DETERMINATION OF REMAINING SERVICE LIFE OF URBAN FLEXIBLE PAVEMENT

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ABSTRACT

Road Roughness acts as a trigger for pavement maintenance and rehabilitation. Road Roughness affects the road user cost to a significant extent. All the relevant data collected from various sources have been utilized for time series prediction of roughness of urban test stretches by making use of pavement deterioration model. The remaining service life of different Urban Bituminous Concrete Surfaced Roads taken in this study, with regard to roughness distress, has been determined. The optimum maintenance and rehabilitation strategies may be developed, considering the roughness distress likely to crop up in the coming time period, for different Urban Bituminous Concrete Surfaced Roads. This study would be useful in planning pavement maintenance strategies in a scientific manner and ensuring rational utilization of limited maintenance funds.

Key words: pavement, roughness, progression, maintenance, rehabilitation, model, calibration
INTRODUCTION

The roughness of a pavement is an important parameter in determining the comfort level of the riding path on a pavement and this roughness is concerned with vehicle vibration, operating speed and wear & tear of the wheels. Therefore, roughness of the pavement plays the decisive role in exercising the option of implementing the optimum maintenance and rehabilitation strategies of the road network at appropriate time.

1.1 Necessity of Road Maintenance Management

The huge amount of expenditure is being incurred in Indian road network, even then there are significant signs of deterioration and disintegration to the pavements. The lack of road maintenance have caused irreparable damage to economic growth rate, since the poorly maintained roads cause delay, road accidents and higher vehicle operating costs. Any neglect of maintenance activity is self defeating as one Rupee spent on maintenance saves 2 to 3 Rupees in vehicle operating cost [MORT&H 2013e]. Also such neglect of maintenance accelerates the process of deterioration leading to the higher cost of rehabilitation and reconstruction. The past investment made in the construction of roads needs to be protected by doing all that is feasible. The main cause of road deterioration and its remedial measure remain unexamined because of the lack of availability of objective data needed for the analysis of various aspects of design, construction and maintenance of pavements. The highway agencies who have adopted pavement technology realize that pavement management is a matter of ‘Pay Now or Pay Much, Later’. Highway agencies cannot afford to pay later since it is very costly to rehabilitate the badly damaged pavements. The problems of pavement management must be countered in a systematic manner otherwise not only significant resources may be spent on pavement repairs but also more resources are required to restore the pavement to a serviceable condition.

1.2 Effect of neglecting road maintenance: The Figure 1.1 shows the effect of neglecting road maintenance. The figure depicts the relative discounted life cycle costs of construction, maintenance and vehicle operation under different maintenance investment conditions. A road in good condition will require about 2 percent of the total discounted costs to be spent on maintenance for a traffic level of about 1000 vehicles/day. The pavement will start showing the signs of distresses if the maintenance funds are reduced. The vehicle operating costs (VOC) are likely to increase by about 10 percent with level of deterioration. If there is a complete neglect of
maintenance, a paved road will start to disintegrate, and annual vehicle operating costs will go up by about 40 percent [Robinson 1998]. Therefore, there is a dire need of deciding about maintenance and rehabilitation strategies which should comprehend all the processes involved in the formulation of pavement maintenance plans and programs. The reviewing and updating the existing design practices and standards of road construction & maintenance should be seriously considered for the cause of concern. The upgradation of the existing roads is also needed to cater to the present day’s requirements of large traffic volumes and heavy traffic loads.

Figure 1.1 Change in Discounted Life Cycle Costs for Different Levels of Pavement Maintenance [Robinson 1998]

2. METHODOLOGY DEVELOPED FOR THE STUDY

2.1 Identification of Urban Road Network

The identification and selection of different categories of roads of various sectors of Panchkula Distt., Haryana has been made. The whole road network comes under the jurisdiction of HUDA (Haryana Urban Development Authority) which can exercise the good control over the PMS analysis, being the only agency. The following urban road network of Panchkula has been considered for the study:

Bituminous Concrete (BC) Roads
- **Road-R1**: 9.7m wide road with 40mm BC top layer, from BEL factory to Amartex Chowk in sector 15, Panchkula.

- **Road-R2**: 9.7m wide road with 40mm BC top layer, between sector 14 and 15, Panchkula.

- **Road-R3**: 9.7m wide road with 40mm BC top layer, between sector 9 and 16, Panchkula.

### 2.2 Types of Data Collected

The process of data collection has been categorized into the following three types:

- Road Network Data
- Vehicle Fleet Data
- Maintenance and Rehabilitation Works Data

### Table 2.1 Details of Identified Urban Road Network

<table>
<thead>
<tr>
<th>Name of Road</th>
<th>Description of Road</th>
<th>Soil Type</th>
<th>Terrain</th>
<th>Rainfall In mm (Annual)</th>
<th>Temp. In °C</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road-R1</td>
<td>40mm BC road from BEL factory to Amartex Chowk in Sector 15,PKL</td>
<td>Loamy Sand Soil</td>
<td>Plain</td>
<td>1057</td>
<td>-1to43</td>
<td>High</td>
</tr>
<tr>
<td>Road-R2</td>
<td>40mm BC road between sector 14 and 15,PKL</td>
<td>Loamy Sand Soil</td>
<td>Plain</td>
<td>1057</td>
<td>-1to43</td>
<td>High</td>
</tr>
<tr>
<td>Road-R3</td>
<td>40mm BC road between sector 9 and 16,PKL</td>
<td>Loamy Sand Soil</td>
<td>Plain</td>
<td>1057</td>
<td>-1to43</td>
<td>High</td>
</tr>
</tbody>
</table>

### 2.3 ROAD NETWORK DATA COLLECTION

#### 2.3.1 General

The data has been obtained from the secondary sources such as the past records of concerned division of Haryana Urban Development Authority (HUDA). The data has been gathered from the selected pavement sections by carrying out the field studies. The data related to the type of soil, terrain, traffic (volume and axle load data), pavement composition and climate has also been gathered through field studies.
2.3.1.1 Road network surveys: The road network surveys is categorized into the following two types

- Primary Survey -- Field data collection
- Secondary Survey – Inventory data collected from HUDA offices

The following secondary data has been obtained from various divisional offices of the HUDA in-charge of construction and maintenance of the respective sections of the selected roadway network.

- Year of original construction and its specification
- Crust thickness of each pavement layer
- Maintenance inputs and its norms
- Traffic details for the last 5 years
- Year of strengthening and its specification
- Year and specifications of last renewal course
- Temperature and rainfall data for the last 5 years

The road network data collection in the field is categorized under the following heads:

- Inventory data
- Structural evaluation/Structural capacity
- Functional evaluation
- Evaluation of pavement material

2.3.2 Inventory Data

The details of Inventory data about the selected pavement section is given below:

Name and Category of road
Carriageway width
Shoulder width
Drainage conditions
Surface type and thickness
Pavement layer details

The above data has been gathered from the visual inspection of the pavement section and from the in-charge of construction and maintenance records of the concerned highway division of HUDA (Haryana Urban Development Authority).
2.3.3 Calculation of Adjusted Structural Number (SNP): The Adjusted Structural Number (SNP) for all the pavement section has been calculated from the Benkelman Beam deflection values by using the following equations [Odoki and Kerali 2000].

For granular base courses such as WBM/WMM
\[ BB_{\text{def}} = 6.5 \times (SNP)^{-1.6} \]

For bituminous base courses such as BM/BUSG
\[ BB_{\text{def}} = 3.5 \times (SNP)^{-1.6} \]

2.3.4 Functional Evaluation

Functional evaluation of pavements pertains to road data collection of surface distresses e.g. cracked area, pothole area, rut depth and surface roughness etc.

2.3.4.1 Surface distress measurements: The type and extent of distress developed at the surface were observed based on the visual inspection. The distresses developed were also measured in quantitative terms.

- **Measurement of cracked area:** In case of single longitudinal/transverse cracks, the width of crack was taken as 50cm and the consequent area was measured by multiplying it with actual length of crack. The cracked area was expressed as percentage of total pavement area.

- **Measurement of pothole area:**
  
  One pothole Unit = 0.1 Sq.m
  
  The minimum diameter 150mm and minimum depth of 25mm of pothole has been considered.

- **Rut depth measurements:** The rut depth was measured with at least 2m straight edge under the wheel path. The maximum value of rut depth was noted down at each observation.

2.3.4.2 Roughness measurements: The pavement roughness was measured on each pavement section with the help of ‘Fifth Wheel Bump Integrator’ towed by the jeep as per the standard procedure. The instrument was made to run at a constant speed of 30kmph. The roughness values were obtained in terms of Unevenness Index using the following equation [Jain et al 1999].

\[ UI = \frac{B}{W} \times 460 \times 25.4 \text{ mm/km} \]

Where,
UI = Unevenness Index, in mm/km
B = Bump Integrator reading
W = Number of Wheel revolutions

The above calculated Unevenness Index (measured in mm/km) has been converted into the universally acceptable International Roughness Index (IRI -measured in m/km) by using the following equation [Odoki and Kerali 2000].

\[ UI = 630 \times IRI^{1.12} \]

2.3.5 Evaluation of Pavement Materials

2.3.5.1 Field evaluation: The test pits of suitable size were dug up at suitable locations in all pavement sections. The following tests were conducted and the observations were taken.

- Thickness of the most recent surfacing course and old surfacing courses
- Thickness of base and sub-base courses
- Field dry density and field moisture content of the soil subgrade

The representative subgrade soil samples were collected from the test pits for marking the characterization of materials in the laboratory.

2.3.5.2 Laboratory evaluation: The evaluation of the subgrade soil samples collected from the field was done in laboratory conforming to the Indian Standard specifications. The tests which were carried out for each soil sample are mentioned below:

- Atterberg’s limits (Liquid limit and Plastic limit)
- Proctor density and optimum moisture content
- CBR (un-soaked and soaked at field conditions)

Table 2.2 Laboratory Test Results of Collected Sub grade Soil Samples on All Pavement Sections of the Selected Roads

<table>
<thead>
<tr>
<th>Name Of the Road</th>
<th>Optimum Moisture Content (%)</th>
<th>Atterberg Limits (%)</th>
<th>CBR In %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LL</td>
<td>PL</td>
</tr>
<tr>
<td>Road-R1</td>
<td>13.0</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Road-R2</td>
<td>15.0</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Road-R3</td>
<td>14.0</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>
2.3.6 Road Network Database

All road network data items which are required to be defined for each pavement section are given in the Table 2.3 to 2.5. All these items are stored in the road network database developed for the identified road network. This road network database has been named as ‘Urban Road Network’ for all references and uses.

Table 2.3 Inventory Data of All Selected Urban Road Sections

<table>
<thead>
<tr>
<th>Name of Road</th>
<th>Description of Road</th>
<th>Flow Type</th>
<th>Carriage-way Width</th>
<th>ADT</th>
<th>ADT Year</th>
<th>Length Of Road (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road-R1</td>
<td>40mm BC road from BEL factory to Amartex Chowk in Sector 15,PKL</td>
<td>One way</td>
<td>9.7m</td>
<td>17,140</td>
<td>2014</td>
<td>1.550</td>
</tr>
<tr>
<td>Road-R2</td>
<td>40mm BC road between sector 14 and 15,PKL</td>
<td>One Way</td>
<td>9.7m</td>
<td>15,975</td>
<td>2014</td>
<td>1.100</td>
</tr>
<tr>
<td>Road-R3</td>
<td>40mm BC road between sector 9 and 16,PKL</td>
<td>One Way</td>
<td>9.7m</td>
<td>22,253</td>
<td>2014</td>
<td>0.960</td>
</tr>
</tbody>
</table>

Table 2.4 Observed Condition Data on All Pavement Sections of Urban Road Network

<table>
<thead>
<tr>
<th>Name of the Road</th>
<th>Condition Year</th>
<th>Roughness IRI(m/km)</th>
<th>Benkelman Beam Deflection (mm)</th>
<th>Adjusted Structural Number of Pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road-R1</td>
<td>2013</td>
<td>2.23</td>
<td>0.42</td>
<td>3.76</td>
</tr>
<tr>
<td>Road-R2</td>
<td>2013</td>
<td>2.17</td>
<td>0.41</td>
<td>3.82</td>
</tr>
<tr>
<td>Road-R3</td>
<td>2013</td>
<td>2.68</td>
<td>0.44</td>
<td>3.65</td>
</tr>
</tbody>
</table>
Table 2.5 Pavement Data Collected from All Sections of Urban Road Network

<table>
<thead>
<tr>
<th>Name of the Road</th>
<th>Surfacing Material Type</th>
<th>Current Surface Thickness (mm)</th>
<th>Last Construction Year</th>
<th>Previous Last Construction Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road-R1</td>
<td>Bituminous Concrete</td>
<td>40</td>
<td>11/2009</td>
<td>5/2004</td>
</tr>
<tr>
<td>Road-R2</td>
<td>Bituminous Concrete</td>
<td>40</td>
<td>11/2009</td>
<td>5/2004</td>
</tr>
<tr>
<td>Road-R3</td>
<td>Bituminous Concrete</td>
<td>40</td>
<td>11/2009</td>
<td>5/2004</td>
</tr>
</tbody>
</table>

2.4 VEHICLE FLEET DATA

2.4.1 Categories of Vehicle

A typical traffic flow on all types of urban road in India consists of both Motorized (MT) and Non-Motorized (NMT) vehicles. Both MT and NMT vehicles have been taken into account in this study.

2.4.2 Traffic Volume Counts

Traffic surveys were conducted manually for 24 hours round the clock for a week by engaging the sufficient number of enumerators. A separate count station was established for each individual road. The vehicles were classified as per the representative vehicles specified in the previous section. The vehicles not covered under the representative vehicles defined above were suitably clubbed with the vehicles similar to them in composition and speed.

2.4.3 Vehicle Growth Rate

The average annual growth rate of vehicles in India has been taken as per the latest code of IRC-37, July’2012. The traffic compositions and annual growth rates have been assumed to be applicable to all different roads in the urban road network under study.

2.5 MAINTENANCE AND REHABILITATION WORKS

2.5.1 Serviceability Levels for Maintenance

The attempts are being made all over the world to develop standards for maintenance quality level for which roads are to be maintained to achieve the requisite level of comfort, convenience
and safety to the road users. The maintenance of roads should be kept upto such a level that the vehicle operating costs and accident costs are minimized. Environmental concerns are also being given due consideration to reduce the level of exhausts from road traffic. The measure of maintenance quality levels which have been accepted in most of the developed countries consists of measuring the service conditions of roads in terms of surface defects such as roughness, potholes, cracking and rutting etc. to determine a ‘Serviceability Index’ which varies from country to country. The suggested serviceability levels and the permissible levels of surface defects based on the measurement of roughness, cracking, rutting etc. are shown in Table 2.6 [MORT&H(2013)].

Table 2.6 Intervention Levels for Urban Roads

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Serviceability Indicator</th>
<th>Serviceability Levels</th>
<th>Level 1 (Good)</th>
<th>Level 2 (Average)</th>
<th>Level 3 (Acceptable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Roughness by Bump Integrator (max. permissible) Equivalent IRI*</td>
<td></td>
<td>2000mm/km</td>
<td>3000mm/km</td>
<td>4000mm/km</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.8m/km</td>
<td>4.0m/km</td>
<td>5.2m/km</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Potholes per km (max. number)</td>
<td></td>
<td>Nil</td>
<td>2-3</td>
<td>4-8</td>
</tr>
<tr>
<td>3</td>
<td>Cracking and Patching Area (max. permissible)</td>
<td>5 percent</td>
<td>10 percent</td>
<td>10-15 Percent</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Rutting- 20mm (max. permissible)</td>
<td>5mm</td>
<td>5-10mm</td>
<td>10-20mm</td>
<td></td>
</tr>
</tbody>
</table>

Source: MORT&H(2013)
*AsperOdoki and Kerali[2000]
Table 2.7 Grouping of Roads as per Maintenance Serviceability level

<table>
<thead>
<tr>
<th>Serviceability Level</th>
<th>Traffic Volume (ADT)</th>
<th>Name of Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (Level 1)</td>
<td>More than 10000</td>
<td>Road-R1, Road-R2, Road-R3</td>
</tr>
<tr>
<td>Medium (Level 2)</td>
<td>5,000 – 10,000</td>
<td>*****************</td>
</tr>
<tr>
<td>Low (Level 3)</td>
<td>Less than 5,000</td>
<td>*****************</td>
</tr>
</tbody>
</table>

2.6 Roughness Progression Model (For BC surfacing)

\[
\Delta RI = K_{gp} \left[ 134 \times \exp(\text{m} K_{gm} \times \text{AGE3}) \times (1 + \text{SNPK}_b)^{-5} \times \text{YE4} \right] \\
+ \left[ 0.0066 \times \Delta \text{ACRA} \right] + \left[ 0.088 \times \Delta \text{RDS} \right] \\
+ \left[ 0.00019 \times (2 - \text{FM}) \times ((\text{NPT}_a \times \text{TLF}) + (\Delta \text{NPT} \times \text{TLF}/2))^{1.5} - (\text{NPT}_a^{1.5}) \right] \\
+ [\text{m} K_{gm} \times \text{RI}_a]
\]

Where,

\[\Delta \text{RI} = \text{Total incremental change in roughness during analysis year, in m/km IRI}\]

\[\text{m} = \text{Environmental co-efficient (default value = 0.025), (= 0.04 for Indian Conditions)}\]

\[K_{gm} = \text{Calibration factor for the environmental component of roughness (default value = 1.0)}\]

\[\text{AGE3} = \text{Age since last overlay or reconstruction, in years}\]

\[\text{SNPK}_b = \text{Adjusted structural number due to cracking at the end of the analysis yr.}\]

\[\text{YE4} = \text{Annual number of equivalent standard axles, in millions/lane}\]

\[\Delta \text{RDS} = \text{Incremental change in standard deviation of rut depth during analysis yr. in mm}\]

\[\text{FM} = \text{Freedom to maneuver index based on carriageway width in m and AADT}\]

\[\text{NPT}_a = \text{Number of potholes per km at the start of the analysis year}\]

\[\text{TLF} = \text{Time lapse factor depending upon the frequency of pothole patching (default value = 1.0)}\]

\[\Delta \text{NPT} = \text{Incremental change in number of potholes per km during the analysis yr.}\]

\[\text{RI}_a = \text{Roughness at the start of the analysis year, in m/km IRI}\]

\[K_{gp} = \text{Calibration factor}\]

2.7 CALIBRATION OF PAVEMENT DETERIORATION MODEL

The calibration of pavement deterioration model has been done with the help of actual field data taken by different methods and equipment used. The numbers of data sets as given in Table 2.8 have been considered for the calibration purposes. All the data values are well within the defined limits of distress model.

Table 2.8 Data Sets for Calibration of Pavement Deterioration Model

<table>
<thead>
<tr>
<th>Types of Roads</th>
<th>YAX (millions)</th>
<th>YE4 (AMSA)</th>
<th>AGE3 (Years)</th>
<th>SNP (mm)</th>
<th>NPT_a (potholes)</th>
<th>RI_a (m/km)</th>
<th>HS (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road-R1</td>
<td>6.99</td>
<td>0.209</td>
<td>4</td>
<td>3.75</td>
<td>1.85</td>
<td>2.10</td>
<td>40</td>
</tr>
<tr>
<td>Road-R2</td>
<td>6.39</td>
<td>0.198</td>
<td>4</td>
<td>3.80</td>
<td>2.27</td>
<td>2.21</td>
<td>40</td>
</tr>
<tr>
<td>Road-R3</td>
<td>9.27</td>
<td>0.263</td>
<td>4</td>
<td>3.85</td>
<td>2.10</td>
<td>2.28</td>
<td>40</td>
</tr>
</tbody>
</table>

The following assumptions have been made for calibration purposes:

- The traffic growth rate has been considered to be 5.0% uniformly and the change in cumulative standard axles and total number of vehicle axles over a time period of one year has been calculated accordingly.
  - The adjusted structural number (SNP) of the pavement for the pavement deterioration models has been assumed to be the same.
  - The pothole area in pothole model has been suitably converted into number of pothole units by considering the following relationship: [0.1 m² pothole area = 1 pothole unit]
  - The value of TLF has been fixed as 1, since the potholes occurring on the roads are usually not patched within 12 months of their occurrence.
  - Freedom to maneuver index (FM) has been fixed as zero for carriageway width of 9.7m.
  - The environmental coefficient ‘m’ in the Pavement Roughness model has been assumed as 0.025 considering the average climatic zone for India as Sub-humid/Sub-tropical hot.
    The environmental factor for BC pavements in Indian Roughness model is taken as 0.04.
  - The relationship given by the following equation has been used to convert the Unevenness Index (UI in mm/km) into the universally acceptable International Roughness Index (IRI in m/km) [Odoki and Kerali 2000]

\[ UI = 630 \times IRI^{1.120} \]
Table 2.9 Calibration Factors Obtained for Pavement Deterioration model

<table>
<thead>
<tr>
<th>Model Description</th>
<th>Road-R1</th>
<th>Road-R2</th>
<th>Road-R3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness Progression</td>
<td>0.68</td>
<td>1.23</td>
<td>0.71</td>
</tr>
</tbody>
</table>

The average calibration factor \( K_{gp} \) obtained for deterioration model is 0.87. It shows that progression of roughness on the pavement surface of the selected test stretches is slower by 13%.

2.8 VALIDATION OF PAVEMENT DETERIORATION MODELS

2.8.1 General

The validity of the calibrated pavement deterioration models has been checked to test the efficacy of these models. The distresses predicted by the calibrated deterioration model were compared with those actually observed on the selected pavement sections to prove the validity of these models. The pavement condition data on all sections of the road network was collected around the starting of the year 2013 with the help of various equipments and methods. The pavement condition data was once again collected around the starting of the year 2014 with help of same equipment and methods so as to ascertain the status of the annual progression of distresses during the year 2013-14. The roughness progression model considered in this study has been validated.

2.8.2 Roughness Progression Model

The observed values of roughness around the starting of the year 2014 for the selected pavement sections have been compared with those predicted by the roughness progression model as shown in the Table 2.10. These values have been plotted against each other as shown in figure 2.1 to determine the correlation between them.

Table 2.10 Variability Between Observed and Predicted Roughness Values

<table>
<thead>
<tr>
<th>Name of the Road</th>
<th>Observed Roughness (m/km IRI)</th>
<th>Predicted Roughness (m/km IRI)</th>
<th>% Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road-R1</td>
<td>2.57</td>
<td>2.89</td>
<td>12.4</td>
</tr>
<tr>
<td>Road-R2</td>
<td>4.12</td>
<td>4.53</td>
<td>9.9</td>
</tr>
<tr>
<td>Road-R3</td>
<td>5.96</td>
<td>6.84</td>
<td>14.7</td>
</tr>
</tbody>
</table>
2.8.3 The ‘t’ Test

The ‘t’ test has been performed to find out the significance of difference between the observed and predicted distress values in response to pavement deterioration model. The calculated ‘t’ value ($t_{cal}$) for pavement deterioration model have been compared with tabulated ‘t’ value for a level of significance of 5% ($t_{0.05}$) as shown in the Table 2.11. From this test, it is inferred that $t_{cal} < t_{0.05}$ for the pavement deterioration model. Therefore, the difference between the observed and predicted distress values is not significant at 5% level of significance. Hence, it is maintained that the pavement deterioration model can be used for prediction of distress.

<table>
<thead>
<tr>
<th>Distress Modeled</th>
<th>Calculated ‘t’ Value ($t_{cal}$)</th>
<th>Degree of Freedom</th>
<th>Tabulated ‘t’ Value ($t_{0.05}$)</th>
<th>Comparison of $t_{cal}$/s $t_{0.05}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>0.24</td>
<td>4</td>
<td>2.776</td>
<td>$t_{cal} &lt; t_{0.05}$</td>
</tr>
</tbody>
</table>

2.8.4 Conclusion on Validation of Models

The calibrated pavement deterioration models have been validated by comparing the value of distresses predicted by the respective model with those actually observed in the field. A variation of 9.9 to 14.7 percent for roughness has been obtained. The above variations are bound...
to exist for such complex phenomena of pavement behaviour under varied conditions of traffic loading, climatic and other conditions.

The regression analysis has been carried out to frame the correlation equations for the given distress parameters. The $R^2$ (coefficient of determination) value for roughness have been obtained as 1.000. Since $R^2$ values depict good agreement between observed and predicted distress values. The ‘t’ test has been carried out to find out the difference between the observed and predicted distress values with regard to pavement deterioration model. The calculated ‘t’ values ($t_{cal}$) for the model has been compared with tabulated ‘t’ values at 5% level of significance ($t_{0.05}$). On the basis of comparison, the conclusion has been made that the difference between the observed and predicted distress values is not significant for the deterioration model. The above statistical data justifies the efficacy of the calibrated pavement deterioration model for the urban road network. Hence, it is concluded that the above deterioration models can be used for prediction of distresses and the development of maintenance management strategies for the identified urban road network.

3. APPLICATION OF METHODOLOGY

This study offers the methodology of computing the Remaining Service Life (RSL) of the pavement sections of the selected roads of the identified urban road network. RSL of a pavement section is defined as the time left in years, till it becomes imperative to reconstruct the pavement, with the condition that no amount of maintenance or rehabilitation works are assumed to be undertaken in the intervening period.

An optimum analysis period of 8 years is selected, considering the fact that almost all the pavement sections will become candidates for reconstruction in the next eight years, if no maintenance or rehabilitation work is undertaken during this period.

3.1 Selected pavement sections: The three pavement sections of the selected roads of the urban road network have been selected for this case study. The selected pavement sections are of the Bituminous Concrete roads viz. Road-R1, Road-R2 and Road-R3. All the selected roads belong to the ‘High Serviceability’ group of pavements.

3.2 Define M&R alternative: The aim of this case study is to determine the time period from the year 2015 before reconstruction of the pavement becomes essential, if no maintenance work
is undertaken in the intervening period. So, only one M&R alternative, namely ‘Do Nothing Up to Reconstruction’ is specified for all selected pavement sections of the roads.

3.3 **Intervention criteria:** As per this intervention criterion, the reconstruction of pavement will respond whenever the roughness value of the pavement section exceeds 8m/km IRI. Since the roughness comprehends the effect of all other pavement distresses, therefore the roughness value has been assumed to be the main dominant factor for triggering off reconstruction of the pavement.

3.4 **Project analysis:** The ‘Project Analysis’ is undertaken by making use of Roughness Deterioration model for simulating the pavement condition of the three pavement sections of the selected roads under the specified M&R alternative. No economic analysis is needed to be conducted in this case, as only one M&R alternative has been specified.

3.5 **Roughness progression:** Since the limiting value of roughness has been selected as the deciding intervention criterion, the progression of roughness value up to the intervention level (i.e. Roughness > 8m/km IRI) shall trigger the reconstruction of the pavement sections in a particular year.

![Figure 3.1 Roughness Progression for Different Urban Test Stretches](image-url)
3.6 Determination of RSL: The remaining service life (RSL) in respect of all the three pavement sections of the selected roads is determined as the time period left in years before the reconstruction of pavement is necessitated on the basis of progression of roughness up to the intervention level (i.e. Roughness > 8m/km IRI). The RSL values for the pavement sections of the selected roads have been determined by making use of pavement deterioration model as shown in the Table 3.1.

Table 3.1 Remaining Service Life of Urban Test Stretches

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of the Road</th>
<th>Reconstruction Year</th>
<th>Remaining Service Life (RSL in Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Road-R1</td>
<td>2020</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Road-R2</td>
<td>2021</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Road-R3</td>
<td>2019</td>
<td>4</td>
</tr>
</tbody>
</table>

It is concluded from the RSL values shown in the Table 3.1 that all the pavement sections of the selected roads will become candidates for reconstruction from 4 to 6 years, if no other maintenance measure is taken during the intervening period. Keeping in view the remaining service life of the pavement sections of the roads, suitable maintenance and rehabilitation measures are to be taken up during the design life of pavement.

4. CONCLUSIONS AND RECOMMENDATIONS

The following inferences have been drawn on the basis of this study.

1. The urban road network selected for the present study consists of three roads (Road-R1, Road-R2, and Road-R3) of bituminous concrete type, which are located in different sectors of Panchkula. The BC roads (Road-R1, Road-R2, and Road-R3) are one-way type. Since, this urban road network covers different types of traffic and pavement composition, therefore, this network may be considered as the representative for other urban road network in India and abroad.

2. As per the current norms for maintenance of roads, all the selected pavement section of the roads need not to be maintained at the same level of serviceability due to functional requirements and funds constraints. Therefore, these three pavement sections of different roads have been categorized into High Maintenance Serviceability Levels as per the volume of traffic carried by them at present i.e. > 10000ADT.
3. The calibration factor ($K_{gp}$) obtained in this study for pavement deterioration model is 0.87 (average). It shows that the progression of roughness of the pavement surfaces on the selected urban test stretches is slower by 13%.

4. The validation has been undertaken through percentage variability in the observed and predicted values, coefficient of determination ($R^2$), and ‘t’ test. Variability of 9.9 to 14.7 percent for roughness has been obtained. This variation is bound to occur for such complex phenomena of pavement behaviour under different conditions of soil type, pavement composition, traffic loading and climatic conditions. The Coefficient of Determination ($R^2$) value for roughness has been obtained as 1.000.

5. The calculated ‘t’ value for roughness is 0.24. The tabulated ‘t’ values for roughness at 5% level of significance is 2.776. The calculated ‘t’ values is less than the corresponding tabulated ‘t’ value. This evinces that the difference between the observed and predicted distress values is not statistically significant at 5% level of significance. Therefore, it is inferred that this deterioration model can be used for prediction of distresses and the development of maintenance management strategies for the urban road network.

6. The optimum maintenance and rehabilitation strategies may be triggered off by the predicted roughness value of the pavement surface.

7. It may be used to determine the opportune time and locations for applying relatively light maintenance to smooth the pavement surface, thereby extending the pavement service life at minimal cost.

8. Similar kind of maintenance management strategies may be developed for different categories of urban road network.

REFERENCES


