Vol. 10 No. 02 October 2025
DOI: 10.29244/jsil.10.2.337-346

Analysis of Road Surfacing Using the Pavement Condition Index (PCI) and Surface Distress Index (SDI)

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Abstract: A roadway is an important infrastructure for the smooth flow of the economy. High traffic volume and frequent use decrease the quality of the road and affect traffic comfort. It is important to maintain roads regularly, effectively, and efficiently. The PCI and SDI methods are effective ways to evaluate road damage advantages reflecting the actual condition of the damage. This study aim to analyze the condition of the road and comparing the maintenance cost based on assessment result from this two methods. The location conducted on connecting road at Cilubang Mekar Road in the city of Bogor. The survey covered damage such as alligator cracking, edge cracking, shoulder settlement, patching, potholes, and deterioration. The PCI value was 66.92, indicating a moderate rating, and the SDI value was 35, indicating a good rating. The recommended methods for handling the severity using the City Road Maintenance System Guidelines No. 02/P/BM/2025 are P2 (paving), P5 (patching), P6 (leveling), and U3 (regrading). An overlay of 4 cm is also recommended. The estimated cost of repairing the Cilubang Mekar road is Rp 50,021,000 based on the PCI method and Rp 30,336,000 based on the SDI method. However, since patching and potholes significantly impact the road, it is sufficient to use the SDI method for repairs.

Submitted: 25 Aug 2025
Revised: 21 Oct 2025
Accepted : 24 Oct 2025

Keywords: *Road Assesment*; *pavement condition index*; *surface distress index*

1. Introduction

Roads are an important infrastructure for facilitating economic and cultural exchange between regions in Indonesia. Good road conditions improve human accessibility for social and economic activities. Economic growth in an area can increase if its network system development has good accessibility [1]. Highways have different roles and benefits, which will only operate efficiently if they are in good condition. Such conditions will facilitate human mobility and ease connectivity with other sectors. Conversely, if roads are in poor condition and damaged, this will result in reduced comfort, safety, and road performance below optimal levels [2].

However, as economic activity increases, heavy traffic volume and high frequency affect road construction conditions. Road construction quality will decline, thereby reducing comfort and safety in traffic [3]. Damaged roads increase the risk of accidents for road users. The impact of reduced comfort can be felt directly (such as when crossing potholes) or indirectly (such as traffic speed reductions). The potential hazards of damaged roads directly affect road users. Driving comfort is also disrupted directly (such as when crossing potholes) or indirectly (such as vehicle slowdowns) [4]. Vehicle slowdowns have a domino effect, causing traffic congestion. This results in increased travel time for vehicles [5].

Road damage is a common problem in land transportation. Indonesia's national road network, which spans 348,241 km, is still not optimal. Only about 54% of roads are in good or adequate condition, while nearly 46% or a significant portion of the national road network is in poor condition. Provincial road networks, according to data, are in slightly better condition than the national road network [6]. Massive road construction without proper maintenance will lead to the deterioration of existing road conditions [7].

Regular road maintenance is important to maintain the quality of roads for the benefit of road users. Road maintenance efforts can take the form of repairing, improving, or replacing existing pavement in the field. Road maintenance activities require considerable costs [8]. Therefore, in practice, comprehensive planning is required to determine the type of treatment. Therefore, the selection of road damage repair methods is based on an evaluation of the extent of road damage [9]. The Pavement Condition Index (PCI) is a structural road condition assessment system, while the Surface Distress Index (SDI) is a functional road condition assessment system. Both methods use visual assessment to determine the type of road maintenance [10]. The PCI method has been widely adopted in various countries, including Indonesia. This method has been officially regulated in accordance with Circular Letter No. 19/SE/M/2016. Meanwhile, the SDI method has been used by the Ministry of Public Works for measuring the condition of national roads based on Decision No. 02/M/BM/2006. Based on field research in Indonesia [11], the PCI and SDI methods have proven to be more sensitive and reflective of the actual condition of road damage because they capture visual damage details compared to other methods such as IRI and PSI.

Data from the Central Statistics Agency (BPS) of Bogor City in 2022 [12] states that the total length of roads in Bogor City is 859,979.84 km. The breakdown of road conditions is as follows: 339,930.98 km in good condition, 418,815.56 km in fair condition, 83,010.50 km in minor disrepair, and 18,222.80 km in disrepair. Cilubang Mekar Road serves as a connecting route between the Bogor Agricultural University (IPB) campus and the Situ Gede tourist area. Additionally, Cilubang Mekar Road also functions as an alternative route for students heading to the Bogor Agricultural University (IPB) campus. This route experiences relatively high vehicle traffic intensity. The high vehicle traffic intensity is a factor contributing to road surface damage. Therefore, this study aims to identification surface damage and scoring using the PCI and SDI methods on the Cilubang Mekar Road and determine the appropriate maintenance measures and associated costs based on Bogor City Unit Price Analysis (AHSP) .

2. Methodology

2.1. Material

The research was conducted on Cilubang Mekar Road, Bogor City, covering a distance of 600 m. The Cilubang Mekar Road study began at STA 0+000, located at coordinates 6°33'5.10"S and 106°44'15.20"E, and ended at STA 0+600, located at coordinates 6°33'7.20"S and 106°44'34.50"E. The research location map can be seen in **Figure 1**. The tools used during the research consisted of measuring instruments, including a measuring tape, measuring tape, and ruler, writing tools for recording data, a camera for documentation, and a laptop for data processing. The materials used in the research were the PCI survey form and the Road Condition Survey form.

2.2. Research Procedures

The research began with a literature study and preparation of tools and materials. Then, the total road area was measured by measuring the length and width of the road. The total road area determines the division of road segmentts. The PCI method refers to ASTM D6433-18 [13] and PD-01-2016-B [14] regarding the Pavement Condition Index Guidelines, which refer to ASTM 6433-09. The PCI method is divided into two types of pavement: flexible pavement and rigid pavement. The pavement at the study site is asphalt, thus falling under the flexible pavement category. The research location is divided into 12 segmentts, each 50 meters long, as shown in **Figure 2**. This follows the reference requirement for each segmentt to be (225±90) m2 in area. The SDI method refers to SMD-03/RCS [15] on Road Condition Survey Guidelines. The SDI method assesses the condition of asphalt roads per kilometer of road.

Figure 1. Research Location

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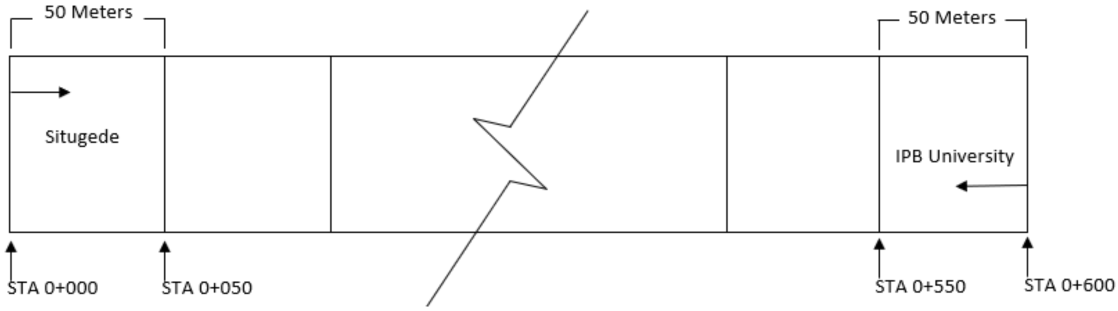

Figure 2. Road are devided into segment

2.2.1. Metode Pavement Condition Index

The assessment of road surface conditions using this method is carried out visually and recorded per 50 meters each segment in a survey form according to the type of distress, such as Alligator cracking, Pothole, Patching, Edge cracking, Shoulder drop, Weathering including length, depth and area each distress. The severity of damage is assessed using the categories low (L), medium (M), and high (H). This data is processed into parameters such as density, deduct value, total deduct value, permitted deduct value, and corrected deduct value. Damage density is the percentage ratio of the area or length of one type of distress to the area of the observation segment. Damage density values can be calculated using **Equations** (1) or (2).

$$Density = \frac{Ad}{As} \times 100\% \quad (1)$$

$$Density = \frac{Ld}{As} \times 100\% \quad (2)$$

where,

Ad : Total area of damage for each type and level of damage (m^2)

Ld : Total length of damage for each type and level of damage (m^2)

As : Total area of road segmentts (m^2)

Then, the deduct value is read based on the graph in the ASTM D6433-18 [astm] reference. The deduct value is a value that describes the type, severity, and density of damage to a pavement layer in the assessed segmentt. The magnitude of the deduct value is directly proportional to the severity of the damage. The determination of the deduct value is performed using a curve showing the relationship between density and deduct value, which varies depending on the type of damage. The deduct value used for road pavement is one with a value > 2. If there is only one or even none with a value > 2, then the total deduct value used is the corrected deduct value (CDV). The deduct values are sorted from the largest. Next, the deduct value permission value (m) is calculated using Equation (3). This value is used to determine the number of deduct values used.

$$m = 1 + \left(\frac{9}{98}\right) \times (100 - HDV) \quad (3)$$

Where,
m : Allowable number ofdeduct value
HDV : Highest deduct value

Next, the corrected deduct value for each segmentt is calculated using an iterative technique. Deducted values greater than 2 are totaled. The corrected deduct value is determined from the total corrected deduct value of individual deduct values greater than 2, then linked to the q value using the CDV curve. Iteratively, deduct values greater than 2 are adjusted to 2. This adjustment is repeated until q = 1. The largest CDV value in a single iteration cycle is used to determine the PCI value using equation (4), and the PCI values are averaged using equation (5). The obtained PCI values are identified based on the PCI value rankings in **Figure 3**.

$$PCI = 100 - CDV\ maximum \quad (4)$$

$$PCIr = \frac{\sum_{i=1}^{n}(PCIri \times Ari)}{\sum_{i=1}^{n}(Ari)} \quad (5)$$

Where,
CDV maximum : corrected deduct value maximum each segmentt
PCIr : Average PCI value overall segmentt
PCIri : PCI value segment-i
Ari : Area segment-i

Figure 3. PCI Rating Scale [13]

2.2.2. Surface Distress Index

The SDI method calculation requires four assessment components based on the SMD-03/RCS [15] reference. These components are the area and average width of cracks, the number of potholes per kilometer, and the average depth of wheel ruts. The SDI value is calculated through four continuous steps. The percentage of crack area relative to the total area is identified based on **Table 1** to obtain the SDI1 value. The average crack width is then assessed based on **Table 2** to obtain the SDI2 value. The assessment continues based on the number of potholes as shown in **Table 3**. Finally, the assessment is based on the depth of wheel ruts as shown in **Table 4**, resulting in the final SDI value.

Table 1. Total crack area assessment (SDI^1) [15]

No	Crack area level	SDI^1
1	N/A	-
2	< 10%	5
3	10 – 30%	20
4	>30%	40

Table 2. Average crack width assessment (SDI^2) [15]

No	Crack width level	SDI^2
1	N/A	SDI^1
2	fine (< 1 mm)	SDI^1
3	Medium (1-3 mm)	SDI^1
4	Wide (>3 mm)	$SDI^1 \times 2$

Table 3. Total pothole assessment (SDI^3) [15]

No	Crack area level	SDI^3
1	N/A	SDI^2
2	< 10 / km	$SDI^2 + 15$
3	10 – 50 / km	$SDI^2 + 75$
4	>50 / km	$SDI^2 + 225$

Table 4. Rutting Depth Assessment (SDI) [15]

No	Crack area level	SDI
1	N/A	SDI^3
2	< 1 cm	$SDI^3 + 5 \times 0,5$
3	1 – 3 cm	$SDI^3 + 5 \times 2$
4	>3 cm	$SDI^3 + 20$

2.2.3. Cost Estimation

The calculation of road damage repair costs is carried out using work volume data obtained from determining the level of road damage. In addition, a repair priority sequence is also required as a reference in determining the type of road maintenance or repair. The work volume will be calculated using the unit price analysis (AHSP) from the Bogor City Public Works Agency 2025 so that the total road repair costs can be obtained.

3. Result and Discussion

3.1. Type of distress

A visual survey was conducted at the research site on Cilubang Mekar Road. There were six types of damage to the road asphalt out of the 19 types of damage listed in ASTM D6433-18. These types of damage included alligator cracking, edge cracking, shoulder deterioration, patching, potholes, and weathering.

Table 5. PCI Results of the Cilubang Mekar Road

Distress	Value	Units
Weathering	1075.20	m^2
Patching	648.00	m^2
Side Cracking	54.60	m^2
Alligator Cracking	6.19	m^2
Shoulder drop	77.30	m
Pothole	6.00	point

Based on Table 5, it can be seen that weathering is the most significant type of damage, covering an area of 1,075.20 m² of the total area of Cilubang Mekar Road. This may be due to the pavement layer being unable to withstand weather conditions and traffic loads that are not appropriate. The next type of damage is patching, covering an area of 648 m². This damage occurs due to insufficient compaction during patching. There are also edge cracks covering an area of 54.60 m², which may have occurred due to poor drainage combined with heavy traffic loads along the road edges. In addition to edge cracks, there are also alligator cracks covering an area of 6.19 m². Alligator cracks occur due to fatigue in the underlying soil layer caused by traffic loads. Shoulder subsidence also occurred along the raod over a length of 77.30 m. Shoulder subsidence can occur due to unstable road shoulders that are frequently loaded by vehicles and has six potholes. This type of damage can occur due to cracks filled with water and loaded by vehicles, causing the asphalt to crack. These damages reduce the final PCI value.

3.2. PCI Assessment Method

PCI assessment uses deduct value. Deduct value is a deduction value that will describe the combined effect of various types and levels of damage severity. The higher the deduct value, the more severe the damage. This value is obtained by reading the curve of the relationship between density and deduct value for each type and level of damage. The total deduct value is determined by adding all deduct values. The total deduct value is then summed for each segment and corrected by the number of individual deduct values greater than 2. The total deduct value (TDV) is then linked to the relationship curve between q and TDV. Deduct values greater than 2 are reduced to 2 through iteration until q=1 is obtained. The PCI value is obtained by subtracting the highest corrected deduct value in an iteration from 100.

Based on the results of the PCI calculation recapitulation in **Table 6**, the quality of the Cilubang Mekar road pavement is in the moderate category with a PCI value of 66.92. Four segments are in the good category because the number and type of damage that occurred did not significantly affect the PCI value reduction factors. However, the segment STA 0+000 - 0+050 has a relatively low PCI value, categorizing it as poor quality. This is due to the numerous potholes in that segment, and the weighting for pothole damage in the PCI calculation is quite high.

Table 6. PCI assessment result

Segment	*PCI*	*Level of Severity*
STA 0+000 - 0+050	46	Poor
STA 0+050 - 0+100	70	Satisfied
STA 0+100 - 0+150	66	Fair
STA 0+150 - 0+200	62	Fair
STA 0+200 - 0+250	80	Satisfied
STA 0+250 - 0+300	68	Fair
STA 0+300 - 0+350	64	Fair
STA 0+350 - 0+400	67	Fair
STA 0+400 - 0+450	68	Fair
STA 0+450 - 0+500	82	Satisfied
STA 0+500 - 0+550	72	Satisfied
STA 0 +550 - 0+600	58	Fair
Average PCI	66.92	Fair

3.3. SDI Assessment Method

The SDI method is carried out by identifying the percentage of crack area relative to the total pavement area. The Cilubang Mekar road was found to have crack damage at several points. Segments with a crack area percentage of less than 10% of the road have an SDI1 value of 5, while segments without cracks have an SDI1 value of 0. The average crack width across all segments was 1-3 mm, classified as moderate width, so the SDI2 value is the same as SDI1. The SDI3 value is obtained from the accumulation of the number of potholes per kilometer. The length of the road segment at the study site is 100 meters, so the number of potholes must be converted by multiplying the number of potholes per 100 meters of road by 10. For segments with more than 10 potholes per kilometer, SDI2 is increased by 15; for 10–50 potholes per kilometer, SDI2 is increased by 75; and if there are no potholes, SDI3 remains unchanged. Additionally, no tire marks were found on any segment, so the final SDI value is the same as SDI3. The summary of SDI values for the Cilubang Mekar Road is presented in **Table 7**.

Table 7. SDI Result of Cilubang Mekar Road

Segment	Crack area (m^2)	Percentage (%)	Crack width (mm)	Pothole/km	
STA 0+000 - 0+100	35.83	8.96	1-3	40	-
STA 0+100 - 0+200	7.64	1.91	1-3	0	-
STA 0+200 - 0+300	12.70	3.18	1-3	10	-
STA 0+300 - 0+400	2.06	0.52	1-3	0	-
STA 0+400 - 0+500	0.00	0.00	1-3	0	-
STA 0+500 - 0+600	2.56	0.64	1-3	10	-

Based on the SDI value calculations shown in **Table 8**, Cilubang Mekar Road is in the good category with one segment in the moderate category. Unlike the PCI value, which tends to be moderate, this is because the SDI assessment only looks at four types of damage. The damage that dominates in Cilubang Mekar street is weathering and patching. These types of damage are not considered in the SDI method. Therefore, the relationship between the PCI and SDI calculation results is analyzed. As a result, the average SDI value obtained is 35, classified as good.

Table 8. SDI Assessment Result

Segment	SDI[1]	SDI[2]	SDI[3]	SDI	Level
STA 0+000 - 0+050	5	5	80	80	Fair
STA 0+050 - 0+100	5	5	5	5	Good
STA 0+100 - 0+150	5	5	20	20	Good
STA 0+150 - 0+200	5	5	5	5	Good
STA 0+200 - 0+250	0	0	0	0	Good
STA 0+000 - 0+050	5	5	20	20	Good

3.4. Recomendation and Manintenance Cost

Based on the City Road Maintenance System Guidelines No. 02/P/BM/2025, moderate damage requires a thin overlay of 4 cm thick structure to improve pavement structure capacity [16]. Routine maintenance is then carried out to improve the functional capacity of the road. Routine maintenance is based on the Standard Repair Manual for Routine Road Maintenance No. 001-02/M/BM/2011. The methods used for the Cilubang Mekar Road are P2 (asphalting), P5 (patching), P6 (leveling), and U3 (re-sloping) [17]

The P2 (asphalting) method was applied due to alligator cracking with crack widths below 2 mm. The P2 method involved cleaning the affected areas with an air compressor, spreading coarse sand with a thickness >10 mm, and compacting it with a baby roller. Then, the P5 (patching) method was applied due to damage to the road pavement edges. The P5 method involved excavating the pavement layer, adding Class “A” aggregate, applying a prime coat, and covering it with cold mix. Next, the P6 method (leveling) was performed due to damage caused by potholes with a depth of less than 50 mm. The P6 method was carried out by applying a tack coat and covering it with cold mix. The U3 method was performed by scraping the area with a motor grader, then adding class “A” aggregate, leveling it, and creating a slope with a motor grader [17].

Summary for maintenance cost based on PCI method in Cilubang Mekar Road among other, Mobilization including demobilization, P2 asphalting, P5 Patching, P6 Leveling, U3 Re-sloping and Overlay forasmuch as SDI method Mobilization, P2 asphalting, P5 Patching, P6 Leveling, U3 Re-sloping. Total cost each method add Value-Added Tax 11%.

The cost required for repairing damage to the Cilubang Mekar Road using the PCI method is Rp 50,021,000, and the cost of repair using the SDI method is Rp 30,336,000. The quantity of work has been adjusted according to the extent of damage for each method. The budget plan was prepared based on the 2025 Bogor City Unit Price Analysis (AHSP) and several price surveys at local building supply stores in Bogor City. The cost required under the PCI method is higher because it involves structural repairs such as road overlay for damage caused by deterioration. Meanwhile, the road condition under the SDI method is considered good, so routine maintenance without structural improvements is sufficient.

4. Conclusion

Based on the research conducted on Cilubang Mekar Road, this study can be summarized as follows.

1. There are six types of damage to the Cilubang Mekar Road, namely alligator cracking, edge cracking, shoulder subsidence, patches, potholes, and weathering. The severity of the damage ranges from low to moderate. Deterioration is the most significant type of damage compared to others.

2. The road condition assessment using the PCI method yielded a score of 66.92 with a moderate rating, while the SDI method resulted in a score of 35 with a good rating. These scores are the average of 12 road segments.
3. Damage management recommendations are based on the final results of the PCI method, which involves routine maintenance using the P2 (asphalting), P5 (patching), P6 (leveling), and U3 (re-sloping) methods to prevent further damage. Structural improvements in the form of a 4 cm overlay are then carried out to repair weathering damage. Meanwhile, the SDI method only involves routine maintenance without an overlay.
4. The budget plan required for damage management on the Cilubang Mekar Road is IDR 50,021,000 according to the PCI method and IDR 30,336,000 according to the SDI method. However, since only patching and potholes have a significant impact, management using the SDI method alone is sufficient.

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