Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 4(4):195-202

Pavement Deterioration and Maintenance Model for Low Volume Roads

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Abstract: Development of an intelligent flexible pavement deterioration and maintenance management model is the need of implementing organizations to prioritize pavement maintenance and rehabilitation works, as this involves cost economics. Pavement deterioration model, is an equation that relates to some extrinsic 'time factor' (age or number of load applications) to a combination of intrinsic factors (structural responses, etc.) and performance indicators which simulate the deterioration process of pavement condition and provide forecasting of pavement condition over a period of time. These pavement deterioration or performance models play a pivotal role in pavement management systems. To develop these models structural and functional response measurement of 18 sections of low volume pavements were carried out for continuous two years in Uttarakhand and Uttar Pradesh states of India. Statistical analysis tools and Artificial Neural Network (ANN) are used to develop the models. Statistical performance indicators and logical relationships between input parameters and output parameters are used to select the best fit model. Polynomial relationship best relates to the input parameters such as pavement age, CBR of subgrade, traffic, pavement thickness and also to the output parameters i.e. pavement condition indicators such as deflection, riding quality, surface roughness. Paired t-test is also carried out for the validation purpose of chosen best fit models. Maintenance Priority Index (MPI) is developed using three parameters named as deflection, riding quality and traffic to decide the priority.

Key words: *Artificial neural network (ANN); Deflection; Maintenance priority index (MPI); Pavement deterioration model; Regression analysis; Riding quality.*

Introduction

Efficient road transportation plays a vital role in the economy of any Nation. Road transport in India, occupies a dominant position in the overall transportation system of the country due to its advantages like easy availability, flexibility of operation, door to door service and reliability. India owns the second largest network of roads in the world, next to USA. As per statistics of year 2009, the total road length in the country is over 3.3 million km, which gives the spatial road density of about 1 km/km^2 of area. Out of the total road network of India, village and other roads (Low Traffic Volume Roads) consist of 80% share. Low traffic volume roads are mainly rural roads in India carrying daily traffic less than 450 Commercial Vehicles per Day (CVPD) [1]. Cross sectional view of Low Volume Roads in India is given in Fig. 1. The thickness of sub-base layer is around 200 mm and the total thickness of each layer of base course varies from 100 – 120 mm. Surface course is usually 20 mm thick premix carpet layer. Low volume roads serve as one of the key infrastructure work, placed for integrated rural development, which has become a matter of growing urgency for considerations of social justice, national integration and economic uplift of the rural areas. The importance of preserving road network in good condition is widely recognized and therefore, performance evaluation of the existing roads is an absolute necessity.

Performance of flexible pavements has long been recognized as an important parameter in their design and maintenance. In order to measure and prepare model for pavement performance, it is necessary to clearly define the pavement performance. According to American Association of State Highway and Transport Officials (AASHTO), pavement performance is defined as "*the serviceability trend of pavement over a design period of time, where serviceability indicates the ability of the pavement to serve the demand of the traffic in the existing conditions*". In other words, pavement performance can be obtained by observing its structural and functional performance or predicting the serviceability of a pavement from its initial service time to the desired evaluation time. Normally, pavement condition can be evaluated on the basis of four aspects i.e. riding quality, surface distress, structural capacity and skid resistance.

Deterioration of pavement can be attributed to various factors like age, traffic, environment, material properties, pavement thickness, strength of pavement as well as subgrade properties which affect the mechanical characteristics of a pavement. These factors affect the performance of the pavement in a complex manner. To understand the mechanism and to forecast the future condition of pavement, these deterioration models are necessary. Pavement deterioration model is a mathematical relationship between the pavement condition and the factors listed above. The pavement deterioration model predicts the future condition of the pavement, which is helpful in development of Maintenance Management Model or Maintenance Priority Index (MPI). This index is a rating used to prioritize the maintenance schedule of pavement based on the severity of distresses and its condition.

Due to constrained budget and increasing challenges in pavement

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Note: Submitted June 14, 2010; Revised September 28, 2010; Accepted October 22, 2010.

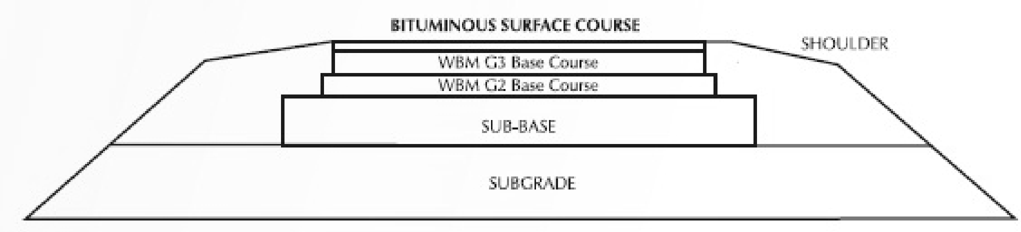

Fig. 1. Cross-sectional Detail of Low Volume Roads in India.

Table 1. Physical Requirements of Aggregates.

Serial No.	Type of Construction	Test (IS: 5640 - 1970)	Requirement
1	Sub-base	Wet Aggregate Impact Value	Maximum 50 %
2	Base Course with Bituminous Surfacing	Wet Aggregate Impact Value	Maximum 40 %
3	Surface Course	Wet Aggregate Impact Value	Maximum 30 %

Table 2. Typical Grading for Aggregates for use as Granular Material.

Serial No.	Sieve Designation (IS: 460 – 1962)	Percent by Weight Passing the Sieve		
		Grading I	Grading II	Grading III
1	80 mm	100	100	100
2	63 mm	90 - 100	90 - 100	90 - 100
3	4.75 mm	35 - 70	40 – 90	50 – 100
4	75 µm	0 - 20	0 - 25	0 - 30

Table 3. Typical Grading Limits for Soil Aggregate Mixture.

Serial No.	Sieve Designation (IS: 460 – 1962)	Nominal Maximum Size of Materials				
		80 mm	40 mm	20 mm	10 mm	5 mm
		Percent by Weight Passing the Sieve				
1	80 mm	100				
2	40 mm	80 - 100	100			
3	20 mm	60 - 80	80 – 100	100		
4	10 mm	45 - 65	55 - 80	80 - 100	100	
5	4.75 mm	30 - 50	40 - 60	50 - 75	80 - 100	100
6	2.36 mm	-	30 - 50	35 - 60	50 - 80	80 - 100
7	1.18 mm	-	-	-	40 - 65	50 - 80
8	600 µm	10 - 30	15 - 30	15 - 35	-	30 - 60
9	300 µm	-	-	-	20 - 40	20 - 45
10	75 µm	5 - 15	5 - 15	5 - 15	10 - 25	10 - 25

maintenance and rehabilitation, Pavement Management System (PMS) has become a very beneficial management tool for highway maintenance agencies. Pavement deterioration model, which acts as the hub of analysis component, is the engine of whole management activity. The pavement deterioration model is the very essence of a pavement management system and is used to determine several fundamentals, including:

- Rate of asset degradation at both micro (project) and macro (network) level,
- Valuation of road assets (service life remaining), and
- Road user costs, including the vehicle operating costs, incurred by the public.

Pavement deterioration models are developed in the present study to evaluate and predict the condition of low volume roads and based on pavement condition, maintenance priority model is suggested in this study. Deflection and riding quality (in International Roughness Index) are considered as pavement condition indicators and pavement age, traffic, CBR of soil subgrade and pavement thickness are considered as independent parameters for the prediction of the same. Pavement material quality is not taken as independent parameter due to the homogenous material used for construction of these roads. The pavement material used was according to the norms and requirements of Indian practice code IRC: SP: 20 – 1997. A brief detail of material requirement for sub-base, base course and surface course are given in Table 1, 2 and 3. Deflection data was collected using Benkelman Beam and ride quality (roughness) measurements were done using MERLIN for two years on the same section of the pavement. After data collection linear and non-linear regression analysis were carried out using DATAFIT statistical software package. Artificial Neural Network model is also developed using MATLAB.

Section Details

Eighteen sections of low volume roads are selected that fall under different districts of Western Uttar Pradesh and Uttarakhand state of

Table 4. Details of Selected Low Volume Road Sections.

S. No.	Name of the Section	District	Length (km)	Terrain	CBR	Thickness (mm)	Design Traffic*	Year & Month of Opening Traffic
1	Kaido-Behda Sadath	Muzaffarnagar	2.7	Plain	7.8	255	23 (B)	April 2005
2	Galhotha- Binauli	Baghpat	2	Plain	4.1	225	40 (B)	January 2002
3	Meerut-Harrakhed	Meerut	2.5	Plain	6.8	285	42 (B)	April 2005
4	Muzaffarnagar Saharanpur to Ruprijunardar	Saharanpur	1.1	Plain	6.3	245	37 (B)	June 2005
5	Muzaffarnagar Saharanpur to Shahpur	Saharanpur	1.5	Plain	5.1	245	37 (B)	June 2005
6	Gulaothi	Bulandshahar	1.7	Plain	4.1	270	19 (B)	April 2003
7	DK Bypass to Mahuakhera	Aligarh	0.5	Plain	4.3	260	20 (B)	June 2003
8	Shantarshah-Sahedepur	Haridwar	4	Plain	2.6	245	35 (B)	June 2003
9	Mathurawala-Doiwala	Dehradun	5	Hilly	4.5	305	15 (A)	May 2006
10	Muradabad-Hat hat Road	Muradabad	4	Plain	5.	250	13 (A)	October 2006
11	Nazarpur-Ronda Road	Muradabad	16.4	Plain	5	340	40 (B)	Dec 2006
12	Dhunayya Road	Rampur	2	Plain	4.5	275	10 (A)	June 2005
13	Panipath-Khatima -Thurkatishour	Rudrapur	1.1	Plain	2.8	245	40 (B)	June 2004
14	Agasthamani-Dadoli Motor Road	Rudraprayag	6.5	Hilly	9	320	20 (B)	Nov 2002
15	Saboor Dungra to Seong Motor Road	Chamoli	2.9	Hilly	9	320	18 (B)	March 2004
16	Jaddhar Road	Tehri	7	Hilly	9	180	8 (A)	February 2004
17	Rishikesh-Gangotri Motor to Baun Motor Road	Uttarkashi	6	Hilly	10	170	15 (A)	June 2005
18	Maldhanchud to Haathi Dangar	Nainitaal	10	Plain	5	320	13 (A)	February 2004

* In the design traffic column, (A) and (B) represent the design traffic curve according to Indian Practice Code (IRC SP: 72-2007).

India. Out of these, 13 sections are in plains and 5 sections are in hilly terrain. A wide variety of the sections are identified to take into account different terrain conditions and climatic conditions. To analyze the effect of vast variation in traffic and extreme variations in temperature, the roads in plains are chosen and to see the effect of moist and cold environment the roads in hilly terrain are selected. Most of the roads were designed according to the design curve 'A' (traffic volume 0-15 CVPD) and some for design curve 'B' (traffic volume 15-45 CVPD) [2]. The sections are segregated on the basis of present traffic (greater than or equal 30 CVPD and less than 30 CVPD), CBR of subgrade soil (less than or equal to 5 and more than 5) and age (either less than 3 years or more than 3 years). The details of pavement test sections selected are given in Table 4.

Database

Structural performance of the sections was evaluated by the Benkelman beam deflection method and functional performance was evaluated using MERLIN (Machine for Evaluating Roughness using Low-cost Instrumentation). Structural performance of flexible pavements is closely related to the elastic response of pavement under the wheel load. The deformation or elastic deflection under a given load depends upon subgrade soil type, its moisture content and compaction, the thickness and quality of the pavement layers, drainage conditions, pavement surface temperature, etc. The Benkelman beam measures the deflections under standard loading condition given in Indian Practice Code (standard truck having a rear axle weighing 8170 kg fitted with dual tire inflated to a pressure of 5.60 kg/cm^2) [3]. For functional performance MERLIN was wheeled along the road and surface undulations at regular intervals were measured. To analyze this measurements graphical procedure was used, so that ride quality can be measured on a standard roughness scale i.e. IRI (International Roughness Index) without the need of complex calculation. Pavement temperature was measured to relate the deflection value to a common standard temperature, i.e. 35ºC [3]. Figs. 2, 3, and 4 below show measurement of deflection, ride quality and temperature in the field. Database includes deflection and ride quality measurements collected for two consecutive years on the same road sections. Deflection and ride quality (IRI) data is given in the Table 5 along with pavement age and traffic.

Data Analysis

Regression Analysis

Statistical tools are used to model the deterioration of the road section. Regression analysis is used first in this context. Mainly two types of regression analysis i.e. linear and non-linear are performed. In the present study, both types of regression analysis are carried out to develop the deflection and ride quality prediction model. Pavements are classified based on independent parameters and

Table 5. Deflection and Ride Quality Data.

Section No.	Pavement Age (in Years)	Traffic (CVPD)	Deflection (mm)	IRI (m/km)
1	2.08	74	0.56	6.67
	3.08	79	0.72	9.41
2	5.33	63	0.88	5.24
	6.33	67	0.91	6.12
3	2.08	32	0.78	5.85
	3.08	35	0.80	6.72
4	2	57	1.6	6.94
	3	60	1.94	6.5
5	2	57	1.16	7.11
	3	61	1.5	7.87
6	4.08	26	0.35	6
	5.08	30	0.44	7.89
7	4	20	0.55	8.13
	5	23	0.66	8.3
8	4	50	0.70	5.33
	5	54	0.76	7.52
9	1	20	0.59	7.46
	2	23	0.44	8.34
10	0.66	9	0.56	8.27
	1.66	11	0.62	9.47
11	0.5	45	0.06	6.53
	1.5	48	0.37	7.83
12	2	15	0.23	7.06
	3	19	0.25	8.17
13	3	50	0.13	5.2
	4	55	0.26	6.75
14	4.58	24	0.34	6.67
	5.58	27	0.46	8.8
15	3.25	24	0.65	9.33
	4.25	28	0.70	9.94
16	3.25	8	0.93	10.81
	4.25	10	1.14	11.89
17	2	15	0.72	7.35
	3	19	0.36	10.62
18	NA	NA	NA	NA
	4.25	30	0.56	10.98

separate model is developed for each classified group of pavement. Out of the developed several models, best is chosen based on the Residual Sum of Squares (SSE) and Coefficient of Multiple Determination (R^2). Logical relationship between independent and dependent variables are also checked for the acceptance of developed model along with above mentioned statistical criteria. Deflection prediction models are given in Table 6 below.

In the linear model, R^2 value is very low as well as SSE value is high, so linear model is not considered. Model number 6 (for subgrade CBR > 5) has the highest value of R^2 among all and lower value of SSE, so as per statistical criteria model number 6 should be considered as the best deflection prediction model. But in this model age is inversely proportional to deflection which is logically not correct. So according to statistical criteria and logical relationship model number 3 (model with less number of parameters) is considered best for prediction of deflection. In some models with increasing traffic the deflection decreases and this may be due to overloading of the commercial vehicles.

Ride quality data is also analyzed same as above and results are given in Table 7 below.

In this case pavements are classified on the basis of subgrade CBR and traffic. Different models are developed for each classified group of pavement. Model number 4 has the highest value of R^2 and lowest value of SSE. So as per statistical criteria model number 4 is best as ride quality prediction model, but in this model ride quality in terms of IRI is inversely proportional to traffic which is logically not correct. So as per both statistical criteria and logical relationship, model number 6 is best to predict ride quality for traffic less than 30 CVPD. For traffic more than 30 CVPD, model number 5 is best. From the above listed models it can be concluded that for better prediction of ride quality, pavements should be classified based on traffic.

After having various models on deflection and ride quality it is clear that main emphasis to select the best model was on statistical criteria and logical relationship. In limited set of data the ability of a certain model to explain the observations is getting better. This has been shown from various parameters having higher powers. The exact and physical behavior is shown by the proportionality (whether direct or inverse) but the effect of higher powers can be seen by plotting the graph of the dependent variable with the independent variable and its higher powers. The higher powers are responsible for the change in curvature with varying value of independent variable. The higher power function is also responsible for accuracy of the model.

Validation of Selected Models

To accept for real field applications, selected models' validity should be checked necessarily, hence Paired t-test is carried out to validate such models. In this test the significance of difference value between observed and predicted deflection is checked. But Paired t-test can be applicable only to those data sets where both observed and predicted data follows normal distribution. So here Chi-Square test is performed on both the data set to check the "goodness of fit". In Chi-Squared test two hypotheses are possible.

Null hypotheses = Deflection data follows normal distribution

Alternative hypotheses = Deflection data dose not follow normal distribution

If $\text{Chi-Square}_{calculated} < \text{Chi-Square}_{tabulated}$ then null hypothesis is accepted and vice-versa.

$$\text{Chi - Square value} = \frac{(O_f - T_f)^2}{T_f} \tag{1}$$

where, O_f = Observed Frequency

T_f = Theoretical Frequency

Result of Chi-Square test is given in Table 8.

Now $\text{Chi-Square}_{calculated}$ = 6.40 and

$\text{Chi-Square}_{tabulated}$ = 11.07 (for, Degree of Freedom (df) = 5 and Significance level α = 0.05)

So $\text{Chi-Square}_{calculated}$ (6.40) < $\text{Chi-Square}_{tabulated}$ (11.07)

So in the observed data case, null hypothesis can be accepted that is observed deflection dataset follows the normal distribution at

Table 6. Deflection Prediction Models Developed Using Statistical Analysis.

Model No.	Model Type	Model	R^2	SSE
1	Linear	$D = -0.0068A + 0.0078Tr + 0.039CBR - 0.003Th + 0.97$	0.28	4.05
2	Polynomial	$D = 0.57 + 0.04\ln(A) - 0.007Tr + 0.0008Tr^2 - 0.000009Tr^3 + \frac{77}{CBR} - \frac{369}{CBR^2} + \frac{512}{CBR^3} - \frac{5159}{Th} + \frac{1567230}{Th^2} - \frac{140339813}{Th^3}$	0.79	1.17
3	Polynomial (with Less no. of Parameters)	$D = 4.12 + 0.21\ln(A) + 0.000008Tr^2 + \frac{101}{CBR} - \frac{473}{CBR^2} + \frac{654}{CBR^3} - \frac{8594}{Th} + \frac{8594}{Th} + \frac{2286499}{Th^2} - \frac{188877031}{Th^3}$	0.68	1.80
4	Polynomial (Pavement Age > 3 yrs)	$D = 25.73 + 0.037\ln(A) - 0.00006Tr^2 + \frac{66}{CBR} - \frac{318}{CBR^2} + \frac{446}{CBR^3} \; \frac{23136}{Th} + \frac{5917539}{Th^2} - \frac{483472284}{Th^3}$	0.86	0.12
5	Polynomial (Pavement Age ≤ 3 yrs)	$D = -155 - 0.002\ln(A) - 0.0003Tr^2 + \frac{597}{CBR} - \frac{2680}{CBR^2} + \frac{3731}{CBR^3} + \frac{85874}{Th} - \frac{21221377}{Th^2} + \frac{1709177092}{Th^3}$	0.86	0.62
6	Polynomial (Subgrade CBR > 5)	$D = 235 - 0.4065\ln(A) + 0.0007Tr^2 - \frac{299}{CBR} + \frac{3728}{CBR^2} - \frac{10927}{CBR^3} - \frac{154967}{Th} + \frac{32657494}{Th^2} - \frac{2210143755}{Th^3}$	0.94	0.18
7	Polynomial (Subgrade CBR ≤ 5)	$D = -11.69 - 0.16\ln(A) - 0.0002Tr^2 + \frac{134}{CBR} - \frac{510}{CBR^2} + \frac{630}{CBR^3} + \frac{6029}{Th} - \frac{3238536}{Th^2} + \frac{445164922}{Th^3}$	0.82	0.19

Table 7. Ride Quality Prediction Models Developed Using Statistical Analysis.

Model No.	Model Type	Model	R^2	SSE
1	Power	$R = 1.35A^{0.35} + 46.68Tr^{-1.18} + 0.56CBR^{0.75} + 0.14Th^{0.51}$	0.50	49.17
2	Polynomial	$R = 39.11 + 2.05\ln(A) - 0.34Tr + 0.005Tr^2 - 0.00001Tr^3 + \frac{235}{CBR} - \frac{1048}{CBR^2} + \frac{1423}{CBR^3} - \frac{25079}{Th} + \frac{4360500}{Th^2} - \frac{223750286}{Th^3}$	0.65	34.13
3	Polynomial (Subgrade CBR > 5)	$R = -79 + 1.44\ln(A) - 0.00005Tr^2 - \frac{1041}{CBR} + \frac{3212}{CBR^2} - \frac{54431}{CBR^3} - \frac{687336}{Th} + \frac{140019197}{Th^2} - \frac{90703036283}{Th^3}$	0.79	10.62
4	Polynomial (Subgrade CBR ≤ 5)	$R = -79 + 1.44\ln(A) - 0.00005Tr^2 - \frac{1041}{CBR} + \frac{3212}{CBR^2} - \frac{3240}{CBR^3} - \frac{150088}{Th} - \frac{38020626}{Th^2} + \frac{3149047348}{Th^3}$	0.83	6.77
5	Polynomial (Traffic ≥ 30 CVPD)	$R = -0.17 + 2.08\ln(A) + 0.0009Tr^2 + \frac{349}{CBR} - \frac{1327}{CBR^2} + \frac{1584}{CBR^3} - \frac{29130}{Th} + \frac{11489887}{Th^2} - \frac{1464061735}{Th^3}$	0.80	7.25
6	Polynomial (Traffic < 30 CVPD)	$R = 566 + 0.23\ln(A) + 0.008Tr^2 - \frac{3549}{CBR} + \frac{21059}{CBR^2} - \frac{39946}{CBR^3} - \frac{287058}{Th} + \frac{71125863}{Th^2} - \frac{5641925522}{Th^3}$	0.82	7.24

Table 8. Chi-Square Test for Observed Deflection Data.

Range of Data Points	Observed Frequency (O_f)	Theoretically Probability	Theoretically Frequency (T_f)	Chi-Squared Value
<0	0	0.05	1.73	1.73
0-0.40	9	0.2	6.96	0.6
0.41-0.80	17	0.37	12.80	1.38
0.81-1.20	6	0.28	9.87	1.52
1.21-1.60	2	0.09	3.2	0.45
>1.60	1	0.01	0.44	0.72

95% confidence level. Similarly same procedure is adopted for the predicted deflection data set and results obtained are given below.

Chi-Squared$_{calculated}$ (1.08) < Chi-Squared$_{tabulated}$ (11.07) (with df = 5 and α = 0.05)

So in this case also, null hypothesis can be accepted and predicted deflection dataset also follows normal distribution.

In Paired t-test, first of all difference between two data set is calculated and remaining process is given below in the Table 9.

Now as $t_{calculated}$ = 0.012 which is less than the $t_{tabulated}$ = 1.65 (df =34 and α = 0.05)

So it can be easily stated that there is no significant difference between observed and predicted deflection data at 95% confidence level.

Same tests are carried out for the classified ride quality prediction models with respect to traffic. Result of chi-square test indicated that observed and predicted ride quality follows normal distribution

Table 9. Paired t-test for Validation of Developed Deflection Prediction Model.

Terms	Formulae	Calculations
Sum of Difference ($\sum z$)	(Observed – Predicted) Deflection	0.07
Total Number of Observation (n)	-	35
Mean of (z)	$(\sum z)/n$	0.002
Sum of Square of Difference	$\sum z^2$	0.98
Square of Sum of Difference	$(\sum z)^2$	0.005
-	$(\sum z)^2/ n$	0.0001
$\sum dz^2$	$\sum z^2-((\sum z)^2/ n)$	0.98
Variance (σ_d^2)	$\sum dz^2/(n-1)$	0.03
Square Root of Variance (σ_n)	$\sqrt{\sigma d^2}$	0.17
$t_{calcualted}$	Mean of (Z)/ σ_n	0.012

and paired t-test shows that there is no significant difference between the observed and predicted ride quality at 95% confidence level. Different chi-square and t values are tabulated in Table 10 for ride quality prediction models.

ANN Modelling using MATLAB

Artificial Neural Network (ANN) modeling is also done to model the deflection and ride quality. Batch Gradient Descent with momentum algorithm is used for the training of the observed data. This algorithm is one type of backpropogation algorithm. Four main parameter in this algorithm are number of epochs, learning rate (lr), momentum constant (mc) and performance goal, which should be mentioned by the model developer. "Tansig" transfer function is used. Output of the deflection model is given in Table 11.

Same algorithm and transfer function was used for ride quality prediction model and result of this model is given in Table 12.

Maintenance Management Model

One of the objectives of this study is also to develop maintenance management plan for low volume roads using the above pavement performance prediction models. Here deflection and ride quality are considered as indicator of road condition. Now based on the predicted value of deflection and ride quality, Deflection Index (DI) and Ride quality Index (RI) can be derived using Eq. 2 and 3.

$$Deflection\ Index(DI) = \frac{Present(Predicted)\ Deflection}{Maximum\ Pemissible\ Deflection} * 5 \quad (2)$$

$$Roughness\ Index(RI) = \frac{Present(Predicted)\ Roughness}{Maximum\ Pemissible\ Roughness} * 5 \quad (3)$$

Maximum permissible limit for deflection is taken from the Indian Practice Code [3]. Here maximum value of MSA (Million Standard Axle) is taken as 10 and corresponding to this maximum permissible deflection is 1.7 mm. Maximum permissible value of ride quality (IRI) is taken as 15 *m/km* [4].

Now as discussed earlier road condition is represented by the deflection and ride quality parameters, Road Condition Index can be simply calculated by adding Deflection Index (DI) and Ride quality Index (RI).

$$\text{Road Condition Index (RCI)} = \text{Deflection Index (DI)} + \text{Ride quality Index (RI)} \quad (4)$$

In this model, traffic is considered as one of the important influencing factor during the prioritization of roads for the maintenance work. So Traffic Factor is introduced to decide the priority of roads. Traffic factor can be easily calculated from Table 13 given below.

Now from the data of present traffic (CVPD), ESAL can be calculated for its design life using Indian Practice Code [2]. Traffic Factor can be selected based on the ESAL from the above table. Priority of road is decided based on its Maintenance Priority Index (MPI) which is calculated using the RCI and Traffic Factor.

$$\text{Maintenance Priority Index (MPI)} = \text{RCI} * \text{Traffic Factor} \quad (5)$$

It is suggested that if a road has either deflection or ride quality value more than its permissible limit then irrespective of its Maintenance Priority Index (MPI), preference should be given to that road for maintenance work. It is also suggested that if a road has DI or RI more than 4 then irrespective of its MPI, corrective

Table 10. Chi-Square and Paired t-test Values for Ride Quality Prediction Models

Ride Quality Prediction Model	Observed		Predicted			
	Chi-Square$_{calculated}$	Chi-Square$_{tabulated}$ (df =6 & α = 0.05)	Chi-Square$_{calculated}$	Chi-Square$_{tabulated}$ (df =6 & α = 0.05)	$t_{calculated}$	$t_{tabulated}$ (df =30 & α = 0.05)
Traffic ≥ 30	1.91	12.59	0.67	12.59	0.0024	1.74
Traffic < 30	1.43	12.59	0.56	12.59	0.0017	1.74

Table 11. Performance Parameters for Deflection Prediction Model.

S. No.	Performance Indicating Parameters	Value
1	Mean Square error (MSE)	0.0013
2	Max Absolute Error	0.09
3	Min Absolute Error	0
4	Linear Correlation Coefficient (R)	0.997

Table 12. Performance Parameters for Ride Quality Prediction Model.

Serial No.	Performance Indicating Parameters	Value
1	Mean Square Error (MSE)	0.0005
2	Max Absolute Error	0.09
3	Min Absolute Error	0
4	Linear Correlation Coefficient (R)	0.997

Table 13. Traffic Factor Based on Cumulative ESAL.

Traffic Category	Cumulative ESAL Applications	Traffic Factor
T1	10000-30000	1
T2	30000-60000	2
T3	60000-100000	3
T4	100000-200000	4
T5	200000-300000	5
T6	300000-600000	6
T7	600000-1000000	7

measures should be adopted for that road on the priority basis.

So based on MPI, concerned authority can decide the priority of road sections for maintenance work as well as can make the next few years maintenance program in advance using deflection and ride quality prediction models. MPI for selected road sections were calculated and given in Table 14 below.

Conclusions

Statistical and ANN modeling is done for performance prediction of low volume roads in terms of deflection and ride quality. It is observed that if pavements are classified on the basis of parameters influencing pavement condition such as pavement age, traffic, CBR of subgrade and pavement thickness then it predicts the pavement condition in a better way in terms of statistical accuracy. Results yielded better accuracy in deflection prediction when significant variables are considered in modeling. In case of ride quality prediction the pavements are classified on the basis of daily traffic and model developed on them yielded better accuracy. Developed model are validated for their better use in field conditions. ANN model is also developed in MATLAB which gives the best accuracy in terms of R^2. Age and traffic are the most important performance indicator for low volume roads. These roads are designed for low traffic but actual traffic on these roads are manifold which results in early deterioration. MPI is also developed on the basis of Maintenance Management Model so that proper and timely maintenance strategy can be applied.

Acknowledgement

The paper is based on the Research Work done under the project "Rural Roads Pavement Performance Studies" for Pradhan Mantri Gram Sadak Yojna (Prime Minister Rural Road Programme) sponsored by National Rural Roads Development Agency (NRRDA), Ministry of Rural Development, Government of India.

List of Notations

D	Deflection (in mm)
R	Ride Quality (in m/km)
A	Age (in years)
Tr	Traffic (CVPD)
Th	Thickness (mm)
CBR	California Bearing Ratio

References

1. Thube, D.T., 2006. *Performance Based Maintenance Management for Rural Roads*. Thesis (Ph.D), Indian Institute of Technology Roorkee, Roorkee.
2. IRC: SP: 72-2007, "Guidelines for the Design of Flexible Pavements for Low Volume Rural Roads", *Indian Road Congress*, New Delhi.

Table 14. MPI of Selected Road Sections.

Section No.	Age (yrs)	Traffic	CBR	Thickness (mm)	Deflection (mm)	Deflection Index (DI)	IRI (m/km)	Ride Quality Index (RI)	Traffic Factor	MPI	Priority Order
1	3.08	79	7.76	255	0.72	2.06	9.41	3.14	4	20.78	3
2	6.33	67	4.1	225	0.91	2.60	6.12	2.04	4	18.56	5
3	3.08	35	6.8	285	0.8	2.29	6.72	2.24	3	13.58	7
4	3	60	6.26	245	1.94	5.54	6.5	2.17	4	30.84	1
5	3	61	5.11	245	1.5	4.29	7.87	2.62	4	27.64	2
6	5.08	30	4.1	270	0.44	1.26	7.89	2.63	2	7.77	12
7	5	23	4.25	260	0.66	1.89	8.3	2.77	1	4.65	15
8	5	54	2.6	245	0.76	2.17	7.52	2.51	4	18.71	4
9	2	23	4.5	305	0.44	1.26	8.34	2.78	1	4.04	17
10	1.66	11	5	250	0.62	1.77	9.47	3.16	1	4.93	14
11	1.5	48	4.97	340	0.37	1.06	7.83	2.61	4	14.67	6
12	3	19	4.5	275	0.25	0.71	8.17	2.72	1	3.44	18
13	4	55	2.83	245	0.26	0.74	6.75	2.25	4	11.97	8
14	5.58	27	9	320	0.46	1.31	8.8	2.93	2	8.50	11
15	4.25	28	9	320	0.7	2.00	9.94	3.31	2	10.63	9
16	4.25	10	9	180	1.14	3.26	11.89	3.96	1	7.22	13
17	3	19	10	170	0.36	1.03	10.62	3.54	1	4.57	16
18	4.25	30	5	320	0.56	1.60	10.98	3.66	2	10.52	10

3. IRC: 81-1997, "Guidelines for Strengthening of Flexible Road Pavements Using Benkelman Beam Deflection Technique", *Indian Road Congress*, New Delhi.

4. Rodrigo, S. and Archondo, C., 1999. Typical Unpaved Roads Roughness Predicted by the HDM-III Model. Infrastructure Notes, *Transport No. RT-1*, World Bank.