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Development of Relationship between Roughness (IRI) and Visible Surface Distresses: A Study on PMGSY Roads

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Abstract

Roughness has been universally accepted as a measure of functional condition of a pavement. It constitutes the smoothness and frictional properties of the pavement surface and in turn is related to the safety, and the ease of the driving path. It is determined using the international roughness index (IRI), which is a measure for texture of the pavement surface, and also depends on the amount of other functional distresses present on the road surface. The present study focuses on developing a relationship between the roughness and other surface distresses of PMGSY roads. Accordingly, eight PMGSY roads were selected in Jhunjhunu and Churu districts of Rajasthan, India. Distress data was collected for every 50m separately. Roughness data was collected using Bump Integrator, which was calibrated using MERLIN on the couple of selected study stretches. Unevenness data was also collected from a newly laid stretch of pavement, and the value thus obtained was subtracted from the observed unevenness values of the test stretches, to get the net effect of the distresses on the pavement condition. A regression equation was then developed with the IRI value and the visible distresses based on the data collected in the field.

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Keywords: Roghness; Bump Integrator; IRI Value; Uneveness Index

1. Introduction

1.1 Background

Rural road connectivity is considered as a key component for rural development that promotes access to economic and social services which in turn generates increased agricultural incomes and productive employment opportunities. It also results in ensuring sustainable poverty reduction. Keeping the above facts in view the Government of India launched the Pradhan Mantri Gram Sadak Yojana (PMGSY) in December 2000 as a fully

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centrally funded programme. Roughness has been universally accepted as a measure of functional condition of a pavement. It constitutes the smoothness, and frictional properties of the pavement surface and in turn related to the safety, and the ease of the driving path. The serviceability or riding quality of the road pavement is the major indicator of its service performance (Fwa et al. 2005). It is determined using the international roughness index (IRI), which is a measure of the texture of a pavement surface and depends on the amount of the other functional distresses present on the road surface.

Measuring the roughness is difficult, since it also depends on the vehicular characteristics in addition to the actual road roughness. There are several methods and techniques of measuring and representing road roughness varying widely in aspects of technical complexity, cost, and speed of use and precision of output. The vehicle-mounted bump integrator, developed more than ten years ago by the British, Transport and Road Research Laboratory (TRRL), is an affordable, easy to use, and probably the most appropriate method of roughness evaluation with respect to the technological base of many developing countries (Mrawira and Haas,1996, Sandra & Sarkar,2012) calibrated Bump Integrator at various speeds, both higher and lower than the standard speed (32 km/h), so that, it could be used in all kinds of roads effectively. (Dewan and. Smith, 2002), through their study, suggested that If an appropriate correlation can be established between IRI and pavement distresses for their streets, the agencies in the cities and counties of the San Francisco Bay Area may need only distress information to estimate the Vehicle Operation Cost (VOC) for those streets.

The aim of the study is to develop a relationship between roughness and all the pavement distresses for the selected PMGSY study stretches, so that, the effect of each one of them could be determined, which in turn would help to take most appropriate decision for maintenance.

1.2 Scope of Research

The present research study is limited to PMGSY roads in Jhunjhunu and Churu districts of the state of Rajasthan, India. The usually observed distresses on Indian rural roads such as cracking, potholes, patching, rutting and ravelling are considered in the study. In addition to above distresses, edge failures (cracking, ravelling and breaking) are also included, which may be useful for taking maintenance decisions. All distresses would be measured in terms of extent and severity. In General, lengths of PMGSY roads are equal to or less than 3Km. Thus, in order to have a sufficient amount of data for analysis, the stretches would be divided into smaller segments of 50 m, each. Pavement distresses data have been measured manually and roughness data is collected using Bump Integrator. In a nutshell, this study attempts to develop the relationship between IRI and other visible pavement distresses. The findings of the study may be useful to the authorities for the purpose of maintenance and classification of road conditions.

2. Literature Review

The functional condition of a pavement stretch, which is expressed in terms of serviceability, has been given its due importance after its inclusion in the American Association of State Highway Transportation Officials (AASHTO) flexible pavement design equation. One of the primary factors that affect the serviceability of roads is the pavement roughness. If the correlation between each type of distress and roughness, and the proof that IRI may completely reflect pavement deterioration, may be obtained. Then it may be possible to regard IRI as pavement performance index without considering other distress types, and to represent the change of performance of the pavement life cycle as the change in IRI. Moreover, deterioration models of other distress types combining two or more distress types, that occur simultaneously may also be created using constructed deterioration model of IRI(Lin, Yau and Hsiao, 2003).

In addition, many countries use the road roughness as one of the primary components in calculating vehicle operating costs (CRRI, 1982; Kadiyali, 2000; Dewan and Smith, 2002). A relationships between PSR(Present Serviceability Index) and IRI also developed by (Al-Omari and Darter,1994) for flexible, rigid and composite pavement types for the state of Louisiana, Michigan, New Jersey, New Mexico and Indiana. They found that there were no significant different between the models for different states and pavement types.The IRI is based on the average rectified slope (ARS), which is a filtered ratio of a standard vehicle's accumulated suspension motion (in mm, inches, etc.) divided by the distance travelled by the vehicle during the measurement (km, mi, etc.). IRI is then equal to ARS multiplied by 1,000 (Bin, 2009, Lin et al, 2003) conducted a study to examine the correlation of pavement roughness and pavement distresses. The study was carried out for predicting pavement roughness based on the ten types of pavement distresses using a back propagation neural network technique. Ten types of distresses, that they considered were rutting, alligator cracking, cracking, digging, pothole, corrugation, man-holes, stripping, patching, and bleeding. From the study, the authors proved that IRI can be used either to evaluate the quality of pavement projects or to fully respond to the characteristics of pavement deterioration process, which can be used as the basis for road maintenance evaluation. While cracking, alligator cracking, bleeding and road level are the least related factors to IRI. Sandra and Sarkar (2012) developed a model for estimating International Roughness Index (IRI) from Pavement Distresses. The study was carried out on state highways and other major district roads of Rajasthan, India.

3. Study Methodology and Data Collection

The main aim of this study is to develop the relationship between International Roughness Index (IRI) and other visible pavement distresses for PMGSY roads, so that appropriate measures for road repair can be taken on the basis of the predicted IRI. The following steps in developing a relationship between IRI and Pavement distresses data: (i) selection and identification of pavement stretches, (ii) distress data collection and Roughness Surveys, and (iii) development of relationship between IRI and pavement are explained briefly below.

3.1 Selection of pavement stretches through reconnaissance survey

A detailed reconnaissance was conducted by visiting the number of PMGSY roads covering two districts in the state of Rajasthan namely Jhunjhunu and Churu. The study stretches were selected based on the following criteria: (i) the condition was essentially poor with at least one visible distress, (ii) they were free from interruptions in the form of intersections, cattle and pedestrian interference to ensure free traffic flow conditions, and (iii) mostly having a straight alignment i.e. free from having vertical and horizontal curves. Based on these criteria, a total of 8 different stretches of variable lengths were chosen.

3.2 Selection of Flexible Pavement Distress Parameters and Levels of Severity

After observing number of road stretches as a part of reconnaissance survey, six different distress parameters, namely, cracking, rutting, ravelling, potholes, patches and edge failures, have been identified as the major factors which affect the functional condition of the flexible pavements. The extent and severity levels of the selected distress parameters also have the varying effects on pavement condition. The extent of the distress parameters can be measured through the visual observation, but it is difficult to quantify the severity level. Hence, it was decided to classify severity in terms of low, medium and high. However, since the perception regarding the severity may vary from person to person and to avoid the discrepancy, while collecting data, descriptions of the severity levels were clearly defined (Table 1) based on the studies carried out by the various researchers (Sandra and Sarkar, 2012; NHCRP, 2004). As a prerequisite for conducting the study, chosen set of enumerators were trained for collecting distress data through visual observation (with the aid of description of pavement distress severity levels presented in the Table 1). They were also trained through actual observations in the field about how to measure the extent of each parameter. This ensured the accuracy and uniformity in the data collection process.

3.3 Pavement Roughness Data

The selected pavement stretches were divided into uniform sections of length 50 m each. Road width of each of the sections was divided into bands of 24 cm width. This width was obtained by calculating the width of Bump Integrator as 12 cm and an addition of 12 cm offset (6 cm on either side). Bump Integrator was run two times in each band and average value of roughness was taken. The average value of all bands over the width of the section for 50 m represents the roughness values of that section. The sample format of roughness data for one of the sections is shown in Table 2.

4. Development of Correlation between Roughness and Distress Parameters

4.1 Calibration of Bump Integrator Using Merlin

The Towed-Fifth-Wheel Bump Integrator is a response type Unevenness Index (UI) measuring system and the UI measured by this system depends on the actual unevenness of the road surface and also on the combined effect of the dynamics due to the vibration of the towing vehicle and the instrument. Hence, it is absolutely essential to calibrate this equipment before it is being used for the actual data collection. Bump Integrator was calibrated on selected calibration stretches using MERLIN, before the actual surveys were conducted. MERLIN is a manually operated instrument which is wheeled along the road and measures surface undulations at regular intervals, it is robust, inexpensive, easy to operate and maintain. The MERLIN D-Values obtained during the data collection on calibrated sections were converted into Bump Integrator roughness values. For this purpose, a relationship suggested by Cundill (1991) and Sayers et al., (1986) between the MERLIN D-Values and the Unevenness Index (mm/km) values obtained using Bump Integrator was used. It has been shown in Equation 1. A simple linear regression model was developed between measured roughness value and corrected roughness value shown in Equation 2. The relationship has also been shown graphically in Figure 1.

$$BI = 574 + 29.9\,D \quad (1)$$

BI Unevenness Index (mm/km) obtained using Bump Integrator
D MERLIN D-Value

$$UI_c = 0.956 * (UI_f) + 114.34 \qquad (R^2 = 0.9946) \quad (2)$$

UI_c Corrected Unevenness Index (mm/km)
UI_f Measured Unevenness Index in the field using Bump Integrator (mm/km)

4.2 Pavement Roughness Model Development

On a freshly overlaid PMGSY pavement surface, roughness has been measured using Bump Integrator running at the standard speed of 32 km/h. This study resulted with an average initial Unevenness Index (UI) value of 2372 mm/km (IRI = 3.23 m/km). The Initial IRI values are free from the surface distresses and have been deducted from the observed roughness and the excess values are considered as due to the distress parameters present on the pavement surface.

In this study, UI values obtained using the Bump Integrator have been converted into IRI values and then used for the model development. In the International Road Roughness Experiment (IRRE) conducted in Brazil, a standard Bump Integrator was calibrated against the IRI standard and a relationship was established as shown in Equation 3. Many researchers (Sayers et al., 1986; Sandra and Sarkar, 2012) used this equation for different situations. The same equation was used in this study also for converting Bump Integrator readings into IRI values. The extent data of all the pavement distress parameters (collected in terms of area in m^2), namely, alligator cracking, potholes, patching and ravelling (collected at three severity levels as given in Table 1), were normalized by converting into percentage with respect to the area total area considered, as shown in Equation 4. The extent of the other pavement distresses like longitudinal/transverse cracking, Rutting and Edge Failures (cracking, ravelling and breaking) were expressed in terms of length (meters) at three severity levels as given in Table 1.

Table1: Description of Flexible Pavement Distress Severity Levels

S.no	Type of Distress	Severity level	Description
1	Cracking(Aligator/ Longitudinal/Transverse)	Low	Width of the cracking is less than 3mm
		Medium	Width of the cracking is greater than 3mm and less than 6mm
		High	Width of the cracking is greater than 6mm
2	Potholes	Low	Depth of the pothole is less than 25mm
		Medium	Depth of the pothole is more than 25mm and less than 50mm
		High	Depth of the pothole is more than 50mm
3	Ravelling (Middle/Edge portion)	Low	The aggregate or binder has started to wear away but has not progressed significantly. The pavement appears only slightly aged and is lightly rough
		Medium	The aggregate or binder has worn away and the surface texture is moderately rough and pitted. Loose particles may be present and fine aggregate is partially missing
		High	The aggregate and/or binder has worn away significantly, and the surface texture is deeply pitted and very rough. Fine aggregate is essentially missing from the surface, and pitting extends to a depth approaching one half (or more) of the coarse aggregate size
4	Patching	Low	Patch has low severity distress of any type including rutting , 6 mm; pumping is not evident
		Medium	Patch has moderate severity distress of any type or rutting from 6 to 12 mm; pumping is not evident
		High	Patch has high severity distress of any type including rutting .12 mm, or the patch has additional different patch materials within it; pumping may be evident
5	Rutting	Low	Barely noticeable, depth less than 6mm
		Medium	Readily noticeable, depth more than 6mm less than 25mm
		High	Definite effect upon vehicle control, depth greater than 25mm
6	Edge Failures	Low	Edge breaks having width < 300 mm, Edge Cracking having width less than 3 mm
		Medium	Edge breaks having width more than 300 mm and less than 600 mm, Edge Cracking having width greater than 3 mm and less than 6 mm
		High	Edge breaks having width > 600 mm, Edge Cracking having width greater than 6 mm

$$IRI = 0.0032 * (BI)^{\hat{}0.89} \quad (3)$$

IRI	International Roughness Index in m/km
BI	Unevenness Index obtained using Bump Integrator (mm/km)

$$PAD = (AD*100/A) \quad (4)$$

PAD	Percentage area of distress parameters
AD	Area of distress parameter
A	Total area of the pavement section considered

4.3 Model development

The pavement distresses and roughness data, collected over the entire width of 136 uniform stretches of 50 m length, covering 8 PMGSY roads in the Jhunjhunu and Churu districts of the state of Rajasthan, have been used for modelling and its validation. Data of randomly selected 94 stretches (approximately 70 percent of the observed values) was used for model development and the data on remaining 42 stretches (approximately 30 percent of the observed values) were reserved for the purpose of model validation.

Table 2: Sample of Unevenness Index Data collected along the entire width of the pavement

Section No	Unevenness Index (UI) in mm/km collected on different bands in a section along the width of the pavement										Avg UI (mm/km)
	1	2	3	4	5	6	7	8	9	10	
1	3200	3000	3000	3400	3400	4200	4000	5200	4600	4800	3880
2	2000	2000	1600	1800	2400	2600	2400	2000	2200	2200	2120
3	2200	2400	2200	2200	2200	2000	2000	2200	2400	2400	2220
4	2800	2800	2800	2600	2600	2800	2400	2600	3600	2600	2760
5	2400	2800	2800	2400	2200	2200	2200	2000	2400	2200	2360

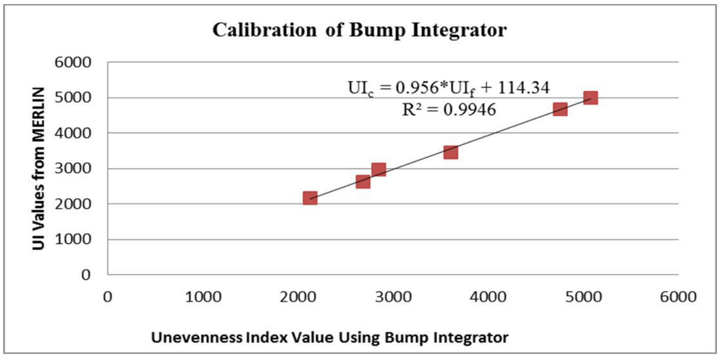

Fig 1: Relationship between Roughness Values obtained from Bump Integrator and MERLIN

A multiple-linear regression model has been developed to find the relation between IRI and pavement distress parameters using SPSS software. In this model, IRI value is taken as the dependent variable and the measured pavement distress parameters, namely, cracking, potholes, patching, rutting, ravelling and edge failures, at three severity levels, were considered as independent variables. 27 variables were obtained by considering each severity level of a distress as an independent variable. For the study purpose, out of the 27 variables only 12 variables were considered for the model development based on correlation matrix. The initial IRI Values were deducted from the observed values to obtain the IRI only due to all pavement distresses. The developed model with the corresponding coefficient of determination (R^2 value) is presented in the Equation 5.

$$IRI_D \text{ (m/km)} = 0.318*ACL + 1.205*ACH + 0.120*L/T\ CL + 0.041*L/T\ CM + 0.023*RH + 0.698*PL + 1.189*PM + 0.125*PAH + 3.00*ECH + 0.162*EBL + 0.269*EBM + 0.145*EBH \quad (R^2 = 0.66) \tag{5}$$

To develop the relationship between Total IRI (initial + due to distresses) and the distress parameters, equation 5, was modified by adding a constant for capturing the effect of initial roughness, which was measured on the newly laid PMGSY road. Accordingly, the total roughness obtained from the model is presented in equation 6.

$$IRI_D \text{ (m/km)} = A + 0.318*ACL + 1.205*ACH + 0.120*L/T\ CL + 0.041*L/T\ CM + 0.023*RH + 0.698*PL + 1.189*PM + 0.125*PAH + 3.00*ECH + 0.162*EBL + 0.269*EBM + 0.145*EBH \tag{6}$$

Where, A = 3.23 for PMGSY Roads

IRI_D	IRI due to distresses only in m/km
ACL	Low level Aligator cracking in % of area
ACH	High level Aligator cracking in % of area
L/T CL	Low level Longitudinal/Transverse cracking in meters
L/T CM	Medium level Longitudinal/Transverse cracking in meters
RH	High level raveling in % of area
PL	Low level Potholes in % of area
PM	Medium level Potholes in % of area
PAH	High level Patching in % of area
ECH	High level Edge cracking in meters
EBL	Low level Edge Break in meters
EBM & EBH	Medium & High level Edge Break in meters

4.3.1 Statistical Validity of the model

To check the statistical validity of the model and checking the significance of the variables, a well-known 'student-t' values and 'p-values' for each of the variables in the model (equation 5), were calculated and are presented in Table 3.

Table 3: Statistics of the Roughness Model

S.No	Distress Parameters	Coefficients	Student-t	p-values
1	ACL	0.318	3.7247	0.0004
2	ACH	1.205	3.0296	0.0033
3	L/T CL	0.120	2.2360	0.0281
4	L/T CM	0.040	2.6188	0.0105
5	RH	0.023	2.1218	0.0369
6	PL	0.698	2.0229	0.0463
7	PM	1.189	2.5262	0.0135
8	PAH	0.126	2.0770	0.0409
9	ECH	3.000	2.6021	0.0110
10	EBL	0.162	3.5409	0.0007
11	EBM	0.145	2.1275	0.0364
12	EBH	0.146	1.9589	0.0535

The acceptable 'student-t' statistic value for 95 % confidence level is 1.645. It has been observed from the Table-4, that the 'student-t' values, estimated for all the distress parameters, are greater than 1.645, which means the dependent variable follows a normal distribution with a constant variance across observations. These values represent the confidence of the parameter to which it can be accepted. As the confidence of 95% is assumed for developing the regression, above values were tested for 95 % confidence level. It has been observed from the above Table that the 'p-values' for all distress parameters are less than 0.05, hence all the variables included in the model acceptable and fund to be significant for model development. Regression statistics and the results of ANNOVA are also presented in Table 4 and 5.From Table 4, it has been observed that the value of Multiple R is 0.815, which means the correlation between the observed IRI_D and IRI_D of the developed model (Predicted) is 81.5 %, which may be acceptable. It can be also observed from the Table 4, that the Standard Expected Error between the observed and predicted IRI_D is 1.58 m/km. It has been observed from the Table 5, the value of 'Significance F' 8.24722E-15 < 0.05, hence the developed model is significant

Table 4: Regression Statistics of the Developed Model

Regression Statistics	
Multiple R	0.815052
R Square	0.664309
Adjusted R Square	0.607083
Standard Error	1.583748
Observations	94

Table 5: ANOVA Results of the Model

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	12	407.0214	33.91845	13.52271	8.24722E-15
Residual	82	205.6771	2.508258		
Total	94	612.6985			

4.3.2 Model validation

It has been already discussed that 30 % of the randomly selected data points were kept aside for validation purpose. Using this data, the IRI values were estimated by substituting the values of the pavement distress parameters in the model developed (equation 5). Then, the estimated and observed data were statistically compared and Mean Absolute Percentage Deviation (MAPD) was calculated using Equation 7 to determine the performance of the developed model. The details of these calculations are shown in Table 6.

$$MAPD = [Observed\ (IRI_D) – Predicted\ (IRI_D)] / Observed\ (IRI_D) \quad (7)$$

It may be observed that there is no significant variation between the observed and the estimated IRI_D. However, in the case of few stretches the deviation was found to be on higher side. This may be also because of lower values of IRI. It may be due to the fact that, all the possible distress parameters, as mentioned earlier, were not considered, while developing the model, only 12 variables were considered out of 27 observed. The MAPD between observed and predicted IRI value was 9.878 %, which may be acceptable.

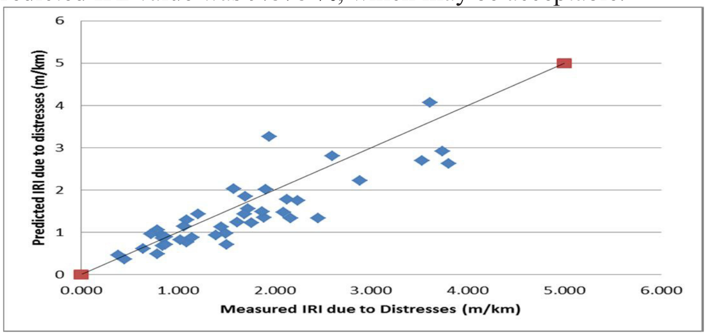

Figure 2: Plot between Predicted and Measured IRI due to distresses

Table 6: Predicting IRI_D values from pavement distress parameters using developed model and calculating Absolute Percentage Deviation

S. no	IRI_T	IRI_I	ACL	ACH	L/T CL	L/T CM	RH	PL	PM	PAH	ECH	EBL	EBM	EBH	IRI_{DO}	IRI_{DP}	Absolute % of Error
1	4.96	3.23	0.15	0.00	3.00	3.00	15.00	0.00	0.15	0.00	0.13	0.60	0.00	0.00	1.73	1.56	10.14
2	6.84	3.23	0.24	0.00	14.00	0.00	0.00	0.00	0.00	0.00	0.50	5.00	0.00	0.00	3.61	4.07	-12.58
3	4.07	3.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.50	0.00	0.00	0.00	0.00	0.84	0.69	18.25
4	4.32	3.23	0.00	0.00	0.00	0.00	22.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.77	29.36
5	4.73	3.23	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.30	0.00	0.00	0.00	1.50	0.97	35.11
6	4.93	3.23	0.00	0.00	0.00	0.00	49.00	0.98	0.00	0.00	0.00	0.00	0.00	0.00	1.70	1.86	-9.05
7	4.32	3.23	0.00	0.00	0.00	0.00	12.00	0.57	0.00	4.88	0.00	0.00	0.00	0.00	1.09	1.30	-18.48
8	4.02	3.23	0.00	0.00	0.00	2.00	5.00	0.02	0.21	0.00	0.20	0.00	0.00	0.00	0.79	1.06	-35.55
		Mean Absolute Percentage Error (MAPE)												9.878			

IRI_T Total roughness on the pavement surface (m/km)
IRI_I Initial roughness in (m/km)
IRI_D Roughness due to distresses (m/km)
IRI_{DO} Observed Roughness due to distresses
IRI_{DP} Predicted Roughness due to distresses using developed regression equation

With a view to validate, a plot is also being drawn between estimated roughness values as ordinates and the observed roughness values as abscissa, as shown in Fig 2. A 45^o line has been drawn to see the distribution of plotted points on either side of the ideal line. From the figure, it can be observed that the majority of the points are close to the line.

4.3.3 Elasticity Analysis

For policy makers, relative measure, elasticity may be more useful than the coefficient of an individual variable, itself. Conventionally, elasticity of the variable 'x' in the model is defined as the percent change in variable 'y', for one percent change in 'x'. Mathematically, elasticity of the independent variable 'x' is expressed as given in the equation 8. The relative effect (e*) normalization of the estimated elasticity (e) in relation to the lowest elasticity, was also calculated to show the extent of each independent variable affecting the dependent variable. The details regarding elasticity calculations are shown in Table 7.

$$\text{Elasticity } e = \text{Regression coefficient} * (\text{Mean X} / \text{Mean Y}) \tag{8}$$

Table 7: Elasticity analysis of the Independent variables

Variable	Mean Values	Regression Coefficients	X mean/ Y mean	Elasticity e	e*
IRI_D	2.217	-	-	-	-
ACL	0.812	0.318	0.37	0.12	5.30
ACH	0.059	1.205	0.03	0.03	1.45
L/T CL	1.007	0.120	0.45	0.05	2.48
L/T CM	2.753	0.040	1.24	0.05	2.26
RH	6.678	0.023	3.01	0.07	3.15
PL	0.237	0.698	0.11	0.07	3.39
PM	0.109	1.189	0.05	0.06	2.66
PAH	0.499	0.126	0.22	0.03	1.29
ECH	0.041	3.000	0.02	0.05	2.49
EBL	1.311	0.162	0.59	0.10	4.35
EBM	0.336	0.145	0.15	0.02	1.00
EBH	0.413	0.146	0.19	0.03	1.23

5. Conclusions and Scope for Future Studies

The estimated coefficient of variable, named (in the present study), high severity edge cracking with a value of 3.00 was found maximum as compared to the coefficients of other parameters considered in the model. To the best of the authors' knowledge, many of the researchers have not considered edge factors in roughness model. In the present study, special attention was given while running the Bump Integrator over the edge (10 cm away from the extreme edge point) to account for the effect of the edge failures in the model. The coefficients of high severity aligator cracking (1.205) and medium severity Potholes (1.189) were also found to be higher than other parameters. This is the established fact that highly expanded cracks and potholes have highly significant effect on roughness of the pavement surface. Besides, the common distresses like potholes, ravelling and patches, as considered by various researchers in the past, it has been observed that edge failures are quite predominant in the case rural roads (one lane roads). The contribution of the distress parameter depends upon its extent and severity. Based on the data collected for the stretches considered in this study (PMGSY roads), the contribution of severe edge cracking was found to be more than the other distress parameters. High ravelling has marginal effects on the roughness of the pavements. The results of the elasticity analysis show that Aligator cracking has more contribution to the roughness, followed by potholes, and then, ravelling.

The initial IRI value (3.23 m/km), which was found in this study, may be useful for predicting the total roughness of the pavements, if roughness due to distresses is known, under similar conditions. If the availability of the equipment is difficult and the distress data of a particular PMGSY road is available, the roughness can be obtained without conducting the roughness survey. If large data is available, relationships can be developed to estimate the Vehicle operating cost (VOC) from the roughness estimated due to pavement distresses. If the data is recorded periodically right from the beginning of road usage along with its level of maintenance for considerable years, a better Pavement Maintenance System (PMS) can be developed for PMGSY roads.

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