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Assessment of Relationship between Asphalt Concrete Pavement Performance Indicators: Pavement Condition Index and RoadRoid based International Roughness Index

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Abstract

Pavement condition assessment is one of the important tasks to be carried out to prioritize maintenance needs of the road. The Pavement Condition Index and International Roughness Index are some of the most widely used and comprehensive indices for the assessment of pavement condition. The maintenance planning is generally carried out in terms of SDI in Nepal which is only a subjective measure so PCI can be used as a more objective indicator than SDI. The PCI is more representative of the overall condition of the pavement surface by considering all forms of distresses. Whereas, IRI, which is a measure of perceived road roughness is mainly concerned with the ride quality and is based on the distresses occurring on the wheel path. The research aimed to develop the correlation between the two indices to look for usability of either of the indices whenever required. For the determination of PCI, visual inspection survey was carried out based on which the distress type, density and severity were quantified. The IRI data was collected with the help of RoadRoid application after calibration and validation using Laser Profiler. The data matching in respective sections was carried out and relationships between the two indices are determined in terms of linear, logarithmic and polynomial models of different degree. The coefficient of determination for polynomial relationship model was found to be the highest with coefficient of determination of 0.7858. All the models presented with negative correlation between the indices indicating the increase in IRI would cause the decrease in PCI value and vice versa.

Keywords: *Pavement Condition Index, International Roughness Index, Coefficient of Determination, RoadRoid, Distress Density, Distress Severity.*

1. Background

Sustained and well maintained road infrastructure is crucial for efficient and effective movement of traffic and goods from one place to another place. The road, a major road infrastructure, on which the vehicle moves deteriorates due to several reasons including the material used for road construction process, volume of traffic, intensity of traffic, weather conditions and so on. Road damage refers to the condition where the functional and structural condition of the road is not up to the mark that it provides optimum comfort or safety to the passengers navigating through the road in various mediums or forms. Whatever may be the reason, the road is to be restored to its original condition to provide with safe and efficient movement of traffic with greatest level comfort. To propose the specific set maintenance activities, the road condition assessment is to be carried out first. In Nepal, the pavement condition is generally assessed in terms of Surface Distress Index (SDI) while IRI data is also collected on yearly basis but not used to make extensive Maintenance decisions except from some cases. SDI is a subjective measure ranging from 0-5 where 0 refers to be best condition of the road and 5 refers to the worst condition of road and is not representative of wide range of pavement

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condition. In several countries with limited maintenance budget like Nepal, an alternative in form of Pavement Condition Index (PCI) has been proposed and used as a more efficient form of pavement condition evaluation technique which is supposed to be more effective than SDI due to the incorporation of distress type, distress severity and distress quantity during its evaluation. The riding quality and pavement roughness, which are important factors for National Highways with significant economic value, are not indicated by the SDI. IRI can be the most useful and impartial measure of pavement performance for road segments where ride quality and comfort are equally important as the structural condition of the road.

In recent years, IRI based contracts have been practiced in some major national projects in Nepal including the IRI based contract for improvement project of East-West highway for an extended maintenance period of four years. Despite IRI not being used in Nepal to that extent, it is collected on a yearly basis (IQL III). The use and implementation of IRI in maintenance planning in country like Nepal can possess significant challenges because of limited budget for road maintenance especially for low volume roads. Most of the roads of Nepal in present are of poor condition therefore specific set of maintenance activities would be required in order to uplift the pavement into fair/good condition. The use of IRI as metric in such cases can propose expensive treatment and maintenance options which is a major constraint in country like Nepal. The application of PCI can be advantageous over IRI for maintenance planning for roads with major distresses requiring localized repair due to maintenance budget constraint as the type of distress along with its severity can be identified which may help to propose specific set of maintenance activities under budget to keep the pavement in serviceable condition (Vidya, et al., 2013). For roads where both IRI and PCI or either of them can't be evaluated, the relation between the two indices can be helpful to generalize the change in the roughness of the pavement with the change in the pavement distresses. i.e. the change in PCI with IRI and vice versa which is the major focus of the study.

1.1. Pavement Condition Index (PCI)

Pavement Condition Index (PCI) is a numerical rating system ranging from 0-100 to indicate the general condition of the road section in consideration. 0 refers to the worst condition of the road whereas, 100 refers to the best condition of the road. A total of 7 groupings of road condition is developed in the standard rating scale of PCI which are also colour graded as shown in figure. The determination of PCI requires manual visual inspection survey of the pavement. The Pavement Condition Index was originally developed by United States Army Corps of Engineers as an airfield pavement rating system, but it was later modified by ASTM for highway and parking. The PCI is considered to be one of the most comprehensive and widely used measure of pavement performance evaluation. The PCI is not often used in countries like Nepal because of its cumbersome procedure of computation and field tediousness. Lower value of PCI refers to high degree of deterioration of road whereas, higher value of PCI represents better roads with lower degree of road deterioration. The PCI is dependent on the distress density, distress severity and distress type so, it gives an idea of the degree of deterioration caused by the distresses. As PCI covers wide range of distress type and their corresponding severity, it is considered to be one of the most comprehensive forms of pavement condition evaluation technique. The standard PCI scale is as shown in Figure 1, whereas, the drastic drop in condition of pavement condition with increase in time is as shown in Figure 2.

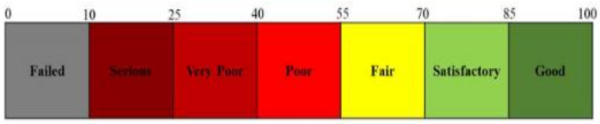

Figure 1. Standard PCI scale (ASTM 6433, 2018)

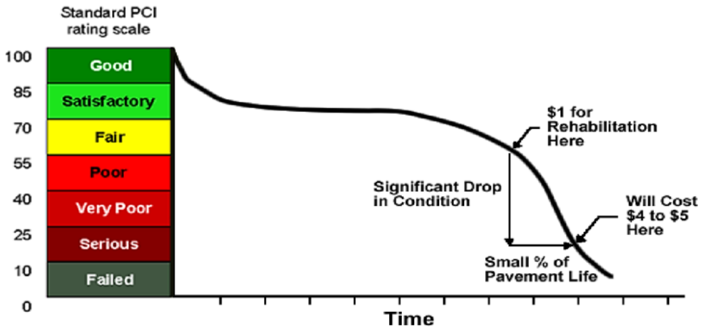

Figure 2. PCI change with time (Arhin et al., 2015)

1.2. International Roughness Index (IRI)

The International Roughness Index is a measurement of perceived road roughness and ride quality. It is often computed using a quarter car vehicle math model or with the aid of a mounted bump indicator or roughometer. (Donny and Mamok, 2018). Nowadays, smartphones may be used to evaluate the roughness of a road profile using their tri-axis accelerometer sensor, Android-based roughness estimate techniques have gained widespread acceptance in recent years. Some of the popular and reliable smartphone apps for measuring IRI are RoadRoid Pro 3 and RoadBump Pro (Hossain, et al., 2019). RoadRoid and RoadBump applications are also used by FHWA for roughly estimating the perceived road roughness of the surface of the road (Lars & Forslof., 2013). The RoadRoid IRI gives a notion of the ride quality in the same area and indicates the roughness of the pavement section under consideration. The kind and quantity of pavement distresses are directly correlated with the IRI, which is assessed using a variety of equipment and methodologies.

2. Literature Review

Park, et al., (2007) developed the relationship between the international roughness index and the pavement condition index with the help of the data collected from a total of nine different states and provinces in United States of America. The Data Pave program was used in order to extract the data set of PCI-IRI for states of New York, New Jersey, Virginia, Vermont, Maryland, Delaware, Quebec (Canada), Ontario and Prince Edward Island for a combined period of nine years ranging from 1991 AD to 2000 AD. The regression model was developed between the 2 variables with a R2 value of 59 %. The relation was in the form of Equation 1(Park et al, 2007).

$$\log PCI = 2 - 0.436\log(IRI) \qquad \text{(Equation 1)}$$

Arhin, et al., (2015) developed a model in order to evaluate the International Roughness index based on the Pavement condition index in California. The main aim of the model was to estimate the ratio of cost and benefit of the users in the pavement management system. The research used SPSS software as the primary tool for analysis and modelling and the regression analysis and its subsequent validations were carried out in order to come up with the equation consisting of PCI in relation to the IRI. The coefficient of correlation between the models was found to be 0.53, Graphical comparison was used in order to graphically compare the data dispersion seen in the model. The relationship between the IRI and PCI was as given in Equation (2) (Arhin et al, 2015).

$$IRI = 0.0171(153 - PCI) \qquad \text{(Equation 2)}$$

The relationship between the SDI and IRI was developed by Suryoto and Siswoyp in 2016. They were able to present the relationship between the two in form of a linear fit equating in the relation of SDI = 32.684 + 3.3455 x IRI. The Pearson correlation analysis was used In order to define the value of coefficient of correlation between the two variables. The correlation coefficient was found to be 0.203 which could be deemed as poor correlation. (Suryoto, et al., 2016)
Based on the study carried out by Donny and Mamok in 2018, it suggested that, as an alternative to more expensive and more sophisticated equipment such as Roughometer or bump integrator for the evaluation of IRI, a simple android based application could be used. To prove this hypothesis, 5 total segments of the road

was considered and analyzed for which the data of distresses were initially collected. Based on the collected data, the PCI was evaluated and based on which the road was assessed to be in good condition. The IRI data was then evaluated with the help of accelerometer sensor present in smartphone with the help of RoadRoid application and the pavement based on IRI was deemed to be in medium condition. Comparing the relation between the two, the correlation value of -0.23 was assessed (Donny & Mamok, 2018).

Based on the research carried out by Jones and Forslof (2016), smartphones contains build in vibration and accelerometer sensors which could be employed for the determination of roughness of the road in terms of IRI relating up to class II or class III equipment effectively. It highlighted that, the value of the roughness of the road changes significantly with time so a cost effective measure to assess the change in the roughness is necessary. They developed a program in form of RoadRoid application which helps to determine the IRI in terms of cIRI and eIRI which yields macroscopic and microscopic roughness in the road segments respectively. Several hundreds of section of the road was selected and IRI was determined with the help of the RoadRoid application and Class I IRI measuring equipment which yielded a correlation of 81 % between the RoadRoid IRI data and Laser profiler IRI data therefore they concluded that RoadRoid could be used for the the determination of IRI as a cost effective alternative to other sophisticated equipment (Forslof & Jones, 2016)

Based on the study carried out by Shrestha in 2023, the RoadRoid application was successfully calibrated with the help of Romdas z-250 reference profiler before using it for the determination of IRI in the road sections in consideration. The chi-squared test of goodness of fit was carried out in order to assess that there was no significant difference between the predicted and actual values of IRI obtained from RoadRoid application. The IRI thus obtained was then used to develop the model between the IRI with the corresponding distress groups developed based on distress quantification survey in the research. The relation between IRI and the corresponding distress groups yielded moderate correlation in both training as well as testing. (Shrestha, et.al. 2023)

The roughness and distresses along the pavement were represented and measured using the IRI. With a width of 250 meters, 83 sections of flexible pavement were evaluated. For each part under evaluation, the IRI data and the distresses were gathered. With the aid of the Dynatest RSP test equipment, the IRI data was gathered, and a correlation between the IRI and the visible pavement distresses was established. The SPSS regression result showed that, with the aid of apparent pavement distresses, the model was sufficiently robust to predict IRI. (Hasan, et.al, 2020)

3. Study Area

The study area was focused only on the Asphalt Concrete pavements in and near districts of Lalitpur, Kathmandu and Bhaktapur. The main criteria for the selection of the study area was the easiness in data collection and the incorporation of pavements in all conditions. i.e.the data collection was carried out in sections with wide range of distresses to section with limited amount of distresses. A total of 468 sections were considered for the collection of roughness data in terms of IRI and distress data for evaluation of PCI contributing to about 468 data for the development of the model between the PCI and the IRI. The study area in which the collection of data was carried out is as presented in table 1.

Table 1. Study area for data collection

Link	Designation	Distance Surveyed
Pepsicola-Sanothimi	F086	2.4 km
Samakhusi-Grande	F082	4.4 km
Lubhu to Lakuri Bhanjyang road	H15	5.0 km
Lainchaur-Budhanilkantha	F021	9.3 km
Hattiban-Godawari	F024	6.6 km
Imadol-Lamatar	F072	7.6 km
Tripureswor-Satungal	H18	6.0 km
Jorpati-Gokarna	F088	5.5 km
Total length surveyed		46.8 km

4. Detailed Methodology

The selection of study area was followed by the collection of the distress data in the pavement section in consideration for the estimation of PCI value followed by the determination of IRI value based on RoadRoid application after its calibration and validation. The data matching of respective sections was carried out and the correlation between the IRI and PCI was determined. The detailed methodology in form of flowchart is as shown in Figure.

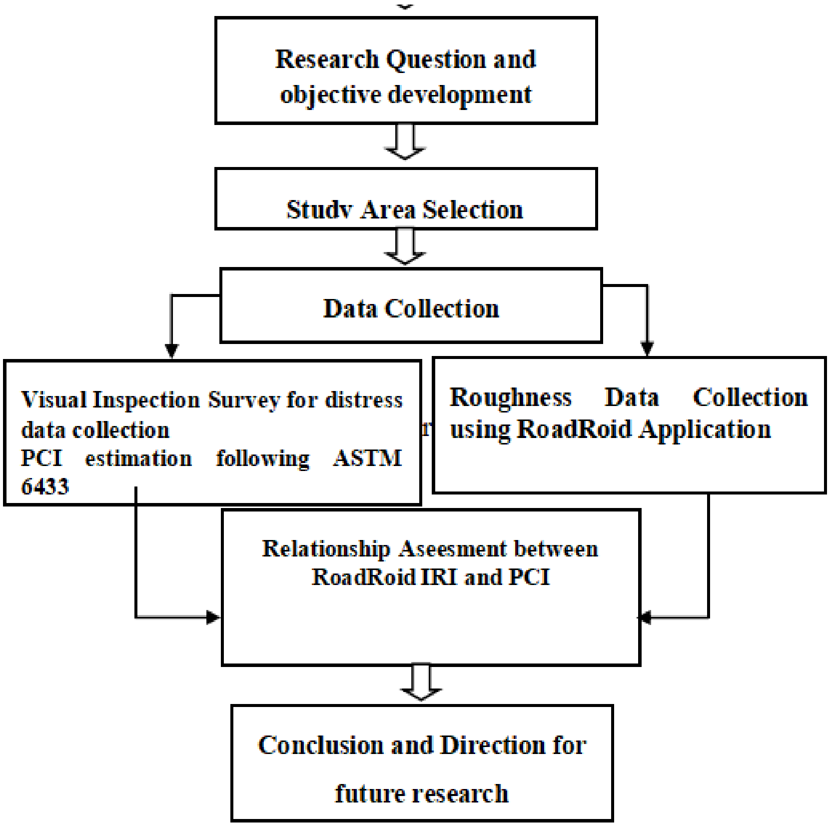

Figure 3. Methodological Flowchart

3.1 Distress data collection

The distress data was collected with the help of visual inspection survey carried out for all the section in consideration. The quantification of distress was carried out as per ASTM 6433 which also provides in detail, the steps for the evaluation of the Pavement Condition Index through evaluation of deduct values and corrected deduct values. A total of 20 type of distress were considered for the determination of PCI value as per ASTM 6433 specification and for each type of distress, the distress severity in terms of low, medium and high was ascertained. Some of the distresses collected in the study area is as shown in table below.

Table 2. Distress data collection

Photo	Interpretation/Distress information
	Section measurement at Pepsicola Chowk-Manohara section
	High severity pothole @ Pepsicola- Manohara section Pothole depth- 35 mm Pothole diameter- 460 mm
	High Severity Alligator Cracking @ Chakrapath - Bansbari section

Medium severity alligator cracking and medium severity patching @ Lainchaur to Chakrapath section

3.2 PCI estimation

The selected road sections are divided into equal sub sections of 100 m length and the corresponding average width of the section are noted. Then the distress are noted and quantified with the help of visual field inspection survey and are the corresponding distress density is determined as percentage of total area of the section by dividing the area of distress with the area of the pavement section. The distress to be evaluated as per ASTM 6433. The deduct values are then determined for each type of distresses and the corresponding severity levels for the particular distress. The PCI is estimated by applying the deduct value for each distress type along with any required correction factors (Corrected Deduct Values, CDVs) to account for multiple distress types. The PCI is obtained by reducing the maximum CDV from 100. If none or only one individual deduct value is greater than two, the total value is used in place of the maximum CDV in determining the PCI; otherwise, maximum CDV is determined using following procedures. The individual deduct values are listed in descending order and the allowable number of deducts are determined with the help of the Equation 3(ASTM 6433, 2018).

$$m = 1 + (9/98)\,(100 - HDV) \leq 10 \qquad \text{(Equation 3)}$$

(ASTM 6433,2018)

The maximum CDV is determined using iterations. The maximum of corrected deduct values is found and the PCI is determined with the help of the Equation 4.

$$PCI = 100 - maxCDV \qquad \text{(Equation 4)}$$

(ASTM 6433,2018)

3.3 RoadRoid IRI estimation

The roughness of the road for the sections in consideration is determined with the help of RoadRoid application. The calibration and validation of RoadRoid application was carried out before carrying out the roughness survey (Shrestha and Pradhananga, 2023). During the calibration process, the sensitivities of the accelerometer sensor were set and the RoadRoid IRI data was compared with the IRI date obtained with the help of Laser Profiler (Class I equipment) and the difference between the observed and expected frequencies of IRI for same section was carried out with the help of Chi square test of goodness of fit. It was found that there was no significant difference between the observed and expected frequencies of IRI so, RoadRoid could be used for the determination of IRI in the section in consideration for the evaluation of the roughness of the section (Shrestha & Pradhananga, 2023). The sensitivities and chi square test tables are as shown in figure 3 and table 3respectively.

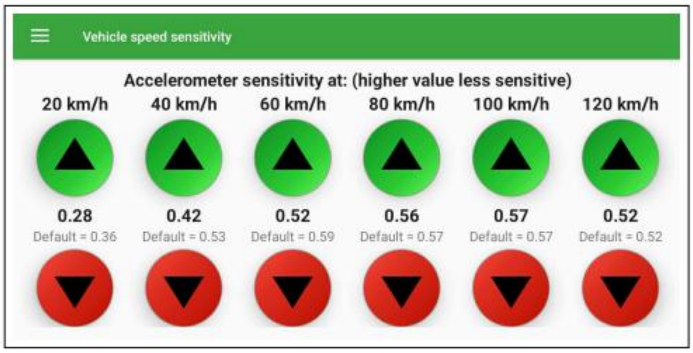

Figure 3. Accelerometer sensitivity for various speeds
(Shrestha & Pradhananga, 2023)

Table 3. IRI values obtained from Laser Profiler and RoadRoid (Shrestha & Pradhananga, 2023)

Section (m)	The ROMDAS Z-250 Reference Profiler IRI	RoadRoid IRI 4 passes same section				RoadRoid average IRI
0-5	1.251	1.5	1.45	1.32	1.36	1.408
5-10	1.631	1.85	2.05	2.12	1.9	1.980
10-15	2.777	2.85	2.98	3.01	2.94	2.945
15-20	10.502	5.88	6.18	6.45	5.98	6.123
20-25	7.253	6.45	6.78	6.12	6.23	6.395
25-30	5.123	4.23	4.12	4.57	4.23	4.288
30-35	1.941	2.05	2.33	2.08	2.06	2.130
35-40	2.530	2.8	2.6	2.56	2.48	2.610
40-45	3.794	3.8	3.98	3.77	3.23	3.695
45-50	6.424	5.21	5.23	5.98	5.15	5.393
50-55	7.156	6.15	6.35	6.66	6.39	6.388
55-60	6.471	6.12	6.32	6.89	6.44	6.443
60-65	3.859	3.5	3.26	3.55	3.68	3.498
65-70	3.491	3.5	3.66	3.45	3.54	3.538
70-75	3.318	3.12	3.28	3.18	3.5	3.270
75-80	3.151	3.05	3.5	3.22	3.32	3.273
80-85	3.246	3.44	3.08	3.2	3.22	3.235
85-90	2.748	2.89	2.85	2.98	2.74	2.865
90-95	2.606	2.4	2.56	2.14	2.71	2.453
95-100	2.484	2.56	2.55	2.87	2.49	2.618

3.4 Data Matching

Based on the collected data of IRI with the help of RoadRoid application and PCI calculated with the help of distress evaluated through visual inspection survey, the relationship between the IRI and the corresponding PCI is developed. In order to do so, the PCI-IRI matching is carried out as per visual cues and markings set during the road inspection survey. The visual cues are identified with the help of video taken during the process of IRI survey using RoadRoid. After data matching, the PCI and IRI are listed in tabular format.

3.5 Relationship Development

The relationship between the PCI and IRI is evaluated based on the data using Excel 2016 software. Initially the linear relationship between the PCI and IRI is evaluated with the help of data analysis tool-pack through add-ins of the excel software. During the development of the model, PCI is taken as the dependent variable and IRI is taken as the independent variable. The relationship is evaluated for 95 % confidence limit which is the default value in the toolpack. Using the scatter plot of excel, the plot between the PCI as well as the IRI is plotted with IRI in horizontal axis and PCI in the vertical axis. The regression equation is then developed for linear regression model and Polynomial regression model with the help of the data analysis toolpack in excel. The linear model is converted into polynomial regression model by developing the polynomial trend line of degree 2 and degree 3 in trend line properties. The regression model is also checked for higher degree polynomials but, it presented with the problem of over fitting of the model. The regression equations for linear regression model, logarithmic regression models and polynomial regression models are represented by the Equation 5, Equation 6, Equation 7 and Equation 8 respectively as follows:

$$PCI = \begin{cases} -7.7046 \text{ x IRI} + 100, & \forall \quad IRI < 12.979 \text{ m/km} \\ 0, & \text{Otherwise} \end{cases} \qquad \text{(Equation 5)}$$

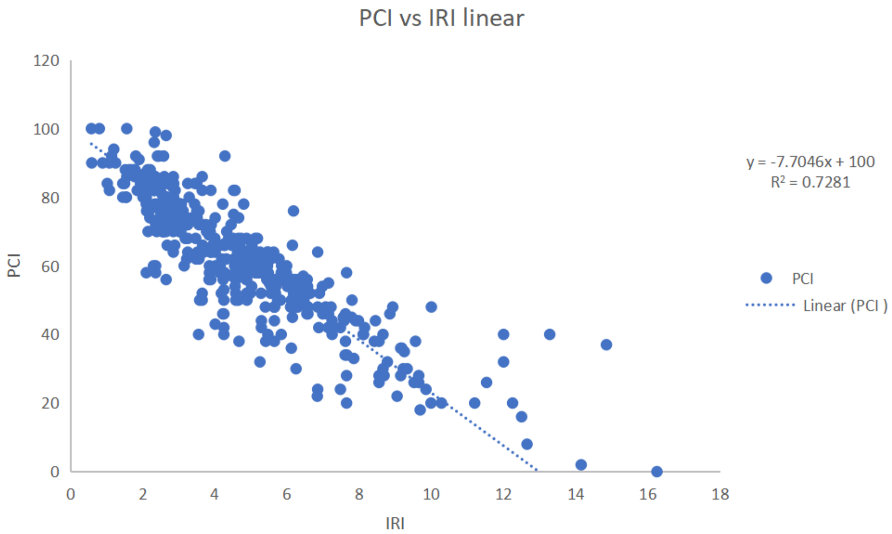

Figure 4. PCI vs IRI linear relationship

$$PCI = \begin{cases} 100, & \forall \ IRI \leq 1.147 \quad \text{m/km} \\ -29.45 \text{ x } \ln(IRI) + 104.05, & \forall \ 1.147 < IRI < 34.23 \text{ m/km} \\ 0, & \text{Otherwise} \end{cases} \qquad \text{(Equation 6)}$$

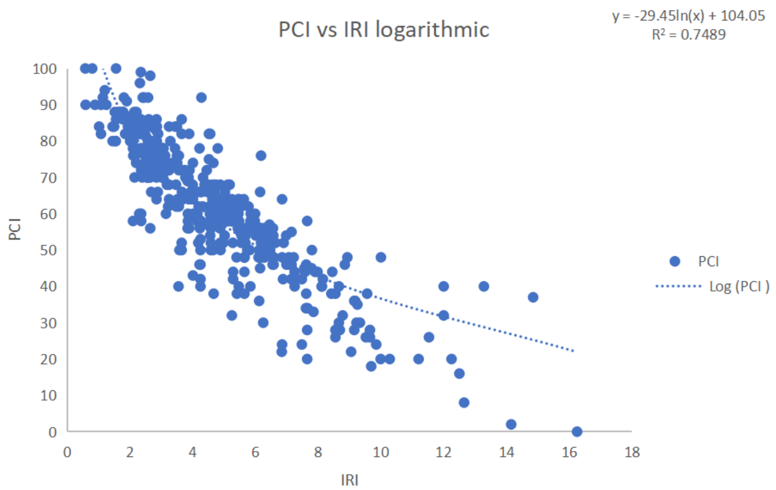

Figure 5. PCI vs IRI logarithmic relationship

$$PCI = \begin{cases} 0.2544 \text{ x } IRI^2 - 9.5505 \text{ x IRI} + 100, & \forall \ IRI < 18.77 \text{ m/km} \\ 0, & \text{Otherwise} \end{cases} \qquad \text{(Equation 7)}$$

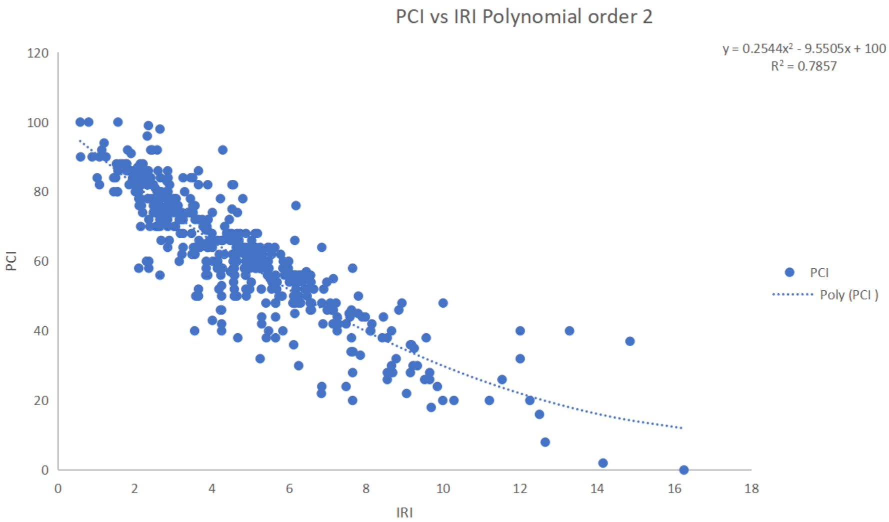

Figure 6. PCI vs IRI polynomial relationship of degree 2

$$PCI = \begin{cases} 0.0027 \text{ x } IRI^3 + 0.2086 \text{ x } IRI^2 - 9.3852 \text{ x } IRI + 100, & \forall\ IRI < 16.92\ m/km \\ 0, & \text{Otherwise} \end{cases} \quad \text{(Equation 8)}$$

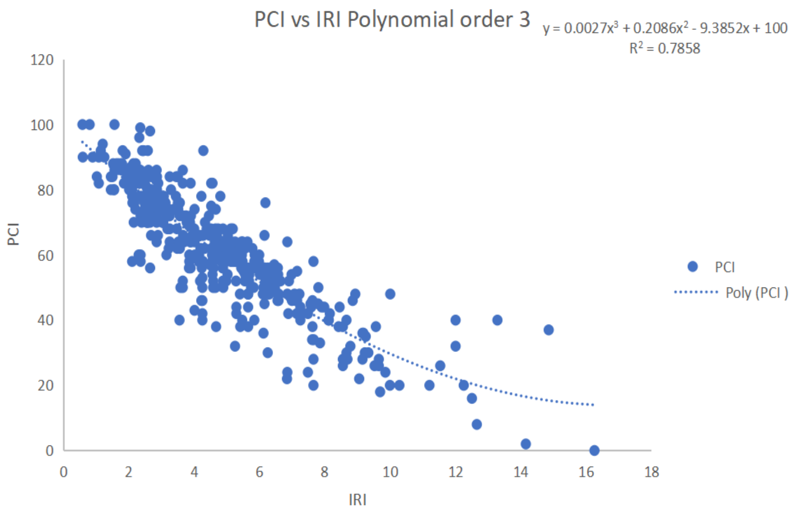

Figure 7. PCI vs IRI polynomial relationship of degree 3

3.6 Results and Conclusion

The coefficient of determination i.e. R2 value is determined as 0.7281 for linear regression model whereas, the coefficient of determination is determined as 0.7857 and 0.7858 for polynomial regression model of degree 2 and degree 3 respectively. Similarly, the coefficient of determination value found to be 0.7489 for logarithmic regression model. The scatter plots with linear, logarithmic and polynomial trend line are as shown in Figure 3, Figure 4, Figure 5 and Figure 6 respectively. For the collected set of data, the polynomial regression models are found to be slightly more accurate in predicting the relationship between the PCI and the IRI as it has higher coefficient of determination by a small amount. The trend lines in each of the developed relationship models indicated negative correlation i.e., the increase in IRI value resulted in the decrease in PCI value and vice versa. The model with polynomial relationship between the two explains that

75 % of the variance of PCI value is explained by the variation of IRI value. The main reason that the remaining proportion is not explained by the model is because of the fact that, PCI considers wide range and form of distresses along with the distresses contributing to the increase or decrease in road roughness. These distresses which are not contributing to IRI contributes to PCI or condition of road therefore reducing the reliability of the model developed where distresses occurring on section other than the wheel path are excessive than the distresses occurring on the wheel path. This model would be useful for roads where both IRI and PCI or either of them can't be evaluated, the relation between the two indices can also prove to be helpful to generalize the change in the roughness of the pavement with the change in the pavement distresses.

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