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Can We Predict the Roughness Index (IRI) of a Road Based on its Pavement Condition Index (PCI)?

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Abstract. Road damages might affect pavement condition which leads to reducing the remaining service life of the pavement. Two methods widely known to measure the pavement condition are among others: the Pavement Condition Index (PCI) and the International Roughness Index (IRI). Both intended to measure the functional condition of the pavement. This study aims to show the relationship between PCI and IRI, hence the road roughness can be predicted from on-foot survey measurements. It will start by collecting the distress and its severity parameter as well as the roughness of 6 road sections using Hawkeye mobile car. The car is a complete modular system to measure roughness (using profilometer), capture images and measure the severity of the road distresses and else. The results show that the pavement condition of the 6 sections fall into the category of poor and above. While 44% of the segments are fair. The roughness conditions of all road sections are good or acceptable. The correlation analysis shows that the PCI cannot necessarily explain the IRI, even though both are used to express the functional condition of road pavements, because what Hawkeye measures for the two indices is different.

1 Introduction

In 2019, the pavement condition of arterial roads in several cities in Central Java, Indonesia, was evaluated. This road condition measurement was done indirectly using Hawkeye. Hawkeye is a mobile car, equipped with modular system to measure roughness (using profilometer), capture images and measure the severity of the road distresses and else[1]. This indirect data measurement provides many advantages, including relatively low-cost pavement distress inspection, consistent method of measuring the distress, improve the efficiency of data collection [1,2].

The problem with IRI data acquisition in Indonesia is the limited equipment [1]especially for roads in remote cities. However, due to this nasional roads's evaluation carried on 2019, especially in central Java region, a large number of data can be generated including Pavement

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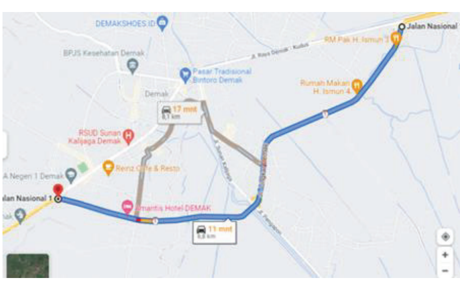
Condition Index (PCI) and International Roughness Index (IRI). This data can of course be used to predict future pavement conditions, once models have been built.

This paper aims to show the relationship between PCI and IRI, hence the road roughness can be predicted from on-foot survey measurements. This prediction is important considering roughness greatly affects the comfort and safety of driving. Many papers presented correlation studies between PCI and IRI[2–5]. By using Pearson correlation analysis based on curve expert programme, Suryoto showed that the relationship between PCI and IRI is quite close, marked by a high correlation coefficient value[4]. In this study, IRI was measured using the NAASRA (National Association Of Australian State Road Authorities) device, while PCI was measured using a survey of road damage and deterioration levels that resulted in a PCI score. Suryoto also produced a linear model between IRI and PCI, with IRI as the independent variable and PCI as the dependent variable[4]. The linear relationship between the two is shown by a positive function, meaning that the higher the IRI, the higher the PCI. This conceptually needs explanation, as the relationship between the two indices should be negative, as shown by Piryonesi [3], Cereceda [6] and Arhin [5]. The study concluded that different functional measurement methods result in different pavement indices, and hence different maintenance/rehabilitation decisions[4].

In this paper, a model of the relationship between PCI and IRI in several road sections will be developed. Then the model will be evaluated whether the two have shown a rational relationship.

2 Methods

Data acquisition was conducted in 2019-2020, using Hawkeye 2000 equipment on 6 road sections, namely the national roads of Lingkar Demak (A), Losari Pejagan (B), Rembang-Bulu (C), Kudus Timur-Pati (D), Wangon-Menganti (E), and Lingkar Pati (F) which are located in the cities of Demak, Pati, Banyumas, Rembang, and Kudus, Central Java (See Figure 1). Hereafter, these road sections will be referred to as road sections A, B, C, D, E and F. The length of each section is divided into segments with a segment length of 1000 metres. Thus the number of segments for each road section A, B, C, D, E, and F are 7, 10, 47, 11, 12, and 13, respectively. There are 100 road segments in total.



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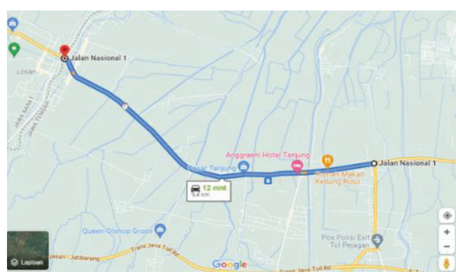

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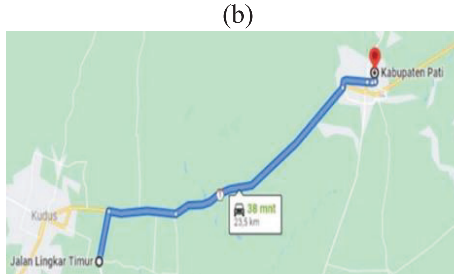

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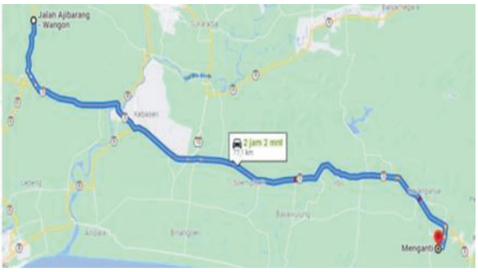

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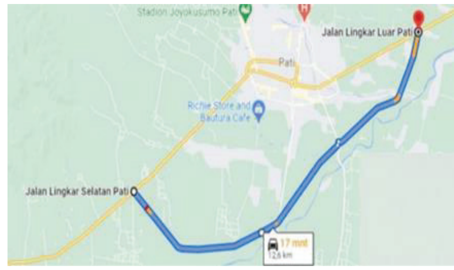


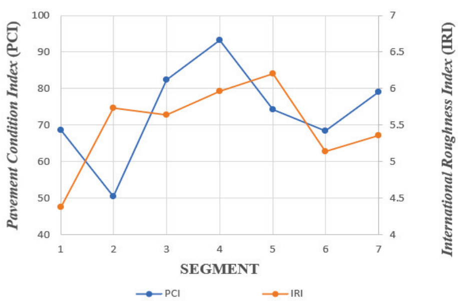
(f)

Fig. 1. Location and length of the 6 road sections at Central Java, Indonesia, (a) Lingkar Demak Road, Length 6780 m, (b) Losari Pejagan Road, Length 9420 m, (c) Rembang-Bulu Road, Length 46510 m, (d) Kudus Timur-Pati Road, Length 10360 m, (e) Wangon-Menganti Road, Length 11600 m, (f) Lingkar Pati Road, Length 12270 m.

IRI and PCI measurements were taken on each lane every 100 metres using Hawkeye 2000. The PCI and IRI values were analyzed from the average PCI and IRI per 100 metres per segment. This secondary data was generated by the National Road Implementation Centre (BBPJN) VII in Central Java and Yogyakarta.

3 Results And Discussion

Road conditions based on PCI and IRI for each segment of all roads are shown in Figures 2.a to 2.f below.



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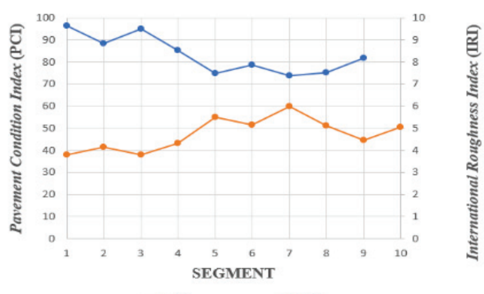

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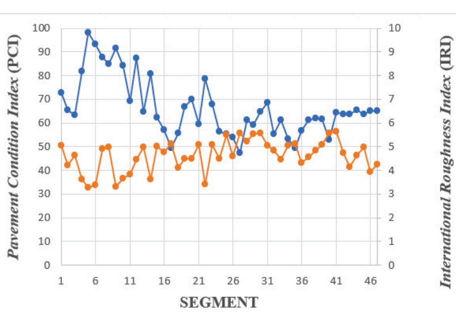

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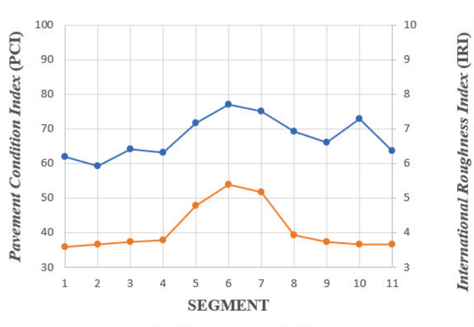

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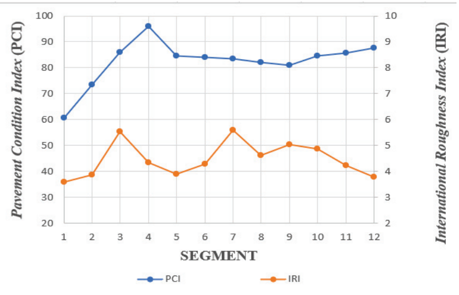

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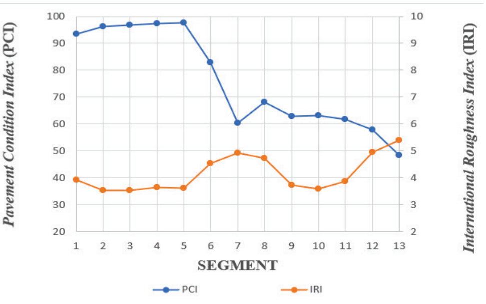

(f)

Fig. 2. PCI and IRI values of 6 road sections, (a) Road segment A, (b) Road segment B, (c) Road segment C, (d) Road segment D, (e) Road segment E, (f) Road segment F.

From Figure 2, it appears that on Road A, only segments 1 and 2 show a 'reasonable' relationship of IRI and PCI. On Road B, almost all road segments show a relationship between IRI and PCI, where when IRI goes up, PCI goes down, and vice versa. On Road C, being the longest road, only about 40% of the road segments show this phenomenon. Road segments D and E, in all segments, show the same shape between PCI and IRI, leading to a positive relationship between the two indices. Road section F, on the other hand, shows that when the PCI goes down, the IRI value goes up, although in the final segment, the increase in IRI is not significant with the decrease in PCI.

The discrepancy of these two indices may lies due to: PCI value collects all types of distress along the road width, while IRI value is a result of roughness measured on tires path. When the distress of the road does not affect the roughness, for example distress in the form of asphalt bleeding, then the IRI value will not rise.

The PCI and IRI were then categorized into road condition classes. The road condition assessment for each segment was carried out by classifying the PCI and IRI data that had been obtained based on the criteria of ASTM D6433-11 [7] and Bina Marga [8]

Table 1. Standard PCI rating scale.

PCI Value	Road Conditions
86-100	Good
71-85	Satisfactory
56-70	Fair
41-55	Poor
26-40	Very Poor
11-25	Serious
0-10	Failed

Source: ASTM D6433-11 [7]

From Table 1 of the Standard PCI Rating Scale above according to Shahin (1994) the assessment of pavement conditions using PCI values has a value range of 0 to 100 with criteria for failed, Serious, very poor, poor, fair, satisfactory, and good. Furthermore, the PCI value of each segment is classified based on Table 1, while the IRI value is classified based on Table 2. The results of the assessment of pavement condition criteria on segments A, B, C, D, E, and F, can be seen in Table 3.

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Table 2. Relationship between IRI value and road condition

IRI Value	Road Conditions
<4	Good
4 – 8	Acceptable
8 – 12	Poor
>12	Very Poor

Source: Bina Marga, [8]

Table 3. Percentage of pavement condition of all segments.

PCI Criteria (Sahin, 1994)	Percentage (%)	IRI criteria (Binamarga, 2011)	IRI criteria Percentage (%)
Good	17%	Good	32%
Satisfactory	28%	Acceptable	68%
Fair	44%	Poor	0%
Poor	11%	Very Poor	0%
Very Poor	0%	Total	100%
Serious	0%		
Failed	0%		
Total	100%		

Based on Table 1 and 2 above, the percentage condition of the 100 road segments is shown in Table 3. It can be seen that based on the PCI value, most of the roads are in fair condition, while based on the IRI value, most of the roads are in acceptable condition (68%). While the percentage of fair criteria is 44% and poor is 11%, it needs to be handled by rehabilitation or reconstruction.

3.1 Correlation analysis of PCI and IRI

The correlation between PCI and IRI of all road segments for each road section was analyzed using the Pearson approach, and is shown in Figure 3. The relationship model between IRI and PCI is shown in Table 4.

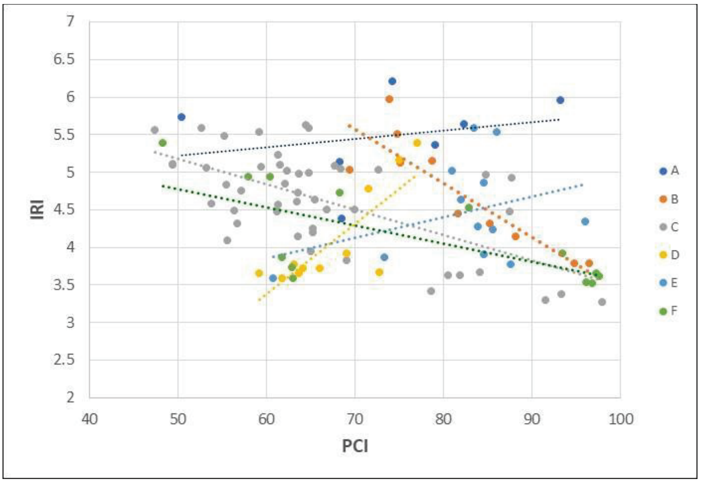

Fig. 3. Correlation between PCI and IRI values of road sections A, B, C, D, E, and F.

Table 4. Relationship between IRI and PCI and coefficient of determination.

Road Sections	Equations	R^2	r
A	y = 0.0113x + 4.6574	0.0632	0.251
B	y = -0.0716x + 10.583	0.7834	0.885
C	y = -0.0337x + 6.855	0.4014	0.634
D	y = 0.093x - 2.199	0.6621	0.814
E	y = 0.0274x + 2.2104	0.1222	0.350
F	y = -0.0241x + 5.9743	0.4508	0.671

From Figure 3 and Table 4, it appears that not all road sections show a negative correlation. Only road sections B, C and F, show it, as it should be.

In addition, based on Guilford criteria[9], the correlation coefficients for these relationships are low for road sections A and E; moderate for C and F; and high for road sections B and D.

An attempt was made to understand the phenomenon that occurred for all road sections by pooling all the data. Unfortunately, the results show that the correlation between PCI and IRI is weaker when these are pooled. In Figure 4, it appears that there is a slight trend that the higher the PCI, the lower the IRI value. The correlation coefficient is 0.325.

Figure 5 shows the relationship between PCI and IRI when an analysis of outliers using Grubb's test is performed [10,11]. For this case, it appears that when the outliers are removed, the correlation coefficient of the relationship between PCI and IRI increases to 0.525

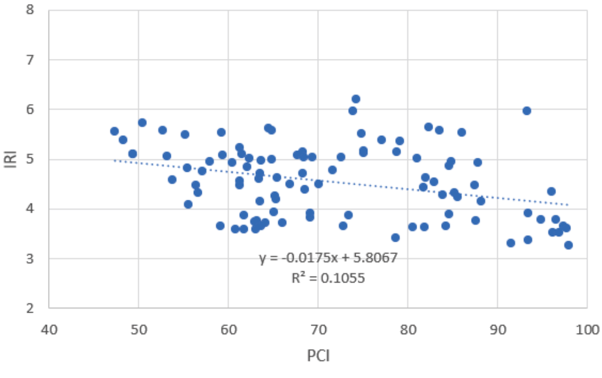

Fig. 4. Correlation between PCI and IRI values of all road segments with outliers.

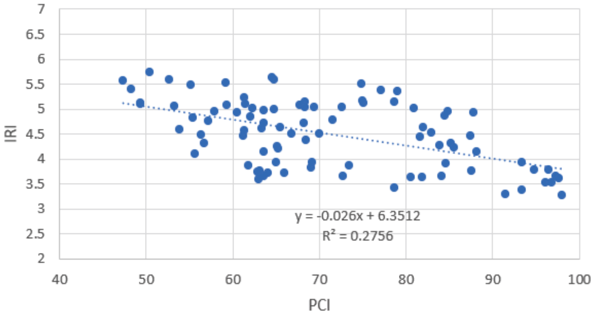

Fig. 5. Correlation between PCI and IRI values of all road segments without outliers.

4 Conclusion

This paper has demonstrated the link between PCI and IRI, allowing for the prediction of road roughness using measurements of road distress. From the study some conclusion may be inferred as:

1. The results of the analysis of the functional condition of the pavement on the 6 sections fall into the category of poor and above. While most are fair with a percentage of 44%. The roughness conditions of all road sections are good or acceptable.
2. The PCI cannot necessarily explain the IRI, even though both are used to express the functional condition of road pavements, because what Hawkeye measures for the two indices is different.

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