BULLETIN OF ENGINEERING SCIENCE, TECHNOLOGY AND INDUSTRY
https://bestijournal.org | PT. Radja Intercontinental Publishing
E-ISSN: 3025-5821

ASSESSMENT OF RIGID PAVEMENT CONDITION USING PAVEMENT CONDITION INDEX METHOD ON THE DENAI-MANDALA BYPASS ROAD SECTION IN MEDAN CITY

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Abstract
Road pavement is a critical component of the transportation system that requires maintenance to ensure the pavement remains safe and comfortable for traffic users. Assessing road conditions is crucial for identifying various types of potential damage, thus necessitating specific methods for evaluating road damage conditions. The Pavement Condition Index (PCI) method is commonly used to assess pavement conditions. The aim of this research is to evaluate rigid pavement damage on the Denai-Mandala Bypass road section in Medan City using the Pavement Condition Index (PCI) method. The methodology used in this research involves field surveys for collecting pavement condition data and analyzing the data using the PCI method to determine pavement conditions and types of damage. This research indicates that the rigid pavement on the Denai-Mandala Bypass road section in Medan City experiences various types of damage, including corner break (2 occurrences), divided slab (1 occurrence), durability ("D") cracking (2 occurrences), faulting (6 occurrences), joint seal damage (10 occurrences), linear cracks (78 occurrences), patching large (11 occurrences), patching small (1 occurrence), polished aggregate (5 occurrences), punchout (2 occurrences), scalling (4 occurrences), shrinkage cracks (10 occurrences), spalling corner (5 occurrences), and spalling joint (30 occurrences). The average PCI value on the Denai road section examined for approximately ±1.4 km is 78.53, categorized as satisfactory with periodic maintenance as the priority for handling, while on the Mandala Bypass road section examined for approximately ±800 m, the average PCI value is 89.93, categorized as very good with routine maintenance as the priority for handling. Assessing pavement conditions using the PCI Method aids in identifying occurring damage and provides necessary information for effective pavement repair planning.

Keywords: PCI, Rigid Pavement, Distress Type

1. INTRODUCTION

Highway is a transportation system that connects various regions and plays a crucial role in facilitating human activities as well as meeting mobility needs to achieve economic and non-economic objectives. As part of the ground transportation infrastructure, roads must provide optimal service to support all activities related to ground transportation. In this regard, the comfort and safety of traffic users are greatly influenced by the condition of the road infrastructure they traverse. Damaged road conditions undoubtedly hinder the smooth movement of goods and services. According to (Sukirman, 1999), road damage is generally caused by several factors, such as aging roads that exceed their planned lifespan, water pooling on the road surface due to inadequate drainage systems, heavy traffic loads accelerating road deterioration, inaccurate planning, implementation not following initial plans, and lack of road maintenance.

In 2017, the Denai-Mandala Bypass road section located in Medan Denai District, Medan City underwent reconstruction due to damage, converting from flexible pavement to rigid pavement. The enhancement of the pavement structure was carried out to improve the deteriorated road condition and ensure its efficient operation in serving traffic, thereby achieving the desired planned lifespan. However, newly discovered road damage post-repair is a recurring issue, indicating the need for evaluation to identify various types of damage and appropriate maintenance techniques based on the identified damage types.

To identify various types of surface road damage, visual surveys are necessary to analyze the damage based on type and severity. One method used to identify road damage is the Pavement Condition Index (PCI) method. According to (Shahin, 2005), the Pavement Condition Index (PCI) is an assessment index ranging from 0 to 100, calculated based on visual surveys of damage types, severity levels, and quantities identified. Information on the damage obtained can be used as a reference for addressing road construction issues. In the context mentioned, this research will evaluate damage based on type, severity, and quantity. The evaluation of road damage will be conducted using the Pavement Condition Index (PCI) approach. The advantage of the PCI method over other approaches is its widespread adoption and internationally accepted standards for road condition assessment (Shahin, 2005). By using PCI, actions to repair or maintain roads with the highest priority based on low PCI scores can be undertaken, aiding in more effective allocation of resources to repair roads most in need of attention.

2. LITERATURE REVIEW

The literature review starts with gathering scientific data and information from various sources such as books, scientific journals, regulations, and others to gain a deep understanding of theories, methods, and approaches relevant to the research. One of the stages in research is the data collection process, which is crucial for obtaining the data used in this study. At this stage, the required data for this research is categorized into primary data and secondary data.

1) Primary Data

The primary data in this research is obtained based on visual surveys conducted in the field. This study requires several types of primary data, including the types and severity levels of damage, the quantity of damage, and the coordinates of each damage site. The mechanism for collecting primary data is described as follows:

a. This research is conducted on a road section with rigid pavement at Denai-Mandala Bypass in Medan. The study area spans 2.2 km, with approximately 1.4 km surveyed on Denai road and around 800 m on Mandala Bypass road.
b. In conducting the survey, measurements are performed on each selected sample unit according to ASTM D6433-11. Once the sample units are determined, a sketch of each sample unit including its orientation (road name, sample unit number, etc.) can be made on the survey form template adopted from the Ministry of Public Works and Housing Pavement Condition Index (PCI) Guidelines.

2) Secondary Data

Secondary data refers to information obtained from existing data sources. In this study, one of the required secondary data is GIS data in the form of a shapefile. A shapefile is a geospatial data format used in Geographic Information Systems (GIS) to store information about geographic locations and associated attributes. This data will be used to assist in creating a Map of Damage Types at the research site.

3. METHOD

At this stage, there are several data processing techniques used to calculate the PCI value, including:

1) Calculating density.
2) Determining the deduct value for each type of damage.
3) Calculating the maximum allowable value (m).
4) Determining the corrected deduct value.
5) Calculating the PCI (Pavement Condition Index) for each sample unit and calculating the PCI (Pavement Condition Index) for the road section.

4. RESULTS AND DISCUSSION

4.1 Survey Data Collection

In survey data collection at the research site, there are several stages that must be conducted, as follows:

1) Determination Of Sample Units (N)

According to the (ASTM D6433-11 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys 1, 2011), Section 2.1.7 on page 1 specifies the requirement for 20 contiguous slabs (±8 slabs if the number of slabs at the site under review cannot be divided by 20 or to accommodate specific field conditions). Additionally, Section 7.3 on page 2 states that if rigid pavement slabs have joint distances exceeding 8 m (25 feet), each slab should be divided into imaginary slabs, each with a length equal to or smaller than 8 m (25 feet). The imaginary joints separating these imaginary slabs should be considered to have perfect conditions. Referring to these requirements, the determination of sample units according to the conditions at the research site can be seen in Table 1 and Table 2.

Table 1. Sample units for denai Road

Sample	Stationing	Length (m)	Sample	Stationing	Length (m)
1	0+000 – 0+052	52	17	0+743 – 0+779	36
2	0+052 – 0+107	55	18	0+779 – 0+815	36
3	0+107 – 0+154	47	19	0+815 – 0+850	35
4	0+154 – 0+207	53	20	0+850 – 0+888	38
5	0+207 – 0+255	48	21	0+888 – 0+924	36
6	0+255 – 0+309	54	22	0+924 – 0+963	39
7	0+309 – 0+365	56	23	0+963 – 0+998	35
8	0+365 – 0+417	52	24	0+998 – 1+037	39
9	0+417 – 0+467	50	25	1+037 – 1+074	37
10	0+467 – 0+515	48	26	1+074 – 1+107	33
11	0+515 – 0+558	43	27	1+107 – 1+145	38
12	0+558 – 0+591	33	28	1+145 – 1+185	40
13	0+591 – 0+629	38	29	1+185 – 1+222	37
14	0+629 – 0+669	40	30	1+222 – 1+259	37
15	0+669 – 0+705	36	31	1+259 – 1+296	37
16	0+705 – 0+743	38	32	1+296 – 1+323	27

Table 2. Sample units for mandala bypass road

Sample	Stationing	Length (m)	Sample	Stationing	Length (m)
1	0+000 – 0+029	29	13	0+356 – 0+385	29
2	0+029 – 0+061	32	14	0+385 – 0+414	29
3	0+061 – 0+090	29	15	0+414 – 0+445	31
4	0+090 – 0+120	30	16	0+445 – 0+474	29
5	0+120 – 0+149	29	17	0+474 – 0+504	30
6	0+149 – 0+178	29	18	0+504 – 0+534	30
7	0+178 – 0+207	29	19	0+534 – 0+564	30
8	0+207 – 0+238	31	20	0+564 – 0+592	28
9	0+238 – 0+267	29	21	0+592 – 0+623	31
10	0+267 – 0+297	30	22	0+623 – 0+653	30
11	0+297 – 0+327	30	23	0+653 – 0+681	28
12	0+327 – 0+356	29			

2) Determination Of Minimum Number Of Sample Units (n)

The minimum number of sample units (n) to be surveyed in a specific section needs to be calculated to ensure statistically adequate estimation of PCI (with a 95% confidence level), calculated using the following equation:

$$n = \frac{Nd^2}{\frac{e^2}{4}(N-1) + d^2} \quad (1)$$

Where:
n = minimum number of sample units
N = total sample units
d = standard deviation (value is 15 for rigid pavement)
e = acceptable error in estimating PCI (value is 5)
In utilizing the aforementioned equation, thus:
For denai road
n is calculated as 32 x 15^2 / ((5^2 / 4)(32 – 1) + 15^2)
n equals 17,2 ≈ 17 sample units
For mandala bypass road
n is calculated as 23 x 15^2 / ((5^2 / 4)(23 – 1) + 15^2)
n equals 14,3 ≈ 14 sample units

3) Determination Of Spacing Interval (i)

The determination of the spacing interval between units is computed using systematic random sampling, calculated by the following equation:

$$i = \frac{N}{n} \quad (2)$$

Where:
i = spacing intervals
N = total sample units
n = minimum number of sample units
In utilizing the aforementioned equation, thus:
For denai road
i = N/n = 32/17 = 1,9 ≈ 1 (rounded down)
The value of i is 1. Starting with a randomly chosen sample unit (s), for example, s = 1. The surveyed sample units are numbered: s, s + (i), s + (2i), s + (3i), s + (4i), and so on, resulting in the numbering of sample units: 1, 1+(1) = 2, 1+(2x1) = 3, 1+(3x1) = 4, 1+(4x1) = 5, and so forth as shown in Figure 1.
For mandala bypass road
i = N/n = 32/17 = 1,9 ≈ 1 (rounded down)
The value of i is 1. Starting with a randomly chosen sample unit (s), for example, s = 1. The surveyed sample units are numbered: s, s + (i), s + (2i), s + (3i), s + (4i), and so on, resulting in the numbering of sample units: 1, 1+(1) = 2, 1+(2x1) = 3, 1+(3x1) = 4, 1+(4x1) = 5, and so forth as shown in Figure 2.

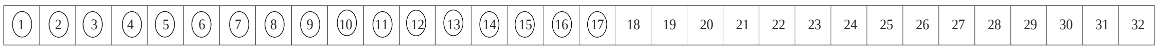

Figure 1. The systematic sampling of sample units on denai roads

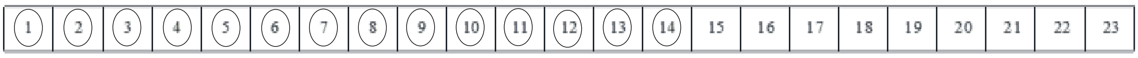

Figure 2. The systematic sampling of sample units on mandala bypass roads

4) Survey Of Rigid Pavement Damage

After determining the number of sample units to be surveyed, the next step involves conducting a visual survey on each sample unit. The surveyed data includes the type of damage, severity level, and quantity of damage in terms of the number of concrete panels/plates affected. Based on the survey results at the research site, here is an overview of the diagram illustrating the types and quantities of damage found on the rigid pavement of the Denai-Mandala Bypass road in Medan.

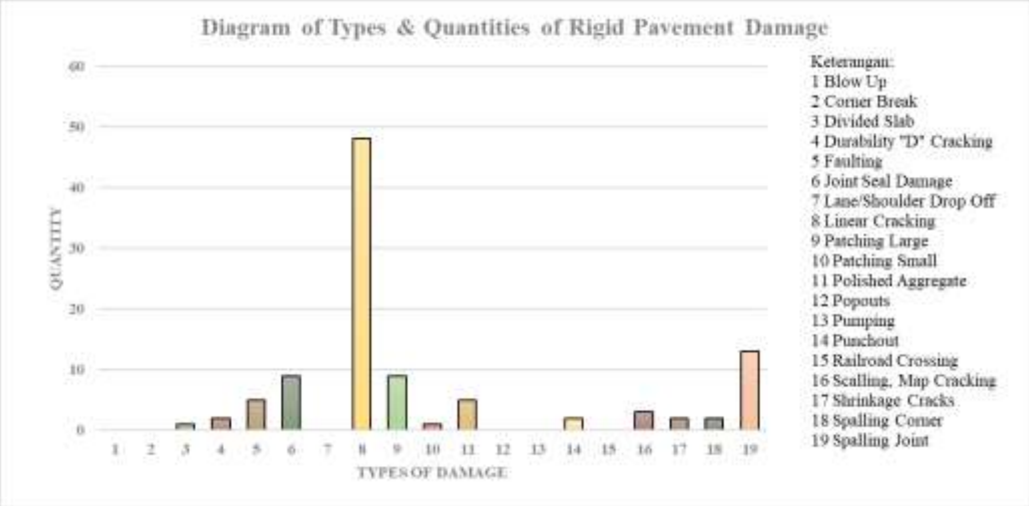

Figure 3. Diagram of types and quantities of damage on the denai road

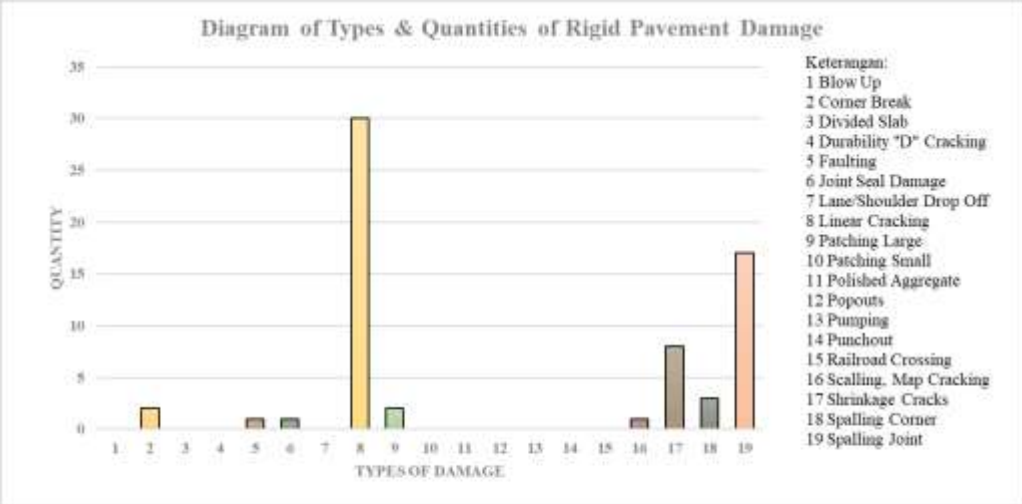

Figure 4. Diagram of types and quantities of damage on the mandala bypass road

4.2 Calculation of Rigid Pavement Condition Index (PCI)

After conducting field surveys, the road damage condition can be analyzed using the Pavement Condition Index (PCI). An example assessment will be taken from sample unit 1 on the Denai section. The survey results of the damage condition for sample unit 1 on the Denai section can be seen in Table 3.

Table 3. Summary of survey, density, and deduct value of sample unit 1 on the Denai road

Types of Damage	Severity Levels	Quantity (qty)	Density (%)	Deduct Value
Polished Aggregate	-	1	4,76	2
Punchout	Low	1	4,76	8
Linear Cracking	Low	1	4,76	3
Patching Large	Medium	1	4,76	3
Linear Cracking	High	2	9,52	20
“D” Cracking	Low	1	4,76	3

1) **Calculating Density**

Density is calculated by summing the quantities of each type of damage and dividing by the total number of panels/slabs in the sample unit.

$$\frac{Jumlah\ pelat\ beton\ yang\ mengalami\ kerusakan\ tipe\ tertentu}{Jumlah\ pelat\ beton\ dalam\ unit\ tertentu} \times 100 \qquad (3)$$

Taking linear crack (High) as an example of damage type on sample unit 1 of the Denai section, the density value for this type of damage is calculated as follows:

Density = (2 / 21) x 100 = 9,52%

2) **Determining The Deduct Value For Each Type Of Damage**

The deduct value is determined using a graph that shows the relationship between distress density and deduct value. Here is an example of determining the deduct value for the type of damage, linear crack.

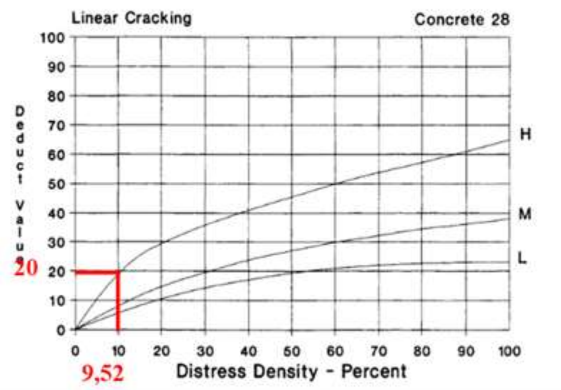

Figure 5. Determining the deduct value for the type of damage, linear crack

3) **Calculating The Maximum Allowable Value (m)**

The maximum allowable value (m) is calculated to determine the maximum deduct value that needs to be considered in determining the PCI value (Sinaga & Buana, 2021). To calculate the maximum allowable value (m), the following equation is used:

$$m = 1 + \frac{9}{98} \times (100 - CDVMaksimum) \qquad (4)$$

Where:

m = maximum allowable value

$CDV_{Maksimum}$ = highest individual deduct value

In the example of sample unit 1 on the Denai section, the highest deduct value is 20. Therefore, the maximum allowable value (m) is:

$$m = 1 + \frac{9}{98} \times (100 - 20)$$

$$m = 8{,}35 > 6$$

(number 6 represents the total count of deduct value data points within the sample unit).

Since the value of "m" is greater than the number of deduct values reviewed, all deduct values can be used.

4) **Determining The Corrected Deduct Value**

The corrected deduct value is obtained by adjusting the total deduct value with the q value through a curve. The steps to determine the corrected deduct value include:

- Arrange all deduct values in the sample unit in descending order, then sum them to obtain the total deduct value. Taking sample unit 1 on the Denai section as an example, the deduct values arranged are 20, 8, 3, 3, 3, 2. Summing all these individual deduct values results in a total deduct value of 39.

- Next, determine the q value by counting the deduct values greater than 2 (for rigid pavements). Therefore, the q value is 5 (20, 8, 3, 3, 3).
- Determine the corrected deduct value using a curve graph of the total deduct value against the q value. Thus, the corrected deduct value (CDV) is found to be 20. The curve graph can be seen in Figure 6.
- Iterate by reducing the smallest deduct value greater than 2 to 2 and repeat the above steps until q=1. This process is shown in Table 4.

Table 4. Results of the iteration for corrected deduct value of sample unit 1 on the denai road

Iteration	Deduct Value						TDV	q	CDV
1	20	8	3	3	3	2	39	5	20
2	20	8	3	3	2	2	38	4	21
3	20	8	3	2	2	2	37	3	23
4	20	8	2	2	2	2	36	2	29
5	20	2	2	2	2	2	30	1	30

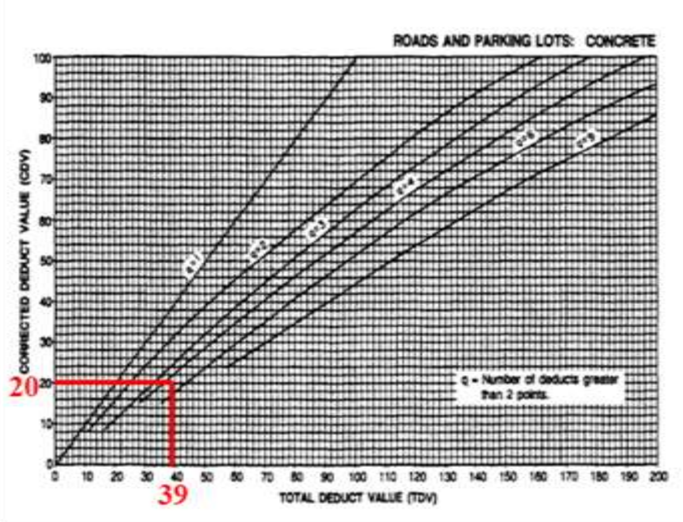

Figure 6. Curve of corrected deduct value of the first iteration

5) **Calculating The PCI (Pavement Condition Index) For Each Sample Unit And Calculating The PCI (Pavement Condition Index) For The Road Section**

After obtaining the maximum corrected deduct value, the PCI (Pavement Condition Index) for the sample unit can be calculated using the following equation:

$$PCI = 100 - CDV_{maksimum} \quad (5)$$

Taking the example of sample unit 1 on the Denai section, with a maximum corrected deduct value of 30, the PCI (Pavement Condition Index) for this sample unit can be calculated as follows:

$PCI = 100 - 30$

$PCI = 70\ (Fair)$

Therefore, the PCI results for all surveyed sample units on the Denai and Mandala sections can be seen in Table 5 and Table 6.

Table 5. Pavement condition index of sample unit on denai road

Sample Unit	PCI	Category	Sample Unit	PCI	Category
1	70	Fair	10	82	Satisfactory
2	62	Fair	11	79	Satisfactory
3	84	Satisfactory	12	90	Good

4	86	Good	13	80	Satisfactory
5	80	Satisfactory	14	76	Satisfactory
6	73	Satisfactory	15	81	Satisfactory
7	70	Fair	16	100	Good
8	73	Satisfactory	17	84	Satisfactory
9	80	Satisfactory			

Table 6. Pavement condition index of sample unit on mandala bypass road

Sample Unit	PCI	Category	Sample Unit	PCI	Category
1	90	Good	8	96	Good
2	85	Satisfactory	9	85	Satisfactory
3	90	Good	10	81	Satisfactory
4	97	Good	11	89	Good
5	90	Good	12	86	Good
6	93	Good	13	87	Good
7	96	Good	14	94	Good

Next, the PCI (Pavement Condition Index) for each road section can be calculated using the following equation:

$$PCIr = \overline{PCIs} = \frac{\sum_{J=1}^{I} (PCI_{s-j} * A_{s-j})}{A_r} \tag{6}$$

Where:

$PCIr$ = pavement condition index (PCI) for the road section

$\overline{PCIs}$ = average PCI of sample units

PCI_{s-j} = pavement condition index of section number j

A_{s-j} = area of section j

A_r = area of the road section

Table 7. Pavement condition index for the denai road section

Sample Unit	PCI	Sample Unit Area A (m^2)	PCI * A	Sample Unit	PCI	Sample Unit Area A (m^2)	PCI * A
1	70	728	50960	10	82	672	55104
2	62	774	47988	11	79	595	47005
3	84	653	54852	12	90	462	41580
4	86	747	64242	13	80	532	42560
5	80	672	53760	14	76	557	42332
6	73	753	54969	15	81	504	40824
7	70	784	54880	16	100	532	53200

8	73	728	53144	17	84	504	42336
9	80	693	55440				
TOTAL		10890	855176				
AVERAGE			**855176/10890 = 78,53 (*Satisfactory*)**				

From the calculation of PCI values for the Denai section, overall, the roads studied are categorized as being in good condition (satisfactory). Next, for the PCI value on the Mandala Bypass section, it is obtained as:

Table 8. Pavement condition index for the mandala bypass road section

Sample Unit	PCI	Sample Unit Area A (m^2)	PCI * A	Sample Unit	PCI	Sample Unit Area A (m^2)	PCI * A
1	90	406	36540	8	96	428	41088
2	85	401	37485	9	85	408	34680
3	90	407	36630	10	81	415	33615
4	97	422	40934	11	89	415	36935
5	90	403	36270	12	86	408	35088
6	93	410	38130	13	87	406	35322
7	96	410	39360	14	94	408	38352
TOTAL		5787	520429				
AVERAGE		**520429/5787 = 89,93 (*Good*)**					

From the calculation of PCI values for the Mandala Bypass section, overall, the roads studied are categorized as being in very good condition (good).

6) **Road Repair & Maintenance**

The types of damage identified on the Denai-Mandala Bypass road section can be recommended with repair methods that can be carried out as part of road maintenance. Several repair methods for the damages found on the rigid pavement in this section can be seen in Table 9.

Table 9. Repair methods for rigid pavement (PUPR, 2006)

Type of Damage	Repair Methods
Blow Up	• Replacement of all slabs. • Replacement of subgrade and patching with preferred materials to restore original strength.
Corner Break	• If the damage is minor, it can simply be filled with sealant or joint material. • If the damage is extensive, it needs to be excavated and replaced with new material.
Faulting	• Replace the slabs with new ones.
Patching	• Patched with stronger material (super joint, friction).
Linear Cracks	• Every crack found is immediately patched with tight water-sealing sealant.
Polished Aggregate	• Can be done using grooving. • Covered with thin asphalt concrete (15 to 30

Type of Damage	Repair Methods
	mm), using non-ionic tack coat.
Shrinkage Cracks	• Covered with sealant • Coated with non-ionic tack coat

As a numerical indicator of pavement condition, PCI (Pavement Condition Index) reflects the level of pavement surface condition. PCI measures the condition of the pavement at the time of survey, based on observed surface damage. PCI provides an objective and rational basis for determining necessary maintenance and repair programs as well as prioritizing treatments. An example of PCI usage to determine treatment types can be seen in Table 10.

Table 10. PCI values for determining treatment types (PUPR, 2016)

PCI	Jenis Penanganan
>85	Pemeliharaan rutin
70 - 85	Pemeliharaan berkala
55 - 70	Peningkatan struktural
<55	Rekonstruksi/daur ulang

Subsequently, for each evaluated road section through pavement condition index assessment, the determined treatment types are as follows:

- For the Denai section with a PCI rating of 78.53 (satisfactory), the implemented treatment type is periodic maintenance.
- For the Mandala Bypass section with a PCI rating of 89.93 (good), the implemented treatment type is routine maintenance.

5. CONCLUSION

5.1 Conclusion

From the analysis presented in this study, the survey results identifying types of damage on the Denai-Mandala Bypass road section in Medan City, several types of damage were identified: linear cracks (78 occurrences), spalling joint (30 occurrences), patching large (11 occurrences), shrinkage cracks (10 occurrences), joint seal damage (10 occurrences), faulting (6 occurrences), polished aggregate (5 occurrences), spalling corner (5 occurrences), scaling (4 occurrences), corner break (2 occurrences), durability cracks (2 occurrences), punchout (2 occurrences), divided slab (1 occurrence), and patching small (1 occurrence). In the Denai section, out of the total sampled units studied, only 3 units experienced damage and were classified as fair. These are sample units 1, 2, and 7. The remaining damaged units are classified as satisfactory in 11 sample units and as good in 3 sample units. In the Mandala Bypass section, 3 sample units are classified as satisfactory, while the remaining 11 sample units are classified as good. The average PCI value on the Denai road section studied over approximately 1.4 km is 78.53, classified as satisfactory, with a treatment priority of periodic maintenance. On the Mandala Bypass road section studied over approximately 800 m, the average PCI value is 89.93, which falls under the category of good, with a treatment priority of routine maintenance.

5.2 Suggestions

From the evaluation of this study, several recommendations and inputs are necessary to enhance its quality. Firstly, there is a need for regular road damage surveys to assess road service levels and determine necessary actions by the local government. This includes implementing regular and periodic maintenance to ensure the comfort and safety of road users. Further research is needed to gain a deeper understanding of the damages occurring at the research site, particularly regarding the most dominant type, which is linear cracking. And then for several types of damages such as corner break, linear cracks, shrinkage cracks, spalling corner, and spalling joint, they can be repaired by filling the gaps with asphalt concrete crack sealant. Additionally, faulting can be repaired by replacing the damaged slab with a new one. Furthermore, joint seal damage can be repaired by replacing the joint filler/seal material. Lastly, patching can be repaired by reapplying new material to the affected area.

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