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Statistical modelling of rutting for low-volume roads in India

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Professional paper

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This study considers a road rutting model better-suited for the flexible pavements in the low-volume roads of India. The rutting on a road directly affects various aspects such as the pavement performance, safety, driving comfort, and travel time. Accordingly, this study is conducted on 173 test sections of low-volume roads, and a mathematical rutting model is developed using a multiple regression analysis. In the model, the rutting is the response variable, whereas the commercial vehicles per day, rainfall, subgrade strength (as a modified structural number), and pavement age are the explanatory variables. The model is statistically validated and used to forecast road rutting and the effectiveness of the rutting prediction is confirmed. The error between the field data and estimated values is within 5 %.

Key words:
rutting, regression analysis, low-volume roads, ground truth verification

Stručni rad

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Statističko modeliranje kolotraženja za ceste s malim volumenom prometa u Indiji

U ovom se istraživanju ispituje model kolotraženja koji je prikladniji za savitljive kolničke konstrukcije na cestama s malim volumenom prometa u Indiji. Kolotrazi na cesti izravno utječu na različite aspekte kao što su svojstva kolnika, sigurnost, udobnost vožnje i trajanje putovanja. Sukladno tome, ovo je istraživanje provedeno na 173 probne dionice cesta s malim volumenom prometa, a matematički model kolotraženja razvijen je pomoću višestruke regresijske analize. U modelu je kolotraženje varijabla odgovora, a broj gospodarskih vozila po danu, oborine, nosivost posteljice (kao modificirani strukturni broj) i starost kolnika su eksplanatorne varijable. Model je statistički potvrđen i primijenjen za predviđanje kolotraga na cesti, a učinkovitost predviđanja je potvrđena. Pogreška između terenskih podataka i procijenjenih vrijednosti je unutar 5 %.

Ključne riječi:
kolotraženje, regresijska analiza, ceste s malim volumenom prometa, provjera točnosti referentnih podataka

1. Introduction

The Indian road network is ranked the second largest in the world, with a length of 5.6 million km. This road network comprises seven categories: expressways, national highways, state highways (SHs), urban roads, major district roads (MDRs), other district roads (ODRs), and village roads (VRs) (NHAI, 2022) [1]. The total length of VRs in India is approximately 2.75 million km and encompasses the roads laid under the Prime Minister Gram Sadak Yojana (PMGSY) scheme. Nevertheless, the amounts of traffic on these roads are generally very low. Despite this, VRs serve as principal arteries interlinking small villages with each other and other categories of roads (including MDRs, ODRs, and SHs) by providing appropriate traffic flows. Moreover, these roads provide direct linkages with agricultural production sectors and access to hospitals, schools, colleges, and markets for the populations residing in the villages [2]. The road network is one of India's most important and valuable assets, as it represents a communicative-economic infrastructure with the highest potential for growth. Roads make it easy and safe for both people and goods to move from one place to another [3]. Therefore, the Government of India has been investing massive amounts of money annually to enhance the connectivity amongst villages by constructing VRs under the PMGSY scheme [2]. According to Makendran et.al (2018, 2020), most VRs are constructed as flexible pavements, but maintaining the PMGSY roads in India is a challenging task [4, 5]. Gaspar, L., and Bencze, Z (2020) studied approaches to extending the life expectancies of road pavements. Currently, high-traffic roadways generally last 10–12 years, depending on local conditions and restrictions. During this time, other maintenance work, such as patching and crack sealing may create closures and delays. Life-cycle maintenance and operation costs sometimes exceed the original construction costs of pavement structures [6]. Makendran et al. (2021) [7] indicated that the most common types of distress parameters observed on low-volume VRs include cracking, potholes, ravelling, and rutting. Rutting is one of the important parameters for low-volume roads as it directly affects the pavement life, travel time, safety, driving comfort, and vehicle operating cost. However, only a few studies have considered the rutting on low-volume roads. Therefore, this study aims to develop a rutting prediction model for low-volume roads.

Flexible pavements consist of three layers: the sub-base, base, and surface courses (American Association of State Highway and Transportation Officials, 1993) [8]. Asphalt concrete is a top surface course layer constructed by packing together crushed rocks of different sizes, crushed powder as a filler, and bitumen. In different environmental conditions, asphalt concrete can act as plastic, viscoelastic, and elastic. Thus, rheology (the science of fluidity) can best describe asphalt concrete operations [9]. In general, asphalt concrete pavements are subject to fatigue cracking and rutting over time.

The rutting owing to flexible pavement distress leads to the risk of traffic and endangers safety while degrading the comfort, convenience, service, travel time, and quality of experience of travellers on the highways. Pavement rutting is observed on all roads, especially low-volume VRs. Rutting is the most evident near intersections, curves, and low-speed, limited areas with many stops and starts. Ali (2006) indicated that rutting endangers safety when it reaches critical depths on pavements. Rutting can be more specifically defined as longitudinal depressions on the wheel paths of flexible pavements [10]. In India, a large number of heavy vehicles with full loads move on roads during the summer season, particularly during agricultural harvesting time, impacting the surfaces of low-volume roads. In addition to causing problems concerning, e.g., speed and comfort, it can also ultimately lead to the failure of such roads.

Rukavina T. et al. (2013) [11] studied traditional waterproofing solutions for narrow asphalt channels causing rutting in bridge traffic areas. The investigations included an analysis of existing systems in use, laboratory testing, and on-site measurements of the relevant system parameters affecting the rutting resistance. The study concluded that the resistance to rutting increased by a factor of approximately 1.5 with a binder polymer-modified bitumen. Roberts et al. (1996) studied hot-mix bituminous materials and construction. They concluded that when traffic loads are applied, rutting may develop for several reasons, including the accumulation of deformation in any one of the asphalt pavements and/or lateral displacements of materials. Vorobjovas, V. and Vaitkus, A. (2013) [12] studied the local aggregates in asphalt concrete layers; all specimens had rut depths below 5 %. A high-modulus asphalt concrete (HMAC) with broken granite and PMB 25/55-60 demonstrated the lowest rut depth value (1.3 %), i.e., 1.3 %–4.5 % lower than that of asphalt concrete. Polymer-modified bitumen is recommended for HMAC bases and binder layers because it is good fatigue- and temperature-resistance. In general, HMACs should have 5 % bitumen. A lower bitumen concentration reduces an HMAC pavement's fatigue resistance and longevity [13]. Bertuliene et al. (2011) [14] inferred that the causes of rutting on single-lane carriageways were insufficient compaction, poor mixes, and failures to follow the specified terms on road surface courses during road construction. Stijanovic et al. (2021) [15] examined cement stabilisation approaches, including adding up to 30 % reclaimed asphalt pavement as a substitute for natural aggregate and fly ash and substituting 20 % or 40 % Portland cement in cement stabilisations with 4 % and 6 % binder. In general, the Proctor test establishes the maximum dry density and optimal moisture content for cement-based stabilisations. The results justify employing recycled materials in pavements.

Shen et al. (2004) [16] indicated that rutting directly affects pavements and reduces the pavement performance, life of the road, comfort of travel, and road safety. Fang (2006) [17] argued that the wear and tear of the bitumen in the wearing course of flexible pavements is worsening. The reduction in the contact between aggregates in the wearing course is also one of the reasons for rutting. Companies including the Central Road Research Institute (CRRI;1994) [18] have developed software such as HDM-4 (2000) to provide rutting performance prediction models for urban and interurban roads [19]. The HDM-4 model is unsuitable for low-volume roads, as it requires additional calibration to obtain more accurate results.

Martin and Choummanivong (2010) [20] conducted a study in Australia by collecting the data of 140 corridors and developed a rutting model using a regression analysis. The five explanatory variables in the model were the pavement strength, traffic loading, climatic condition, maintenance of the pavement, and age. The goodness-of-fit (R^2) value was 0.44. The model predicted the impact of rutting when the traffic load was increased, and the pavement subgrade strength was low. Martin et al. (2011) [21] developed a rutting model based on 500 test sections using linear and nonlinear regression analyses. The explanatory variables utilised for this model included the traffic, age, climatic conditions, maintenance of the roads, and pavement strength. Azevedo et al. (2015) [22] developed a rutting model using regression analysis by considering explanatory variables such as the volume of traffic, surface preparation, binder content, and void content. A total of eight sections spanning a length of approximately 150 m were considered for the experiments. The model demonstrated ab excellent coefficient of determination of 0.98. The study concluded that a thicker overlay does not significantly improve the rutting resistance under a lower traffic load. Sen (2012) [23] developed a rutting model using a multiple linear regression analysis. This model utilised independent variables such as traffic loading, soil, climate, rainfall, drainage, and age. This study considered 10 study sections, with each section length ranging between 2.5 and 10 km and concluded that higher traffic loading results in higher rutting progression rates. Pavement age is one of the variables that contribute highest to the rutting progression rate. Gustafsson et al. (2006) [24] revealed that the flexible pavement smoothness, serviceability, and vehicle speed are notably affected by variances in the rutting depth. Medved et al. (2018) [25] conducted finite element model analysis of unreinforced and geocell-reinforced pavements. The independent variables were geocells' positions, and strengths and thicknesses of the pavements. Geocells considerably increase the capacity of the asphalt layers in pavement structures and reduce permanent asphalt deformation. Reddy and Veeraragavan (1997) [26] concluded that an increase in heavy traffic volumes accelerates the creation of rutting on pavements. Archilla and Madanat (2000) [27] concluded that the initial rutting on a pavement led to deformations of the flexible pavement layers in wheel paths owing to repetitive traffic loads. Overall, low-volume roads experience significant distress rates. Rutting directly affects the riding quality and structural integrity of low-volume roads. From the above discussion, it can be observed that only a limited number of studies have focused on the rutting in low-traffic-volume roads in India. Hence, this study develops a rutting prediction model for low-traffic volume roads. The present study was expected to be helpful to highway engineers for providing effective pavement management of low-volume roads.

2. Study area

The study area was the state of Tamil Nadu, India, which extends over an area of 130,060 square kilometres (sq.km.). The total population is 76,417,030 (7.64 Crore) and the population density is 587 per sq.km [28]. In consultation with Rural Road and Panchayat Raj Department officials, 173 test sections on low-volume roads (200 m each) were chosen for the study.

In the first phase, 173 low-volume roads were selected for the test purpose. The second phase comprised data collection during which there will be no compromise in the quality of roads. The data of the entire road will be collected to confirm the distress. The road data included the rutting, pavement strength as determined from modified structural numbers (MSNs) using the California Bearing Ratio (CBR) test, pavement age, and commercial vehicles per day (CVPD). The rutting model was developed in the third phase by using multiple linear regression techniques and statistically validated. The final phase of this study generated conclusions and recommendations.

2.1. Criteria for selection of test sections

The criteria adopted for selecting the test sections were as follows.

- Low-volume roads with less than 150 CVPD.
- Straight test sections without any intersections or T, X, or Y-sections.
- Test sections without curves.
- Sections with regularity in the longitudinal and transverse directions insofar as the crust composition and sub-grade.
- Good drainage and surface conditions to the best possible extent.

The above criteria were fulfilled for the 173 test sections in consultation with Rural Road and Panchayat Raj department officials in Tamil Nadu. The stretches were divided into smaller 200-m segments and the rutting was manually measured with a measuring tape.

2.2. Data collection

In this study, traffic volume survey, subsoil investigation, and road distresses data were collected from all study sections, as described in the following paragraph. Figure 2a and 2b are sample photos of low-volume roads in Tamil Nadu.

2.3. Traffic surveys

The traffic surveys were continuously conducted on consecutive days for three months using a manual counting method (Indian

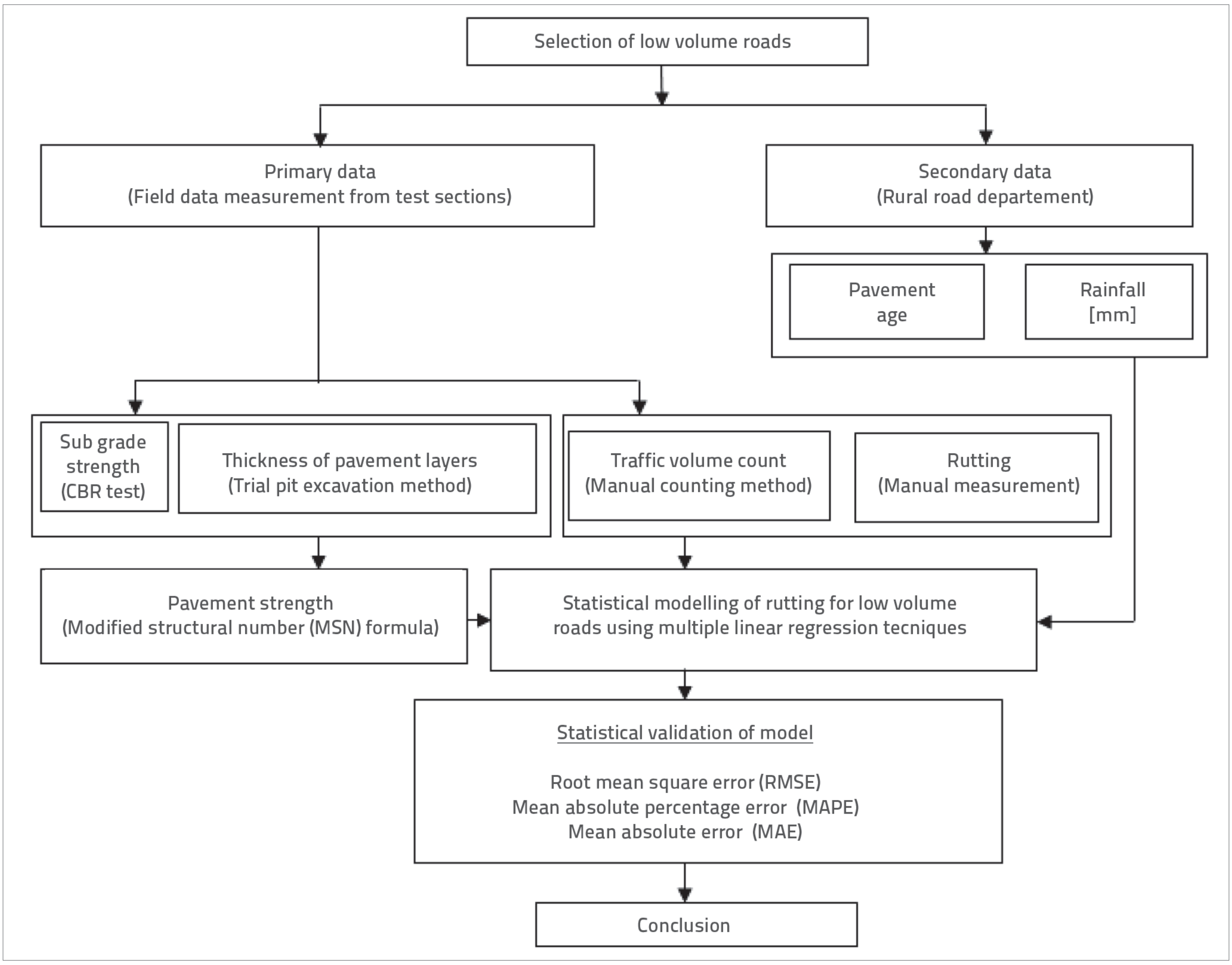

Figure 1. Methodology flowchart

Figure 2. a) and b) Sample photos of low-volume roads in Tamil Nadu

Road Congress (IRC) 9, 1972) [29]. According to the surveys, the maximum and minimum traffic volumes for the test sections were nine and two CVPD, respectively. As per IRC guidelines, a vehicle with has a gross weight of 3 tonnes or more was treated as a commercial vehicle.

2.4. Soil samples

Soil samples were collected from test pits at the subgrade level in all 173 test sections and CBR tests were conducted in a laboratory to determine the subgrade strength (IS 2720-16, 1987) [30]. The thickness of the pavement layers was physically measured from the test pits. A pit of size of 1 m × 1 m was dug for all test sections. The test pits were formed under the wheel path at a distance of 0.5 m from the edge of the pavement. The test pits were dug up to the subgrade level and the thicknesses of each layer and that of the total crust were measured accurately for all 173 test stretches.

2.5. Rutting measurements

The rutting was measured in each section; the maximum rut depth was measured to the nearest millimetre with a 1.2-m straight edge. The straight edge was placed across the rut and the dip below the straight edge was measured using a steel scale (John et.al 2014 [31], CRRI, 1994 [18], Makendran et.al 2015) [32].

2.6. Thickness of pavement

All of the low-volume roads were constructed with a minimum thickness of the pavement composition; the width of the pavement was 3 m as per IRC SP 20: 2002 [33]. The 'Manual for Rural Roads' was followed to design the pavement composition. The low-volume road layer details are presented in Figure 3.

The pavement was designed to carry a single wheel load of 5100 kg with a total pavement thickness of 295 mm. These low-volume VRs were constructed in three major layers over the sub-grade gravel layer. The entire set of test sections in this study was constructed with a gravel and sand mix as a sub-base layer (125-mm thickness) for the first layer.

The second layer comprised water-bound macadam as the base course (150-mm thickness). The third layer comprised premix carpet as the bituminous surface course (20-mm thickness). The detailed quality of materials and construction provisions guided in IRC SP-20 (2002) were followed for the construction of the low-volume roads [33].

2.7. Modified structural number (MSN)

This study employed the concept of a structural number (SN), i.e., a pavement strength indicator developed by the American Association of State Highway and Transportation Officials and given in Equation (1) [34].

$$SN = a_1 \cdot t_1 + a_2 \cdot t_2 + a_3 \cdot t_3 + \ldots\ldots + a_n \cdot t_n = \sum_{i=1}^{n} a_n \cdot t_n \qquad (1)$$

where, a_1, a_2, a_3 ....a_n, are the strength coefficients of the road materials used in the different pavement layers and t_1, t_2, t_3,... t_n are the corresponding thicknesses in inches. The pavement strength was calculated in terms of a MSN based on Equation (2) below as developed by Hodges et al. [35]. The strength coefficients proposed by the CRRI (1994) [18] in New Delhi for Indian conditions and various materials were utilised in this investigation. As mentioned above, the SN obtained from Equation (1) was modified into the MSN shown in Equation (2).

$$MSN = \mathrm{SN} + 3{,}51(\log_{10}\mathrm{CBR}) - 0{,}85(\log_{10}\mathrm{CBR})^2 - 1{,}43 \qquad (2)$$

The pavement age particulars for the test sections were collected from the Rural Roads and Panjachayat Raj Department in Tamil Nadu, India, which is responsible for the construction and maintenance of low-volume roads. The road construction details were collected from 2014–2021.

2.8. Rainfall

The rainfall and precipitation date were collected from the Indian Meteorological Department from 2014–2021 [36].

3. Correlation analyses

A correlation analysis was conducted to measure the degrees of the relationships among the five variables considered in this study. The Pearson's correlation coefficient method was adopted. In this approach, the correlation coefficient estimation can differ from one variable to another. A negative MSN value represents an ideal negative correlation, whereas a positive value denotes an ideal positive correlation. For a zero-correlation value, there is no connection between the two factors. Table 1 represents the significant correlations at the 0.01 level (two-tailed). The results show relatively good

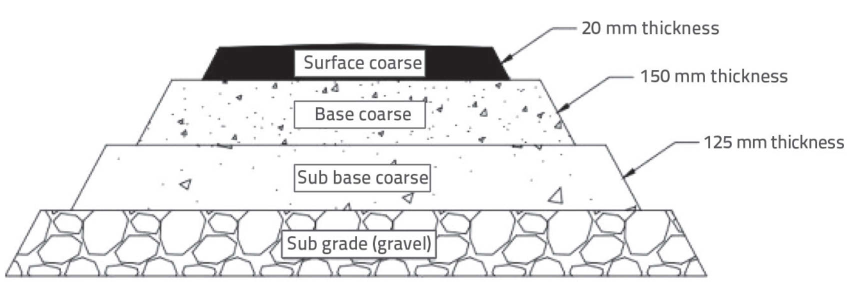

Figure 3. Cross-section of low-volume road

Table 1. Coefficients of correlation among variables

Br.	Modelling parameter	Age [years]	Modified structural number (MSN)	Commercial vehicles per day (CVPD) [number]	Rainfall [mm]	Rutting [mm]
1	Age [years]	1	-0.459**	0.518**	0.976**	0.846**
2	MSN [number]	-0.459**	1	-0.457**	-0.462**	-0.427**
3	CVPD [number]	0.518**	-0.457**	1	0.527**	0.536**
4	Rainfall [mm]	0.976**	-0.462**	0.527**	1	0.834**
5	Rutting [mm]	0.846**	-0.427**	0.536**	0.834**	1
** Correlation is significant at the 0.01 level (two-tailed)						

correlations between each pair of attributes in the rankings with the highest degree of agreement (approximately 84.6 %) between the rutting and pavement age, whereas the lowest correlation is between the pavement strength of the MSN and pavement rutting (approximately 42.7 %).

4. Development of rutting model

A multiple linear regression analysis was used to develop a functional relationship between the rutting and the explanatory variables. The functional relationship is presented in Equation (3).

$$\text{Rutting} = a_0 + a_1 \cdot \text{Age} + a_2 \cdot \text{MSN} + a_3 \cdot \text{CVPD} + a_4 \cdot \text{RN} \qquad (3)$$

Where a_0 denotes the model constant, and a_1, a_2, a_3, and a_4 are the coefficients of the age, MSN, CVPD, and rainfall for the rutting model, respectively. The model coefficients of the rutting model are summarised in Table 2. The mathematical expression for the rutting model is given in Equation (4).

Table 2. Rutting model coefficients

Model parameter	Coefficients	t-statistic	P-value
Križanje	5.108	2.512	0.012
Age [years]	1.171	3.676	0.000
MSN [number]	-2.759	-3.116	0.002
CVPD [number]	0.475	2.595	0.010
Rainfall [mm]	0.000	0.410	0.681

$$\text{Rutting} = 5{,}108 + 1{,}171\text{AGE} – 2{,}759\text{MSN} + 0{,}475\text{CVPD} \qquad (4)$$

A plus (+) sign for an estimated model coefficient for age, CVPD, and rainfall indicates a possible contribution to rut depth. A minus (–) sign for the model coefficient of the MSN denotes a negative contribution to the rut depth. The t-statistic values over 1.95 indicate that the age, MSN, and CVPD independent variables have statistically significant influences on the rut depth. A t-statistic value less than 1.95 indicates for rainfall indicates that it is statistically insignificant in the rut depth model. The estimated R^2 value is 0.74, indicating that the rutting model can explain 74 % of the predictions of the rut depth.

The validity of the above-developed regression model is ascertained by considering the results for the (t-Statistics) t-test (Equation (5)) and F value (Equation (6)). The estimated t-values for the coefficients and F value are significant, reinforcing the benefits of deploying the developed model to predict the rutting on road sections. Murray and Larry (1999) [37] assessed the statistical validity of a mean between observed and estimated values. The multiple linear regression analysis models developed for low-volume road data were validated by using the Student's t-test and F values to determine if any significant differences existed between the observed and modelled mean rutting values using Equations (5) and (6).

$$t = \frac{X_a - X_m}{\sqrt{\frac{s_a^2}{N_a} + \frac{s_m^2}{N_m}}} \qquad (5)$$

In the above, X_a and X_m are the mean values of the observed and modelled rutting values, respectively; s_a^2 and s_m^2 are their variances, respectively; and N_a and N_m are their sample sizes, respectively. For the F test, the below equation must be used.

$$F = \frac{s_1^2}{s_2^2} \qquad (6)$$

Here, s_1^2 and s_2^2 denote the larger and smaller two sample variances of the observed and model rutting values, respectively. The regression statistics and analysis of variance results are presented in Tables 3 and 4, respectively.

Table 3. Multiple linear regression statistics

Multiple R-value	0.862
R^2 value	0.744
Adjusted R^2	0.738
Standard error	0.380
Total sample	173

Table 3 indicates that the 'Multiple R' value is 0.862 for the rutting prediction model for low-volume roads. Notably,

Table 4. Analysis of variance (ANOVA)

ANOVA					
	Degree of freedom (Df)	Sum of square (SS)	Mean sum of square (MS)	Statistics F	Significance F
Regression	4	5586.807	1396.702	122.1875	0.000
Residual	168	1920.376	11.43081	---	---
Total	172	7507.183	---	---	---

in Table 3, the standard error between the field data and predicted rutting value is 0.38 %. Table 4 shows that the value of 'Significance F' is less than 0.05 for the rutting model, indicating that the developed model is statistically acceptable.

The model developed from Equation (4) was used to predict the rutting on low-volume roads. These predicted rutting values are compared with the actual observed field values in Figure 4 to elucidate the fitness of the mathematical model. The position of the scattering plotted values along the line of equality indicates the best fitness of the model. Moreover, the high value of R^2 (0.937) confirms the good fitting of the model. The model was developed using the SPSS software [38-39].

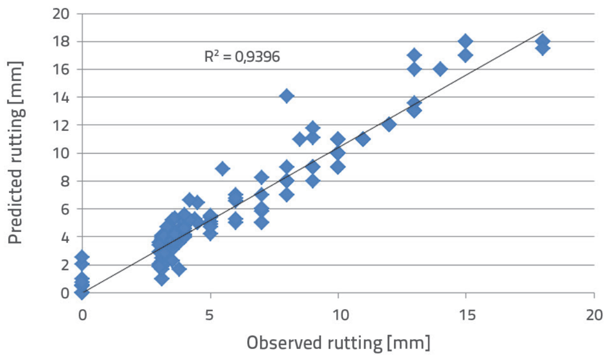

Figure 4. Values predicted via rutting model and observed values

5. Statistical validation of the model

The regression model is evaluated for the low-volume road data. The following performance measures are used in the validation process.

a) Mean Absolute Error (MAE - *Mean Absolute Error*)

$$MAE = \frac{\sum_{i=1}^{n} |yi - \bar{y}i|}{n} \tag{7}$$

Here, yi is the observed rutting value and $(\bar{y}i)$ is the rutting value as estimated from the regression model.

b) Mean Absolute Relative Error (MARE - *Root Mean Squared Error*)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} |yi - \bar{y}i|} \tag{8}$$

c) srednja apsolutna relativna pogreška (MARE)

$$MARE = \frac{1}{n}\frac{\sum_{i=1}^{n} |yi - \bar{y}i|}{yi} \tag{9}$$

The relative measures of the rutting model are summarised in Table 5. From Table 5, it is observed that the MAE of the model is 0.629 %, mean absolute percentage error is 0.043 %, and RMSE is 0.281 %. It is concluded that the multiple regression model improves the forecasting of road rutting for India's low-volume roads.

Table 5. Statistical evaluation of rutting model

No.	Relative measures	Values [%]
1	Root mean square error	0.281
2	Mean absolute percentage error	0.043
3	Mean absolute error	0.629

For the ground-truth verification of the model for the low-volume roads, the rutting values on 15 roads were manually measured in the field; the initial rutting value was 0.00 mm. The developed rutting model incorporated the information on the age, MSN, and CVPD values for the selected roads, as presented in Table 6. For example, Pinjivakkam Road was constructed in January 2015, the measured rutting value was 3.6 mm, and the predicted rutting value was 3.81 at the end of June 2017. The rutting values were measured on the same road as a new road and old road as shown in Figures 5 and 6, respectively. Similarly, the rutting values for the remaining roads are presented.

Figure 5. Newly constructed road surface on January 2015

Table 6. Ground truth verification

No.	Name of the low-volume road	Age [years]	MSN [number]	CVPD [number]	Rutting value at field [mm]	Predicted rutting [mm]
1	Sethilpakkam Anna Nagar	1.0	1.84	5	3.5	3.57
2	Elavoor Marichetty Chatram	1.0	1.52	3	3.5	3.50
3	Karani	1.5	1.84	4	3.5	3.68
4	Koduveli	1.5	1.74	3	3.5	3.48
5	KBP - Madurvasal	2.0	1.88	6	5	5.11
6	Irulanjeri - Narasingapuram	2.0	1.88	6	5	5.11
7	Nungambakkam - Thandalam	10.5	1.52	7	18	16.52
8	Satharai - Satharai	10.5	1.52	7	18	16.52
9	Keelachery - Cheyyapakkam	10.5	1.64	7	18	16.19
10	Elambakkam – Koovam	0.5	1.52	4	3	3.39
11	AKM - Vellerithangal	10	2.03	8	18	15.00
12	Elambakkam - Koovam	2.0	2.23	5	3.5	3.67
13	Koovam - Pillaiyar Kuppam	2.0	2.03	4	3.2	3.74
14	Pinjivakkam	2.5	2.39	5	3.6	3.81
15	Thirupandiyur	2.5	1.84	4	4.2	4.85

From Table 6, it can be inferred that the real rutting value is much closer to the value attained from the model, indicating that the strength of the model developed in this study is acceptable.

Figure 6. Rutting formed on the road surface in June 2017

6. Conclusions

In this study, a rutting model was developed using a multiple linear regression analysis. The ANOVA results for multiple linear regression analysis indicate that pavement age, MSN, and CVPD exhibit high correlations with pavement rutting. However, none of the above explanatory variables exhibit any multicollinearity amongst themselves. The t-statistic values of the explanatory variables are greater than the critical value of 1.96, indicating that each model parameter is significant in the estimation of the pavement rutting. The p-value of the 'rainfall' parameter exceeds 0.05, implying that it is insignificant at a 5 % level of significance. Moreover, the t-statistics value for 'Rainfall' is less than 1.96, indicating that rainfall does not have any significant influence on the rutting model. In contrast, the 'p-values' for pavement age, MSN, and CVPD are less than 0.05. The above three variables are included in the model. This study concludes that an increase in heavy traffic volume (i.e., CVPD) and age accelerates the creation of rutting on pavements. Furthermore, the rutting prediction model is thoroughly evaluated for effectiveness by comparing the predicted values with actual values. The rutting model is a powerful scientific tool for forecasting the maintenance management systems for the flexible pavements of low-volume roads in India.

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