 0.012, which is well below the maximum threshold of 0.10. This result confirms that the expert judgments were consistent and reliable for further AHP based analysis [13]. Notably, the findings of this study contrast with previous research conducted within the same region [15], which emphasized the dominance of technical parameters in road prioritization. The shift toward non-technical dominance in this study suggests that current prioritization frameworks are increasingly influenced by the strategic role of road infrastructure. Beyond mere physical condition, the model highlights the critical importance of roads in supporting connectivity, zone development, primary road networks, and social services accessibility.

Based on weights derived from AHP analysis, a mathematical model was formulated to calculate the priority score (Y) for road maintenance sections. This model is expressed as $Y = 22A1 + 7A2 + 23B1 + 10B2 + 21B3 + 17B4$, where A1 represents road condition, A2 traffic volume, B1 connectivity, B2 zone development, B3 primary road network, and B4 social services accessibility. To demonstrate the application of this model, a simulation of the priority calculations for selected road sections is provided in Table 2.

Table 2. Road Maintenance Priority Score Derived from the AHP Method

No.	Road Section Name	Total Score
1	Tegaltamu – Payangan – Baturanyar	70.529
2	Bts. Kota Amlapura – Seraya – Culik	63.266
3	Simp. Br. Abian Base – Tuban	62.643
4	Teges – Tegallalang – Bayung Gede	62.428
5	Rendang – Bts. Kota Amlapura	62.065
6	Denpasar – Simp. Tohpati	56.863
7	Sp. Kargo – Sp. Imam Bonjol (Denpasar)	52.498
8	Denpasar – Sanur	51.039
9	Paksebali – Selat	50.575
10	Jln. Udayana – Hassanudin (Dps)	46.651
11	Pupuan – Seririt	46.242
12	Wanagiri – Munduk – Mayong	45.557
13	Baturanyar – Tajun – Kubutambahan	45.172
14	Ketewel – Sukawati	44.143
15	Simp. TL. Nitimandala – Sp. Imam Bonjol	44.083
16	Sidan – Bts. Kota Bangli	43.390
17	Jln. Gunung Agung – Gunung Sanghyang (Denpasar)	42.601
18	Bts. Kota Negara – Cupel - Banyubiru	42.439
19	Gempol – Banyuning – Penarukan (Sgr)	42.211
20	Jln. Rama (Semarapura)	41.929
21	Jln. Kusanegara (Klungkung)	41.503

Road maintenance prioritization using PKRMS was based on technical parameters, specifically pavement condition and traffic volume. These factors were quantified through the Triggered Priority Index (TPI). The analysis revealed significant variations in priority rankings across the evaluated road sections, as summarized in Table 3. The results identify the Ketewel–Sukawati road section as the highest priority, achieving a TPI value of 103.616. This elevated index signifies a higher urgency for maintenance relative to other segments, driven by the critical intersection of severe pavement deterioration and high intensity average daily traffic. Such findings underscore the sensitivity of the TPI to technical distress levels and traffic load requirements within the PKRMS framework.

Table 3. Road Maintenance Priority Rankings Calculated from the PKRMS Application

No.	Road Section Name	TPI Value
1	Ketewel – Sukawati	103.616
2	Tampaksiring – Tegallalang	101.249
3	Paksebali – Selat	101.083
4	Abianbase – Lebih (Gianyar)	69.823
5	Simp. Kediri – Kapten Tendean – Bts. Kediri (Tabanan)	68.461
6	Bts. Kota Bangli – Kayuambua	67.741
7	Rendang – Bts. Kota Amlapura	67.446
8	Teges – Tegallalang – Bayung Gede	53.421
9	Simp. Sekardadi – Simp. Bayung Gede	49.710
10	Simp. Lateng – Madenan – Bondalem	48.329
11	Tegaltamu – Payangan – Baturanyar	47.161
12	Bts. Kediri – Tanah Lot	46.187
13	Batusesa – Besakih	44.260
14	Bts. Kota Amlapura – Seraya – Culik	41.283
15	Simp. Penelokan – Suter – Besakih	35.077
16	Pempatan – Ban	33.028
17	Bts. Kediri – Belayu – Mengwi	32.077
18	Baturanyar – Tajun – Kubutambahan	30.286
19	Simp. Petang – Simp. Kintamani	29.835
20	Gempol – Banyuning – Penarukan (Sgr)	26.822

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No.	Road Section Name	TPI Value
21	Simp. Rambutsiwi – Pura Rambutsiwi	25.888

These findings demonstrate that while the PKRMS application effectively identifies road maintenance requirements through objective technical parameters, its scope remains primarily limited to pavement integrity and traffic volume. Consequently, the standalone PKRMS framework does not fully account for essential non-technical dimensions, such as regional connectivity, strategic network functions, and the socio-economic impact on public services and regional development.

To bridge this gap, the combination of PKRMS and AHP analysis was executed utilizing the Multi Criteria Analysis (MCA) module. This approach synthesized technical robustness with the strategic weighting derived from the AHP process. The comprehensive priority results from this integrated model are detailed in Table 4. A comparative review of the output reveals significant shifts in the priority rankings for several road segments. Specifically, sections that serve critical strategic functions in facilitating interregional connectivity moved to higher priority positions, despite having moderate technical distress. This indicates that the combination of PKRMS and AHP analysis successfully reconciles physical engineering needs with regional policy objectives and social connectivity requirements.

Table 4. Road Maintenance Priority Rankings Based on the Combination PKRMS and AHP

No.	Road Section Name	TPI Value
1	Ketewel – Sukawati	159.740
2	Tampaksiring – Tegallalang	152.362
3	Paksebali – Selat	148.609
4	Rendang – Bts. Kota Amlapura	115.115
5	Simp. Kediri – Kapten Tendean – Bts. Kediri (Tabanan)	111.063
6	Abianbase – Lebih (Gianyar)	95.160
7	Bts. Kota Bangli – Kayuambua	91.221
8	Teges – Tegallalang – Bayung Gede	90.438
9	Tegaltamu – Payangan – Baturanyar	83.035
10	Simp. Sekardadi – Simp. Bayung Gede	71.436
11	Bts. Kota Amlapura – Seraya – Culik	69.750
12	Simp. Lateng – Madenan – Bondalem	61.823
13	Simp. Penelokan – Suter – Besakih	49.422
14	Bts. Kediri – Tanah Lot	48.862
15	Pempatan – Ban	46.033
16	Wanagiri – Munduk – Mayong	45.056
17	Batusesa – Besakih	42.025
18	Bts. Kediri – Belayu – Mengwi	41.756
19	Simp. Rambutsiwi – Pura Rambutsiwi	39.046
20	Gempol – Banyuning – Penarukan (Sgr)	35.814
21	Baturanyar – Tajun – Kubutambahan	35.607

The research findings demonstrate that the combination of PKRMS and AHP approach yields a more comprehensive prioritization framework compared to the standalone use of the PKRMS application. This combination of PKRMS and AHP analysis effectively identifies road segments with strategic roles within the regional transportation network, even those that do not technically exhibit the highest levels of deterioration.

To evaluate model alignment with actual policy, resulting rankings were compared against road maintenance program realization as documented in the 2025 Fiscal Year Budget Implementation

Document. According to the program records, 12 provincial road sections received maintenance in 2025. The comparative results, summarized in Table 5, indicate that the AHP method achieved a conformity level of 58.33% (7 road sections), the standalone PKRMS application reached 66.67% (8 road sections), while the combination of PKRMS and AHP approach demonstrated the highest conformity at 75.00% (9 road sections).

Table 5. Conformity Analysis Between Prioritization Models and Actual Implementation

No.	AHP Method	The PKRMS Application	Combination PKRMS and AHP	Program Implementation
1	Tegaltamu – Payangan – Baturanyar	Ketewel – Sukawati	Ketewel – Sukawati	Tampaksiring - Tegallalang
2	Bts. Kota Amlapura – Seraya – Culik	Tampaksiring – Tegallalang	Tampaksiring – Tegallalang	Ketewel - Sukawati
3	Simp. Br. Abian Base – Tuban	Paksebali – Selat	Paksebali – Selat	Rendang - Bts. Kota Amlapura
4	Teges – Tegallalang – Bayung Gede	Abianbase – Lebih (Gianyar)	Rendang – Bts. Kota Amlapura	Bts. Kediri - Tanah Lot
5	Rendang – Bts. Kota Amlapura	Simp. Kediri – Kapten Tendean – Bts. Kediri (Tabanan)	Simp. Kediri – Kapten Tendean – Bts. Kediri (Tabanan)	Tegaltamu - Payangan - Baturanyar
6	Denpasar – Simp. Tohpati	Bts. Kota Bangli – Kayuambua	Abianbase – Lebih (Gianyar)	Bts. Kota Amlapura - Seraya - Culik
7	Sp. Kargo – Sp. Imam Bonjol (Denpasar)	Rendang – Bts. Kota Amlapura	Bts. Kota Bangli – Kayuambua	Pempatan - Ban
8	Denpasar – Sanur	Teges – Tegallalang – Bayung Gede	Teges – Tegallalang – Bayung Gede	Wanagiri - Munduk - Mayong
9	Paksebali – Selat	Simp. Sekardadi – Simp. Bayung Gede	Tegaltamu – Payangan – Baturanyar	Jln. Udayana - Hassanudin (Dps)
10	Jln. Udayana – Hassanudin (Dps)	Simp. Lateng – Madenan – Bondalem	Bts. Kota Amlapura – Seraya – Culik	Sp. Kargo - Sp. Imam Bonjol (Denpasar)
11	Pupuan – Seririt	Tegaltamu – Payangan – Baturanyar	Simp. Sekardadi – Simp. Bayung Gede	Jln. Setiabudi - Wahidin (Dps)
12	Wanagiri – Munduk – Mayong	Bts. Kediri – Tanah Lot	Simp. Lateng – Madenan – Bondalem	Buruan - Gianyar
13	Baturanyar – Tajun – Kubutambahan	Batusesa – Besakih	Simp. Penelokan – Suter – Besakih	
14	Ketewel – Sukawati	Bts. Kota Amlapura – Seraya – Culik	Bts. Kediri – Tanah Lot	
15	Simp. TL. Nitimandala – Sp. Imam Bonjol	Simp. Penelokan – Suter – Besakih	Pempatan – Ban	
16	Sidan – Bts. Kota Bangli	Pempatan – Ban	Wanagiri – Munduk – Mayong	
17	Jln. Gunung Agung – Gunung Sanghyang (Denpasar)	Bts. Kediri – Belayu – Mengwi	Batusesa – Besakih	
18	Bts. Kota Negara – Cupel - Banyubiru	Wanagiri – Munduk – Mayong	Bts. Kediri – Belayu – Mengwi	
19	Gempol – Banyuning – Penarukan (Sgr)	Simp. Petang – Simp. Kintamani	Simp. Rambutsiwi – Pura Rambutsiwi	
20	Jln. Rama (Semarapura)	Gempol – Banyuning – Penarukan (Sgr)	Jln. Udayana – Hassanudin (Dps)	

No.	AHP Method	The PKRMS Application	Combination PKRMS and AHP	Program Implementation
21	Jln. Kusanegara (Klungkung)	Simp. Rambutsiwi – Pura Rambutsiwi	Gempol – Banyuning – Penarukan (Sgr)	

These findings confirm that the combination of PKRMS and AHP provides a more representative and policy-oriented framework for provincial road maintenance prioritization compared with standalone technical or expert based approaches.

CONCLUSION

Based on the analysis of provincial road maintenance prioritization in Bali Province, the Analytical Hierarchy Process (AHP) method indicates that non-technical criteria exert a greater influence than technical criteria. The prioritization is driven by technical criteria (29%), comprising road condition (22%) and traffic volume (7%), and non-technical criteria (71%), which include connectivity (23%), the primary road network (21%), social services accessibility (17%), and zone development (10%). Based on the AHP analysis, the Tegaltamu–Payangan–Baturanyar road section obtained the highest priority score of 70.529. The analysis using the Provincial/Kabupaten Road Management System (PKRMS) application identified the Ketewel–Sukawati road section as the highest maintenance priority, with a Triggered Priority Index (TPI) value of 103.616. Similarly, the combination of PKRMS and AHP models generated the highest TPI value of 159.740 for the same road section. Comparative validation against the realization of the 2025 provincial road maintenance program showed that this combination model achieved the highest conformity level of 75.00%, outperforming the standalone PKRMS application (66.67%) and the AHP method (58.33%). The novelty of this study lies in the combination of PKRMS-based technical assessment with AHP-derived strategic non-technical criteria. This combination model provides a more representative, objective, and applicable framework for supporting planning and decision-making in provincial road infrastructure maintenance.

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