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## Analysis of Pavement Damage on Jakarta–Merak Toll Road Using PCI Approach

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**Abstract:** The Jakarta–Merak Toll Road serves as a vital transportation corridor connecting Java to Sumatra, and is heavily utilized by freight vehicles, particularly those operating in industrial areas along its path. This study aimed to assess the current condition of road pavements along both directions between Km 31.600 and Km 97.700 using the Pavement Condition Index (PCI) method. The novelty of this research lies in the comprehensive and systematic application of PCI to real-world toll road conditions, offering objective field-based data to guide infrastructure maintenance decisions. Field surveys were conducted to identify and classify visible surface distresses such as potholes, cracks, and other forms of deterioration. A total of 118 instances of damage were recorded in lane A (Jakarta to Merak) and 108 in lane B (Merak to Jakarta). The severity and density of these distresses were quantified by PCI calculations. The results showed that lane A had an average PCI score of 61%, categorized as “good,” while lane B scored 54%, categorized as “moderate.” This variation suggests uneven pavement degradation, potentially owing to the asymmetric traffic volume and vehicle loading patterns. This study confirms that the PCI method provides a reliable framework for evaluating the surface conditions of toll roads. The derived PCI values serve as a practical reference for prioritizing maintenance efforts, planning rehabilitation schedules, and ensuring the longevity of the pavement infrastructure. These findings emphasize the importance of condition-based assessment tools for optimizing road asset management strategies and ensuring user safety and satisfaction with national toll road networks.



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**Keywords:** Toll Road; Damage Type; Damage Analysis; PCI; Average Value.

## 雅加达–默拉克高速公路路面损坏的PCI方法分析

**摘要：**雅加达–默拉克高速公路是连接爪哇岛与苏门答腊岛的重要交通走廊，尤其在沿线工业区，常有大量货运车辆通行甚至超载，对路面状况造成显著影响。本研究采用路面状况指数（PCI）方法，对位于31.600公里至97.700公里之间的高速公路双向路段进行系统性评估，旨在提供实地量测的客观数据，以支持道路基础设施的维护与管理决策。通过实地调查识别并分类常见的表面病害类型，如坑洞、裂缝及其他损坏形式。在A车道（雅加达至默拉克）共记录到118处病害，而在B车道（默拉克至雅加达）记录到108处。使用PCI方法对病害的严重程度与密度进行了量化分析。结果显示，A车道的平均PCI评分为61%（评价为“良好”），而B车道为54%（评价为“一般”），反映出由于车流量及车辆负载分布不均可能导致的路面性能差异。研究表明，PCI方法是评估收费公路路面状况的可靠工具，所获得的PCI值可作为制定养护优先顺序与维修计划的实用依据，有助于延长路面寿命。研究强调了以路况为基础的评估工具在优化道路资产管理、提升公路服务质量与用户满意度方面的重要作用。

**关键词：**高速公路；损坏类型；损坏分析；PCI；平均值。

### 1. Introduction

Toll roads play a significant role in supporting national transportation systems, enabling faster and more efficient mobility of both passengers and goods. However, the development of toll roads inevitably impacts physical, socio-economic, and environmental aspects throughout the pre-construction, construction, and post-construction phases [1]. As infrastructure that facilitates public accessibility, toll roads are expected to meet certain durability and design standards [2]. In practice, however, road surfaces often experience damage before reaching their planned service life because of various factors, such as terrain conditions, material quality, environmental influences, construction errors, inadequate planning, and overloading of vehicles.

Road damage not only reduces the functional and structural performance of toll roads but also endangers users. Accidents are frequently reported on toll roads, many of which are attributed to the inability of drivers to anticipate or control vehicles on damaged surfaces [3]. Heavy vehicles with excessive loads are particularly problematic because they typically travel at speeds below the designated toll road limit of 60 km/h, contributing to accident risks and premature pavement deterioration [4]. The repeated passage of such vehicles, especially on routes serving industrial areas, accelerates the degradation of both flexible and rigid pavements [5].

Road damage is generally classified into structural and functional categories [6]. Structural damage

involves changes in material cohesion and composition that affect the load-bearing capacity of the pavement, whereas functional damage reduces the comfort and safety levels for users. This is manifested by unevenness, slipperiness, and other surface irregularities. Factors such as water stagnation, improper drainage, and poor construction practices further exacerbate these issues, creating defects such as cracks, potholes, rutting, and bleeding [7]. If left unaddressed, these defects may lead to traffic congestion, time inefficiency, and potentially fatal accidents.

Recent field surveys conducted along the Jakarta–Merak Toll Road revealed several types of surface damage, including block cracking, longitudinal and transverse cracking, rutting, corrugation, potholes, and asphalt bleeding [8]. These forms of damage occur predominantly in sections that are frequently traversed by overloaded trucks. To quantitatively assess the extent of surface deterioration, this study applies the Pavement Condition Index (PCI) method, which is a standardized evaluation tool for determining pavement quality based on observed damage types and severities [9][10].

While several studies have previously explored toll road damage and its causes, few have focused specifically on applying the PCI method to long highway sections, such as the Jakarta–Merak corridor. Therefore, this study aims to fill this gap by calculating PCI values for segments between Km 31.600 and Km 97.700 in both travel directions. This analysis is expected to provide accurate information on the average

condition of the road surface and assist toll authorities in prioritizing maintenance and rehabilitation strategies. Furthermore, this study was limited to surface damage assessment and did not include subgrade or structural evaluation. The final goal is to calculate the density, deduct values, and total and corrected deduct values, leading to a comprehensive PCI evaluation for each damage instance as well as the average condition of the toll road [11][12].

## 2. Methods

This study was conducted along the Jakarta–Merak and Merak–Jakarta toll roads, from KM 31+600 to KM 97+700, as illustrated in Figure 1. The purpose of this study is to evaluate the pavement conditions of the Jakarta–Merak toll road and identify the types of surface damage observed in the field. Data collection was conducted in the morning to avoid the influence of high traffic volumes and to ensure better visibility and accuracy during measurement.

This study employed a quantitative observational method involving systematic field measurements and standardized analysis based on pavement engineering principles. The Pavement Condition Index (PCI) was selected as the primary assessment technique because of its widespread use and reliability in evaluating surface integrity through objective indicators.



**Figure 1. Jakarta–Merak Toll Road**

Source: [Trans Java Toll Road Network.png - Wikimedia Commons](#)

Field data were collected through direct observations and manual measurements using the Pavement Condition Index (PCI) method. PCI methodology is a widely accepted engineering approach that quantifies pavement conditions by evaluating the type, severity, and extent of surface distress. The process begins with a preliminary survey to identify the location and length of each segment. Each segment was then divided into smaller sample units, typically 100 m<sup>2</sup> in area, in accordance with PCI manual guidelines. This was followed by a detailed distress survey to record the type of damage and its dimensional characteristics, including the width, depth, and length of the affected areas, as suggested by Fatikasari [13].

Each type of surface distress was classified by severity level (low, medium, or high), and the surface area affected was recorded precisely using field measurement tools, such as measuring wheels and rulers, to ensure accuracy and repeatability.

The subsequent stage involved calculating the key values necessary to determine PCI scores, such as density, deduct, total deduct (TDV), and corrected deduct (CDV) values, as outlined by Ibrahim [14].

The damage types assessed in this study include block cracking, longitudinal and transverse cracking, rutting, corrugation, bleeding, and potholes. The densities for block cracking, longitudinal and transverse cracking, rutting, corrugation, and bleeding were calculated using the following formulae:

$$\text{Density} = \left[ \frac{A_d}{A_s} \right] \times 100\% \quad (1)$$

where  $A_d$  is the total area of each type of damage (m<sup>2</sup>) and  $A_s$  is the total area of the segment unit (m<sup>2</sup>).

For potholes, the density was calculated using a different approach:

$$\text{Density} = \left[ \frac{N}{A_s} \right] \times 100\% \quad (2)$$

Where  $N$  is the number of potholes and  $A_s$  is the total area of the segment unit (m<sup>2</sup>).

The deduct value (DV) for each damage type was determined using PCI reference curves that relate density to DV, considering the type and severity of each distress (low, medium, and high). These values are summed to obtain the total deduct value (TDV) for each segment. When multiple DVs within a segment exceeded five, a correction factor was applied using the PCI correction curve to derive the corrected deduct value (CDV), ensuring a more accurate representation of compound distress effects.

Once the CDV was obtained, the Pavement Condition Index (PCI) for each unit was calculated using the equation below:

$$\text{PCI} (s) = 100 - \text{CDV} \quad (3)$$

Where: PCI(s) is the pavement condition index for each unit/segment, and CDV is the corrected deduct value for that unit.

To determine the overall PCI value for the full length of the toll road section, the following formula is applied:

$$\text{PCI} = \left[ 1 - \frac{\sum \text{PCI} (s)}{N} \right] \quad (4)$$

Where: PCI is the total PCI value, PCI(s) is the PCI value for each segment, and  $N$  is the total number of evaluated segments.

Based on the resulting PCI values, the pavement conditions were classified into categories such as perfect, very good, good, fair, poor, very poor, and failed. The classifications are presented in Table 1.

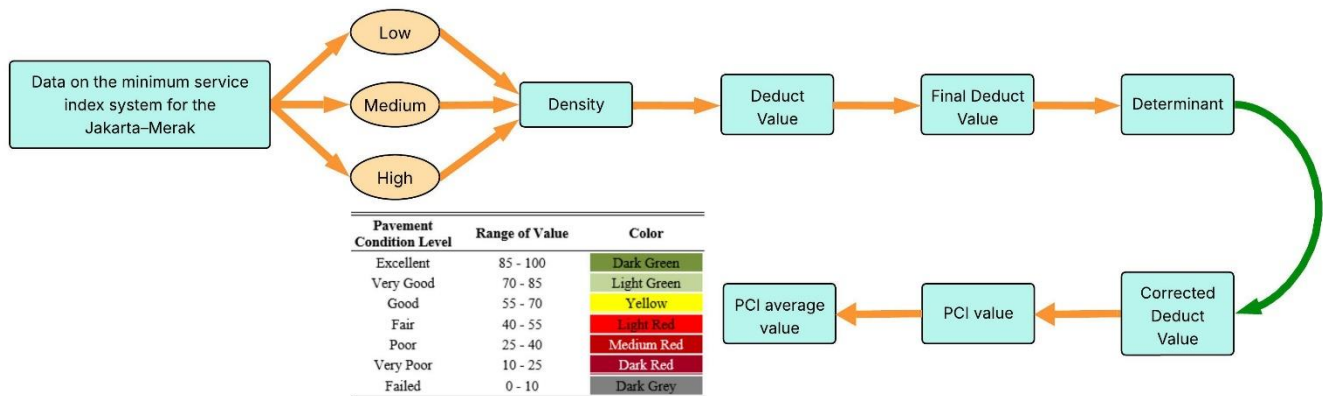
**Table 1. Pavement Classification**

Pavement Condition Level	Range of Value	Color
Excellent	85 - 100	Dark Green
Very Good	70 - 85	Light Green
Good	55 - 70	Yellow
Fair	40 - 55	Light Red
Poor	25 - 40	Medium Red
Very Poor	10 - 25	Dark Red
Failed	0 - 10	Dark Grey

Source: [14]

This structured procedure provides replicable data-driven insights into pavement health, which is essential for informed decision-making in infrastructure maintenance planning.

To provide an overview of the entire analytical process from data collection to PCI evaluation, the flow of the research is illustrated in Figure 2.



**Figure 2. Flowchart of Calculation**  
Source: Developed by the authors (2025)

### 3. Results

#### 3.1. Pavement Condition Survey and Damage Inventory

Based on field observations, 118 types of road surface damage were identified along Route A (Jakarta-Merak), spanning from KM 31+600 to KM 97+600, and 108 types along Route B (Merak-Jakarta), spanning

from KM 97+700 to KM 31+600. Each Route A divided into segments for analysis: 45 segments for route A, and 44 segments for Route B. The damage types were dominated by potholes and cracks. Detailed documentation of the damage, including its type, location, size (length, width, and depth), and frequency per segment, is presented in Table 2 for Route A and in Table 3 for Route B.

**Table 2. Survey of the condition of the Jakarta-Merak toll road pavement, total data Jakarta-Merak 118**

ROAD PAVEMENT CONDITION SURVEY FORM		
AIRFIELD ASPALT PAVEMENT CONDITION SURVEY DATA SHEET FOR SAMPLE		
UNIT : Jakarta - Merak Toll Road		
Length of Toll Road : 97 Km		
Calculation ; per 50 m with the width of the road 3.8 m		
Section 0+500 m		
Date :		
1. Alligator Cracking	6. Jet Blast	12. Ravelling Weathering
2. Bleeding	7. JT. Reflection Cracking	13. Rutting
3. Block Cracking	8. Long and Trans Cracking	14. Sloving
4. Corrugation	9. Oil Slipper	15. Slipagage Cracking
5. Depression	10. Patching	16. Swell
	11. Polhised Agregat	17. Potholes

No	DISTREASS SEVERITY	Lokation ( KM)		Quality of damage	Quantity								Total	Dencity	Deduct Value
					c										
a		Line A ( jkt - Merak)		b	c								d = total c	e = d/Lu*100	f = Grafik
1	17	31+600	32+200	L	1.00	0.2							1.2	0.1	20
2	17	32+450	33+000	L	0.2	0.4							0.6	0.029	8
3	17	33+500	34+800	L	0.4	0.3							0.7	0.014	4
4	17			M	0.8								0.8	0.016	13
5	17	35+300	35+900	L	0.4	0.77	0.4	0.11	0.4				2.08	0.1	20
6	17			M	0.3	0.1	0.3	0.25					0.95	0.042	21
7	17	36+100	36+900	L	0.17	0.07	0.12	0.12	0.1	0.4	0.2	0.09	1.27	0.04	12
8	17			M	0.25								0.25	0.008	7
9	17	37+000	37+900	L	0.2	0.183	1						1.383	0.040	10
10	17			M	1.3	0.45	0.25	0.12	1.3				3.42	0.1	33
11	3			M	15								15	0.4	20
12	17	38+100	38+850	L	0.2	3.8							4	0.140	20
13	17			M	1.3	2.5							3.8	0.13	55
14	17	39+100	39+700	M	2.5	1	1.2						4.7	0.206	50
15	17			H	1.2	1.5							2.7	0.1	50
16	17	40+200	40+800	L	1.2								1.2	0.05	11
17	17			M	3.5								3.5	0.2	40
115	3	93+200	93+250	M	6	2							8	1.1	6
116	17	96+700	97+700	M	0.4								0.4	0.01	7
117	17			H	0.6								0.6	0.02	27
118	3			L	1								1	0.03	0

Source: Developed by the authors (2025)

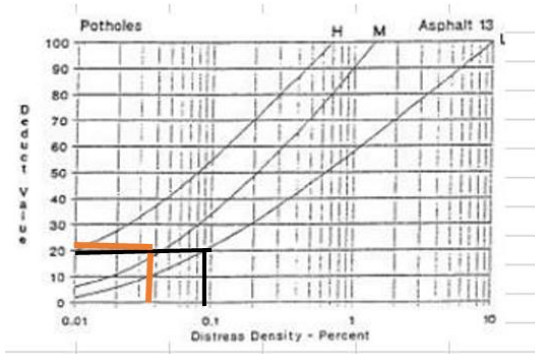
**Table 3. Survey of Jakarta–Merak toll road pavement, total data Merak–Jakarta 108**

ROAD PAVEMENT CONDITION SURVEY FORM															
AIRFIELD ASPALLT PAVEMENT CONDITION SURVEY DATA SHEET FOR SAMPLE															
UNIT : Jakarta - Merak Toll Road															
Length of Toll Road : 97 Km															
Calculation ; per 50 m with the width of the road 3.8 m															
Section 0+500 m															
Date :															
Lu = ( Segment length x width )															
1 Alligator Cracking			6. Jet Blast			12. Ravelling Weathering									
2 Bleeding			7. JT. Reflection Cracking			13. Rutting									
3 Block Cracking			8. Long and Trans Cracking			14. Sloving									
4 Corrugation			9. Oil Slipper			15. Slipagage Cracking									
5 Depression			10. Patching			16. Swell									
			11. Polhised Agregat			17. Potholes									
No	DISTREASS SEVERITY	Lokation ( KM)		Quality of damage	Quantity								Total	Density	Deduct Value
a		Line B ( Merak - Jkt)		b	c								d = total c	e = d/Lu*100	f = Grafik
1	17	+56+000	56+280	L	0.40	0.3	0.44	0.4					1.54	0.14	18
2	17			M	2.00								2	0.2	49
3	3			L	2.00								2	0.2	0
4	3			M	2.00								2	0.2	0
5	3	+55+450	55+910	M	15.00	7							22	1.259	3
6	8			M	7.00								7	0.400	3
7	17	+54+830	54+890	L	0.4								0.4	0.175	23
8	3			L	3								3	1.316	1
9	17	+53+270	53+900	L	0.3	1.3	0.8	0.6	0.6				3.6	0.2	30
10	13			M	15								15	0.627	13
11	17	+51+050	51+800	M	2								2	0.07	12
12	17			L	2								2	0.070	0
13	3			M	6								6	0.211	0
14	17	+50+150	50+200	L	0.2	0.183	1						1.383	0.040	10
15	17			M	1.3	0.45	0.25	0.12	1.3				3.42	0.1	33
16	3			M	15								15	0.4	20
17	17	+49+300	49+900	L	1.3	0.3	1.3						2.9	0.127	17
105	3			L	7	6							13	0.39	0
106	3			M	4								4	0.1	0
107	17	62+410	62+900	L	1.1								1.1	0.06	12
108	17			M	1.1	5.8	3.1	3.5	4	3.1			20.6	1.11	90

**3.2. Density and Deduct Value Analysis**

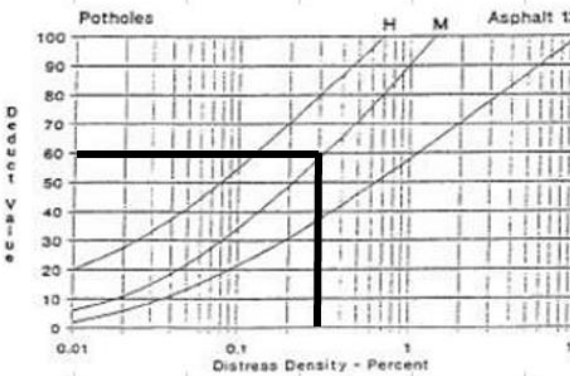
The amount of damage for each segment was calculated and used to determine the density value using Equation 5. These density values form the basis for calculating the deduct value, which quantifies the impact of each type of damage based on its severity and extent.

For example, segments KM 35+300 to KM 35+900 contained pothole damage categorized as both low and medium. The respective density values were 0.091 and 0.042, leading to deduct values of 20 and 21. These values are illustrated in the pothole reduction graph in Fig. 3.

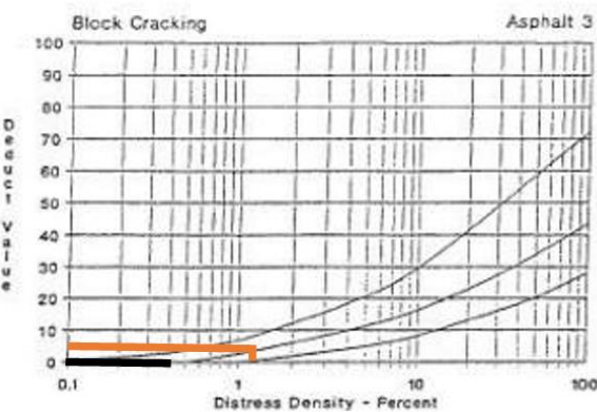


**Figure 3. Potholes reduction value graph for segment KM 35+300 – 35+900 (ASTM D6433 – 07)**  
Source: Developed by the authors (2025)

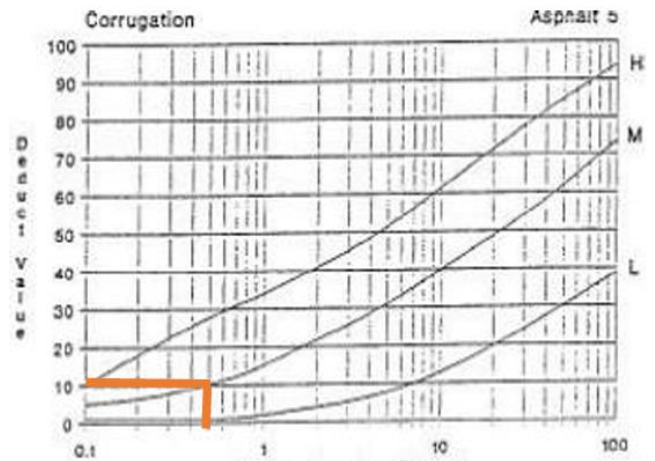
For segments KM 86+200 to KM 86+950 on Route A, three types of damage were recorded: potholes, block cracking, and corrugation. The low-severity pothole damage had a density of 0.01 (deduct value 2), and the medium-severity damage had a density of 0.3 (deduct value 60), as depicted in Figure 4. Block cracking damage at low and medium severities resulted in density values of 0.4 (deduct value 0) and 1.2 (deduct value 5), as shown in Figure 5. At medium severity, corrugation damage with a density of 0.3 at medium severity yielded a deduct value of 10, as illustrated in Figure 6.



**Figure 4. Potholes reduction value graph for segment KM 86+200 – 86+950 (ASTM D6433 – 07)**  
Source: Developed by the authors (2025)

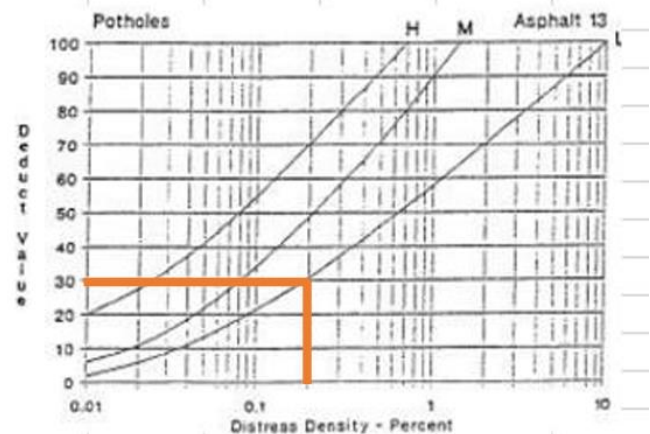


**Figure 5. Block cracking reduction value graph (ASTM international D 6433 – 07)**  
Source: Developed by the authors (2025)

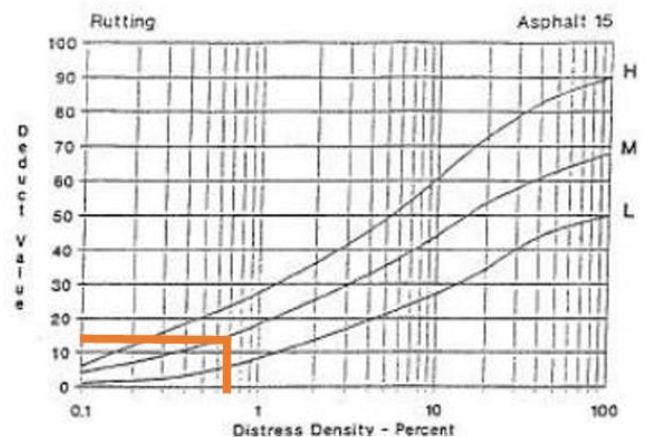


**Figure 6. Corrugation reduction value graph (ASTM international D 6433 – 07)**  
Source: Developed by the authors (2025)

On Route B, at segments KM 53+270 to KM 53+900, the pothole damage had a low severity with a density value of 0.2, corresponding to a deduct value of 30 (shown in Figure 7), while rutting (groove damage) at medium severity had a density of 0.627 and a deduct value of 13, as shown in Figure 8.



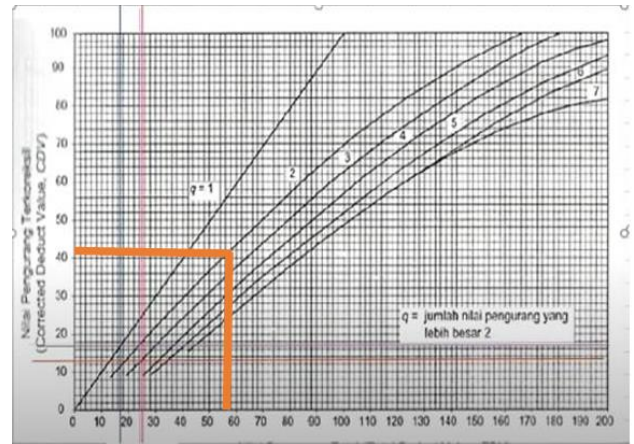
**Figure 7. Potholes reduction value graph (ASTM international D 6433 – 07)**  
Source: Developed by the authors (2025)



**Figure 8. Rutting reduction value graph (ASTM international D 6433 – 07)**  
Source: Developed by the authors (2025)

**3.3. Corrected Deduct Value (CDV) and PCI Analysis – Route A**

The corrected deduct value (CDV) was derived by applying interaction correction using Equation 6, which considers the number of deduct values exceeding 2. At segments KM 35+300 to KM 35+900, a total deductvalue (TDV) of 41 and multiple deduct values greater than 2 resulted in a CDV of 42, as illustrated in Figure 9. Consequently, the PCI was calculated using Equation 7, resulting in a value of 58. A summary of HDV, TDV, total TDV, q value, and CDV for all Route A segments is presented in Table 4.



**Figure 9. CDV graph (KM 35+300 – 35+900) (ASTM international D 6433 – 07)**  
Source: Developed by the authors (2025)

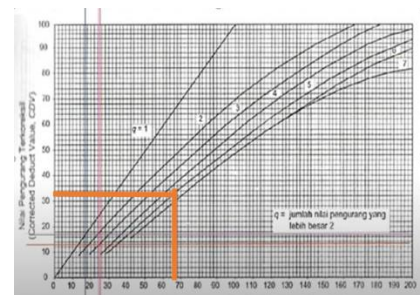
**Table 4. Calculation PCI (HDV, m, TDV, Total TDV, q, CDV) line A**

No	Location (KM)	Deduct Value	Hdvi	Mi	TDV	Total TDV	q	CDV	PCI	Condition	PCI average For Jakarta - Merak Segment	
f = Grafik												
1	31+600	32+200	20	20	8.3	20	0	20	1	18	82	Very Good
2	32+450	33+000	8	8	9.4	8	0	8	1	8	92	Very Good
3	33+500	34+800	4	13	9.0	13	4	17	1	18	82	Very Good
			13			13	2	15		17		
4	35+300-	35+900	20	21	8.3	21	20	41	1	42	58	Good
			21			21	2	23		24		
5	36+100	36+900	12	12	9.1	12	7	19	1	18	82	Vey good
			7			12	2	14		13		
6	37+000	37+900	10	33	7.15	33	20	63	2	45	48	FAIR
			33			33	20	55	1	52		
			20			33	2	37				61
43	+92+200	92+800	6	45	6.05	45	6	53	3	35	65	Good
			0			45	2	47	2	33		
			45									
44	+93+200	93+250	6	6	9.63	6	2	8	1	8	92	Very Good
45	+96+700	97+700	7	27	7.70	27	7	36	2	25	73	Good
			27			27	2	29	1	27		
			0									
TOTAL										2752		

Source: Developed by the authors (2025)

**3.4. Corrected Deduct Value (CDV) and PCI Analysis – Route B**

Similarly, for Route B at segments KM 53+270 to KM 53+900, a total TDV of 43 and two deduct values greater than 2 led to a CDV of 33. This is illustrated in Figure 10. The corresponding PCI calculated using Equation 7 was 67. The detailed calculation of all the variables for Route B is presented in Table 5.



**Figure 10. CDV graph (KM 53+270 – 53+900) (ASTM international D 6433 – 07)**  
Source: Developed by the authors (2025)

**Table 5. Calculation PCI (HDV, m, TDV, Total TDV, q, CDV) line B**

No	Location ( KM)	Deduct Value	Hdvi	Mi	TDV	Total TDV	q	CDV	PCI	Condition	PCI average For Merak - Jakarta Segment			
f = Grafik														
1	+56+000	56+280	18	49	5.7	49	18	2	69	2	47	53	fair	
			49			49	2		51	1	47			
			0											
2	+55+450	55+910	3	3	9.9	3	3	2	8	2	10	90	Very Good	
			3			3	2		5	1	8			
3	+54+830	54+890	23	23	8.1	23	1	2	26	2	18	82	Very Good	
			1			23	2		25	1	17			
4	+53+270	53+900	30	30	7.4	30	13		43	2	33	67	Good	
			13			30	2		32	1	30			
5	+51+050	51+800	12	12	9.1	12	2		14	2	12	88	Vey good	
			0											
6	+50+150	50+200	10	33	7.15	33	20	10	63	2	45	48	FAIR	54
			33			33	20	2	55	1	52			
			20			33	2	2	37					
42	+64+000	64+150	18	100	1.00	100	2		102	1	100	0	fail	
43	63+020	63+900	19	33	7.15	33	19	2	54	2	36	64	Good	
			33			33	2		35	1	33			
			0											
			0											
44	62+410	62+900	12	90	1.92	90	12	2	104	1	100	0	fail	
			90											
TOTAL											2363			

Source: Developed by the authors (2025)

### 3.5. Overall Pavement Condition Index (PCI)

PCI values across all segments were averaged to assess the general condition of each route. On Route A, the total PCI across 45 segments was 2,752, resulting in an average PCI of 61, indicating the pavement is in "good" condition. On Route B, the cumulative PCI across the 44 segments was 2,363, with an average of 54, categorized as "fair."

## 4. Discussion

The findings of this study demonstrate that the pavement condition of the Jakarta–Merak toll road, as assessed using the Pavement Condition Index (PCI) method based on ASTM D6433-07, varies significantly across segments and is strongly influenced by the type and severity of surface distress. In general, Route A (Jakarta–Merak) exhibited more severe pavement deterioration than Route B (Merak–Jakarta), especially in segments where potholes and block cracking were dominant at higher severity levels. This observation is consistent with research by Putra et al. [15], who found that potholes and surface deformation are the most prevalent types of damage on Indonesian urban toll roads.

Based on the calculated PCI values, several segments fall into the "Poor" to "Fair" condition categories, indicating that although full reconstruction may not yet be required, these areas need immediate maintenance to prevent further degradation. These results align with those of Shahin [16], who emphasized that early and preventive maintenance significantly reduces future repair costs and extends pavement service life. When

compared with similar studies in Southeast Asia, such as Nguyen and Pham [17], who assessed Vietnamese national highways, the levels of damage in this study were relatively moderate, but showed a consistent pattern in terms of the types of distress, particularly potholes and rutting. One contributing factor is the high intensity of heavy vehicle traffic on the Jakarta–Merak route, which, according to Tjokro and Salim [18], contributes to the rapid structural wear and fatigue.

The PCI method used in this study provides a standardized framework for evaluating pavement conditions through a combination of deduct value calculations and visual surveys. However, compared to newer methods involving real-time monitoring systems or AI-based detection, such as those described by Rahman and Wahid [19], the PCI method has limitations, including the degree of subjectivity in visual inspection. Therefore, future assessments could benefit from the integration of traditional PCI analysis with automated scanning technologies or drone imagery to increase the accuracy and efficiency.

One of the strengths of this study is the use of primary field data from both directions of the toll road, which enables a direct comparison of the two routes. In addition, the use of ASTM standards enhances the reliability of the findings and allows them to be referenced in wider international contexts. However, this study has some limitations. The primary limitation lies in the reliance on surface-level visual inspections without the use of supporting tools, such as the Falling Weight Deflectometer (FWD), which could offer insights into subsurface conditions. Moreover, this study does not explore the influence of external environmental

factors, such as drainage systems, subgrade stability, and climatic conditions, which are known to affect pavement performance, as discussed by Molenaar et al. [20].

The data used in this research reflect the conditions at a specific time, meaning that long-term deterioration trends are not captured. A longitudinal approach would offer more detailed insights into how pavement conditions evolve under ongoing traffic and weather conditions. Overall, this study concludes that the primary pavement distress affecting PCI values on the Jakarta–Merak toll road includes potholes, block cracking, corrugation, and rutting, with each contributing at varying levels depending on the road segment. PCI analysis has proven to be a practical method for identifying maintenance priorities and directly addressing the research question related to pavement condition classification and maintenance strategy planning.

From a practical standpoint, the use of PCI-based evaluations should be incorporated into regular maintenance programs, especially for toll roads that experience high volumes of freight traffic. This method can be further developed into a comprehensive Pavement Management System (PMS) to improve predictive maintenance decisions and resource allocation. It is recommended that stakeholders in road infrastructure combine PCI analysis with more advanced technologies to overcome the limitations in accuracy and detection. Future research should expand the scope of the analysis to include environmental, structural, and economic factors to construct a more holistic model for road performance management.

## 5. Conclusion

This study evaluated the pavement condition of the Jakarta–Merak toll road using the Pavement Condition Index (PCI) method outlined in ASTM D6433. The analysis revealed 118 types of surface damage on the Jakarta–Merak route and 108 on the Merak–Jakarta route. These include potholes, block cracking, longitudinal cracking, rutting, corrugation, and bleeding. The PCI assessment covered 45 segments in Route A and 44 segments in Route B. The lowest PCI values on Route A were recorded at STA 39+100 to STA 39+700 and STA 59+100 to STA 59+900 (classified as Fail), as well as at STA 57+860 to STA 58+900 and STA 74+200 to STA 74+850 (Very Poor). On Route B, the Fail classifications were observed at STA 62+410 to STA 62+950, STA 64+000 to STA 64+150, and STA 69+150 to STA 69+350, whereas Very Poor conditions were noted at STA 39+200 to STA 39+400 and STA 75+700 to STA 75+900.

The average PCI value for the Jakarta–Merak direction was 61, indicating good condition, whereas the Merak–Jakarta direction averaged 54, placing it in the Fair category. These findings highlight the need for

immediate maintenance in segments with PCI values below 50, for which major maintenance, such as overlay or full-depth reconstruction, is recommended. Furthermore, given that the Jakarta–Merak toll road is a long-standing corridor with high volumes of freight traffic, routine maintenance is essential for ensuring sustained serviceability and safety.

Although the PCI method provides an effective snapshot of the current pavement conditions, it does not offer predictive insights into future deterioration. This is a limitation of the current study, and future research should consider integrating PCI analysis with predictive modeling or structural evaluation tools, such as the Falling Weight Deflectometer (FWD) or pavement performance forecasting systems. Additionally, broader investigations into the impact of environmental conditions, subgrade strength, and drainage systems are recommended to develop more comprehensive pavement management strategies.

The academic contribution of this study lies in its systematic application of the PCI method along a major Indonesian freight corridor, producing a segment-level diagnosis of surface damage that can directly inform maintenance prioritization.

Unlike previous studies that provide general assessments, this study highlights critical failure zones supported by quantitative PCI values and spatial references, thereby offering actionable insights for infrastructure management.

This study recommends the implementation of immediate major maintenance on segments rated as “Very Poor” and “Fail,” and suggests routine monitoring using PCI in combination with structural tools to enhance predictive capabilities.

Future research should integrate this methodology with long-term performance models to support sustainable and data-driven pavement asset management in Indonesia.

## Declarations

### *Author Contributions*

Conceptualization: J.P.P. and L.S.P.; methodology: J.P.P.; software: J.P.P.; validation: J.P.P., L.S.P., and R.B.A.; formal analysis, J.P.P.; investigation, J.P.P.; resources, J.P.P.; data curation, J.P.P.; writing—original draft preparation, J.P.P.; writing—review and editing, L.S.P.; visualization, J.P.P.; supervision, L.S.P.; project administration, J.P.P.; funding acquisition, J.P.P. All authors read and agreed to the published version of the manuscript.

### *Data Availability Statement*

The data presented in this study are available upon request from the corresponding authors. The data were

not publicly available because of institutional privacy restrictions.

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#### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this manuscript. All ethical considerations including plagiarism, informed consent, data integrity, and publication ethics were fully observed.

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