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GIS-Based Comparative Analysis of Pavement Damage Using PCI and Bina Marga Methods

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ABSTRACT

Pavement damage directly impacts road performance, particularly safety, comfort, and mobility. Therefore, regular pavement condition assessments are essential to support the selection of appropriate maintenance actions. This study focuses on identifying pavement distress types, assessing road conditions using the Pavement Condition Index (PCI) and Bina Marga methods, and mapping the spatial distribution of damage using a Geographic Information System (GIS). This study was conducted on the Gayam–Sidorejo road section in Kediri District, approximately 8.383 km in length, divided into nine segments to facilitate analysis. Field surveys were undertaken to document the type, severity, and size of pavement damage. The obtained data were further analysed using the PCI method to produce a numerical representation of pavement condition, while the Bina Marga approach was used to determine condition classifications and maintenance priority levels. The results show that the dominant types of damage include alligator cracking, edge cracking, longitudinal cracking, transverse cracking, rutting, patching, potholes, and surface wear. The PCI values range from 36.20 to 87.10, with the lowest value observed in Segment 5 (36.20), indicating a very poor condition and severe pavement deterioration. Meanwhile, the Bina Marga method assigns priority values between 2 and 6, with higher values indicating higher maintenance priority levels, particularly for Segment 5. Moreover, GIS mapping provides a clear representation of pavement damage distribution and helps identify critical segments requiring priority maintenance. The analysis indicates that Segment 5 is the most deteriorated section according to both methods, supporting more effective maintenance decision-making.

Contribution to Sustainable Development Goals (SDGs):

SDG 9: Industry, Innovation and Infrastructure
SDG 11: Sustainable Cities and Communities

1. INTRODUCTION

1.1. *Research Background*

Road infrastructure plays a crucial role in supporting regional connectivity, mobility, and economic activities. Poor pavement conditions may reduce transportation efficiency, increase vehicle operating costs, and pose safety risks for road users. A well-maintained road network can improve transportation efficiency, facilitate the distribution of goods and services, and enhance connectivity between regions. However, pavement conditions tend to deteriorate due to increasing traffic volume and repeated vehicle loading. As traffic volume increases, various types of distress may develop, including cracking, potholes, deformation, and surface wear, which ultimately reduce road performance and compromise user safety. Therefore, proper evaluation of pavement conditions is necessary to maintain the serviceability and safety of road infrastructure [1], [2].

Several factors, including increasing traffic loads, environmental conditions, inadequate drainage systems, and subgrade instability generally influence pavement deterioration. In addition, heavy vehicles with excessive loads may accelerate pavement degradation and shorten the service life of road structures. This condition is consistent with previous studies, which indicate that repetitive and excessive traffic loads significantly contribute to pavement damage and reduce road performance [3] These conditions can lead to various pavement distresses, including alligator cracking, longitudinal cracking, potholes, and surface disintegration. If these damages are not identified and addressed at an early stage, they may develop into more severe structural problems that require higher maintenance costs and may potentially cause traffic accidents [4], [5]. Furthermore, overloading on industrial roads can reduce the remaining service life of flexible pavement structures by increasing the stress on pavement layers [6].

To effectively evaluate pavement conditions, a systematic, quantitative assessment method is required. One commonly applied method for evaluating pavement conditions is the Pavement Condition Index (PCI). This method determines pavement performance by considering the type, severity, and extent of surface distress identified during field observations. The resulting PCI value ranges from 0 to 100 and corresponds to pavement condition levels from failed to excellent. This method allows researchers and practitioners to evaluate road conditions objectively and determine appropriate maintenance strategies based on the calculated pavement condition index [7], [8].

In addition to the PCI method, the Bina Marga approach is widely applied in Indonesia to assess pavement conditions and establish maintenance priorities. This method considers traffic volume, pavement damage level, and road condition scores to determine maintenance program priorities. The results of the Bina Marga method can serve as a reference in selecting appropriate road maintenance actions, including routine maintenance, periodic maintenance, rehabilitation, or reconstruction. Therefore, combining PCI and Bina Marga methods can provide a more comprehensive evaluation of pavement conditions and help decision-makers determine effective maintenance strategies [9], [10].

Along with the advancement of geospatial technology, Geographic Information Systems (GIS) have increasingly been utilized in transportation infrastructure studies, particularly for spatial analysis and visualization of road damage conditions. GIS enables integrating spatial and attribute data, allowing road damage information to be visualised as thematic maps. This spatial visualization provides a clearer representation of pavement conditions across different road segments and facilitates decision-making in road maintenance planning. Therefore, integrating pavement condition assessment methods with GIS technology can provide more comprehensive information for infrastructure management and improve the effectiveness of road maintenance planning [11], [12].

1.2. Literature Review

Several studies have investigated pavement conditions using various analytical methods. Earlier research has primarily examined pavement distress identification, condition assessment, and the development of appropriate maintenance strategies. To support these analyses, several methods have been used, including the PCI method, the Bina Marga approach, and GIS-based spatial analysis. Each of these approaches provides different perspectives in evaluating road conditions and supporting infrastructure management decisions. Therefore, reviewing previous studies related to these methods is necessary to understand their application, advantages, and limitations in pavement condition analysis [13], [2], [10].

1.2.1. Pavement Condition Index (PCI)

The PCI method is widely used as a standardised approach to evaluate pavement conditions through visual inspection of pavement distress and provides reliable, objective results forssessing pavement performance [3]. This method evaluates pavement performance by analyzing the type, severity, and extent of surface distress identified during field observations. The PCI scoring system uses a scale from 0 to 100, with higher values indicating better pavement condition and lower values indicating more severe deterioration. Through this evaluation process, the PCI method provides a quantitative indicator for classifying pavement conditions and determiningropriate maintenance strategies [7], [8].

A number of studies have utilized the PCI method to assess pavement damage across different road segments. These studies are typically conducted through field surveys to identify various types of distress, such as cracking, potholes, rutting, and surface disintegration. The collected data are subsequently processed to determine PCI values for each segment, which are then used to evaluate the level of deterioration and identify appropriate maintenance actions. Previous findings indicate that the PCI method offers a structured, objective approach toessing pavement conditions, making it widely adopted in pavement management practices [1], [4].

In addition, the PCI method has also been utilized in various road condition studies to support infrastructure maintenance planning. By analysing PCI values for each road segment, researchers and practitioners can identify priority locations that require immediate maintenance or rehabilitation. This method also enables classification of pavement conditions into several categories, including excellent, good, fair, poor, and failed. As a result, the PCI method plays an important role in helping decision-makers develope effective road maintenance programs [2], [14].

1.2.2. Bina Marga Method

In Indonesia, the Bina Marga method is widely used to evaluate pavement conditions and set maintenance priorities. It assesses pavement performance by incorporating parameters such as traffic characteristics, condition ratings, and the degree of surface deterioration. The outcomes of this method are used to arrange maintenance priorities, including routine maintenance, periodic maintenance, rehabilitation, and reconstruction. Consequently, the Bina Marga method contributes to road management systems and supports authorities in planning efficient and appropriate maintenance actions [13], [5].

A number of studies have utilized the Bina Marga method to assess pavement conditions and determine maintenance priorities across different road segments. In these studies, field surveys are conducted to record the types and severity levels of pavement damage, which are then analyzed to obtain the road condition value. The calculated condition value is combined with traffic data to determine the maintenance priority for each road segment. The results of these analyses provide important information for decision-makers in determining appropriate road maintenance

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programs and allocating infrastructure budgets more efficiently [9], [10].

Furthermore, several researchers have compared the results of the Bina Marga method with those of other pavement evaluation methods, particularly the Pavement Condition Index (PCI). These comparisons indicate that each method offers distinct perspectives for assessing pavement conditions. While the PCI method focuses on detailed pavement distress analysis and produces numerical condition values, the Bina Marga method emphasizes the determination of maintenance priorities based on traffic and road condition parameters. As a result, the combined use of these methods offers a more comprehensive evaluation of pavement conditions while improving the effectiveness of road maintenance planning [1], [4].

1.2.3. Geographic Information System (GIS)

In transportation infrastructure management, GIS technology is widely used to analyse and visualise spatial data on road conditions. GIS technology enables the integration of spatial and attribute data, allowing road condition data to be analysed and presented as digital maps. Through this capability, GIS can support the identification of pavement damage distribution across road segments and assist decision-makers in understanding the spatial characteristics of infrastructure conditions. As a result, GIS has been widely used in pavement condition assessment studies to improve the effectiveness of road management and maintenance planning [11], [15].

Several previous studies have used GIS technology to map pavement damage and visualise road condition data collected from field surveys. In these studies, GIS is used to process spatial data and generate thematic maps that represent different levels of pavement conditions across road segments. The resulting maps provide clear visual information on the location and severity of pavement damage, which can help transportation authorities prioritise road maintenance and rehabilitation programs more effectively. Therefore, integrating GIS intoement condition evaluation can significantly enhance the quality of infrastructure management systems [12], [16].

In addition, the application of GIS in pavement condition studies allows researchers to combine road condition analysis with other supporting spatial data, such as traffic volume, road networks, and administrative boundaries. This integration provides a more comprehensive perspective on road infrastructure conditions and supports more informed decision-making processes in transportation planning. Consequently, GIS-based analysis is increasingly recognized as an effective approach for visualizing pavement condition data and supporting sustainable road infrastructure management [2], [11].

1.3. Research Gap

Although previous studies have widely applied various methods to evaluate pavement conditions and identify types of road damage, most focus on a single evaluation method without integrating multiple analytical approaches. Several researchers have used the Pavement Condition Index (PCI) method to assess pavement condition based on visual evaluation of pavement distress and to classify pavement deterioration across different road segments. These studies successfully demonstrated that the PCI method provides a quantitative indicator of pavement conditions that can assist in determining appropriate maintenance actions. However, most of these studies primarily focus on evaluating pavement conditions without integrating other analytical approaches to support maintenance prioritisn and infrastructure management [7], [8].

In addition, previous studies have used the Bina Marga approach, incorporating road condition values and traffic characteristics to establish maintenance priority levels. The results of these studies indicate that the Bina Marga method is effective in determining the priority order of road maintenance programs and supporting infrastructure management decisions. Nevertheless, many of these studies use the Bina Marga method independently, without combining it with other pavement evaluation approaches that can provide more detailed information onement distress conditions [9], [10].

Furthermore, several researchers have incorporated Geographic Information Systems (GIS) into pavement condition studies to visualise spatial distributions of road damage. The use of GIS enables the integration of spatial data and road condition information into thematic maps, facilitating the identification of damaged road segments and supporting infrastructure management. However, previous studies generally focus on mapping pavement damage using a single evaluation method, such as PCI or Bina Marga, without integrating multiple analytical approaches to provide a more comprehensive assessment of road conditions [12], [15].

Therefore, further research is needed to integrate diverse pavement evaluation methods and spatial analysis approaches to obtain a more comprehensive understanding of pavement conditions. Combining the Pavement Condition Index (PCI) method, the Bina Marga method, and Geographic Information System (GIS) technology is expected to provide more detailed information regarding pavement damage levels, maintenance priorities, and spatial distribution of road conditions. This integrated approach can support more effective road maintenance planning and improve the decision-making process in infrastructure management [2], [5].

1.4. Research Objective

Based on the identified research gap, this study evaluates pavement conditions on the selected road segment using several analytical approaches. The analysis includes identifying the types and severity levels of pavement distress, assessing pavement conditions using the PCI approach, and determining maintenance priorities through the Bina Marga method. In addition, GIS technology is used to visualise the spatial distribution of pavement damage, supporting more effective road maintenance planning and infrastructure management.

2. MATERIALS AND METHODS

2.1. Study Area

This research was carried out on the Gayam–Sidorejo road segment in Kediri District, East Java, Indonesia. This road segment serves as an important transportation route, connecting several local areas and supporting daily travel in the region. The road section has a total length of approximately 8.383 km and was divided into several segments to facilitate pavement condition analysis. Road infrastructure evaluation is essential to maintain pavement performance and ensure transportation safety for road users [4].

The study area is shown in Figure 1, which includes an inset map illustrating the location of the research site within Kediri District. The inset map provides a clearer spatial overview of the study area and illustrates the geographic context of the analyzed road segment.

Fig. 1 Location of the Study Area Showing the Gayam – Sidorejo Road Section in Kediri, East Java, Indonesia

2.2. Data Collection

The data used in this study comprised both primary and secondary sources, including field survey data and supporting documents. Primary data were collected through direct observations to identify the types, severity levels, and dimensions of pavement damage along the study road segment. Field surveys are widely used in pavement condition assessments to obtain reliable information on surface conditions and to record various types of distress observed along road sections [13], [1].

Various pavement distresses, including cracking, potholes, patching, surface wear, and other visible damage, were observed and recorded during the field survey. The survey process involved visual inspection of the road surface to determine the extent and severity level of each type of damage. This approach is widely applied in pavement condition studies because visual inspection allows researchers to systematically classify pavement distress and measure the dimensions of damaged areas for further analysis [7], [4].

In addition to primary data, secondary data were also collected to support the analysis of pavement conditions. Secondary data included road network and administrative boundary maps, as well as other supporting spatial information used for geographic analysis and mapping. These data were used to provide spatial context for the study area and to support the integration of pavement condition data with geographic information systems (GIS) to visualise spatial distribution of road damage [11], [12].

Furthermore, the collected data were organized and processed to support subsequent analysis of pavement conditions using the PCI and Bina Marga approaches. A structured data collection procedure is essential to ensure that pavement damage information can be analyzed systematically and used to determine appropriate maintenance actions [5], [9].

2.3. Pavement Condition Assessment Using PCI

The Pavement Condition Index (PCI) method is widely used to evaluate pavement condition by identifying pavement distresses observed on road surfaces. This method provides a quantitative index that represents the overall pavement condition by accounting for the type, severity, and extent of pavement damage within a road segment. The PCI scoring system uses a scale from 0 to 100, with higher values indicating better pavement condition and lower values indicating more severe deterioration. Due to its structured evaluation process, the PCI approach is widely utilized in pavement condition assessments and infrastructure management practices [7], [8].

In this study, pavement damage was identified through field surveys conducted along the study road segment. Various pavement distresses were recorded during the survey, including cracking, potholes, patching, and surface deterioration. The observed pavement damage was then classified by severity and measured to determine the extent of the damaged area. This classification process is important in the PCI method because it allows researchers to evaluate pavement conditions systematically and calculate the contribution of each damage type to the overall pavement condition index [2], [14].

After pavement distress was identified, the PCI value was determined using the standard PCI evaluation procedure. The calculation process includes determining the density of each distress type, calculating the deduct value (DV), obtaining the total deduct value (TDV), and then deriving the corrected deduct value (CDV). The final PCI value for each road segment was then calculated using the following equation [17]:

$$\text{PCI} = 100 - \text{CDV}$$

The resulting PCI value was used to classify pavement condition into several categories, including excellent, very good, good, fair, poor, and failed. These classifications help determine the level of pavement deterioration and provide important information for planning appropriate road maintenance strategies [1], [4].

2.4. Pavement Evaluation Using Bina Marga Method

In addition to the PCI method, the Bina Marga approach was employed in this study to evaluate pavement conditions and define maintenance priorities. This method is widely used in Indonesia, as it considers bothavement deterioration and traffic characteristics in the assessment process [18]. This method evaluates road conditions by analyzing several parameters, including traffic volume, pavement damage level, and road condition values, which are then used to determine the priority level for road maintenance programs [9], [10].

In this study, pavement damage identified during field surveys was analyzed to determine the road condition value for each segment. The resulting condition value was then combined with the traffic class to establish maintenance priority levels. This approach allows road managers to classify segments by the urgency ofntenance actions, including routine maintenance, periodic maintenance, rehabilitation, or reconstruction [5], [13]. The priority order value in the Bina Marga method is calculated using the following equation:

$$\text{UP} = 17\ (\text{Traffic Class Value} - \text{Road Condition Value})$$

The priority value obtained from the analysis is used to assign appropriate maintenance programs to each road segment. In the Bina Marga classification system, higher values reflect segments that demand more immediate maintenance actions. Therefore, the Bina Marga method provides practical guidance for determining maintenance priorities and supports effective road infrastructure management [4], [1].

2.5. Geographic Information System (GIS)

In this study, GIS technology was used to visualize the spatial distribution of pavement damage along the road segment. GIS technology enables the integration of spatial and attribute data, allowing road condition information to be analysed and displayed as thematic maps. The application of GIS in pavement condition studies provides a clearer understanding of the spatial pattern of road damage and helps identify road segments that require maintenance actions [11], [15].

In this research, pavement condition data from field surveys and analyses were integrated into a GIS environment. Spatial data, such as road network and administrative boundary maps, were used as base maps for the analysis. The attribute data obtained from PCI and Bina Marga evaluations were then linked to the spatial road segment data to enable spatial visualization of pavement conditions along the study road section [12], [16].

After integrating the spatial and attribute data, thematic maps were generated to represent the condition level of each road segment. These maps provide visual information on the distribution of pavement damage and help illustrate pavement condition assessment results more clearly. The use of GIS in pavement damage mapping is particularly useful for supporting infrastructure management and facilitating decision-making processes in road maintenance planning [2], [11].

2.6. *Workflow*

The research workflow in this study was designed to systematically evaluate pavement conditions and visualize the spatial distribution of road damage. The study began with the identification of the study area and preliminary observation of the selected road segment to determine the scope of pavement condition analysis. This initial stage is important in pavement condition studies because it helps researchers define the study boundaries and prepare appropriate data collection procedures for evaluating road infrastructure conditions [13], [4].

The next stage involved collecting primary data through field surveys to identify and document pavement distress along the study road segment. During the survey, various types of pavement damage were observed, classified, and measured to determine the severity and extent of pavement deterioration. Field survey activities are commonly conducted in pavement evaluation studies to obtain accurate data regarding pavement distress characteristics and to support further pavement condition analysis [7], [2].

Following data collection, pavement conditions were analysed using the PCI method to obtain condition ratings for each segment. Furthermore, the Bina Marga approach was applied to define maintenance priority levels, taking into account road condition values and traffic characteristics. The integration of these methods allows researchers to obtain a comprehensive evaluation of pavement conditions and identify appropriate road maintenance strategies [9], [10].

Finally, the results obtained from the PCI and Bina Marga analyses were integrated into a Geographic Information System (GIS) environment to produce thematic maps representing pavement condition levels across the study road segments. The GIS-based mapping process allows the spatial distribution of road damage to be visualized more clearly and supports infrastructure management by providing spatial information for road maintenance planning [12], [15].

3. RESULTS AND DISCUSSION

3.1. *Pavement Distress Identification*

Pavement distress identification was carried out through field surveys along the Gayam–Sidorejo road section in Kediri Regency, East Java. The surveyed segment has a total pavement area of 34,293.7 m², which was examined to identify the types and extent of deterioration along the road. Field observation is commonly used in pavement condition assessment studies because it allows researchers to systematically record pavement distress and evaluate the level of road deterioration prior to further analysis using pavement evaluation methods [19], [1].

The identified distress types consisted of cracking in several forms (alligator, longitudinal, transverse, and edge cracking), as well as rutting, potholes, and patching. Each type of distress was measured to determine the damaged area, which was then used to calculate the percentage contribution of each distress type relative to the total pavement area. Similar types of pavement distress are commonly found in flexible pavement structures and are often used as indicators for evaluating pavement performance and structural deterioration [4], [19].

The results of the measurement indicate that the total pavement distress area reached 4,984.03 m², representing 14.53% of the total pavement area. Among the observed distress types, alligator cracking was identified as the most dominant form of pavement damage, accounting for a total damaged area of 2,414.94 m² (7.04%). Other significant distress types include patching (742.63 m², or 2.17%), rutting (706.27 m², or 2.06%), and edge cracking (880.78 m², or 2.57%). Meanwhile, longitudinal cracking, potholes, and transverse cracking were found in relatively smaller proportions.

The distribution of pavement distress identified during the field survey is summarized in Table 1, which presents the damage area and percentage of each distress type along the Gayam–Sidorejo road section. These results provide important information on the dominant pavement deterioration patterns and serve as a basis for further pavement condition evaluation using the Pavement Condition Index (PCI) and Bina Marga methods.

Table 1. Distribution of pavement distress on the Gayam – Sidorejo road section

Pavement Distress Category		Segment Area (m²)	Damage Area (m²)	Damage Proportion (%)
Cracking	Alligator	34,293.7	2,414.94	7.04%
	Edge		880.78	2.57%
	Longitudinal		115.18	0.34%
	Transverse		3.38	0.01%
Rutting			706.27	2.06%
Potholes			120.85	0.35%
Patching			742.63	2.17%
Total		**34,293.7**	**4,984.03**	**14.53%**

In addition to quantitative measurements, visual documentation of pavement distress was also conducted during the field survey to provide a clearer representation of actual field conditions.

Representative examples of the observed pavement damage are presented in Figure 2.

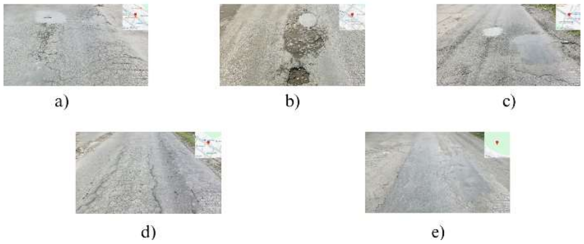

Fig. 2 Visual documentation of pavement distress along the study area: (a) edge and longitudinal cracking, (b) potholes accompanied by surface disintegration, (c) patching with adjacent deterioration, (d) severe alligator cracking, and (e) longitudinal cracking with surface wear (ravelling).

The inclusion of visual documentation supports the identification of pavement distress types and enhances the interpretation of quantitative analysis results obtained in this study.

3.2. *Pavement Condition Evaluation Using PCI*

The condition of the Gayam–Sidorejo road section was assessed using the Pavement Condition Index (PCI), which quantifies pavement performance based on the type, severity, and extent of observed distress. The PCI is commonly used in pavement management systems because it quantifies pavement condition on a scale from 0 to 100, with higher values indicating better performance.

The PCI results reflect the overall pavement condition for each road segment and are strongly influenced by the identified distress characteristics from field observations. As presented in Section 3.1, the dominant distress includes multiple forms of cracking (alligator, longitudinal, and edge), as well as potholes, rutting, and patching. Among these, distress related to structural damage, such as alligator cracking and potholes, has a significant impact on PCI values.

Table 2 presents the PCI analysis results for each road segment, including the corresponding pavement condition classifications. The data indicate that pavement conditions along the Gayam–Sidorejo road section vary across segments, with PCI values ranging from 36.20 to 87.10. This variation suggests that pavement deterioration is unevenly distributed across the study area.

As shown in Table 2, Segment 3 had the highest PCI value of 87.10 and is categorised as being in good condition, indicating that the pavement surface remains relatively intact with satisfactory structural performance. This condition is likely due to the low incidence of distress types observed in this segment, suggesting that the pavement has experienced lower cumulative traffic loading and limited environmental impact. As a result, the pavement's structural integrity remains well preserved. In contrast, Segment 5 recorded the lowest PCI value (36.20), indicating severe pavement deterioration. This condition is strongly associated with the high occurrence of alligator cracking and potholes observed during the field survey, which typically reflect structural failure due to repeated traffic loading and possible subgrade instability. Therefore, this segment may require rehabilitation or reconstruction.

Table 2. Pavement Condition Index (PCI) values for each road segment

Segment	PCI Value	Pavement Condition
STA 0+000 – 1+000 Segment 1	43.60	Poor
STA 1+000 – 2+000 Segment 2	44.20	Poor
STA 2+000 – 3+000 Segment 3	87.10	Good
STA 3+000 – 4+000 Segment 4	49.20	Poor
STA 4+000 – 5+000 Segment 5	36.20	Very Poor
STA 5+000 – 6+000 Segment 6	42.50	Poor
STA 6+000 – 7+000 Segment 7	40.18	Poor
STA 7+000 – 8+000 Segment 8	56.73	Fair
STA 8+000 – 8+383 Segment 9	63.00	Fair

Furthermore, Segments 8 and 9 are classified as fair condition, indicating moderate pavement performance that still functions adequately but requires preventive maintenance to prevent further deterioration. Meanwhile, most of the remaining segments, including 1, 2, 4, 6, and 7, fall into the poor category, indicating noticeable pavement distress that may reduce riding quality and structural performance if left unaddressed.

The variation in PCI values presented in Table 2 shows that segments with lower PCI values are generally associated with more severe and extensive pavement distress, particularly alligator cracking and potholes. Conversely, segments with higher PCI values exhibit fewer and less severe distress types, indicating better pavement condition.

These findings suggest that several factors, including traffic loading, environmental conditions, and existing pavement defects, influence pavement deterioration along the study road. Therefore, segment-based evaluation is essential for accurately identifying critical locations and determining appropriate maintenance strategies. Overall, the PCI evaluation provides a reliable quantitative representation of pavement condition and serves as a fundamental basis for further analysis and comparison with the Bina Marga method in determining road maintenance priorities.

3.3. *Road Condition Assessment Using the Bina Marga Method*

In addition to the PCI method, the Bina Marga approach was also used to evaluate pavement conditions along the Gayam–Sidorejo road section. This method is commonly used in Indonesia to set maintenance priorities. Unlike the PCI method, which primarily focuses on surface distress, the Bina Marga method considers both pavement condition values and traffic characteristics to determine the priority order (UP) of maintenance actions.

The priority order value (UP) is calculated by combining the traffic class and road condition values, reflecting the urgency level of maintenance for each road segment. Through this approach, road segments can be classified into appropriate maintenance categories-routine maintenance, periodic maintenance, rehabilitation, or reconstruction-thereby supporting effective infrastructure management.

The results of the Bina Marga analysis for each road segment are presented in Table 3, which shows the priority order values along with their corresponding maintenance categories. Based on the data in Table 3, the priority order values along the Gayam–Sidorejo road section range from 2 to 6, indicating varying maintenance urgencies across segments.

Table 3. Summary of maintenance priority levels based on the Bina Marga approach

Segment	Priority Value (UP)	Maintenance Type
STA 0+000 – 1+000 Segment 1	5	Periodic Works
STA 1+000 – 2+000 Segment 2	5	Periodic Works
STA 2+000 – 3+000 Segment 3	2	Routine Works
STA 3+000 – 4+000 Segment 4	6	Periodic Works
STA 4+000 – 5+000 Segment 5	5	Periodic Works
STA 5+000 – 6+000 Segment 6	6	Periodic Works
STA 6+000 – 7+000 Segment 7	6	Periodic Works
STA 7+000 – 8+000 Segment 8	6	Periodic Works
STA 8+000 – 8+383 Segment 9	6	Periodic Works

Based on Table 3, Segment 3 has the lowest priority (UP = 2) and is categorised as routine maintenance, indicating that the pavement condition remains relatively good and requires only minimal intervention to maintain performance. This finding is consistent with the PCI analysis, which also showed that Segment 3 had the highest PCI value, suggesting strong agreement between the methods in identifying segments with well-maintained structural integrity.

In contrast, the majority of the remaining segments (Segments 1, 2, 4, 5, 6, 7, 8, and 9) fall within the periodic maintenance category, with priority values ranging from 5 to 6. This condition indicates that these segments have experienced moderate to significant pavement deterioration, requiring more substantial maintenance actions, such as surface treatment or structural improvement. The dominance of periodic maintenance categories suggests that deterioration is widespread along the road section rather than being localized in specific segments.

The variation in priority values shown in Table 3 reflects the uneven distribution of pavement deterioration along the road segment. Segments with higher priority values correspond to more critical conditions that require more immediate and intensive maintenance actions, whereas segments with lower priority values indicate relatively better pavement performance. This variation highlights the importance of segment-based analysis in accurately identifying maintenance needs and preventing further deterioration.

Furthermore, the Bina Marga evaluation highlights the importance of considering both pavement condition and traffic characteristics in determining maintenance priorities. Road segments with similar levels of pavement distress may exhibit different priority rankings due to variations in traffic volume and load intensity, which directly influence pavement deterioration rates. This demonstrates that maintenance prioritisation cannot rely solely on surface condition assessment; it must also incorporate traffic-related factors to ensure more effective infrastructure management.

Overall, the Bina Marga evaluation indicates that the Gayam–Sidorejo road section primarily requires periodic and routine maintenance to maintain the serviceability of the pavement structure. The maintenance priority determined using the Bina Marga method provides important guidance for road infrastructure management and helps decision-makers allocate maintenance resources effectively.

3.4. Comparative Analysis of PCI and Bina Marga Methods

The comparison between the Pavement Condition Index (PCI) method and the Bina Marga method was conducted to evaluate the consistency and relationship between the two approaches in assessing pavement condition along the Gayam–Sidorejo road section. Although both methods aim to evaluate pavement performance, they are based on different evaluation principles. The PCI method focuses on the type, severity, and extent of pavement distress, whereas the Bina Marga method incorporates both pavement condition values and traffic characteristics to determine maintenance priorities. This fundamental difference implies that the two methods may produce similar trends but not necessarily identical results.

Since the PCI method produces values in the range 0 to 100, while the Bina Marga method uses a different numerical scale, a normalisation process was applied to enable direct comparison between the two methods. In this study, min–max normalisation was used to transform the Bina Marga values into a comparable range of 0-100, enabling both methods to be evaluated within the same numerical framework. The normalization was performed using the following equation:

$$X' = \frac{X - Xmin}{Xmax - Xmin} x\ 100$$

Table 4. Comparative results of PCI scores and normalized Bina Marga values for each road segment

Road Segment	PCI		Bina Marga	
	Score	Condition	Normalized Score	Maintenance Type
Segment 1	43.60	Poor	50.00	Periodic Works
Segment 2	44.20	Poor	50.00	Periodic Works
Segment 3	87.10	Good	87.50	Routine Works
Segment 4	49.20	Poor	37.50	Periodic Works
Segment 5	36.20	Very Poor	50.00	Periodic Works
Segment 6	42.50	Poor	37.50	Periodic Works
Segment 7	40.18	Poor	37.50	Periodic Works
Segment 8	56.73	Fair	37.50	Periodic Works
Segment 9	63.00	Fair	37.50	Periodic Works

In the equation, X′ refers to the normalized value, X corresponds to the original Bina Marga value, and X_{min} and X_{max} denote the minimum and maximum values of the dataset. The comparison of PCI values with normalized Bina Marga values for each road segment is shown in Table 4.

Based on the data presented in Table 4, both methods demonstrate generally consistent trends in evaluating pavement conditions. Segments with lower PCI values tend to correspond to lower normalised Bina Marga values, indicating poorer pavement condition and greater maintenance needs. For instance, Segment 5, which recorded the lowest PCI value (36.20), is also classified under periodic maintenance in the Bina Marga method. This correspondence suggests that both methods are sensitive to segments with significant structural deterioration, particularly those dominated by severe distress types such as alligator cracking and potholes.

Conversely, Segment 3 exhibits the highest PCI value (87.10) and is categorised as routine maintenance under the Bina Marga method, indicating a relatively good pavement condition. This agreement reinforces the ability of both methods to consistently identify segments with well-preserved pavement performance. It also implies that, when pavement distress is minimal, the influence of additional factors, such as traffic characteristics, does not significantly alter the maintenance classification.

To further examine the relationship between the two evaluation methods, a scatter plot was generated of PCI values versus normalised Bina Marga values, as illustrated in Figure 3. This analysis provides a quantitative basis for assessing the degree of correlation between the two approaches and helps to identify the extent to which both methods align in representing pavement condition and maintenance priorities.

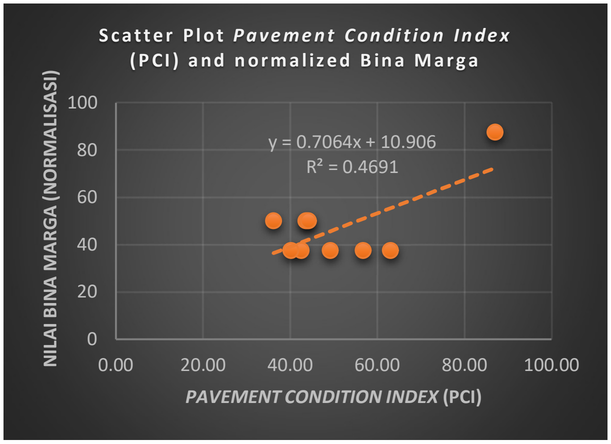

Fig. 3 Comparison of PCI scores and normalized Bina Marga values

Figure 3 presents a scatter plot of PCI values versus normalised Bina Marga values. The regression analysis yields a coefficient of determination (R^2) of 0.4691, indicating a moderate correlation between the two methods. This result implies that approximately 46.91% of the variation in the normalised Bina Marga values can be explained by PCI values, while the remaining variation is influenced by factors not captured by the PCI method.

This moderate correlation suggests that, although both methods exhibit similar general trends in assessing pavement conditions, they differ in sensitivity and evaluation approach. The PCI method provides a detailed assessment of surface distress conditions, whereas the Bina Marga method incorporates traffic-related parameters to determine maintenance priorities. As a result, segments with comparable distress levels may still be assigned different priority levels depending on traffic intensity and loading conditions.

Furthermore, the results indicate that segments with severe distress types identified in Section 3.1, such as alligator cracking and potholes, tend to produce lower PCI values and higher maintenance priority levels. This finding demonstrates that both methods are responsive to actual field conditions, although they interpret them through different evaluation frameworks.

Therefore, the combined application of the PCI and Bina Marga methods provides a more comprehensive evaluation of pavement conditions. While the PCI method offers detailed insight into pavement surface performance, the Bina Marga method supports practical decision-making by incorporating traffic considerations. The integration of both approaches enhances the effectiveness of road maintenance planning and infrastructure management.

3.5. GIS-Based Pavement Damage Mapping

The pavement condition assessment results from both the PCI and Bina Marga methods were further represented using GIS to describe the spatial distribution along the Gayam–Sidorejo road section. This approach allows integration of spatial and attribute data, enabling pavement condition information to be visualised in a thematic map to support interpretation and decision-making.

To provide a more comprehensive spatial analysis, separate thematic maps were developed based on PCI values and Bina Marga priority order (UP). These maps provide a clearer understanding of pavement condition variation and the distribution of maintenance priorities across the study area.

A thematic map based on the PCI values was generated to illustrate the spatial variation of pavement conditions along the study road segment. The PCI-based map classifies pavement conditions into several categories, including very poor, poor, fair, and good, which are represented using different color gradients. Segments with lower PCI values are highlighted to indicate more severe pavement deterioration, while segments with higher PCI values indicate better pavement performance.

Based on the PCI map, it can be observed that pavement conditions vary along the road segment. Segments in poor and very poor condition are distributed across several locations, indicating localised deterioration in pavement performance. In contrast, segments categorized as fair and good are relatively limited and represent areas with better structural integrity and surface condition.

This spatial visualisation confirms the PCI analysis results presented in Table 2, which show that most segments fall into the poor category, indicating that the overall pavement condition of the study area requires appropriate maintenance interventions.

Alongside the PCI-based map, a thematic representation based on the Bina Marga method was created to illustrate the distribution of maintenance priority levels (UP) across road segments. In this map, segments are categorized based on priority values and their respective maintenance types, including routine and periodic maintenance.

The Bina Marga map classifies road segments into maintenance categories such as routine maintenance and periodic maintenance based on their priority order values. Segments with higher UP values indicate greater urgency for maintenance actions, while segments with lower UP values represent relatively better pavement conditions.

https://doi.org/10.29165/ajarcde.v10i1.971

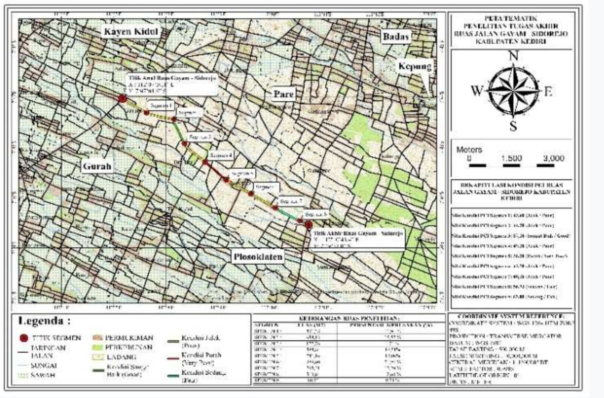

Fig. 4 GIS-based pavement condition map of the Gayam–Sidorejo road section based on PCI values

Based on the map, most road segments fall into the periodic maintenance category, indicating moderate pavement deterioration that requires planned maintenance actions. Only a limited number of segments fall under routine maintenance, reflecting relatively better pavement conditions.

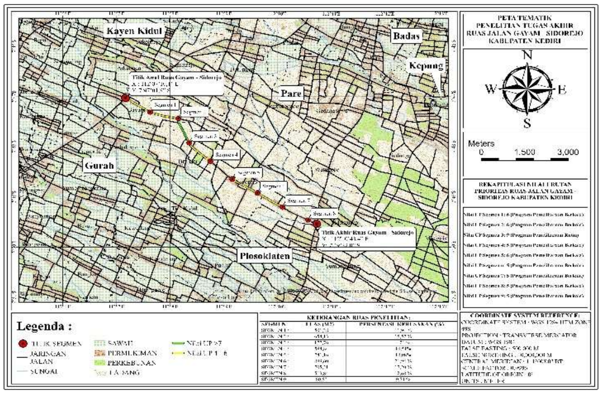

Fig. 5 GIS-based map of maintenance priority levels (UP) on the Gayam–Sidorejo road section using the Bina Marga method

The comparison between the PCI-based map and the Bina Marga-based map shows generally consistent spatial patterns along the study area. Segments with lower PCI values tend to correspond to higher maintenance priority levels (UP), indicating that both methods identify similar critical locations requiring maintenance.

However, slight differences are observed due to the inclusion of traffic characteristics in the Bina Marga method, which affects the determination of maintenance priorities. This indicates that while the PCI method focuses on detailed pavement distress conditions, the Bina Marga method offers a more practical approach to maintenance prioritisation by accounting for traffic-related factors. Therefore, integrating PCI and Bina Marga results within a GIS framework provides a more comprehensive evaluation of pavement conditions and enhances decision-making in road maintenance planning.

4. CONCLUSION

This study evaluated pavement conditions along the Gayam–Sidorejo road section using the Pavement Condition Index (PCI) and Bina Marga methods, with the results further visualised in a Geographic Information System (GIS). The findings indicate that pavement deterioration is dominated by structural and surface distress, particularly alligator cracking and potholes, which significantly influence overall pavement performance. The total damaged area reached 4,984.03 m² (14.53%), indicating a considerable level of deterioration along the study section.

The PCI analysis revealed that pavement conditions vary significantly across segments, with values ranging from 36.20 to 87.10. Most segments fall within the poor category, indicating that the overall pavement condition requires systematic maintenance intervention. Meanwhile, the Bina Marga evaluation shows that the majority of segments fall into periodic maintenance, with moderate to high maintenance urgency based on pavement condition and traffic characteristics.

The evaluation using the Bina Marga method indicates that most road segments fall into the periodic maintenance category, while a limited number require only routine maintenance. This suggests that the majority of the road section requires planned maintenance actions to prevent further deterioration.

The comparative analysis between the PCI and Bina Marga methods demonstrates a moderate correlation ($R^2 = 0.4691$), indicating that both methods exhibit consistent trends but differ in evaluation sensitivity. The PCI method provides detailed insight into pavement surface distress, whereas the Bina Marga method offers a more practical framework for maintenance prioritization by incorporating traffic-related factors. This highlights that relying on a single method may not fully capture the complexity of pavement condition assessment.

Furthermore, integrating PCI, Bina Marga, and GIS provides a more comprehensive approach to pavement evaluation by combining quantitative assessment, maintenance prioritisation, and spatial visualisation. This integrated framework enhances the ability to identify critical road segments and supports more effective decision-making in road maintenance planning.

Therefore, this study contributes to pavement management practices by demonstrating that the combined application of PCI, Bina Marga, and GIS can improve the accuracy and effectiveness of road condition assessment. The results of this study can serve as a practical reference for transportation agencies in developing more targeted, data-driven, and efficient road maintenance strategies.

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