Linking pavement condition index and international roughness index: Insights from rural roads in Myanmar

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Abstract: There is no comprehensive understanding of the relationship between the Pavement Condition Index (PCI) and the International Roughness Index (PCI) in rural road in Myanmar, which is important for developing effective and efficient maintenance strategies. This study evaluated the relationship between the Pavement Condition Index (PCI) and the International Roughness Index (IRI) in flexible rural roads in Myanmar. The aim of this study is to examine how these two key variables correlate and how their relationship can optimize maintenance strategies. Data were collected from ten flexible rural roads in Shan State over 3 years, divided into 25-meter subsections per road. The analysis showed that PCI and IRI have a strong negative linear relationship, with an R-value (0.748) and an R-squared value (0.559). The study demonstrates the significance of IRI as a key predictor of pavement condition by showing that IRI can account for 55.9% of the variability in PCI. The study concluded that increasing IRI leads to a fall in the PCI, suggesting poorer pavement conditions. These findings emphasize incorporating IRI measurements in pavement maintenance planning to ensure smoother and safer roads, especially in rural areas. The results contribute to more effective and sustainable maintenance practices, optimizing resource allocation and extending pavement lifespan.

Keywords: Pavement Condition Index (PCI); International Roughness Index (IRI); Rural roads; Infrastructure; Sustainable communities

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1. Introduction

The International Roughness Index (IRI) and the Pavement Condition Index (PCI) are commonly used as two main indicators to investigate road conditions in pavement management systems. The PCI is a comprehensive measurement which can estimate the degree and extent of pavement surface distress and indicate the overall situation of the pavement. The IRI is also an indicator which can establish the road irregularity situation and affect riding quality and vehicle running cost (Opanayake & Amarasingha, 2022).

Although maintenance decision-makers commonly use these indicators separately, the relationship between PCI and IRI indices were used to estimate maintenance procedures in most previous literature reviews (Adeli et al., 2021; Minu et al., 2014; Shrestha & Khadka, 2021). Mainly, these previous studies indicated that IRI has a strong negative relationship with PCI and this conduct to the decision that can decrease the requirements and need to repair and extend the pavement life and can affect the effective maintenance measures. More supportive decisions can be sometimes obtained to draw an economical maintenance plan by taking IRI and PCI into account (Adeli et al., 2021; Minu et al., 2014; Shrestha & Khadka, 2021).

Moreover, higher PCI values and lower IRI values of the pavement served a more comfortable riding quality, reduced vehicle operation cost and increased levels of satisfaction for road users. Especially, in rural areas, this is significant and crucial because the situation of the roads impacts the ability of the local population and directly supports their social and economic lifestyles. Therefore, the predictive model of the IRI and PCI relationship was created in previous studies and indicated that these model helps to make decisions based on data to improve pavement management procedures (Minu et al., 2014). Before pavement deteriorations and after pavement deterioration, such models can be utilized to predict future road conditions and to schedule preventative maintenance actions.

In the previous literature review, a number of relationship models have been studied to investigate the relationship between PCI and IRI for pavement management systems. Rijal & Medis (2019) developed the equation from PCI and IRI parameters and evaluated that PCI has a significant effect on the IRI value. Ali et al. (2019) built a new set of IRI and PCI models to find out other distress that may have an impact on these indices. Adeli et al. (2021) used a linear regression model to find out the relationship between PCI and IRI in rural road networks. This study showed a strong significance of other distresses and weathering that can influence the PCI calculation and also recommended that this developed model is most suitable for rural road networks.

In Myanmar, the relationship between PCI and IRI has not been fully investigated, particularly in relation to rural road maintenance, although there are many previous studies in other countries. These studies have found that PCI has a significant effect on IRI values and new models have been introduced to identify other distresses that may influence these indices. Adeli et al. (2021) used a linear regression model to analyse the relationship between PCI and IRI, highlighting the role of additional distress and weathering. In addition, Piryonesi & El-Diraby (2021) calculated the combination of IRI values and PCI values using distress data. The results showed that the relationship between PCI and IRI could change dramatically depending on some distresses such as location, slope and functional class. Azhary et al. (2023) created both non-linear and linear regression models to observe the relationship between PCI and IRI and investigated that the IRI value decreased as the PCI value increased.

While international studies have shown that the interaction between PCI and IRI is critical for understanding pavement conditions and optimising maintenance strategies, more research is needed in Myanmar to evaluate the correlation between these indices under Myanmar's unique environmental and infrastructure conditions. This gap in understanding how PCI and IRI can be used effectively in the management of rural road networks is significant. Without this knowledge, maintenance strategies may not fully take into account the challenges of Myanmar's terrain, climate and road use patterns, leading to inefficient resource allocation and inadequate road maintenance and rehabilitation outcomes.

Studying the relationship between PCI and IRI on Myanmar's rural roads is crucial for developing maintenance strategies that are adapted to the country's environmental and infrastructure conditions. This localised research will prevent inefficient resource allocation and inadequate road maintenance, improve rural connectivity and ensure effective use of limited resources. This study is essential to adapt global knowledge to Myanmar's situation, supporting the socio-economic development of rural communities.

Therefore, this study aims to investigate the relationship between PCI and IRI in rural areas and to evaluate the economic implications of this relationship for rural road maintenance. Furthermore, it is important to understand this relationship for a number of reasons. A detailed understanding of the relationship between PCI and IRI can lead to a more comprehensive and integrated assessment of road conditions and more effective prioritisation of maintenance work by allocating limited resources to parts of the road network. With these considerations in mind, it is clear that investigating the relationship between PCI and IRI on rural roads in Myanmar is of critical importance. This study will contribute to more effective, efficient and sustainable maintenance practices in the development of rural road networks in Myanmar.

2. Material and methods

Selecting the study location, collecting data, analysing the data and finding a relationship between PCI and IRI are just some of the key tasks in the methodology. In this study, the primary method used to assess the relationship between IRI and PCI on rural roads is regression analysis.

2.1 Study area

The study focuses on ten flexible rural roads in southern Shan State, Myanmar, constructed and maintained under the supervision of the Department of Rural Road Development (DRRD). Each of these roads was constructed according to the principles outlined in Overseas Road Note 31. These roads were selected based on their long pavement history and their importance to the rural transport network. The selection criteria include a comprehensive pavement history with detailed records of construction and modifications, importance in the rural transport network as a vital link for local communities, availability of historical data on pavement conditions and maintenance activities, and representation of a variety of environmental and terrain conditions in Shan State. In this study, a flexible rural road is a pavement structure usually consisting of asphalt or bituminous layers over a granular base. For rural areas in Myanmar with limited maintenance resources, this adaptability helps the pavement to adapt to changes in the ground, making it easier to repair and maintain. The roads in the study are vital to the overall transport network in the region. Each road, while serving its specific purpose, contributes to the wider objective of improving mobility, economic activity and access to services. The roads connect different villages, agricultural fields and markets, forming a network that supports the movement of people, goods and services throughout the region.

To facilitate detailed evaluation and analysis, each road section was divided into twenty sub-sections, each 25 metres long, resulting in a total test section length of 0.5 kilometres per road. The test sections on ten roads are shown in Table 1.

Table 1. List of selected road sections

Road ID	Name of Project Road	Type of Pavement	Length of Road(km)
R1	Kanlaung-Zale Road	Flexible	2.1
R2	Nyaung Shwe-Kanu Road	Flexible	4.53
R3	Lwe Ont-Hti Bwar Road	Flexible	5.67
R4	Hlegon-Moenethraphu Road	Flexible	12.48
R5	Moenetharaphu-Kyar Ton Road	Flexible	11.37
R6	Kanlaung-Zale Road	Flexible	17.36
R7	Nyaung Shwe-Kanu Road	Flexible	6.51
R8	Lwe Ont-Hti Bwar Road	Flexible	7.11
R9	Hlegon-Moenethraphu Road	Flexible	7.8
R10	Moenetharaphu-Kyar Ton Road	Flexible	6.5

This systematic segmentation allows for a granular analysis of pavement condition and roughness, providing a well-built dataset for investigating the IRI and PCI relationship.

2.2 Data collection

Over the course of three years, data was collected using a pavement condition survey five times: in January 2020, April and August 2019, and July and October 2018. The Department of Rural Road Development (DRRD) in Myanmar is implementing Long-Term Pavement Performance (LTPP) monitoring initiatives to improve rural road infrastructure. Technical assistance from the Research for Community Access Partnership (ReCAP) is supporting these efforts. The Raters' Guidelines for Visual Assessment of Road Pavements are being used to comprehensively assess and monitor road pavement conditions. These Guidelines for the Visual Assessment of Road Pavements were followed to collect surface, structural and functional assessments during each survey. These assessments were categorised according to type, extent and severity. In addition, roughness data was collected using the free mobile application 'Road Lab Pro'.

2.3 PCI

The PCI value was calculated using equations taking into account the severity and extent ratings and weights for each identified distress. The PCI value ranged from 0 to 100, indicating that the higher the PCI value, the better the pavement condition.

$$PCI = 100(1 - C\ \Sigma_{i=1}^{n} Fi) \quad (1)$$

$$Fi = Di \times Ei \times Wi \quad (2)$$

$$C = 1\ C \div \Sigma_{i=1}^{n} Fi(max) \quad (3)$$

Data analysis was then performed using the PCI index with a visual assessment of the pavements. The condition categories, which classify pavement conditions as very good, good, moderate, poor or very poor, are shown in Table 2 (Pinard & Geddes, 2019)

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Table 3. IRI index

IRI (Value)	Degree (Index)
Below 2.5	Very good
2.5-3.69	Good
3.7-4.09	Moderate
4.1-5.59	Poor
Above 5.6	Very poor

IRI is used to assess the condition of road networks and prioritise maintenance activities. During the construction of new roads, IRI measurements help to ensure that the surface meets specified smoothness standards. Over time, IRI can be used to monitor the deterioration of roads and the effectiveness of maintenance interventions.

3. Results and discussion

3.1 PCI and IRI value of rural road in Myanmar

The analysis of PCI and IRI statistics for rural roads in Myanmar shows a clear inverse relationship between pavement condition and road roughness. The results are consistent with international studies such as Adeli et al. (2021; Piryonesi & El-Diraby, 2021) which also show a strong negative correlation between PCI and IRI. The observed trend highlights the need for regular monitoring and proactive maintenance to manage deterioration and maintain road quality, particularly in Myanmar's rural areas. Integrating PCI and IRI data into pavement management practices is essential to optimise maintenance strategies and extend pavement life in resource-constrained environments. PCI values show a decreasing trend, indicating progressive deterioration of pavement conditions due to environmental influences and traffic loads, as shown in Figure 1.

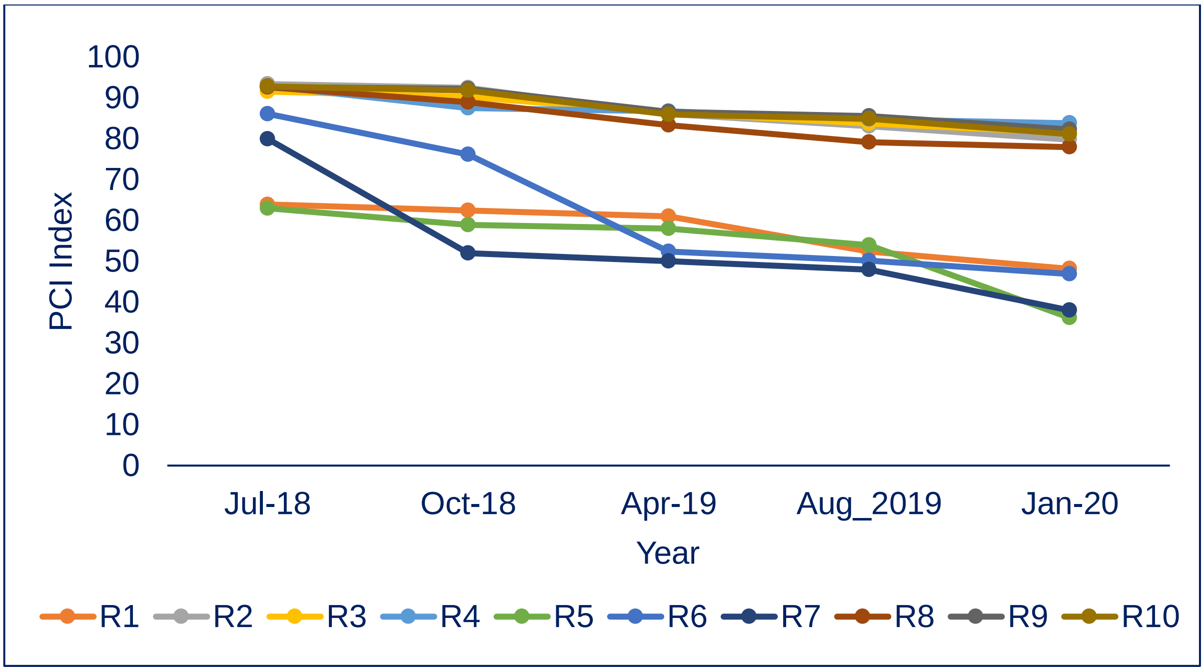

Figure 1. Average PCI values over time for each road

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The rate of decline in PCI varies between roads. R1, R2, R4 and R6 show relatively moderate declines and these roads have a better initial condition and are better maintained. R3, R5 and R9 show significant declines, indicating rapid deterioration and the need for urgent maintenance to prevent further deterioration. These declines highlight the importance of regular monitoring and timely maintenance to address emerging problems before deterioration occurs.

The rate of increase in IRI varies between the roads. R1, R2, R4 and R6 have a gradual increase in IRI values and R3, R5 and R6 have a more rapid increase in IRI values. In comparison, two increases, R3, R5 and R6, require intensive maintenance to ensure surface condition improvement, road safety and more comfortable driving. This inverse relationship between PCI and IRI highlights the importance of maintaining good pavement conditions to ensure smoother and safer roads. The IRI values show an increasing trend, which means that the roughness of the roads is getting worse over time, as shown in Figure 2.

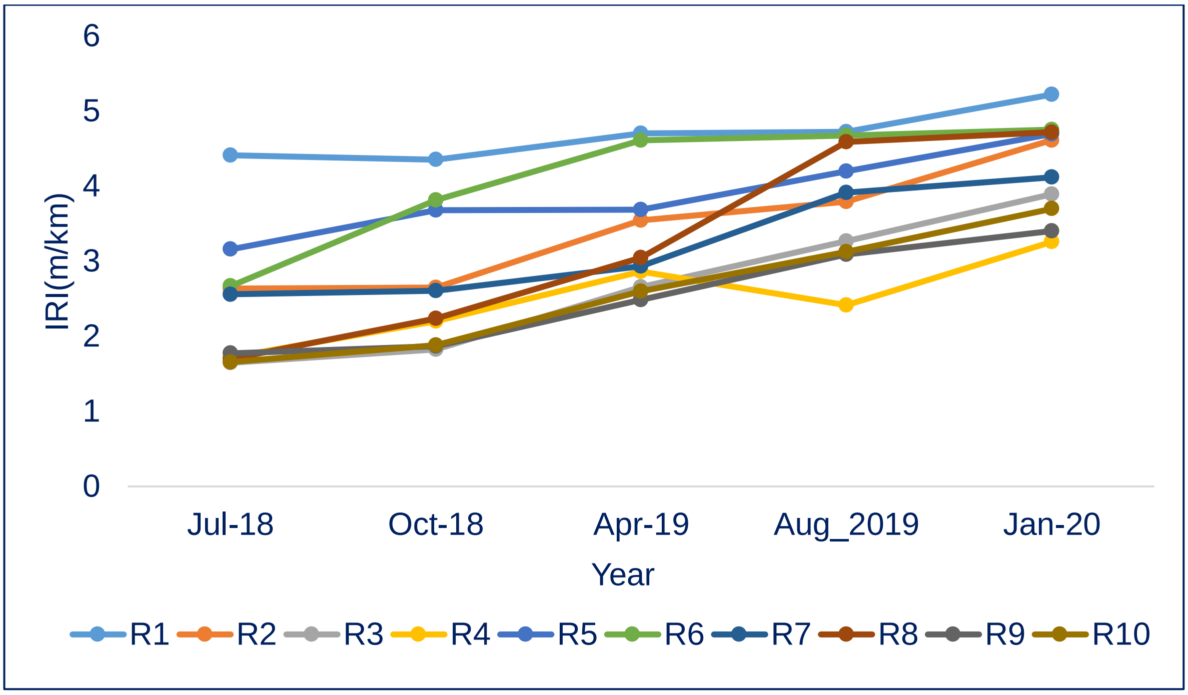

Figure 2. Average IRI values over time for each road

3.2 Model validation

To validate the accuracy of the data and to evaluate the model, the relationship model was developed on 20% of the data points. The correlation coefficient (R) value for the test data is 0.670, which also indicates a negative relationship between PCI and IRI, as shown in Table 4. The R-squared value for the test data is 0.449. This value also explains that when the values of IRI affect PCI, IRI also partially affects other variables.

Table 4. Model summary for testing data

Model	R	R Square	Adj; R Square	St. Err; of the Estimate
1	0.670	0.449	0.446	11.5851053

The constant for the test data is 110.356 and the coefficient (-9.657) indicates that the IRI has a negative relationship with the unit decrease in PCI as shown in Table 5. The data shows that the condition of the pavement decreases significantly when the roughness of the pavement surface also increases. And then the model on the test data is also significant.

Table 5. Coefficients for testing data

Model	Unst: Coefficient		St; Coefficient	t	Sig.
	B	St. Error	Beta		
1 (constant)	110.356	2.661		41.464	.000
IRI	-9.657	0.775	-0.670	-12.467	.000

According to the training and test data sets, the R-squared values for the training (0.559) and test (0.449) data sets are similar, as shown in Tables 3 and 5. Furthermore, the model shows a strong negative correlation between IRI and PCI, suggesting that pavement condition deteriorates as road roughness increases. The R-squared values and standard errors of both data sets confirm that this model is reliable in predicting pavement condition as a function of pavement roughness. This result proves that this relationship is important for pavement maintenance planning and resource allocation. To optimise pavement maintenance, it's important to keep roads within certain index ranges. A good PCI is typically between 70 and 100, indicating little to no significant distress. A good IRI is between 1.0 and 3.69 m/km, reflecting a smooth surface that provides a comfortable ride. The IRI should therefore be checked regularly to optimise maintenance schedules and extend the life of the pavement.

3.3 PCI and IRI relationship model

Linear regression analysis was used to establish a relationship model between PCI and IRI, to predict one index from the other, and to facilitate more efficient road maintenance and management strategies by analysing data from different road segments. The results were very useful as they provided a clear numerical analysis of the factors linking IRI to PCI. The model was validated using the coefficient of determination (R^2) and the significance of the regression coefficients. The validation of the performance model is considered with the consistent R-squared values and standard errors, this model confirms its reliability in predicting pavement conditions based on roughness measurements (Chopra et al., 2018).

The data was split into two sets: 80% for training and 20% for testing. The training data was used to develop the model and the test data was used to validate the predictive model. The correlation coefficient (R) value for the training data is 0.748, indicating a strongly negative linear relationship between PCI and IRI, as shown in Table 6. The R-squared value for the training data is 0.559, indicating that 55.9% of the variability in PCI can be accounted for by IRI. This certainly suggests that although IRI is a significant predictor of PCI, there is still a 44.1% other variance. And then the result implies that other factors influence PCI.

Table 6. Model summary for training data

Model	R	R Square	Adj; R Square	St. Err; of the Estimate
1	0.748	0.559	0.559	10.6333958

Table 7 shows the measured effect of IRI on PCI. The coefficient for IRI (-11.035) indicates that for every one-unit increase in IRI, PCI decreases by 11.035 units, holding all other variables constant. This negative relationship is significant ($p < 0.001$). This result shows that road roughness increases as the pavement condition deteriorates significantly.

Table 7. Coefficients for testing data

Model	Unst; Coefficient;		St; Coefficient;	t	Sig.
	B	St. Error	Beta		
1 (constant)	115.059	1.196		96.084	.000
IRI	-11.035	0.345	-0.748	-13.975	.000

4. Conclusion

The study aimed to analyse and calculate the relationship between the Pavement Condition Index (PCI) and the International Roughness Index (IRI) for rural roads in Myanmar. The analysis included expressive statistics of PCI and IRI, and a linear regression model was constructed to investigate the predictive interactions between these indicators. The current study provides strong evidence of a significant negative relationship between PCI and IRI over three years for rural roads in Myanmar. The model variance in PCI is 56% and 45% for the training and test datasets respectively. As the IRI value increases by one unit, the PCI results decrease by 9.66 to 11 units. On the other hand, over time, the PCI values showed a decreasing trend that the pavement conditions on the road sections were gradually deteriorating, and the IRI values showed an increasing situation that the roughness of the pavement surface was getting worse.

This linear relationship is critical for pavement maintenance planning and resource allocation. Regular monitoring of IRI can help to identify sections of the network that need maintenance, optimise maintenance schedules and extend the life of pavements. Policymakers and authorities responsible for road maintenance can improve the durability and safety of rural road networks by using this data to inform their decisions. The study has many limitations, including the consideration of environmental factors, the geographical focus on roads in Shan State, the reliance on a simplified linear regression model, and the lack of detailed analysis of traffic load and maintenance history. In addition, cross-validation techniques were not used extensively, which may affect the strength of the model. Future research should additionally consider variables such as maintenance history, traffic load and environmental factors, and predict non-linear relationships and correlations between different predictors. Cross-validation methods should be used to ensure the strength of the model under different circumstances. The approach and conclusions of the study also contribute to carrying out similar studies in different locations to validate and generalise the results for pavement management systems.

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Declarations

Author contribution

Nandar Tun: Conceptualization, methodology of the study, formal analysis, software and writing – original draft, data validation. Kyaing and Moe Thet Thet Aye: Methodology, supervision, review and editing.

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Competing interest

The authors declare no competing interests.

Ethical Clearance

There are no human subjects in this manuscript and informed consent is not applicable.

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