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Beyond Traffic Volume: Assessing the Impact of Heavy Vehicle Composition on Pavement Distress Using the Surface Distress Index

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ABSTRACT

Road damage caused by high traffic volume, particularly in industrial areas such as Narogong–Cileungsi, disrupts the comfort and safety of road users. This study analyses the correlation between traffic volume and road damage using the Surface Distress Index (SDI) method on four road sections in Bogor Regency. SDI is assessed based on crack area and width, the number of potholes, and rutting. Traffic data were collected during peak hours and analysed using Pearson correlation. The results show that Nagrak–Bojongkulur Road is in good condition (SDI < 50), while the other three road sections are in moderate to severely damaged condition (SDI 50–>150). The correlation results cannot be used as a basis for determining a causal correlation. Therefore, an analysis of vehicle composition and vehicle weight was conducted, showing that total traffic volume does not affect road damage; rather, the dominance of heavy vehicles such as trucks and buses does.

Keywords: pavement distress; traffic volume; Surface Distress Index; SDI; vehicle load; vehicle composition.

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INTRODUCTION

Road damage caused by high traffic volume is a common problem, particularly in vehicle-dense areas such as industrial regions. Roads that are traversed beyond their planned capacity will experience excessive loading, thereby causing damage such as potholes, cracks, and rutting. One example occurs on the Narogong–Cileungsi Road section, which is frequently traversed by heavy vehicles.

Several studies state that an increase in traffic volume is directly proportional to pavement distress (Da Cunha, 2022; Darwonto et al., 2023; Saragi et al., 2022). In addition to accelerating deterioration, high traffic volume also causes congestion and increases road maintenance costs (Afrin & Yodo, 2020; Boga et al., 2024; Harahap et al., 2022). This study was conducted quantitatively to analyze the correlation between traffic volume and pavement distress using the Surface Distress Index (SDI) method. Vehicle volume data were calculated with reference to the Indonesian Road Capacity Guidelines (PKJI, 2023), while pavement condition was analyzed through the parameters of the percentage of crack area, crack width, number of potholes, and rutting (Oktopianto et al., 2025, 2026).

Different from previous studies, this study examined four road sections in Bogor Regency, namely Nagrak–Bojongkulur Road, Kedep–Cileungsi Road, Cileungsi Kidul–Gandoang Road, and Tunggilis–Situ Sari Road. These road sections were selected because they frequently experience damage and high traffic, particularly from trucks from industrial companies. Based on these conditions, this study aims to analyze the level of pavement distress, analyze the correlation between pavement distress and traffic volume, and evaluate differences in pavement distress across road sections with high and low traffic volumes.

RESEARCH METHOD

This study was initiated by conducting an inventory survey of the four road sections examined.

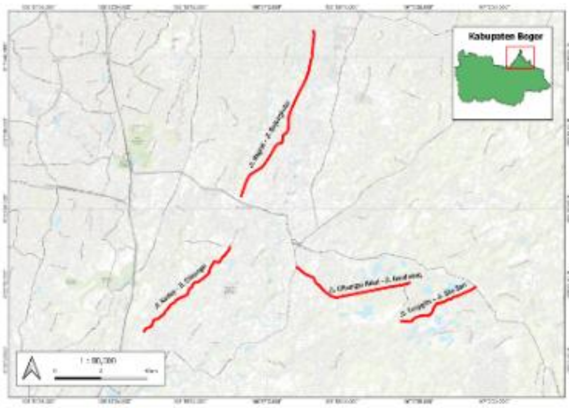

Figure 1. Research Location Map

The pavement condition assessment was conducted by carrying out a pavement condition survey every 100 m segment, totaling 1.5 km or 15 stationing points. The analysis of the pavement condition level used the Surface Distress Index (SDI) method, which consists of four calculation parameters, including:

$$\text{Percentage of Crack Area} = \frac{A_r}{A_t} \times 100\% \qquad (1)$$

Table 1. Crack Area Value

Weight	Crack Area Category	SDI_1 Value
1	None	0
2	<10%	5
3	10-30%	20
4	<30%	40

Source: Directorate General of Highways, Indonesia (2011)

Table 2. Crack Width Value

Weight	Crack Width Category	SDI_2 Value
1	None	SDI_1
2	Fine < 1 mm	SDI_1
3	Moderate 1–3 mm	SDI_1
4	Wide > 3 mm	SDI_1 x 2

Source: Directorate General of Highways, Indonesia (2011)

Table 3. Number of Potholes Value

Weight	Pothole Number Category	SDI_3 Value
1	None	SDI_2
2	1/100m	SDI_2+15
3	2-5/100m	SDI_2+75
4	>5/100m	SDI_2+225

Source: Directorate General of Highways, Indonesia (2011)

Table 4. Rutting Value

Weight	Rutting Depth	SDI_4 Value
1	None	SDI_3
2	<1 cm deep	SDI_3+(5x0,5)
3	1-3 cm deep	SDI_3+(5x2)
4	>3 cm deep	SDI_3+20

Source: Directorate General of Highways, Indonesia (2011)

Tabel 5. Pavement Condition Based on SDI_4 Value

SDI_4 Value	Pavement Condition
<50	Good
50-100	Moderate
100-150	Lightly Damaged
>150	Severely Damaged

Source: Directorate General of Highways, Indonesia (2011)

The motor vehicle traffic volume was calculated using the traffic-counting method. The traffic volume variable is symbolized by (X), consisting of five vehicle type variables, including:

Table 6. Classification of Motor Vehicle Types

Variable	Symbol	Vehicle Type
X_1	SM	Motorcycle
X_2	MP	Passenger Car ≤ 5.5 m (sedan, minibus, pick-up, box car)
X_3	KS	Medium Vehicle ≤ 9 m (medium bus, light 2-axle truck)
X_4	BB	Large Bus ≤ 12 m (large bus, heavy 2-axle truck)
X_5	TB	Heavy Truck (3-axle truck) ≥ 12 m

Source: (PKJI, 2023)

To analyze the correlation between the pavement distress variable and traffic volume by motor vehicle type, a correlation test was conducted in RStudio. The following is the interpretation of the correlation test results.

Table 7. Interpretation of Correlation Test Results

r	Interpretation
0.00 – 0.199	Very Low
0.20 – 0.399	Low
0.40 – 0.599	Moderate
0.6 – 0.799	Strong
0.80 – 1	Very Strong

Source: (Syafril, 2021)

Descriptive analysis is the final method used to determine differences in pavement distress between high and low traffic volumes by describing the conditions using words clarified by the actual conditions at the time of the study. In addition, the inclusion of vehicle load and vehicle composition calculations is also used to ensure that the differences in pavement distress are not only caused by traffic volume, but also by other factors such as vehicle load and vehicle composition. The load calculation is in accordance with the guidelines of the Road Pavement Design Manual 2024 (Bina Marga., 2024).

RESULT AND DISCUSSION

Geometric Characteristics of Road Sections

The geometric description of the road sections in the study area is presented to provide an overview of the fundamental physical characteristics, including road width and segment length. These parameters serve as a critical basis for the analysis of pavement Surface Distress Index (SDI) and for interpreting the level of distress observed on each road segment. Table 8 summarizes the geometric characteristics of the road sections under study.

Table 8. Geometric Characteristics

Road Section	Geometric Description	
	Total Road Width (2 Lanes)	Road Segment Length
Nagrak–Bojongkulur Road	10 m	10628 m
Kedep–Cileungsi Road	10 m	7850 m
Cileungsi Kidul–Gandoang Road	9 m	6509 m
Tunggilis–Situ Sari Road	8 m	3893 m

SDI Field Survey Implementation

This section presents the implementation of the Surface Distress Index (SDI) field survey on the selected road sections, encompassing the data collection techniques employed to systematically and consistently evaluate pavement surface conditions. The assessed distress parameters include crack area and width, pothole, and rutting.

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The field survey implementation is documented and illustrated in Figure 2.

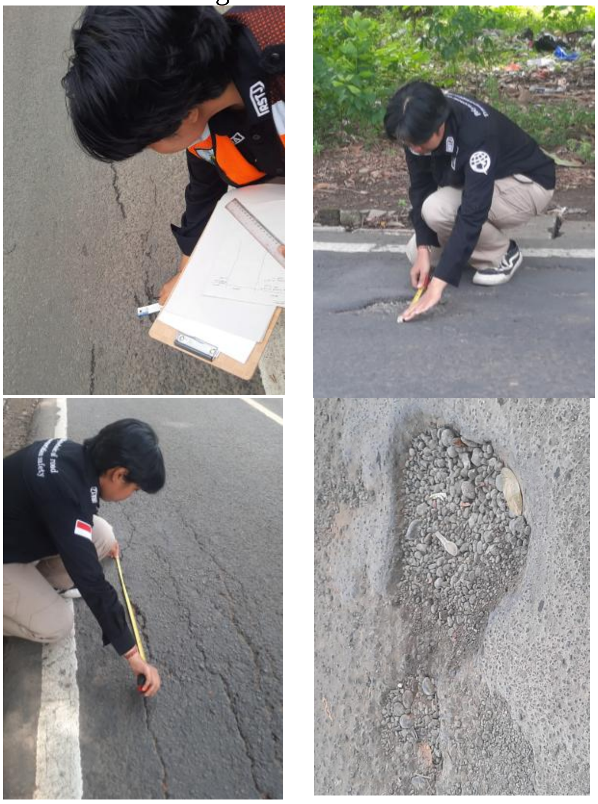

Figure 2. Field implementation of the Surface Distress Index (SDI) survey

Analysis of Pavement Distress Level

The four road sections that became the research locations connect national activities, such as industrial factories, with environmental activities, such as residential settlements. These roads are located in Bogor Regency, West Java Province. The pavement condition assessment used the Surface Distress Index (SDI) method, which was conducted visually using four calculation parameters, namely the percentage of crack area (SDI_1), crack width (SDI_2), number of potholes (SDI_3), and rutting (SDI_4). This survey was conducted by dividing the road section into two movement directions, with each segment 100 m long, for a total of 15 road segments or stationing points. The SDI value entered into the table is the (SDI_4) value because it represents the sum of all calculation parameters. The calculation results are shown in the following table 9.

Based on Table 9, the results show that the highest pavement condition value is found on the Tunggilis – Situ Sari Road section, with an average value of SDI_4= 76.33, which is included in the moderate pavement condition category. Meanwhile, the lowest pavement condition value is found on the Nagrak–Bojongkulur Road section, with an average value of SDI_4= 47.83, which is included in the good pavement condition category. The results of this pavement condition calculation are used as the dependent variable (Y), which will be correlated with the traffic volume variable.

Table 9. Results of Pavement Condition Calculation

Road Section	Average SDI_4 Value			Pavement Condition
	West	East	Two Directions	
Nagrak–Bojongkulur Road	51	44.67	47.83	Good
Kedep–Cileungsi Road	50.66	59.33	55	Moderate
Cileungsi Kidul–Gandoang Road	57.33	53.66	55.5	Moderate
Tunggilis–Situ Sari Road	76	76.66	76.33	Moderate

Source: Calculation results, 2025.

Traffic Volume Analysis

The collection of primary traffic-counting data was conducted during peak hours, namely 06.00–08.00 WIB and 16.00–18.00 WIB. This survey was also conducted by dividing the road section into two movement directions, namely westbound and eastbound, to determine differences in traffic volume and conditions during peak hours. Table 10 presents the results of traffic counting conducted during peak hours.

Table 10. Traffic Counting of Vehicles During Peak Hours

Road Section	Direction	Number (Veh/hour)				
		SM	MP	KS	BB	TB
Nagrak–Bojongkulur Road	West	2399	317	9	7	2
	East	2731	307	12	5	1
Kedep–Cileungsi Road	West	1797	311	13	5	2
	East	1671	321	14	7	3
Cileungsi Kidul–Gandoang Road	West	1982	316	13	6	2
	East	1769	321	13	6	3
Tunggilis–Situ Sari Road	West	1826	329	15	7	4
	East	1686	331	19	9	3

Source: Survey results, 2025.

The results of this traffic-counting survey are used as the independent variable (X) to determine the correlation between pavement distress and vehicle volume using a correlation test.

Normality Test

This statistical test is used as an initial step to determine whether the data are normally distributed. The normality test was conducted using the Shapiro–Wilk test because the number of data is <50. The result of this test indicates that if the p-value > 0.05 (α), the data are normally distributed. However, if the p-value < 0.05 (α), the data are not normally distributed (Budiyono, 2025).

Table 11. Normality Test

Variable	p-value	Distribution
Pavement distress (Y)	0.1462	Normal
Motorcycle volume (X_1)	0.03003	Not normal
	0.06063 (log)	Normal
Passenger car volume (X_2)	0.8187	Normal
Medium vehicle volume (X_3)	0.4234	Normal
Large bus volume (X_4)	0.2828	Normal
Heavy truck volume (X_5)	0.5224	Normal

Source: Results of the RStudio normality test, 2025.

In Table 11, one variable is not normally distributed because the data range is much wider than the other variables. Therefore, data transformation is needed to ensure the data are normally distributed.

Correlation Test

This test is the next stage after the normality test. This test aims to determine whether there is a correlation between two variables and to determine the direction and strength of the correlation that occurs. If the result of this test is negative (−), an inverse correlation is present. This means that if one variable increases, the other variable decreases. Conversely, if the correlation test result is positive (+), the correlation is directly proportional. This means that if one variable increases, it is followed by an increase in the other variable (Nurhaswinda, 2025).

The Pearson correlation test is used because the data are measured on a ratio scale. Before conducting the test, the data must be ensured to be normally distributed. The following are the results of the Pearson correlation test in RStudio. The Pearson correlation analysis was performed using RStudio, and the results are presented in table 12.

Table 12. Pearson Correlation Test

Road Section	Average SDI_4 Value (Y)	Number (Veh/hour) SM (X_1)	MP (X_2)	KS (X_3)	BB (X_4)	TB (X_5)
Nagrak–Bojongkulur Road	51	2399	317	9	7	2
	44.67	2731	307	12	5	1
Kedep–Cileungsi Road	50.67	1797	311	13	5	2
	59.3	1671	321	14	7	3
Cileungsi Kidul–Gandoang Road	57.33	1982	316	13	6	2
	53.66	1769	321	13	6	3
Tunggilis–Situ Sari Road	76	1826	329	15	7	4
	76.66	1686	331	19	9	3
Correlation Test	Y	-0.61	0.93	0.8	0.79	0.81

Source: Results of the Pearson correlation test using RStudio, 2025.

The results of the Pearson correlation test show that the correlation between the pavement distress variable (Y) and the motorcycle volume variable (X1) has a negative value (−). This means that the increase in the number of motorcycles is inversely proportional to pavement distress, where pavement distress decreases (low SDI value). Meanwhile, the correlation between the pavement distress variable (Y) and the other motor vehicle volume variables (X2–X5) produces a positive correlation value (r) (+). This means that the increase in the number of vehicles is directly proportional to the increase in pavement distress (as indicated by a high SDI value). The results of the correlation analysis between the studied variables are presented in fugure 3.

Figure 3. Pearson Correlation Heatmap

The green color indicates a positive correlation, where a correlation value (r) approaching 1 indicates a very strong positive correlation, while the red color indicates a negative correlation, where a correlation value (−) approaching −1 indicates a very strong negative correlation.

Significance Test

After the correlation coefficient value is known, a significance test needs to be conducted. This test aims to determine whether the observed correlation between the two variables is due to coincidence. The result of this test indicates that if the p-value > 0.05 (α), the correlation is not significant. This means the correlation may be coincidental. However, if the p-value is < 0.05 (α), a significant correlation is present. This means that the correlation between the variables truly exists and is not merely the result of coincidence in the sample. The results of the significance test are presented in table 13.

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Table 13. Significance Test

Significance Test	p-value	Result
Pavement Distress (Y) wi Motorcycle Volume (X_1)	0.1041	Not Significant
Pavement Distress (Y) wi Passenger Car Volume (X_2)	0.00072	Significant
Pavement Distress (Y) wi Medium Vehicle Volume (X_3)	0.01562	Significant
Pavement Distress (Y) with Lar Bus Volume (X_4)	0.01717	Significant
Pavement Distress (Y) with Hea Truck Volume (X_5)	0.01337	Significant

Source: Results of the RStudio significance test, 2025.

Based on the table 13, one variable has no significant correlation, and the correlation for the other is due to coincidence. A high correlation value does not necessarily indicate a causal or appropriate correlation between variables. Therefore, an analysis of other factors that cause pavement distress, such as vehicle load and vehicle composition, is needed.

Table 14. Data Grouping (Y) and (X)

Road Section	Average $\boldsymbol{SDI_4}$ Value	Total Traffic Volume
Nagrak–Bojongkulur Road	47.83	5.790
Kedep–Cileungsi Road	55	4.144
Cileungsi Kidul–Gandoang Road	55.5	4.431
Tunggilis–Situ Sari Road	76.33	4.229

Source: Calculation results, 2025.

If reviewed based on the overall traffic volume, there is no linear correlation between traffic volume and the level of pavement distress (SDI). This is caused by the types of vehicles passing through the area being divided into two groups: light and heavy. Light vehicles include motorcycles and passenger cars. Meanwhile, heavy vehicles include medium vehicles, large buses, and heavy trucks. One of the causes of pavement distress is traffic volume, when it is reviewed based on the load it carries. According to the pavement theory by (Kinder & Lay (1988), a single heavy truck can cause damage equivalent to that of thousands of motorcycles.

Therefore, light vehicles are often neglected in pavement distress analysis because their contribution is minimal. The separation of vehicle types and vehicle classes is used to determine whether a vehicle belongs to the light or heavy vehicle category. In addition, the calculation of vehicle load (ESAL) is required to strengthen the argument, because each type of vehicle produces a different level of pavement damage depending on its heaviest axle load (Novela et al., 2022; Pasiak et al., 2020; Qadir et al., 2024)

Table 15. Comparison of ESAL on High and Low Traffic Volume Road Sections

Type	Class	VDF	Nagrak–Bojongkulur Road		Tunggilis–Situ Sari Road	
Large Bus	Class 5B	2.6	5	13.00	6	15.60
2-Axle Truck 1.2L	Class 6A	0.3	10	3.00	15	4.50
2-Axle Truck 1.2H	Class 6B	3.3	7	23.10	10	33.00
3-Axle Truck 1.22	Class 7A2	4.3	3	12.90	7	30.10
Total ESAL (ton)				52.00		83.20

Source: Calculation results, 2025.

The calculation results table 15 show that the Nagrak–Bojongkulur Road section has the lowest SDI value among the four road sections, namely 47.83, with peak-hour total traffic volume higher than the other road sections, reaching 5,790 vehicles. This produces a total ESAL value of 52 tons because the number of vehicles is dominated by Class 1 vehicles (motorcycles), which are classified as light vehicles. However, the number of vehicles in Classes 5B–7A2 (heavy vehicles) is lower than that on the other road sections.

Conversely, the Tunggilis–Situ Sari Road section has the highest SDI value among the four road sections, namely 76.33, with peak-hour total traffic volume lower than that of the Nagrak–Bojongkulur Road section, at 4,229 vehicles. This produces a total ESAL value of 83.20 tons because the number of heavy vehicles is higher than on the other road sections.

To support this finding, further analysis is needed on the composition of heavy vehicles relative to the total number of vehicles passing through the road. The following presents the percentage results of the classification of medium vehicles, large buses, and heavy trucks.

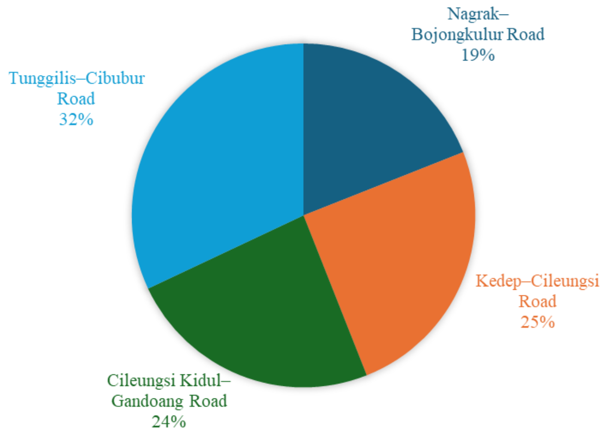

Figure 4. Percentage of Medium Vehicle Composition

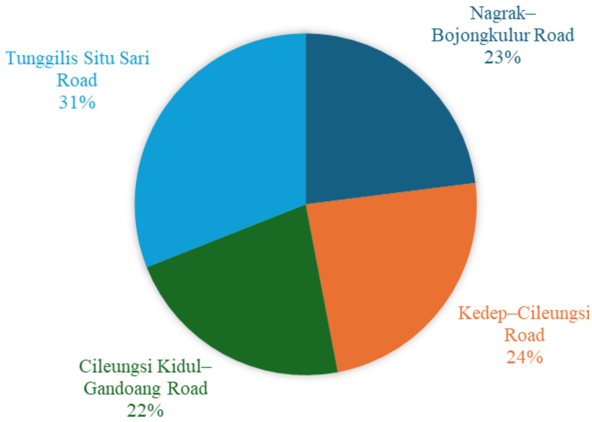

Figure 5. Percentage of Large Bus Composition

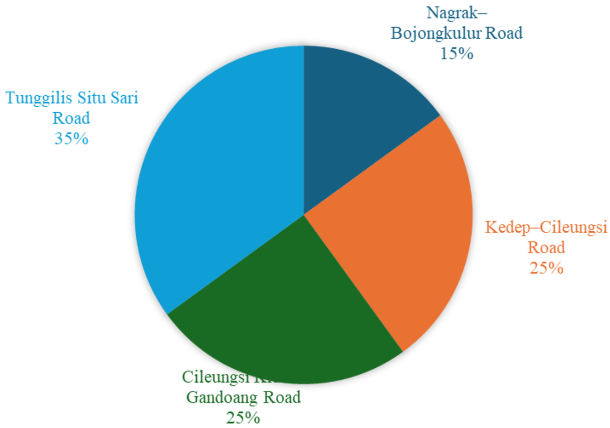

Figure 6. Percentage of Heavy Truck Composition

Based on the figures 4, 5 and 6 above, the Tunggilis–Situ Sari Road section has a higher percentage of medium vehicles, large buses, and heavy trucks than the other road sections. When reviewed from the overall total traffic volume, this road section has a lower number, namely 4,229 vehicles; however, the high proportion of heavy vehicles is the main factor contributing to pavement distress. If reviewed from the pavement distress value, the Tunggilis–Situ Sari Road section records the highest Surface Distress Index (SDI) value, namely 76.33, which reflects a moderate level of pavement distress.

Conversely, the Nagrak–Bojongkulur Road section shows that the percentage values of medium vehicles and heavy trucks are the lowest among the other road sections. If reviewed from the overall total traffic volume, this road section has a higher number than the other road sections, namely 5,790 vehicles. However, when evaluated by pavement distress, this road section has the lowest Surface Distress Index (SDI) of 47.83, indicating good pavement condition.

The analysis results show that the number of vehicles is not the only indicator in assessing pavement distress potential; rather, the type and weight of the vehicles passing through the road, especially heavy vehicles, have a much more significant effect on pavement deterioration. These findings are consistent with the studies by Marks (2023) and Al-Janabi (2024) which states that pavement distress is predominantly triggered by heavy vehicles rather than by traffic volume. However, this finding is not consistent with the study conducted by Dadi (2023), which states that the higher the traffic volume, the greater the pavement distress that occurs, and only examines traffic volume as the cause of pavement distress without distinguishing vehicle types, thus not reflecting the actual load received by the pavement.

CONCLUSSION

This study shows that pavement conditions across the four road sections in Bogor Regency vary. The Nagrak–Bojongkulur Road section is classified as being in good condition with an SDI value of 47.83, while the Kedep–Cileungsi, Cileungsi Kidul–Gandoang, and Tunggilis–Situ Sari road sections are in moderate condition with SDI values above 50. The Pearson correlation results show a significant positive correlation between pavement distress and the volumes of passenger cars, medium vehicles, heavy trucks, and large buses.

Conversely, motorcycle volume shows a negative, non-significant correlation with the level of pavement distress. Correlation analysis cannot conclude a causal correlation. Therefore, additional analysis, such as calculating the percentage of vehicle composition and vehicle load, shows that the level of pavement distress is more affected by vehicle type and vehicle load than by the total number of vehicles.

The recommendation, derived from the essence of the research results, is to implement restrictions on the maximum load of heavy vehicles and to monitor traffic composition, especially on road sections with high levels of pavement distress. In future studies, the study area can be expanded to more road sections with diverse characteristics.

ACKNOWLEDGMENT

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LIST OF NOTATIONS

A_r = total crack area (m^2)
A_t = total pavement surface area (m^2)

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