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Development of Model for Estimating IRI from Pavement Distress: A Study on PMGSY Roads

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Abstract:
Roughness, universally accepted as a measure of functional condition of a pavement constitutes the smoothness and frictional properties of the pavement surface which 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 it depends on the amount of other functional distresses present on the road surface. The present study develops a relationship between the roughness and other surface distresses of PMGSY roads Roughness data is to collected using ARRB Roughometer III. Roughness data also has to be collected from a newly laid pavement stretch, and the value thus obtained is subtracted from the observed roughness values of the test stretches, to get the net effect of the distresses on the pavement condition. A regression equation is then developed with the IRI value and the visible distresses based on the data collected in the field. PCI value is also determined for each stretch and attempts to develop a relationship between IRI and PCI.

Keywords: Roughness, Distress, Roughness Index

1. INTRODUCTION

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 centrally funded programme. Even though the Government of India is investing huge quantum of money on road construction every year, poor control over the quality of road construction and its subsequent maintenance is leading to the faster road deterioration. In this regard, it is essential that scientific maintenance procedures are to be evolved on the basis of performance of low volume flexible pavements. Even though, many scientific models are available for assessing the performance of flexible pavements, these cannot be applied to low volume roads providing connectivity primarily to the villages

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. It is determined using the international roughness index, 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.

Studies have reported that roughness has been usually manifested as a combined effect of different individual pavement distresses such as cracking, potholes, ravelling, patching and rutting. However, enough studies have not been reported in the literature on the development of models, which are capable of expressing the roughness at a given point of time as a function of noticeable distresses on the pavement.

2. NEED FOR THE STUDY

- To understand the progression of roughness in flexible pavements exposed to least or nil routine maintenance.
- The models considering all the distresses together that are predominantly seen in Indian conditions are limited.
- Level of severity of a particular distress has differential impact on roughness and hence they need to be considered that would be relevant in Indian context.
- Models developed can serve as a useful tool for practicing engineers maintaining flexible pavement on low volume roads.
- Helps to identify the major contributing parameters causing road roughness and accordingly higher priority can be given in repairing them

3. OBJECTIVES OF THE STUDY

- Determination of roughness using Roughometer.
- To classify the type, severity and quantity of the distress along road stretches.
- Development of correlation between Roughness and other surface distresses using SPSS Package.
- To develop a model for determination of IRI accounting for PCI encompassing the flexible pavements in village roads and validate the model

4. LITERATURE REVIEW

A number of studies such as Central Road Research Institute (CRRI 1994), HDM-4 (Odoki and Kerali 2000), Brazil – United Nations Development Programme (Paterson 1987, George 2000), Transportation Road Research Laboratory –

Kenya model (Hodges et al. 1975, Linda and Rabinson 1982) and roughness progression models (Reddy 1996, George 2000) by considering various combinations of influencing parameters are collected.

Velmurugan S. et al., (2015) made an attempt to develop prediction models to understand the progression of roughness, cracking, and potholes in flexible pavements exposed to least or nil routine maintenance. Distress data were collected from the low volume rural roads covering about 173 stretches spread across Tamil Nadu state in India. Based on the above collected data, distress prediction models have been developed using multiple linear regression analysis. Further, the models have been validated using independent field data. It can be concluded that the models developed in this study can serve as useful tools for the practicing engineers maintaining flexible pavements on low volume roads.

Santhakumar M. S. et al., (2013) presented a case study of IRI (International Roughness Index) estimation at NH 67 during four laning of Trichy - Tanjavur section. An attempt has been made to evaluate the IRI of construction work zones using Levenberg- Marquardt Back-Propagation training algorithm. A MATLAB based model was developed and the data from the case study were used to train and test the developed model to predict IRI. The model performances were evaluated through Correlation coefficient and Mean Square Error (MSE).

Lin et al., (2003) correlated IRI and pavement distresses by using feed-forward back-propagation neural network methodology. They considered pavement distresses such as rutting, alligator cracking, patching, potholes, corrugation, manholes, stripping and bleeding as input variables. Based on the weights obtained from the neural network architecture, they have reported that potholes, patching and rutting have the highest correlation; manholes, stripping and corrugation have low correlation and cracking, alligator cracking and bleeding have the lowest concentration correlated with IRI.

However, none of these studies considered all the important distresses together that are usually predominant on Indian roads and that directly affect the pavement roughness. While the distress parameters such as cracking, potholes, rutting, ravelling and patching directly affect the IRI value, the impact of each distress in terms of severity needs to be considered to develop a model which would be relevant in Indian context. This would also help the decision makers to identify the major contributing parameters causing road roughness and accordingly higher priority could be given in repairing them.

5. METHODOLOGY

5.1 . Selection of Study Stretch

A detailed reconnaissance was conducted by visiting the number of PMGSY roads covering Pampady Block in the district of Kottayam, Kerala. 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.
The project study stretch chosen for this research include 8 PMGSY Roads consisting of 50 stretches of 100m length in Pampady block panchayath of Kottayam district. The details of road stretches shown in the following table 5.1.

Table. 5.1: Showing the details of study stretches

No	Road Name	Length in km	Width in m	No of section
1	Velloor – Manjamattom Road	3	4	6
2	Oravackal – 7th mile Road	2	4	8
3	Makkalpadi – Pangada Jn Road	6	4	9
4	Chembarathy moodu Jn – Kooropada Road	2	4	4
5	Mukkali - Mandhiran Jn Road	2	4	7
6	Aruvikuzhy – Kadhalimattom Road	1.3	4	6
7	Aruvikuzhy – Alampally Road	3	4	6
8	Alampally – K. G. College Road	2	4	4

5.2 Pavement Distress Parameters

Pavement distresses are visible imperfections on pavement surface and are measured by visual condition survey. Distress evaluation, or condition survey, includes detailed identification of pavement distress type and severity. After observing number of road stretches as a part of reconnaissance survey, five different distress parameters, namely, cracking, rutting, ravelling, potholes and patching have been identified as the major factors which affect the functional condition of the flexible pavements. Visual condition survey was conducted on 8 PMGSY roads comprising of 50 road stretches of 100 m length each. The various cracks such as alligator cracks, block cracks, longitudinal and transverse cracks are incorporated as cracking. The severity levels of the selected distress parameters also have the varying effects on pavement condition but it is difficult to quantify the severity level. Hence, it was decided to classify severity in terms of low, medium and high. For maintaining uniformity in the data collection, clear description of the severity levels based on the studies carried out by various researchers (IRC: 82 1982, Miller and William 2003, NCHRP 2004) and ASTM D 6433-07, Distress Identification Manual FHWA USDOT-2003 are used.

5.3 Roughness Data

Roughness is measured using ARRB Roughometer. The Roughometer III is a response – type roughness device, complying with World Bank Class 3 requirements. While deciding about the maintenance measures to be taken over a stretch of pavement, usually the distress data are collected over the entire width, whereas the roughness data are collected only over the wheel path. It was felt that to develop a relationship between the distresses and roughness, it would be appropriate to measure the roughness values over the entire width of the pavement. Hence, to obtain appropriate roughness three runs of roughometer survey was conducted on each 100 meter stretch ant the average value is considered as the roughness value of each stretch. The IRI profile and map of 6 stretches of Aruvikuzhy – Alampally Road that was obtained from the instrument and are shown in figure 3.14 and figure 3.15.

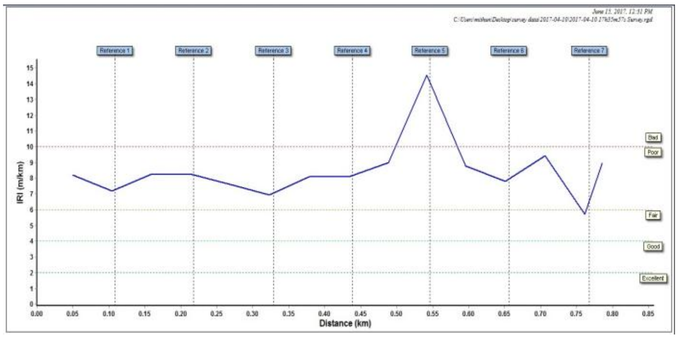

Figure. 5.1 IRI Profile

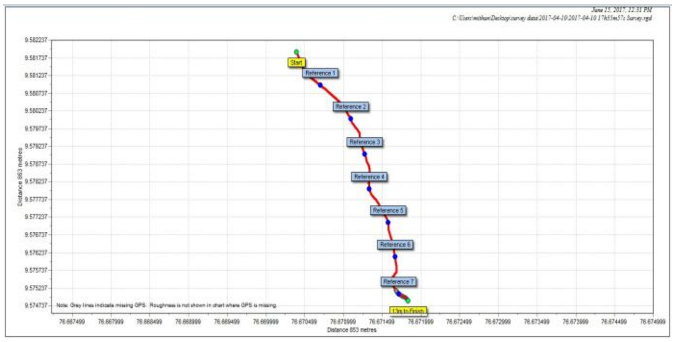

Figure.5.2 The study stretches of Aruvikuzhy - Alampally Road

5.4 Initial Roughness Value on a Newly Laid Road Surface

It was decided to find the International Roughness Index values of newly laid PMGSY roads as the IRI presents the condition of pavement at a particular point of time and depends on the initial quality of construction represented by the value measured immediately after the construction. Hence, a newly overlaid PMGSY Road (Mundankavala Jn – Ilamkavu Road) of Pampady Block Panchayath were selected and roughness values were measured using the ARRB Roughometer III. An average initial roughness value of 4.2 m/km was obtained. These values, being free from surface distresses, have been deducted from the observed roughness, and the excess values were considered due to the distress parameters present on the pavement surface.

5.5 Distress Parameter Standardization

Five different distress parameters namely cracking, ravelling, potholes, patching and rutting were identified as the major distresses. All the selected distresses were expressed in terms of three severity levels namely low, medium and high. All the pavement distress parameters namely cracking, potholes, patching and ravelling collected in three severity levels are normalised by converting them into percentage of the total area considered using Equation

$$PADi = ADi * (\frac{100}{A})$$

where PADi is the percentage area of the ith distress parameter; ADi is the area of the ith distress parameter measured in the field and A is the total area of the pavement considered. Rutting and edge failure are expressed in terms of metre per km.

5.6 Pavement Condition Index

One of the most comprehensive visual inspection systems developed is the Pavement Condition Index (PCI) procedure, developed by the U.S. Army Corps of Engineers in the early 1970's and extensively refined and improved over the past 20 years. The system is built around the concept of the PAVEMENT CONDITION INDEX or PCI. A new pavement (theoretically distress-free) has a PCI of 100. The PCI is a numerical index, ranging from 0 for a failed pavement to 100 for a pavement in perfect condition. Calculation of PCI is based on the result of visual condition survey in which distress type, severity, quantity are identified.

6. DEVELOPMENT OF PAVEMENT ROUGHNESS MODEL AND VALIDATION

The preliminary step for any model development is to identify the highly influenced parameters which affect the model. The data collected from the study stretches were analyzed to evaluate the highly significant parameters or variables which affect the performance of pavement.

6.1 IRI – Distress Model Development

The pavement distresses and roughness data collected over 50 uniform stretches of 100m length covering different PMGSY roads of Pampady Block Panchayath have been used for modelling. . The sample data of distress parameters of 20 stretches are shown in Table 6.1. Data on the randomly selected 35 stretches (approximately 70% of the observed

Table 6.1 Sample data of Distress parameters

STRETCH	IRI	CL	CM	CH	PL	PM	PH	RAL	RAM	RAH	PAL	PAM	PAH	RL	RM	RH	PCI
1	11.9	10	5	2.4	4	1	0.4	18	16	2.5	5.6	7.8	2	2.3	3	2.3	6
2	11.7	9.5	5	3.1	0	3	0.2	13	5.2	6.5	3.5	6.8	5	1.9	2	2.6	7
3	11.5	7.6	6	4.3	4	0	0.3	7.9	8.6	7.2	6.2	3.4	4	2.7	2	2.4	8
4	9.8	6.4	7	2.9	1	0	2.5	6.5	7.2	6.1	3	3.1	4	3.1	2	1.6	12
5	6.6	10	2	1.6	0	2	0.1	2	5	12	1.5	8	4	9.4	2	1.2	26
6	8.5	2.1	2	1.8	0	0	2.2	15	14	3.1	5.4	7.8	1	1.6	3	1.1	15
7	11.5	8.2	4	4.1	2	0	1.4	6.5	7.2	7.1	5.6	4.8	3	2.9	2	2.2	5
8	8.7	2.1	3	1.2	0	2	0.5	22	12	0.8	1.7	1.7	1	2.9	3	0.8	10
9	12.4	11	4	2.6	1	1	0	17	13	6.5	7.3	7.7	4	2.5	2	1	5
10	13.6	9.3	6	3.1	0	2	1.8	16	18	8.1	2.1	2	2	2.8	2	1.6	4
11	8.7	9	7	0	2	0	0.5	23	9.2	4.1	0.3	0.1	0	3.8	0	0	11
12	10.2	6.8	7	2.8	0	1	1.8	6.4	7.1	5.9	2.9	2.9	3	2.9	2	1.8	8
13	7.6	7.5	7	0.3	1	0	1.3	13	5.1	6.4	9	0.9	0	19	16	0	29
14	13.5	12	8	3.4	1	0	1.9	23	18	4.5	6.6	8.1	2	2.6	2	1.6	4
15	6.2	9.5	0	1.4	0	0	1.3	1.2	5.2	12	1.6	7.5	5	8.4	0	0	36
16	8.5	8.7	7	0.4	3	0	0	23	8	4	0.3	0.7	0	3.8	2	1.2	18
17	8.4	7.9	5	1.3	1	2	1.3	19	4.2	5.8	3.6	3.2	4	2.3	3	1	14
18	7.5	7.4	7	0.3	1	0	0.3	12	6.1	5.6	8.1	1.2	1	18	14	0.8	32
19	13.2	8.1	5	2.1	1	2	0.8	15	17	9.1	2.6	2.1	2	2.7	4	2.1	4
20	11.7	8.6	4	4.4	0	2	1.9	6.4	7.1	6.9	5.4	4.9	4	2.7	3	1.9	6

Values) were used for model development, and the remaining 15 stretches (30% of the observed values) were kept aside for the model validation. 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 distresses namely cracking, potholes, patching, ravelling and rutting in three severity levels as independent variables. Although the distresses independently contribute to the roughness, there may be auto correlation among the distress parameters and hence, correlation coefficients between all the independent variables were found prior to the model development.

It was observed that the correlation coefficients among some of the independent variables were high, and hence, for the study purpose, out of the 15variables only 10 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 (6.1).

IRI_D (m/km) = 0.066 CL + 0.000228 CM + 0.301 PL + 0.418 PM + 0.846 PH + 0.097 RAL + 0.021 PAL + 0.113 PAM + 0.003 RM + 1.502 RH (6.1)

Correlation Coefficient, R^2 = 0.969

Where,

IRI_D= IRI due to distresses only in m/km
CL: Low Severity cracking in % of area;
CM: Medium Severity cracking in % of area;
PL: Low Severity potholes in % of area;
PM: Medium Severity potholes in % of area;
PH: High Severity potholes in % of area;
RAL: Low Severity ravelling in % of area
PAL: Low Severity patching in % of area;
PAM: Medium Severity patching in % of area;
RM: Medium Severity rutting in metres per km
RH: High Severity rutting in metres per km.

To compute the overall roughness of the pavement stretch from distress parameters the equation (4.1) is modified by adding initial roughness i.e. roughness of newly laid pavement stretch. Hence the total roughness from the model is presented in equation (4.2)

IRI (m/km) = 4.23 + 0.066 CL + 0.000228 CM + 0.301 PL + 0.418 PM + 0.846 PH + 0.097 RAL + 0.021 PAL + 0.113 PAM + 0.003 RM + 1.502 RH (6.2)

6.1.1 Model validation

The acceptable value of t – statistic for 95% confidence interval is 1.645, the t-values obtained for all the parameters are greater than 1.645 that means IRI follows a normal distribution with a constant variance across observations. As the confidence of 95% is assumed for developing the regression, above values were tested for 95 % confidence level. The t – statistics of various parameters of model are given in Table 6.2.

The results of ANOVA and Model Summary are also presented in Table 6.3 and 6.4. From Table 6.4, it has been observed that the value of Multiple R is 0.984, which means the correlation between the observed IRI_D and IRI_D of the developed model (Predicted) is 98.4 %, which may be acceptable. It can be also observed from the Table 6.4, that the Standard Expected Error between the observed and predicted IRI_D is 1.26 m/km.

Table.6.2 Parameter estimates of IRI - Distress Model

Parameter	Variables	Student - t	Coefficients
A	CL	4.515	.066
B	CM	3.859	.000228
C	PL	5.163	.301
D	PM	4.606	.418
E	PH	4.511	.846
F	RAL	3.114	.097
G	PAL	3.379	.021
H	PAM	4.165	.113
I	RM	5.881	.003
J	RH	3.775	1.502

Table.6.3 Analysis of Variance table of IRI (Source: SPSS statistical tool

ANALYSIS OF VARIANCE				
Source	Sum of squares	df	Mean Square	F
Regression	1244.675	10	124.46	77.71
Residual	40.039	25	1.602	
Total	1284.713	35		

Table 6.4 Regression statistics of the developed model

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
IRI	.984	.969	.956	1.2655205

It has been already said that the 30 % of the total data is used for the validation of model. Goodness of fit of the model is done by comparison between observed IRI and predicted IRI, which gives the model performance. The predicted IRI values were computed by substituting the pavement distress values on the model developed (equation 6.2). The Absolute Percentage Error (APE) was calculated using equation (6.3) to determine the model performance.

APE = ((Observed IRI – Predicted IRI)/Observed IRI) X 100 (6.3)

From the APE of all the stretches, Mean Absolute Percentage Error (MAPE) between the observed IRI and the predicted IRI was calculated. The Absolute Percentage Of Error was not very high in most of the cases. However, in a few cases, the deviations were as high as 23.59%, and thus, the MAPE were found to be 6.84%. The MAPE value should be in between 0 to 10 % and hence the developed model is more significant.

6.2 IRI – PCI Model Development

The Pavement Condition Index (PCI) for 50 number of road stretch is calculated as (PCI = 100 – CDV), where CDV = Corrected or Normalised Deduct Value using corrected deduct values depending on the number and combination of distress parameters. Data of 35 stretches were used for model development and remaining data of 15 stretches were used for its validation. Linear regression approaches were tried primarily on SPSS software to get a best fit model, but was not satisfactory. Then through a large number of trial and error approaches on the performance parameters a best fit Non Linear regression model was generated in the software. Derivatives were calculated numerically in SPSS and run stopped after 8 iterations as optimal solution was found. The developed IRI – PCI Model is represented in equation (6.4)

$$IRI = 13.425\ e^{-0.021xPCI} \qquad (6.4)$$

Correlation Coefficient, $R^2 = 0.832$

The acceptable student t value for 95 % confidence interval comes in the range of 1.74. It has been observed from the table that the 'Student-t' values for parameter is greater than 1.74, hence are statistically acceptable. The result of ANOVA and Parameter estimates are shown in the Table 6.5 and 6.6

Table .6.5 Parameter estimates of IRI - PCI Model

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	13.425	.348	12.716	14.134
B	-.021	.002	-.024	-.017

Table 6.6 Analysis of variance table of IRI - PCI Model (Source: SPSS statistical tool)

ANALYSIS OF VARIANCE			
Source	Sum of Squares	df	Mean Squares
Regression	3529.502	2	1764.751
Residual	29.175	33	.884
Uncorrected Total	3558.677	35	
Corrected Total	173.519	34	

6.2.1 Model validation

Validation of the generated IRI – PCI model is done to ensure their better use in field condition. The set of data, which constitutes about 30 % of the total data, are used for the validation of the model. The predicted IRI values were computed by substituting the pavement condition index values on the model developed (equation 6.2). The Absolute Percentage Error (APE) was calculated using equation (6.3) to determine the model performance. From the APE of all the stretches, Mean Absolute Percentage Error (MAPE) between the observed IRI and the predicted IRI was calculated. The Absolute Percentage Of Error was not very high in most of the cases. However, in a few cases, the deviations were as high as 19.6 %, and thus, the MAPE were found to be 9.846%. The MAPE value should be in between 0 to 10 % and hence the developed model is more significant.

7. SUMMARY AND CONCLUSIONS

It was observed from model that, the coefficients for potholes and rutting are quite high as compared to other distress parameters. Coefficients for patching are also significant for small and medium severities, respectively. Most of the cases patching was not being done properly and a level difference between the existing pavement and the patched surface was observed. The impact of cracking on IRI was low. Coefficients for rutting were very significant when compared to those of other distresses. Rutting was mostly visible on the PMGSY roads with clear wheel path. Hence, when Rough meter III mounted vehicle passed over the rutted pavement surfaces, there was more undulation and thus its influence on roughness was significant. Pavement Condition Index for all road stretches was calculated by considering all the type of distress. The result of analysis shows that Ravelling are the major distresses occurred in all sections of the study area followed by cracking. Study stretches are having PCI value in the range of 15-50. Hence the pavement study stretches require rehabilitation or reconstruction.

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