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|---|---|
| Date of Submission | 02/07/2019 |
| Date of Acceptance | 29/07/2019 |
| Date of Publication | 07/08/2019 |
| Page numbers | 3261-3268(8 Pages) |

Cite This Paper: Akhilesh Nautiyal, Sunil Sharma (2019). A model to compute service life of rural roads using present pavement condition and pavement age, 8(7), COMPUSOFT, An International Journal of Advanced Computer Technology. ISSN: 2320-0790, PP. 3261-3268.



ISSN:2320-0790

COMPUSOFT
An International Journal of Advanced Computer Technology

# A MODEL TO COMPUTE SERVICE LIFE OF RURAL ROADS USING PRESENT PAVEMENT CONDITION AND PAVEMENT AGE

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**Abstract**: This paper presents a scientific approach to forecast Remaining Service Life (RSL) of low volume rural roads. A case study of twenty six roads constructed under Pradhan Mantry Gram Sadak Yojna in Hamirpur district of Himachal Pradesh state in India has been selected to implement the approach. Pavement age and Pavement Condition Index (PCI) are the key factors considered to predict RSL of each road. PCI is calculated from the pavement surface distress and roughness data. Bump Integrator is used to calculate the pavement condition based on surface roughness (PCIR)and seven major types of pavement surface distresses namely: alligator cracking, edge cracks, pothole, patching, ravelling, rutting and longitudinal cracks are used in calculating pavement condition index based on distresses (PCID). PCIO is defined as the overall PCI computed from assigning 40% weight to the PCID and 60% to the PCIR. A correlation equation is developed between the pavement age and the PCIO using linear regression analysis: y = -25.62ln(x) + 116.16. However, this equation is valid in conditions similar to those in the study area. A correlation coefficient (r) of 0.8899 was obtained which shows that the curve is a good fit. The developed relationship can help plan repair and maintenance works based on RSL of each road.

***Keywords:*** Pavement distress; international roughness index; linear regression analysis pavement maintenance; remaining service life.

## I. INTRODUCTION

Road construction projects involve massive amounts of capital funds. More than two thousand roads have been constructed under Pradhan Mantry Gram Sadak Yojna (PMGSY) in the state of Himachal Pradesh in India. These roads need time to time maintenance. Due to the large number of roads and limited funds availability for road maintenance, the selection of roads for maintenance is critical. Roads are constructed with a designed life. However, low volume roads can have large service lives due to low traffic on these roads. Hence, a road should be maintained only when it has damaged to the extent that it is neither comfortable nor safe to drive on it. These roads are monitored regularly and any damages are recorded in a central database. If we can forecast expected Remaining Service Life (RSL) of these roads, we can plan their repair and maintenance judiciously [1]. RSL is calculated using performance characteristics of roads with respect to their age. Twenty six low volume rural roads constructed under PMSGY by Government of India have been taken as a case study to develop the model for predicting RSL of these roads. Roads constructed under PMGSY are low volume roads built primarily to connect habitations to the adjoining major roads. They carry very low traffic and therefore called low volume rural roads.

## II. STUDY AREA

The study area comes under sub humid sub-tropical region with a maximum temperature of 37-39° Celsius. In winters, the temperature drops down to a minimum temperature of about 3-5° Celsius. The roads are spread over a small area of about 400 square kilometers. Hence, there are hardly any climatic variations among the roads. Figure 1 show the road map of all six blocks of Hamirpur district.

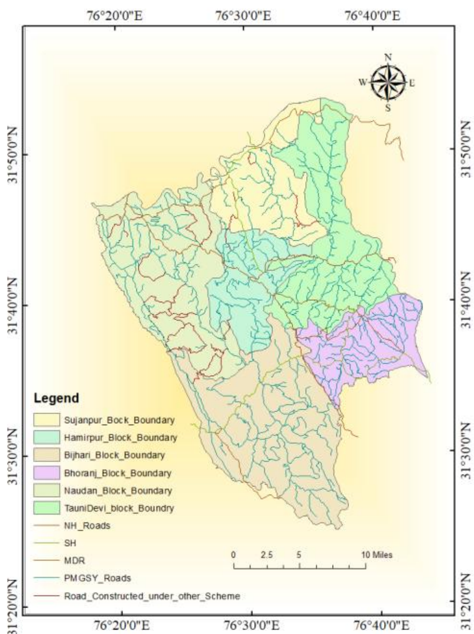


Figure 1: Road map of study area (Developed in ArcGIS 10.4)

## III. PAVEMENT CONDITION

The capability of pavement to achieve a specific level of serviceability during application of traffic loadings is known as pavement condition. Pavement condition rating (PCR) has been used in condition records by the Ohio Department of Transportation since 1985 for their highway frameworks [2]. U.S. Army Corp. of Engineers calculated Pavement Condition Index (PCI) for the first time through a visual study of existing pavement distresses. PCI is an easy and economical measure to judge the condition of pavement surface. It is a numerical value usually computed from a manual survey of the pavement throughout the length of road. Surface quality of pavement in terms of roughness and other pavement distresses is used to assign a unique value to each road which is termed as its Pavement Condition Index (PCI).

### 3.1 Pavement condition Index

PCI is a numeric rating given to each road, which varies from 0 to 100 [3, 4]. Typical values of PCI and corresponding condition of road is shown in table 1. In this study PCI is mainly calculated by two approaches: (1) category, magnitude and severity of surface distresses ($PCI_D$) and (2) surface roughness and ride quality ($PCI_R$).

Table 1: Rating to PCI range

| PCI range | Condition of Road |
|---|---|
| 0-40 | Failed |
| 40-50 | Very poor |
| 50-60 | Poor |
| 60-70 | Fair |
| 70-80 | Good |
| 80-90 | Very good |
| 90-100 | Excellent |

$PCI_D$ includes evaluation of distress data: alligator cracking, edge cracking, longitudinal cracking, pothole, patching, rutting, and ravelling. Visual survey was done on twenty six roads to collect the distress data and determine $PCI_D$ [5]. $PCI_R$ was computed from pavement surface roughness data which can be measured by developing indirect techniques [6]. In this study, pavement roughness was obtained using Bump Integrator. Basic information of these roads was collected from the Public Works Department which is responsible for construction of these roads. The length and construction year of each road are shown in Table 2.

**Table 2:** General data

| Road name | Road ID | Length | Construction year |
|---|---|---|---|
| Mohin-darkpti | PR1 | 1.75 | 2007 |
| Gaddi | PR2 | 0.96 | 2010 |
| Salehar | PR3 | 5 | 2009 |
| Jol sappar | PR4 | 3.25 | 2007 |
| Bharmar | PR5 | 5.15 | 2004 |
| Garne da galu to paniala | PR6 | 3.9 | 2002 |
| Chalokhar to ree | PR7 | 5 | 2001 |
| Patlander ranger road | PR8 | 6.5 | 2001 |
| Lambri to nalhai | PR9 | 2 | 2002 |
| Ansla bhadera | PR10 | 1.5 | 2002 |
| Janglu kuthera | PR11 | 2 | 2007 |
| Sai to galol | PR12 | 2.39 | 2013 |
| Bara Batali | PR13 | 2.6 | 2001 |
| Sukrala | PR14 | 5 | 2007 |
| Rangas kangoo | PR15 | 6 | 2007 |
| Darohi barnward | PR16 | 2.09 | 2010 |
| Matani to saster | PR17 | 2 | 2009 |
| Miharpura | PR18 | 1.3 | 2002 |
| Matial tikkar | PR19 | 4 | 2010 |
| Bhumpal to sadwan | PR20 | 3.21 | 2006 |
| Kudiyar masiana | PR21 | 13 | 2007 |
| Laleen | PR22 | 2.2 | 2001 |
| Putriyal | PR23 | 2.35 | 2002 |
| Patta jalari to man | PR24 | 4.06 | 2006 |
| Saphal | PR25 | 1.5 | 2011 |
| Lingwin khatwin | PR26 | 2.2 | 2001 |

### *3.1.1 Calculation of PCID*

Seven types of major distresses in a pavement were measured individually and seven indexes namely: Pothole index, alligator cracking index, rutting index, longitudinal cracking index, patching index, raveling index, and edge cracks index were obtained [7].

Table 3: Severity levels of distress

| S.No | Distress | Severity Levels | | |
|---|---|---|---|---|
| | | **Low** | **Medium** | **High** |
| 1. | Longitudinal cracks | Mean width of crack < 6mm | Mean width of the crack is 6mm to 19mm | Mean width of crack > 19mm. |
| 2. | Alligator cracks | The cracks area that are no or only few inter-connecting cracks. | Interconnected cracks area is forming a complete pattern. | An area of interconnected severe cracks which forms a complete pattern. |
| 3. | Edge cracks | Mean width of crack < 6mm, | Mean width of the crack is 6mm to 19mm | Mean width of crack > 19mm. |
| 4. | Pothole | < 25mm depth | 25-50mm depth | > 50mm depth |
| 5. | Patching | Patch is of low severity of distress and ride quality is not much affected by the patch. | Patch is of moderate severity of distress and ride quality is much affected by the patch. | Patch is of high severity of distress and ride quality is highly affected by the patch. |
| 6. | Rutting | Rut depth 6mm to 12mm | Rut depth 12mm to 25mm | Rut depth >25mm |
| 7. | Ravelling | No severity levels are applicable in Ravelling | | |

Each type of distress is evaluated manually in terms of its extent and severity. A severity level is then assigned in terms of low, medium and high based on percentage area affected as shown in table 3. Figures 2-8 show the percentage low, medium and high severity level of each distress type on each road. Figure 9 shows a combined graph of all distresses for each road.

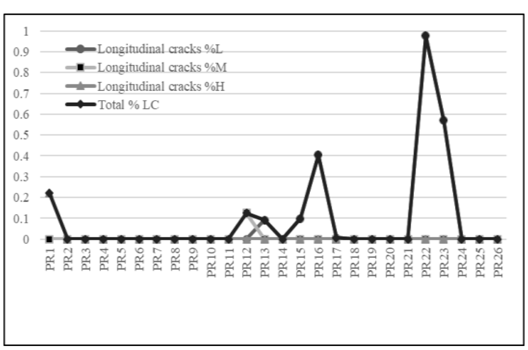


Figure 2: Percentage area of longitudinal cracks

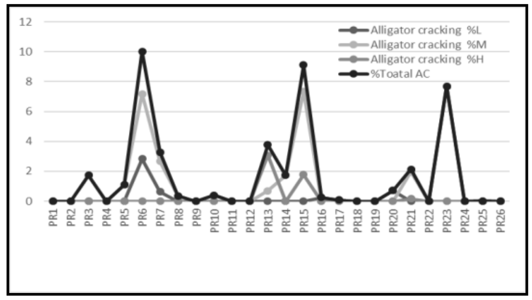


Figure 3: Percentage area of alligator crack

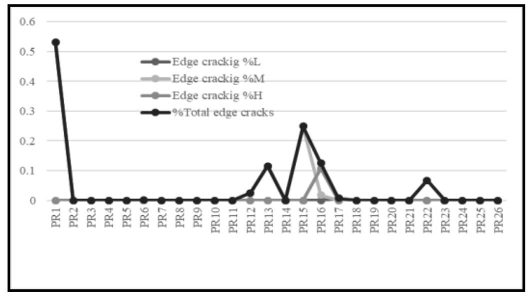


Figure 4: Percentage area of edge crack

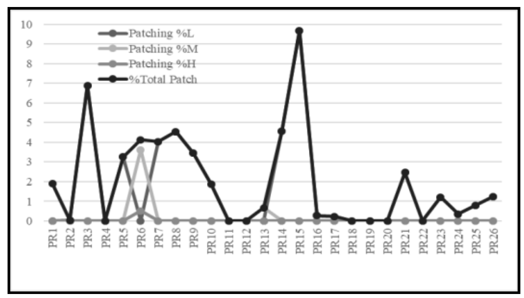


Figure 5: Percentage area of patching

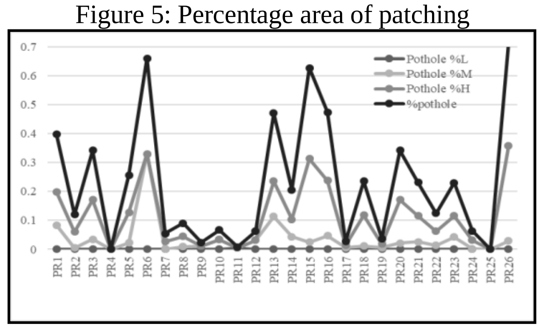


Figure 6: Percentage area of potholes

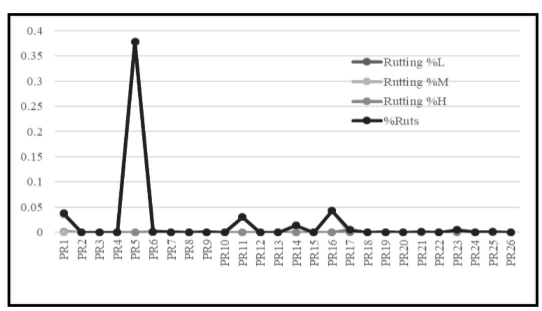


Figure 7: Percentage area of rutting

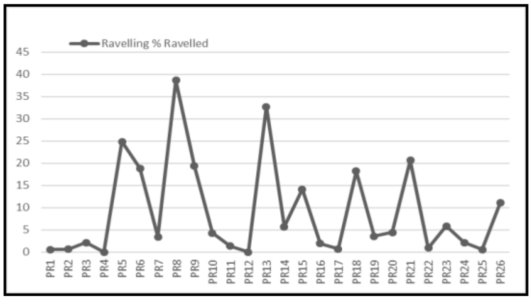


Figure 8: Percentage area of Ravelling

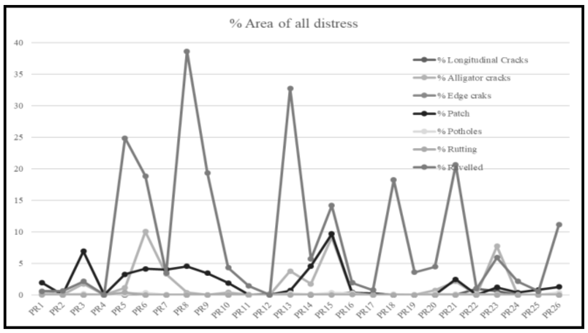


Figure 9: Percentage areas of all distress for all roads

***Longitudinal cracking index***

Longitudinal cracks are formed mostly in the lay-down direction of the road or parallel to the centre line of road. Longitudinal cracking index was calculated using the following formula obtained from FWHA:

$$LCI=100-40\left(\frac{\%L}{350} + \frac{\%M}{200} + \frac{\%H}{75}\right) \quad (1)$$

Where, %L, %M, and %H are percentage areas of low, medium, and high severity levels; 350 is the Maximum Allowable Extent (MAE) for low severity of distress, 200 is MAE for medium severity distress and 75 is MAE for high severity distress.

***Alligator cracking index***

Repeated traffic movement causes fatigue failure of pavements due to which interconnected cracks are formed on the road surface. These interconnected cracks are known as alligator cracks. Alligator cracking index is calculated using the following formula:

$$ACI=100 - 40\left(\frac{\%L}{70} + \frac{\%M}{30} + \frac{\%H}{10}\right) \quad (2)$$

***Pothole index***

Potholes are vertical depressions in the pavement which are less than 750 mm in depth. Pothole index is calculated using the following formula:

$$PHI=100 - 40\left(\frac{\%L}{50} + \frac{\%M}{30} + \frac{\%H}{10}\right) \quad (3)$$

***Edge cracking index***

Edge cracks are usually found 0.3 to 0.5 meters away parallel to the external edge of the pavement. Edge cracking index is calculated using the following formula:

$$ECI=100 - \left(20\left(\frac{\%L}{15.1} + \frac{\%H}{7.5}\right) + 40\left(\frac{\%M}{1.9}\right)\right) \quad (4)$$

***Patching index***

Patch is a portion of pavement which is substituted by a new material to repair the damaged portion of the pavement. Patch will always come under the category of defect no matter how well it is laid and performing. Patching index is calculated using the following formula:

$$PI=100 - 40\left(\frac{\%PATCHING}{80}\right) \quad (5)$$

***Rutting index***

Vertical deformations along the wheel path are known as rutting, it is a permanent deformation. Rutting is measured using a 3 meter straight edge. Rutting index is calculated using the following formula:

$$RI=100 - 40\left(\frac{\%L}{160} + \frac{\%M}{80} + \frac{\%H}{40}\right) \quad (6)$$

***Raveling index***

Raveling is surface disintegration of the pavement caused by loss of binder from the aggregate-binder mix. It is calculated from the following formula:

$$RAI=100 - 40\left(\frac{\%RAVELING}{70}\right) \quad (7)$$

***Distress PCI***

All the indices are combined into a common index named as PCID computed from the following formula. Table 4 shows each type distress index and PCID

$$PCID=100-((100-LCI)+(100-ACI)+(100-ECI)+(100-PI)+(100-PHI)+(100-RI)+(100-RAI)) \quad (8)$$

**Table 4:** Various condition indices

| Road ID | LCI | ACI | ECI | PI | PHI | RI | RAI | $PCI_D$ |
|---|---|---|---|---|---|---|---|---|
| PR1 | 99.9 | 100 | 99.3 | 99.0 | 99.4 | 100 | 99.7 | 97.3 |
| PR2 | 100 | 100 | 100 | 100 | 99.8 | 100 | 99.6 | 99.4 |
| PR3 | 100 | 97.7 | 100 | 96.6 | 99.4 | 100 | 98.8 | 92.4 |
| PR4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| PR5 | 100 | 98.5 | 100 | 98.4 | 99.5 | 99.9 | 85.8 | 82.2 |
| PR6 | 100 | 88.8 | 100 | 97.9 | 99.6 | 100 | 89.2 | 75.5 |
| PR7 | 100 | 96.1 | 100 | 98 | 99.9 | 100 | 98.0 | 92.0 |
| PR8 | 100 | 99.5 | 100 | 97.7 | 99.8 | 100 | 77.9 | 75.0 |
| PR9 | 100 | 100 | 100 | 98.3 | 100 | 100 | 88.9 | 87.2 |
| PR10 | 100 | 99.8 | 100 | 99.1 | 100 | 100 | 97.5 | 96.3 |
| PR11 | 100 | 100 | 100 | 100 | 100 | 100 | 99.2 | 99.2 |
| PR12 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99.9 |
| PR13 | 100 | 86.8 | 99.8 | 99.7 | 99.4 | 100 | 81.3 | 66.9 |
| PR14 | 100 | 97.7 | 100 | 97.7 | 99.7 | 100 | 96.7 | 91.8 |
| PR15 | 100 | 83.1 | 99.3 | 95.2 | 98.8 | 100 | 91.9 | 68.3 |
| PR16 | 100 | 99.9 | 97.7 | 99.9 | 99.2 | 100 | 98.9 | 95.4 |
| PR17 | 100 | 100 | 100 | 99.9 | 100 | 100 | 99.6 | 99.4 |
| PR18 | 100 | 100 | 100 | 100 | 99.6 | 100 | 89.6 | 89.1 |
| PR19 | 100 | 100 | 100 | 100 | 99.9 | 100 | 98.0 | 97.9 |
| PR20 | 100 | 99.6 | 100 | 100 | 99.4 | 100 | 97.5 | 96.4 |
| PR21 | 100 | 96.7 | 100 | 98.8 | 99.6 | 100 | 88.2 | 83.3 |
| PR22 | 99.9 | 100 | 99.8 | 100 | 99.8 | 100 | 99.4 | 98.9 |
| PR23 | 99.9 | 95.6 | 100 | 99.4 | 99.7 | 100 | 96.6 | 91.2 |
| PR24 | 100 | 100 | 100 | 99.8 | 99.9 | 100 | 98.8 | 98.5 |
| PR25 | 100 | 100 | 100 | 99.6 | 100 | 100 | 99.7 | 99.3 |
| PR26 | 100 | 100 | 100 | 99.4 | 98.6 | 100 | 93.7 | 91.7 |

### *3.1.2 Roughness PCI calculations*

Apart from pavement distresses which are usually present locally, surface roughness is an important parameter of pavement performance. Roughness is the measurement of riding quality which in turn is the effect of total surface undulations. Bump integrator shown in figure 10 is used to measure pavement surface undulations from which PCIR is determined using IRC SP: 16-2004 [8].

Figure 10: Bump Integrator with Recorder

Bumps count in road sections

Bump integrator's recorder is set to give reading on every 200 m, so after every 200m bumps on upside and downside of the road are recorded and average of these two sides reading is taken as the bumps count for a particular road. The average bumps in cm for each road is shown in figure 11.

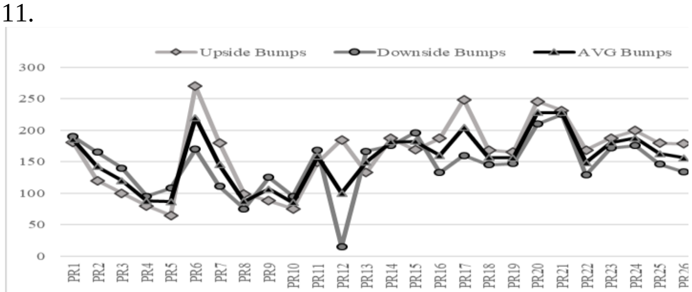


Figure 11: Bumps on road

Unevenness index (UI)

UI is computed from the total bumps in cm and total length in km of the road section in which test is performed as given in equation 9. The UI for all twenty six roads is shown in figure 12.

UI = (Bumps (cm)) / (Length of section (Km)) (9)

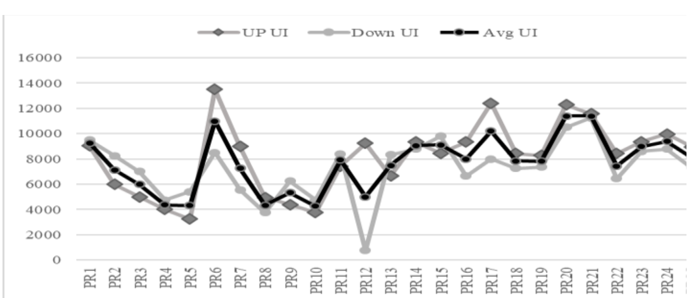


Figure 12: Unevenness index on road

International roughness index (IRI)

IRI is a scale for roughness based on the simulated response of a generic motor vehicle to the roughness in single wheel path of road surface. A relationship as shown in equation 10 given by Central Road Research Institute (CRRI) between unevenness index and International Roughness Index has been used to evaluate IRI of road [9, 10]. IRI is defined separately for the left wheel path and the right wheel path and the average of these two IRI values is taken as the IRI of the road as shown in equation 11. Table 5 shows IRI values corresponding to different severity levels of roughness and figure 13 shows IRI values of each of the twenty six roads selected in the present study.

IRI=UI/720 (10)

Avg. IRI= (Left wheel path IRI + Right wheel path IRI)/2 (11)

**Table 5:** IRI Severity levels

| Type of Road | IRI |
|---|---|
| No noticeable roughness | <90 |
| Small level of roughness | 90-126 |
| Road of average roughness | 126-190 |
| Road with above average roughness | 190-253 |
| Road with severe roughness | 253-380 |
| Not usable | >380 |

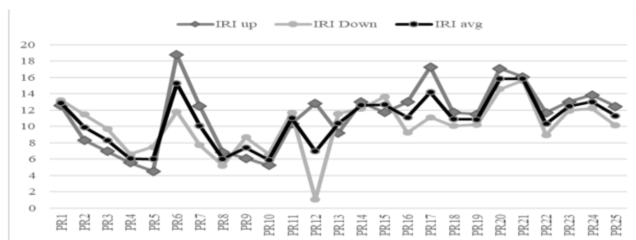


Figure 13: IRI of each of the 26 roads

Roughness PCI

Roughness PCI is basically defined as the extent of unevenness in a particular road section, therefore to calculate this extent IRI values of each roads are used to calculate roughness PCI. The PCIR for all twenty six roads is shown in figure 14.

$PCI_R$=32 * [5 * (2.718282 ^ (-0.0041 * Avg IRI))] (12)

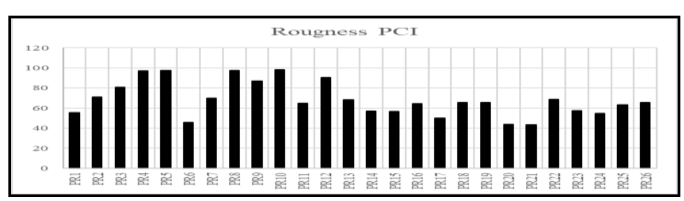


Figure 14: Roughness PCI of all 26 roads

### *3.1.3 Overall PCI*

After calculating $PCI_D$ and $PCI_R$ separately, we need to combine these to compute overall PCI denoted by $PCI_O$. FHA norms are used which give 40% weight to PCIR and 60% to $PCI_D$ as give by equation 13 [11, 12]. Table 6 and figure 16 show the $PCI_O$ value computed for each road in the present study. The $PCI_O$, $PCI_R$, and $PCI_D$ for all twenty six roads are shown in figure 15.

$$PCI_O = 0.4(PCI_R) + 0.6(PCI_D) \quad (13)$$

Table 6: Pavement condition index of each road

| Road ID | $PCI_D$ | $PCI_R$ | $PCI_O$ |
|---|---|---|---|
| PR1 | 97.29435 | 55.71659 | 80.66324 |
| PR2 | 99.40077 | 71.07356 | 88.06989 |
| PR3 | 92.4334 | 80.78897 | 87.77563 |
| PR4 | 100 | 97.21353 | 98.88541 |
| PR5 | 82.16841 | 97.76869 | 88.40852 |
| PR6 | 75.51253 | 45.71361 | 63.59296 |
| PR7 | 92.02194 | 69.9095 | 83.17696 |
| PR8 | 75.03447 | 97.49071 | 84.01697 |
| PR9 | 87.20211 | 87.24458 | 87.2191 |
| PR10 | 96.33776 | 98.49513 | 97.20071 |
| PR11 | 99.18917 | 64.84727 | 85.45241 |
| PR12 | 99.89614 | 90.45705 | 96.1205 |
| PR13 | 66.94788 | 68.21848 | 67.45612 |
| PR14 | 91.83923 | 56.98403 | 77.89715 |
| PR15 | 68.34001 | 56.59596 | 63.64239 |
| PR16 | 95.437 | 64.33235 | 82.99514 |
| PR17 | 99.35773 | 50.00302 | 79.61585 |
| PR18 | 89.14218 | 65.49673 | 79.684 |
| PR19 | 97.90455 | 65.75832 | 85.04606 |
| PR20 | 96.42225 | 43.7027 | 75.33443 |
| PR21 | 83.30488 | 43.6281 | 67.43417 |
| PR22 | 98.94072 | 68.60805 | 86.80765 |
| PR23 | 91.21926 | 57.48921 | 77.72724 |
| PR24 | 98.47482 | 54.96031 | 81.06901 |
| PR25 | 99.27441 | 63.35081 | 84.90497 |
| PR26 | 91.67879 | 65.72089 | 81.29563 |

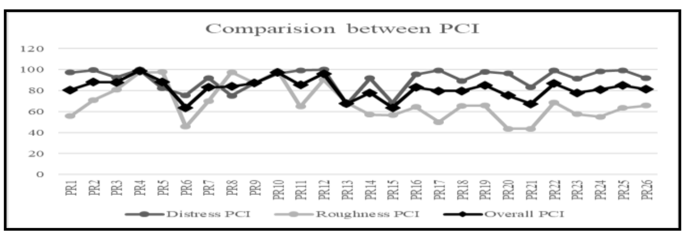


Figure 15: $PCI_D$, $PCI_R$ and $PCI_O$ of 26 roads

## IV. REMAINING SERVICE LIFE

RSL can be defined as the total time in years a road can serve with effective and smooth movement of traffic [13, 14]. There are various methods to estimate the RSL like fatigue test [15- 17] or to develop a relationship between the quantities of failures per mile to the remaining equivalent single axle loads on the road. Dossey et al [18] and Ferregut et al. [19] applied Simulated Neural Networks to evaluate RSL in Texas. AASHTO proposed a technique in 1986 to evaluate RSL of overlay which involves Non Damaging Test (NDT) to calculate the current pavement condition. In the present study, linear regression analysis is used to plot a relationship between pavement age and present pavement condition. Information related to construction year of road and year of last maintenance was obtained from Himachal Pradesh Public Works Department (HPPWD) Hamirpur. Pavement age was determined using equation 14. Pavement age of each of the twenty six roads is shown in table 7.

$$\text{Pavement age} = (\text{Current Year} - \text{Year of Last Maintenance}) \quad (14)$$

**Table 7:** Pavement age of each road

| Road ID | YEAR of first construction | Served life | Last maintenance done | pavement new age |
|---|---|---|---|---|
| PR1 | 2007 | 11 | 2014 | 4 |
| PR2 | 2010 | 8 | 2015 | 3 |
| PR3 | 2009 | 9 | 2015 | 3 |
| PR4 | 2007 | 11 | 2016 | 2 |
| PR5 | 2004 | 14 | 2015 | 3 |
| PR6 | 2002 | 16 | 2012 | 6 |
| PR7 | 2001 | 17 | 2014 | 4 |
| PR8 | 2001 | 17 | 2014 | 4 |
| PR9 | 2002 | 16 | 2015 | 3 |
| PR10 | 2002 | 16 | 2016 | 2 |
| PR11 | 2007 | 11 | 2015 | 3 |
| PR12 | 2013 | 5 | 2016 | 2 |
| PR13 | 2001 | 17 | 2012 | 6 |
| PR14 | 2007 | 11 | 2013 | 5 |
| PR15 | 2007 | 11 | 2012 | 6 |
| PR16 | 2010 | 8 | 2014 | 4 |
| PR17 | 2009 | 8 | 2013 | 5 |
| PR18 | 2002 | 16 | 2013 | 5 |
| PR19 | 2010 | 8 | 2015 | 3 |
| PR20 | 2006 | 12 | 2013 | 5 |
| PR21 | 2007 | 11 | 2012 | 6 |
| PR22 | 2001 | 17 | 2015 | 3 |
| PR23 | 2002 | 16 | 2013 | 5 |
| PR24 | 2006 | 12 | 2014 | 4 |
| PR25 | 2011 | 6 | 2014 | 4 |
| PR26 | 2001 | 17 | 2014 | 4 |

### 4.1 Relationship between PCIO and Served life

A correlation between PCIO and pavement age was developed to calculate the RSL of a pavement. A PCIO value of 40 is assumed as terminal PCI value which indicates that the road requires immediate reconstruction and movement of traffic is not safe on such roads. Total Service Life (TSL) of a road in terms of PCI value is the duration in years in which the PCI value falls to 40 from 100 (PCI of a newly built road). Figure 16 shows the pavement performance curve from which the following equations are derived.

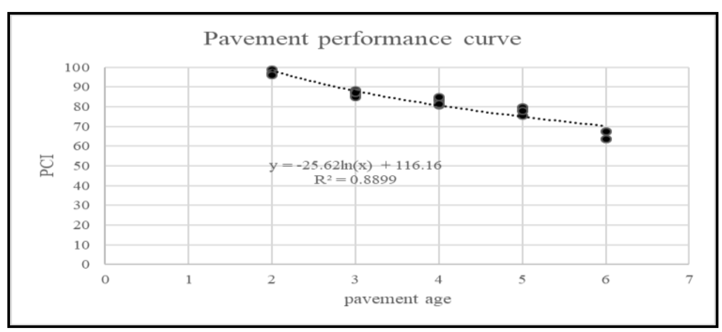


Figure 16: Pavement performance curve

Pavement age = -25.62ln(x) + 116.16, where x is current PCI which varies from 0 to100.

Total Service Life = -25.62ln (40) + 116.16, where 40 is the terminal PCI after which the pavement is assumed to be failed.

Hence, RSL = 25.62 ln(PCIO) – 25.62 ln(40) (15)

RSL of all the twenty six roads selected in the present study is shown in figure 17.

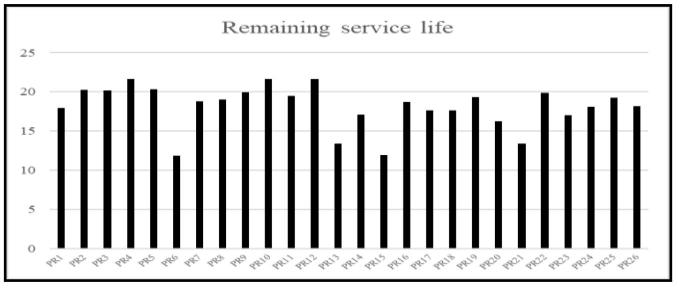


Figure 17: RSL of 26 roads selected in the case study

## V. CONCLUSION

Equation RSL = 25.62 ln($PCI_O$) – 25.62 ln(40) gives the relationship between RSL and the overall PCI of low volume rural roads with climate and traffic conditions similar to those in study area. This relationship is applicable within acceptable error to most of the low volume roads in the state of Himachal Pradesh. A correlation coefficient of 0.8899 shows that the curve is a good fit. The study concludes that the maximum pavement age for the roads of Hamirpur district is 21.65 years. Maximum and minimum areas of various types of distresses are: patching -9.67% & 0%, Ravelling -38.61% & 0%, longitudinal cracking -0.97% & 0%, Potholes-0.35% & 0%, Edge cracking -0.53% & 0%, and alligator cracking -10.01% & 0%. Average bumps value per 200 m is ranging from 85.2 cm to 228.2 cm. All roads fall under PCIO range of 98.88 to 63.59, ranging from fair to excellent. PCIO value of 40 is considered as terminal PCI below which full depth reclamation or reconstruction should be done. This means that these roads are not in need of reconstruction at present and only need specific repairs depending on major distress types on each road. Prediction of RSL is important for optimum benefits of maintenance program with respect to efficient fund utilization and service to road users.

## ACKNOWLEDGEMENT

The work presented in this paper was supported by State Council for Science, Technology & Environment (SCSTE), Himachal Pradesh, INDIA and National Institute of Technology, Hamirpur, INDIA. Authors would like to acknowledge Ministry of Human Re-source Development (MHRD), India, for financial support to carry out this research.

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