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# PAVEMENT DISTRESSES AND ROUGHNESS MODELING – A CASE STUDY

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## ABSTRACT

Pavement deterioration is very complex. It involves structural fatigue as well as functional distresses. It results from the interaction between traffic, climate, material and time. Deterioration is the term used to represent the change in pavement performance overtime. The ability of the road to satisfy the demands of traffic and environment over its design life is referred to as performance. Due to the great complexity of the road deterioration process, performance models are the best approximate predictors of expected conditions.

In this study main distresses were identified from the selected road stretches. Regression models are then developed using SPSS (Statistical packages for social sciences) package.

## 1. INTRODUCTION

It is necessary to provide a good road network for the development of any country. India has the second largest highway and road networks system on the world. The total length of roads in the country exceeds 3.01 million kilometers. There is a great need for the effective and efficient management and maintenance of the road network. The funding available for periodic maintenance and management system is limited. In order to determine the most economical strategies, most essential input is development of deterioration models for structural and functional conditions of flexible pavements. Pavement performance is a function of its relative ability to serve traffic over a period of time (Highway Research Board,1962). Due to the great complexity of the road deterioration process, performance models are the best approximate predictors of expected conditions.

## 2. OBJECTIVES OF THE STUDY

The main objectives of the present study are

- Evaluate the functional condition of flexible pavements;
- To develop performance prediction models using SPSS package;
- To test the reliability of model using T- test;
- To develop a model for determination of Riding Comfort Index (RCI);

## 3. LITERATURE REVIEW

Large numbers of studies have been conducted globally for developing pavement performance models. Pavement performance models are of three types namely distress characteristics based models, pavement performance rating models and models based on environmental factors. Regression can be either linear or non linear. When more than one variable is included in the deterioration model, multiple linear regression or non-linear regression is resorted to (Gupta et al.).

Different techniques available for developing pavement deterioration models were reviewed. Regression technique is empirical in nature and it tries to build a relationship between the pavement condition and its causative factors. The reliability of a regression model is measured by its goodness of fit, in terms of co-efficient of determination ( $R^2$ value).

Mathew et al.(2008) developed deterioration models for ravelling initiation and progression, pothole progression, roughness progression and edge failure using neural network and regression techniques. The ANN models were compared and found to be more suitable to the rural roads as compared with the conventional empirical statistical models.

Sreedevi et al.(2011) conducted Field performance indicators for NRMB in a tropical setting. Pavement performance indicators for road sections constructed using Natural Rubber Modified Bitumen and Ordinary bitumen operating under identical conditions has been derived from periodic field data collection and analysis.

Study on decision support system for performance based maintenance management of highway pavements was done by Muralikrishna and Veeraragavan(2011). Deterioration models were developed for deflection progression and roughness progression. One set of data was used for the validation process, done by chi-square test.

Reddy et al (2005) developed flexible pavement preservation framework for an integrated asset management. In this study methodology integrates pavement condition data management, pavement performance and its standards to generate pavement preservation program. Riding Comfort Index (RCI) has been established to determine the preservation needs. Various maintenance management tools were derived as part of this study.

## 4. STUDY AREA

The scope of the study was limited to five stretches distributed on two roads three from Kottayam- Kumili Road and two from Varkala- Kallambalam. Study area stretches were selected based on the category of the road, terrain and traffic conditions, geographical location etc. Homogenous sections were selected based on the factors like traffic, pavement layer details, type of surfacing, general surface condition, subgrade soil conditions and terrain type. Figure 1& 2 shows the location of study area and Table 1 details of study stretches.

TABLE 1

DETAILS OF STUDY STRETCHES

| Sl No | Name of the Road | Category | No of Homogenous Sections with chainage | Terrain |
|---|---|---|---|---|
| 1 | Kottayam-Kumili | NH | HS-1(118-119)<br>HS-2(141-142)<br>HS-3(180-181) | Plain<br>Plain<br>Hilly |
| 2 | Kallambalam-Varkala | ODR | HS-4<br>HS-5 | Plain<br>Plain |

## 5.DATA COLLECTION

Data collection was done by taking out five representative sections each of length 1km from the study roads. Eleven sets of data were already available from previous studies. Additional one set was collected in this year.

### 5.1 Pavement Construction History Data

Pavement history data collected in this study include Pavement layer details, time of maintenance or strengthening etc. The surface layer details during the first set of data collection are shown in the Table 2:

### 5.2 Structural Condition Data

The structural condition data collected for the study include road inventory data and CBR value. Vehicle Damage Factors obtained from previous studied were used as a performance parameter.

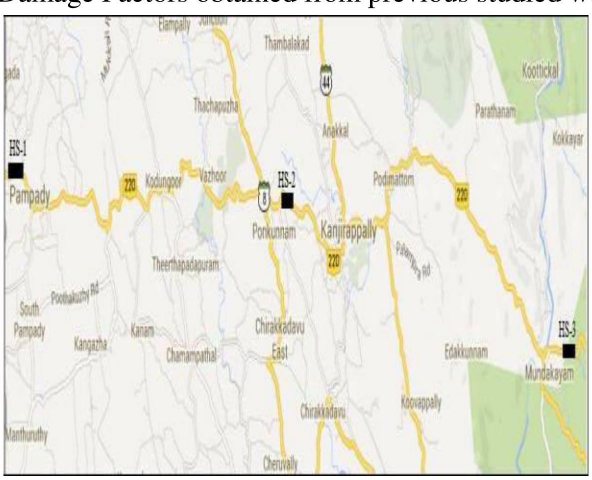


FIGURE 1 KOTTAYAM – KUMILI ROAD STRETCH

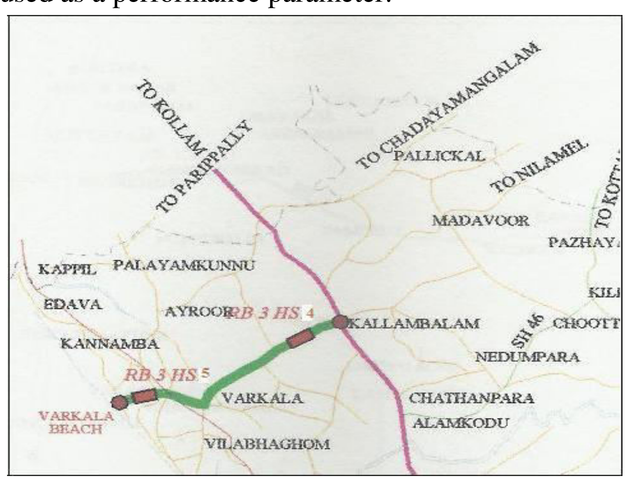


FIGURE 2 VARKALA KALLAMBALAM ROAD STRETCH

TABLE 2 PAVEMENT LAYER DETAILS OF STUDY ROADS

| **Study Stretch** | **Pavement Layer details in the year 2003** |
|---|---|
| Kottayam – Kumili Road | 250mm WBM + 50mm BM + 40 mm BC |
| Varkala – Kallambalam | 200mm WBM + 70mm BM + 40mm BC |

**5.3 Road inventory data:** In the road inventory data details of pavement type, terrain, carriage way width, pavement drainage characteristics, land use etc are taken.

**5.4 California Bearing Ratio :** Field investigation and laboratory tests were conducted on the sub grade soil in order to determine CBR value. Soil samples were taken to laboratory in sealed containers for moisture content determination and for conducting CBR tests.

**5.5 Benkelman Beam Deflection Method :** Benkelman beam is a device used to measure the rebound deflection of pavement. It is the most commonly used instrument and is simple and cheap. Deflections were measured at 20 points in each kilometre, staggered at 50 meter interval in both directions with truck having rear axle load of 8.17 tonnes and tyre pressure of 5.6 kg/cm$^2$. The measurements are taken as per the procedure given in IRC:81-1997. The deflection progression of Kottayam Kumili road is shown in the Figure 2.

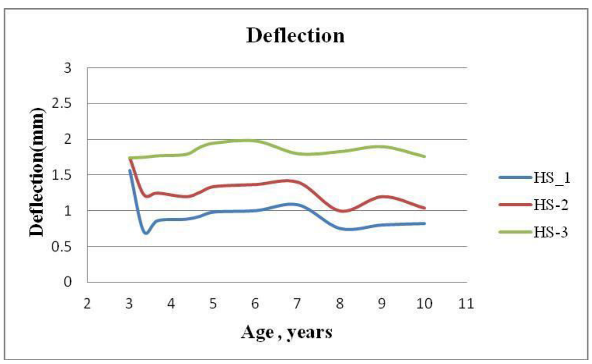


FIGURE 2 DEFLECTION PROGRESSION OF KOTTAYAM – KUMILI ROAD

### 5.5 Functional Condition Data

**5.5.1 Condition Survey :** Functional condition data were collected by walk survey associated with actual measurements. One set of condition data was collected in this year. A representative section of 1000 m length was selected from each stretch. The different types of distress observed on these roads included ravelling, cracking, potholes and fretting. Rutting was not observed on these roads. Fretting is not considered as major distress, therefore it gets eliminated. The distresses were measured in terms of their severity. The length and width of each were measured with tape. Analysis was carried out by converting it in to percentages of total carriageway affected.

**5.5.2 Roughness survey :** Roughness of pavement is an indication of its riding quality and level of service. The fifth wheel bump integrator was used for the roughness measurement. The vehicle was driven through the test sections and bumps were measured. With the fifth wheel bump integrator the value obtained is in mm/km. The data obtained from fifth wheel bump integrator is converted to standard roughness value (IRI in m/km) using calibration equation. The roughness progressions in Kottayam Kumili road and Varkala Kallambalam road during last ten years were shown in the Figure 3 and 4 below.

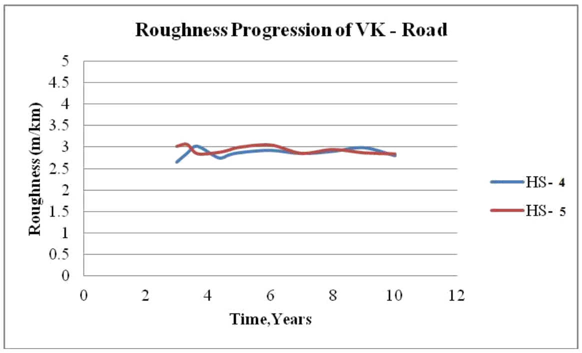


FIGURE 3 ROUGHNESS PROGRESSION IN KOTTAYAM – KUMILI ROAD

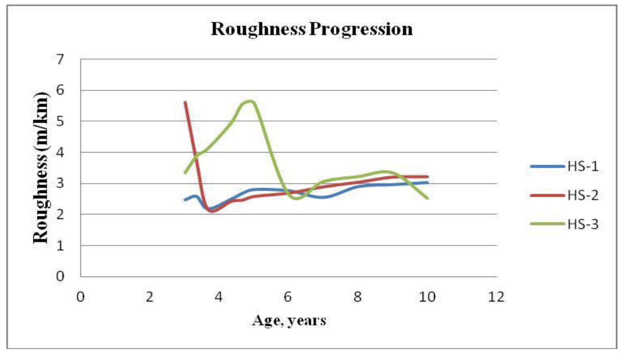


FIGURE 4 ROUGHNESS PROGRESSION IN VARKALA- KALLAMBALAM ROAD

The basic statistics of performance parameters are shown in the Table 3 below. The performance parameters along with minimum, maximum, mean and standard deviation of each parameter are listed below.

TABLE 3 STATISTICS OF PERFORMANCE PARAMETERS

| Parameter | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|
| Cracking area(%) | 0.000 | 5.800 | 0.133 | 0.790 |
| Pothole area(%) | 0.000 | 0.976 | 0.160 | 0.310 |
| Roughness(m/km) | 2.160 | 5.601 | 3.077 | 0.754 |
| Ravelling | 0 | 6.097 | 0.753 | 1.326 |
| MSN | 2.531 | 5.595 | 4.279 | 0.960 |
| VDF | 1.292 | 4.612 | 2.590 | 1.250 |
| Age | 3 | 10 | 5.816 | 2.293 |

## 6. ANALYSIS AND RESULTS

Total eleven sets of data were used for the modeling purpose. One set was collected as part of the present work. Remaining sets were available from previous study. Detailed structural and functional data collected were analyzed. Main distresses were identified and models were developed.

### 6.1 Modified Structural Number

Pavement strength was expressed in terms of Modified Structural Number (MSN). The concept of structural number was first introduced as a result of the AASHO Road test. It is a measure of total thickness of the road pavement weighted according to the 'strength' of each layer and calculated as follows:

$$SN = \sum a_i d_i \quad (1)$$

i = summation over layers

$a_i$ = a strength coefficient for each layer

$d_i$ = is the thickness of each layer measured in inches

The strength coefficients suggested for different pavement materials are shown in the Table 4 below:

TABLE 4
STRENGTH COEFFICIENTS

| Layer/Specification | Strength Coefficients |
|---|---|
| Bituminous Concrete (BC) 40mm | 0.3 |
| Bituminous Concrete (BC) 25mm | 0.28 |
| Semi Dense Bituminous Concrete (SDBC) 25mm | 0.25 |
| Dense Bituminous Macadam(DBM) | 0.28 |
| Premix Carpet (PC) 20 mm( only in the case of overlaid pavements which have PMC as original surfacing) | 0.18 |
| Bituminous Macadam(BM) | 0.18 |
| Water Bound Macadam(WBM Gr I,II,or III) Wet mix macadam / (Lime cement) stabilized | 0.14 |

(Source: Guidelines for maintenance of primary, secondary and urban roads)

The AASHO Road Test was constructed on a single uniform subgrade therefore the effect of different subgrades could not be estimated and the structural number could not include a subgrade contribution. Pavements of a particular structural number but built on different subgrades will therefore not carry the same traffic to a given terminal condition. To overcome this problem and to extend the concept to all subgrades, a subgrade contribution was derived by Hodges et al.,and a modified structural number defined as follows:

$$MSN = SN + 3.51\log_{10}(CBR_s) - 0.85(\log_{10} CBR)^2 - 1.43 \quad (2)$$

$CBR_s$ = California Bearing Ratio of the subgrade.

This modification has been used extensively and forms the basis for defining pavement strength in many pavement performance models.

### 6.2 Riding Comfort Index

In order to determine the riding quality of pavement an index called riding quality index was developed. The first step was to classify the unevenness values different range. Range selection was based on the data collected. RCI is primarily a function of pavement unevenness and is measured on a scale of 0 to 5(Table 5). RCI of zero indicates well constructed new pavement and five represents an extremely rough pavement. If the unevenness index value of a particular pavement stretch is known, the RCI value can be obtained directly.

TABLE 5
RIDING COMFORT INDEX VALUES

| Unevenness Index | Riding Comfort |
|---|---|
| | |
| (mm/km) | Index |
| | |
| <2500 | 0 |
| | |
| 2500-3500 | 1 |
| | |
| 3500-5000 | 2 |
| | |
| 5000-7000 | 3 |
| | |
| 7000-10000 | 4 |
| | |
| >10000 | 5 |

### 6.3 Regression Models

Regression models are empirical models and were developed using Statistical Packages for Social Sciences (SPSS). Models were developed for

**Cracking progression :** A common defect in thick bituminous surfaces is formation of cracks. Oxidation of binder makes the bituminous surface brittle and cause cracking on the surface of the pavement. Cracks on pavement surface weaken the pavement structure. The various factors influencing cracking progression were identified as cracking initiation, deflection, vehicle damage factor and modified structural number (Eqn. (3)).

$$Cr = 0.985XCr_i + 0.269XDef - 0.764X(VDF/MSN) + 0.186 \quad (3)$$

$R^2 = 0.977$
SE = 0.367

**Pothole Progression :** Pothole is defined as any localized loss of material or depression in the surface of a pavement. The performance parameters of pothole progression are taken as Age, VDF, MSN and pothole initiation. Eqn.(4) shows the equation for pothole progression.

$$Pt = 1.075XPt_i + 0.013XAge - 0.226X(VDF / MSN) + 0.109 \quad (4)$$

$R^2 = 0.644$

SE = 0.381

**Roughness progression :** Roughness was modeled as a function of roughness initiation, raveling area, pothole area, vehicle damage factor, modified structural number and pavement age(Eqn.(5)).

$$RG_t = -0.159XRG_i + 0.347XRVX(VDF / MSN)^{Age} + 3.24XPtX(VDF / MSN)^{Age} + 1.171XCrX(VDF / MSN)^{Age} + 0.553X(VDF / MSN)^{Age} + 3.211 \quad (5)$$

$R^2 = 0.748$

SE = 0.725

**Riding Comfort Index Model :** The assessment of riding quality is considered to be the most important component of pavement surface condition. Here riding quality of pavements in the form of Riding Comfort Index (RCI) has been correlated with the unevenness index values and an equation was developed.

$$RCI = 2.9897\ln(u) - 22.902 \quad (6)$$

$R^2 = 0.873$

Cr = cracking area in percentage at time t
$Cr_i$ = Initial cracking area in percentage
Def = Deflection at time t in mm
MSN = Modified Structural Number
Pt = Pothole area in percentage at time t
$Pt_i$ = Initial pothole area in percentage
RCI = Riding Comfort Index(RCI)
$RG_i$ = Initial roughness in m/km
$RG_t$ = Roughness at time t in m/km
RV = Ravelling area in percentage at time t
u = Unevenness in mm/km
VDF = Vehicle damage factor

**Validation of the models**

Developed roughness progression model was validated with one set of data collected. The final set of data collected was used for the validation purpose (Table 6). It was not possible to validate the distresses models due to periodic maintenances. T- test was done to check the reliability of the model. The T-values observed at 5% level of significance is well below critical values hence the models are reliable (Table 7).

TABLE 6 COMPARISON OF ACTUAL AND REGRESSION PREDICTED VALUES

| Study stretches | Roughness (m/km) | |
|---|---|---|
| | Actual | Regression model (Predicted) |
| HS -1 | 3.02 | 2.99 |
| HS -2 | 3.25 | 3.01 |
| HS-3 | 2.92 | 2.71 |
| HS-1 VK | 2.86 | 2.84 |
| HS-2 VK | 2.88 | 2.87 |

TABLE 7
T –TEST RESULTS

| Models | DF | Calculated values | Critical values |
|---|---|---|---|
| Roughness Model | 4 | 1.77 | 2.776 |

## 7. DISCUSSIONS

Detailed pavement condition survey on all the study stretches showed that the main distresses were pothole, ravelling and craking. Rutting was absent on these roads. Percentage of fretting was high on all road stretches. But fretting is not considered as a major distress. It may further leads to ravelling. It is very difficult to distinguish between fretting and ravelling. Thus fretting may be sometimes noted as ravelling.

Roughness values were getting lowered after maintenance works.

## 8. CONCLUSIONS

Detailed literature review and pavement evaluation studies were conducted on selected road stretches. The different parameters affecting the pavement performance were identified. It includes Modified Structural Number (MSN) and Vehicle Damage Factor (VDF). Non linear regression models were formulated for ravelling initiation, cracking progression, pothole progression and roughness. SPSS predicted values are nearer to observed values. Hence these models are suitable for the performance predictions of selected roads. The reliability of roughness progression models was checked by T-test.

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