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RURAL ROAD MAINTENANCE PRIORITIZATION INDEX BASED ON FUNCTIONAL AND STRUCTURAL PARAMETERS FOR RURAL ROAD NETWORK IN HIMACHAL PRADESH




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ABSTRACT

Pavements are essential assets of highways which need timely maintenance for efficient use of road maintenance fund. The deferred pavement maintenance strategies result in enormous economic loss and severely affect the development of any country. The available fund for road maintenance is also limited. Hence, for proper utilization of road maintenance funds, it is required to assess the condition of pavements which needs to be maintained first and is in worst conditions. Rural Roads in Himachal Pradesh, India plays a vital role in the development of the state as it connects the rural regions with the urban ones. With an increasing pace of rural road construction of 1000 Km per year and introduction of Pradhan Mantri Gram Sadak Yojna (PMGSY), the total rural road network contribution in the state is approximately 26000 Km with 62% of tarred roads. To preserve this critical asset, along with the rapid construction pace of this vast rural road network, simultaneous maintenance is also required promptly. In this context, prioritization of pavements is required to assess the pavement conditions and providing maintenance to the deprived ones. Various pavement indexes such as Pavement Condition Index (PCI), Roughness Index (RI), etc., have been used to assess the condition of pavements. An attempt has been made to develop Rural Road Maintenance Priority Index (RRMPI) for the rural road network in Himachal Pradesh, India. Rural Road Maintenance Priority Index is a function of Overall Functional Condition Index (OFCI) and Overall Structural Condition Index (OSCI). RRMPI is an index of scale 0-100, in which 0 signifies the worst condition of pavement and 100 signifies the best condition of the pavement. The developed RRMPI is also compared with the currently available pavement maintenance prioritization solution based on objective Analytical Hierarchy Process (AHP). The proposed index is expected to provide a better reflection of pavement condition as compared to other developed traditional method and helps in prioritizing maintenance strategies. In the present study, the developed RRMPI has been used to select a maintenance strategy for the selected 12 rural road stretches in Himachal Pradesh.

1. INTRODUCTION

Prioritization of roads with respect to their pavement condition is requisite to utilize the available road maintenance fund fruitfully. Pavement condition needs to be assessed both functionally and structurally. Functional evaluation implies the analysis of exterior road surface conditions such as International Roughness Index (IRI), pavement distresses, skid resistance and other associated factors. Pavement distresses such as cracking, ravelling, rutting, potholes, patching and similar such parameters, majorly affect the pavement condition. Pavement Roughness also affects the riding quality or riding comfort of the passengers. Apart from Functional evaluation, Structural condition of pavements also contributes a major role in determining the maintenance strategies. The characteristic deflection values determined by conducting Benkelman Beam Study helps in determining the thickness of overlay required. Modified Structural Number (MSN) has been found to be a good indicator of the structural condition of the pavement. The Modulus of subgrade reaction (K) is also described as a structural parameter of pavements.

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In this study, an attempt has been made to prioritize the rural roads in Himachal Pradesh, India regarding their functional and structural conditions, in order to provide timely maintenance as required using Rural Road Maintenance Priority Index (RRMPI). RRMPI is a function of Overall Functional Condition Index (OFCI) and Overall Structural Condition Index (OSCI) and having a scale of 0-100, in which 0 signifies the worst condition of pavement and 100 signifies the best condition of the pavement. OFCI depends on the International Roughness Index, total pavement distress and skid resistance. Hence, OFCI is a function of Functional Condition Roughness Index (FCI_{IRI}), Functional Condition Total Pavement Distress Index (FCI_{TPD}) and Functional Condition Skid Resistance Index (FCI_{SR}). Also, OSCI depends upon Modified Structural Number (MSN) and Modulus of subgrade reaction (K-value). Hence, OSCI is a function of Structural Condition MSN Index (SCI_{MSN}) and Structural Condition K-value Index ($SCI_{K\text{-}value}$). The weightage has been given to each parameter using the Analytical Hierarchy Process (AHP). The developed RRMPI model has been validated by comparing it with already developed prioritization model based on objective AHP, which utilizes only pavement distresses. The final predicted RRMPI is a useful tool for various highway agencies and engineers in order to prioritize the maintenance strategies for the rural road network in Himachal Pradesh for efficient use of road maintenance fund in a genuine manner.

2. LITERATURE REVIEW

Various studies related to pavement condition evaluation have been presented and available as scientific literature. AASHTO had developed PSI (Present Serviceability Index) model based on objective ground analysis and subjective rating of PSR (Pavement Serviceability Rating) after conducting studies on 123 road sections which includes 49 rigid sections and 74 flexible pavement sections. A mathematical regression analysis index was developed, and validation of the model was done so that pavement ratings could be established through objective measurements of pavements (Cary 1960). The U.S. Army Corps of Engineers (1982) also developed Pavement Condition Index (PCI) to assess the pavement condition. A deduct value has been deducted from PCI based on severity and extent of particular distress. Karan et al., 1983 analysed 40 road sections to provide an approach of Pavement Quality Index (PQI) based on suggestions and objectivity of expert panel regarding Riding Comfort Index (RCI), Surface Distress Index (SDI) and Structural Adequacy Index (SAI) on a scale of 0 to 10. FHWA, 1990 proposed an overall index which represents the overall condition of pavements. Juang and Amirkhanian (1992) have proposed a Unified Pavement Distress Index (UPDI) using fuzzy theory. Zhang (1993) developed an overall acceptability index (OAI) which was developed for flexible pavements based on the theory of fuzzy logic. OAI includes four different parameters i.e. pavement distress, structural capacity, pavement roughness and skid resistance. Shoukry et al. (1997) developed a fuzzy distress index (FDI) based on the fuzzy theory which mainly evaluates the various pavement distresses. Thube et al. (2007) developed an index for low volume rural roads in India with PSI and PCI as indicators of pavement deterioration. Gharaibeh et al. (2010) studied various pavement condition indexes and compared from five DOTs in the United States, and the results showed significant differences due to different pavement distress types considered, weightage factors and the mathematical forms of the indexes. Shah et al (2013) proposed an overall pavement condition Index for Urban Road Network considering the functional and structural parameters excluding modulus of subgrade reaction collecting data on 10 urban road sections on 29.92 Km of Noida city. Shah et al (2014) developed a Road Condition Index (RCI) for the roads of Noida City which indicates the overall condition of the pavement and prioritize the maintenance of pavement sections. Also, Ahmed et al (2017) used objective based Analytical Hierarchy Process approach to prioritize the pavement sections of Mumbai City.

Under the Rural Roads development scheme, the Government of India introduced The Pradhan Mantri Gram Sadak Yojna (PMGSY) scheme in order to enhance the growth and development of rural roads in India. The scheme was launched on The 25th December 2000 to provide all-weather roads as a goal to reduce poverty and to establish a connection with all unconnected habitats with population up to 500 in plain terrain and up to 250 on hilly terrain with states like North-East, Jammu & Kashmir, Uttarakhand and Himachal Pradesh. The PMGSY scheme is running under stages and currently the PMGSY-III scheme (PMGSY-III scheme, GoI, August 2019) is under progress followed by PMGSY-II (PMGSY-II scheme, GoI, August 2013) and PMGSY-I.

3. METHODOLOGY AND FIELD DATA COLLECTION

The overall flowchart of the methodology adopted in order to develop the Rural Road Maintenance Priority Index (RRMPI) is presented in **Fig. 1.**

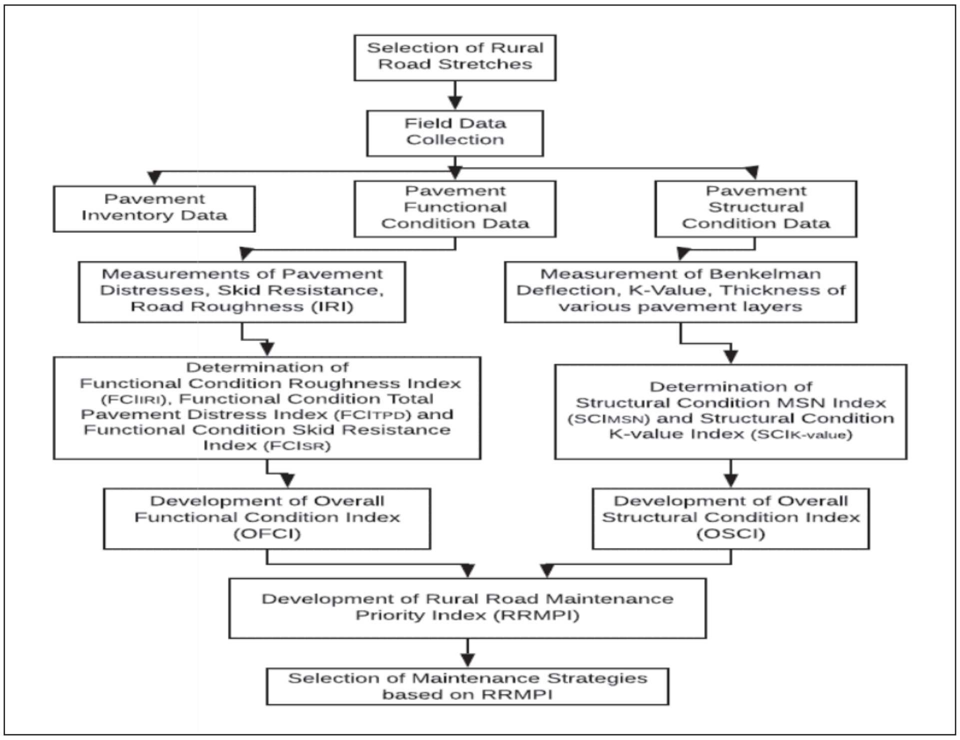

Fig. 1 Flowchart Showing Detailed Methodology to Develop RRMPI

In the present study, 12 rural road sections have been studied in order to develop the RRMPI. The 12 rural road sections of 2.5 km each in length have been selected in the vicinity of Shimla and Solan Districts of Himachal Pradesh, India. The selected each rural road section has been designated with rural road ID as follows- RR1-Domehar-Waknaghat Road, RR2-Solan-Ashwini Khad Road, RR3-Kyari Bangla-Dera Road, RR4-Basha Road, RR5-Khawara Chowki-Mashru Road, RR6-Shoghi-Dooh Road, RR7-Shoghi-Heon Road, RR8-Shoghi-Jaog Road, RR9-Kandaghat-Kot Road, RR10-Chail Road, RR11-Nain-Basal Road, RR12-Solan-Malaun Road. All the road sections have been selected in such a way that the selected length of 2.5 Km each represents the condition of the whole length of the road, both in terms of traffic volume and climatic condition. The width of each selected rural road stretch is around 3.5 m. The field data has been collected in terms of Pavement Inventory, Functional condition of roads and Structural condition of roads. Pavement inventory details include Name of the road, Category of the road viz. rural road, NH or SH, number of lanes, carriageway width of the road, surface type, maintenance and construction history of the roads, etc. The collected data on the rural roads of Himachal Pradesh has been checked for the normal distribution before developing the current methodology using PYTHON by plotting the histogram to check the Gaussian distribution (a bell-shaped curve) of the data by using histogram 'matplotlib' function. Also, the p-value has been calculated using PYTHON only which shows that p-value is greater than 0.05 (5% confidence level) and it signifies to fail to reject the null hypothesis where null hypothesis, H_o states that the sample is taken from a Gaussian distribution.

4. FUNCTIONAL EVALUATION OF SELECTED RURAL ROADS

The functional evaluation of the selected rural road sections has been conducted, which involves the evaluation of characteristics of the pavement that directly affects the safety and comfort of road users and road services. In the present study, the functional evaluation includes measurements of pavement distresses, skid resistance and road roughness. The pavement distresses which has been considered and prevailed mostly on the selected road sections includes longitudinal cracking, transverse cracking, alligator cracking, rutting, ravelling, patching, potholes and mean texture depth. The pavement distress measurement for cracking, ravelling and patching has been done using a simple measuring tape. Rutting and mean texture depth has been measured using 3 m straight edge and sand patch method respectively. The sand patch test assesses the macro-textural characteristics of pavement surfaces. The depth and mean diameter of potholes has been measured, along with the volume of potholes by pouring the known volume of sand in the bowl of the pothole. Road Roughness which is the undesirable deviation of the surface of pavement from its planar surface has been measured using MERLIN. The Machine for Evaluating Roughness using Low-cost INstrumentation (MERLIN) is a road-roughness measuring apparatus that comes with the advantages of being simple to operate, robust, easy to fabricate, reasonably accurate, reliable and almost maintenance-free. The objective Ride Comfort Rating (RCR) of the pavement has been done by a panel provided on a scale of 0-100 where 0 depicts the worst road and 100 depicts the best road as a reference to panel comfort ride and provided guidelines in **Table 4.** Skid Resistance has been measured using a portable skid resistance tester machine.

5. STRUCTURAL EVALUATION OF SELECTED RURAL ROADS

Pavement Structural evaluation which deals with the structural adequacy of the pavement has been conducted on the selected rural road sections. Characteristic Deflection study has been conducted using Benkelman Beam Deflection as per guidelines provided in IRC:81-1997. The moisture and temperature correction factors have been incorporated accordingly. The standard rear dual wheel axle load of 8170 kg of the loaded truck and tyre pressure of 5.6 kg/cm^2 has been maintained and observed precisely during the test as per the guidelines provided in IRC:81-1997.

The thickness of various pavement layers has been measured for all selected rural road stretches either by using core cutter or by taking test pits where strata are hard. The California Bearing Ratio (CBR) value of subgrade soil (soaked and un-soaked both) of all selected rural road stretches has been measured in the laboratory by taking subgrade soil samples. The soaked CBR value has been used to determine K-value, i.e. modulus of subgrade reaction using the correlation table given in IRC:58-2015. The structural evaluation of selected rural road sections is depicted in **Photo 1.**

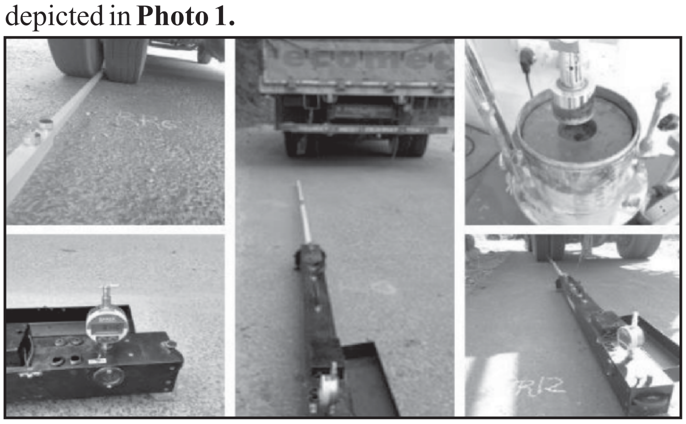

Photo 1 Structural Evaluation of Selected Rural Road Sections

6. ANALYSIS FOR DEVELOPMENT OF RURAL ROAD MAINTENANCE PRIORITY INDEX (RRMPI)

6.1 Functional Condition Total Pavement Distress Index (FCI_{TPD})

Various pavement distresses such as cracking, ravelling, patching, potholes, rutting and other associated parameters have been observed on the selected 12 rural road sections in Himachal Pradesh. The functional condition total pavement distress index (FCI_{TPD}) has been generated using the concept of Maximum Allowable Extent (MAE) as prescribed in Yogesh U. Shah et al. (2013). The maximum allowable extents (MAE) of different pavement distresses with their severity levels, and corresponding illustrations have been presented in **Table 1.**

Table 1 Illustration of Severity Levels and MAE for Different Pavement Distresses

Sl. No.	Pavement Distress	Severity	Illustration	Maximum Allowable Extent
1	Longitudinal & Transverse Cracking	L	Crack mean width < 3 mm	25
		M	> 3 mm and < 6 mm	20
		H	> 6 mm	10
2	Alligator Cracking	L	Few connected cracks with width between 1 to 3 mm	50
		M	Moderate connected cracks width between 3 to 6 mm	25
		H	Extensive connected mapped cracking with width > 6mm	15
3	Potholes	L	< 25 mm deep and < 200 mm wide	50
		M	25-50 mm deep and 200-500 mm wide	30
		H	> 50 mm deep and >500 mm wide	10
4	Patching	L	Patching with low distress of any type and rutting < 4mm	50
		M	Patching with moderate distress and rut depth 4-10 mm	15
		H	Patching with extensive distress and rut depth > 10 mm	10
5	Rutting	L	Rut depth <4 mm	80
		M	4-10 mm	60
		H	> 10 mm	30
6	Ravelling	L	Loss of aggregate is low and ride quality affected low	70
		M	Loss of aggregates moderate and ride quality appreciably affected	30
		H	Loss of aggregates extensive and ride quality is poor	20
7	Mean Texture Depth	L	0-0.25 mm	90
		M	0.25-0.50 mm	65
		H	> 0.50 mm	40

In the present study, the threshold value for the rural road sections in Himachal Pradesh has been taken as 50. The threshold value indicates that the pavement has reached a state where preventive and corrective measures are required for its rehabilitation.

Analytical Hierarchy Process (AHP), a complex decision-making tool, has also been used to give weightage to various distress parameters in order of their relative importance to each other. The AHP incorporates the imagination, knowledge and experience of each individual into the analysis of any problem. It synthesizes the numerous decisions or perceptions mathematically for which the consistency of the judgements is checked to evaluate each decision and, finally, the output is arrived to model the concerned problem statement. The questionnaire is given in Appendix-1 (PART-A) that has been disseminated to Highway Engineers, Scientists, Academicians and Research Scholars for their individual perception based on their experience and knowledge. A total of 157 questionnaires have been distributed out of which 123 responded and used to determine the relative weights of various distress parameters. In order to check the Consistency Ratio (CR) of 123 responses, Expert Choice 11 software has been used.

If the consistency ratio of any response was more than 0.1 than that particular response has been discarded. Hence out of total 123 responses, 31 responses whose consistency ratio greater than 0.1 were discarded and the weightages were calculated based on the remaining 92 responses (75% sample size). The final average weightages of each pavement distress after incorporating 92 responses whose inconsistency values were less than 0.1 are given in **Table 3.** The weightages to different severity levels of distresses has also been taken as 1, 0.75 and 0.50 to high (H), medium (M) and Low (L) Severity, respectively.

The distress index calculated using equations given in **Table 2** are subjected to a minimum value of 0 and maximum value of 100 where %L, %M and %H indicated the percentage of distress area measured using a simple measuring tape (longitudinal cracking, transverse cracking, alligator cracking, patching, and ravelling) with low, medium and high severity respectively.

Table 2 Distress Index Corresponding to Low, Medium and High Severity

Distress	Low Severity Index (LSI)	Medium Severity Index (MSI)	High Severity Index (HSI)
Longitudinal Cracking	100- 50* (%L/25)	100- 50* (%M/20)	100- 50* (%H/10)
Transverse Cracking	100- 50* (%L/25)	100- 50* (%M/20)	100- 50* (%H/10)
Alligator Cracking	100- 50* (%L/50)	100- 50* (%M/25)	100- 50* (%H/15)
Potholes	100- 50* (%L/50)	100- 50* (%M/30)	100- 50* (%H/10)
Patching	100- 50* (%L/50)	100- 50* (%M/15)	100- 50* (%H/10)
Rutting	100- 50* (%L/80)	100- 50* (%M/60)	100- 50* (%H/30)
Ravelling	100- 50* (%L/70)	100- 50* (%M/30)	100- 50* (%H/20)
Mean Texture Depth	100- 50* (%L/90)	100- 50* (%M/65)	100- 50* (%H/40)

Table 3 Weightages determined using AHP Expert Choice 11 software

Pavement Distress Type	Weightage (W_i)
Longitudinal Cracking	0.15
Transverse Cracking	0.12
Alligator Cracking	0.23
Potholes	0.14
Rutting	0.22
Ravelling	0.05
Patching	0.07
Mean Texture Depth	0.02

Percent of rut depth and potholes within each severity is measured using the following equation.

(Number of ruts or potholes within each severity/15)* 100

Percent of mean texture depth within each severity is measured using the following equation.

{Number of sand patch test results (test conducted subjected to 15 samples per 100 m length of road and 3.5 m wide) within each severity/Total Number of tests conducted} * 100

Further, each pavement distress index has been calculated by incorporating the weight factors of different severity levels. The distress index for each distress of pavement can be calculated using equation (i).

Each Pavement Distress Index

$$(\text{PDI}) = \frac{[0.50*LSI+0.75*MSI+1.0*HSI]}{[0.50+0.75+1.0]} \quad \text{(i)}$$

The functional condition Total Pavement Distress has been calculated by incorporating the weightages determined by the Analytical Hierarchy Process (AHP) using Expert Choice 11 software given in **Table 3**. The functional condition total pavement distress has been determined by using equation (ii).

$$\text{FCI}_{\text{TPD}} = \sum w_i * PDI \quad \text{(ii)}$$

Where, w_i= weightage given in **Table 3**

PDI = Each Pavement Distress Index corresponding to longitudinal cracking, transverse cracking, alligator cracking, potholes, patching, rutting, ravelling and mean texture depth calculated from equation (i).

6.2. Functional Condition Roughness Index (FCI_{IRI})

The functional condition roughness index has been determined by correlating the International Roughness Index (IRI) and Ride Comfort Rating (RCR) as given by non-linear regression equation (iii). The International Roughness Index (IRI) has been calculated using MERLIN on the selected rural road sections. A panel of four members has done the Ride Quality Rating (RCR) survey on the selected road sections and their average rating depending upon the guidelines given in **Table 4** and their perception has been considered in the study.

Table 4 Guidelines for Panel Conducting Ride Comfort Rating (RCR)

Ride Comfort Rating (RCR)	Section Evaluation	Description
0-20	Very Poor	More than 75% of the pavement section is drastically affected by presence of large, deep and wide cracks and potholes. The riding quality/comfort is drastically affected and speed is reduced. The pavement surface possesses water logging problem in rainy season.
20-40	Poor	About 50% of the pavement surface is affected with deep and wide cracks, large potholes, free flowing speed reduced drastically and other type of high severity distresses are prevailing on the section surveyed.
40-60	Fair	Ride comfort quality is moderately affected which affects high-speed flow of traffic. Moderate alligator cracking, patching, rutting observed over the surface.
60-80	Good	Riding Comfort may be good but apart from it, very low severity visible micro-cracks and initiation of rutting or ravelling over the surface observed.
80-100	Very Good	Conditions similar to a newly constructed pavement having smooth surface and no visible pavement distress on the surface.

$$FCI_{IRI} = RCR = -606.40 + 848.80 * (IRI)^{(-0.14)} \quad (R^2 = 0.85) \qquad \text{(iii)}$$

Where, RCR = Ride Quality Rating subjected to Minimum value 0 and Maximum value 100 IRI = International Roughness Index in (m/km)

6.3 Functional Condition Skid Resistance Index (FCI_{SR})

The skid resistance has been obtained by using skid resistance pendulum testing machine. The scale of skid resistance pendulum testing machine is between 0-100 in which higher value depicts a good pavement surface with high skid-resistant surface and low value depicts that the pavement surface is slippery and skid-resistant is low. Hence, the functional condition skid resistance index (FCI_{SR}) has been taken directly from the result obtained by the skid-resistant pendulum testing machine.

6.4 Structural Condition MSN Index (SCI_{MSN})

The best indicator of the structural condition of the pavement is its structural number which depends on the rebound deflection of the surface of the pavement, layer coefficients, and thickness composition of each layer of pavement. The characteristic deflection of the surface of pavement has been measured using Benkelman beam as shown in **Photo 1** and as per the procedure recommended in IRC 81:1997. The AASHTO test developed the concept of Structural Number (SN), which is the indicator of the strength of any pavement. Further, the Structural Number has been modified after incorporating the California Bearing Ratio (CBR) of subgrade and defined as Modified Structural Number (MSN) (Hodges 1975). The Modified Structural Number is calculated using equation (iv) subjected to a maximum value of 100 and a minimum value of 0.

$$MSN = SN + 3.51\,(\log_{10} CBR) - 0.85(\log_{10} CBR)^2 - 1.43 \qquad \text{(iv)}$$

Where, $SN = \sum_{i=1}^{n} a_n * t_n$

Where, a_n = layer coefficients of n layers, t_n = thickness of n layers of pavement in inches CBR = California Bearing Ratio of pavement subgrade (%)

The layer coefficients of different layers as prescribed by the Central Road Research Institute, New Delhi have been used in the present study (CRRI, 1994). The structural condition, i.e. MSN Index, has been determined using equation (v).

$$SCI_{MSN} = \left(\frac{MSN}{SN_{effective}}\right) X\ 100 \qquad \text{(v)}$$

Where, $SN_{effective}$ =3.2* (Characteristic Deflection in mm using Benkelman Beam) - 0.63 MSN= Modified Structural Number from equation (iv)

6.5 Structural Condition K-Value Index ($SCI_{K\text{-}value}$)

The modulus of subgrade reaction is an important structural parameter which indicates the structural adequacy of the concerned pavement. The K-value can be obtained by conducting plate bearing test, but the test is too expensive; hence the required K-value for the selected 12 rural road sections has been obtained using the relationship given between soaked CBR and K-value as per IRC 58-2015. The range of K-value for a soaked CBR range of 2% - 100% is 21 – 220 MPa/m. Since the subgrade CBR value of 15% is considered very good for rural road sections in Himachal Pradesh and 2% CBR as very poor as per IRC-SP: 72-2015; hence, the subgrade CBR value of 15% is taken as the upper limit, and the structural condition K-value index has been obtained by normalizing it in range of 0-100 by using the formula given in equation (vi), where the high value of index depicts stiffer and good structural adequacy of pavement whereas low value directs poor structural adequacy of pavement.

$$SCI_{K\text{-value}} = 100 * \frac{(K_{value} - 21)}{(62-21)} = 2.44 * (K_{value} - 21) \quad \text{(vi)}$$

7. DEVELOPMENT OF OVERALL FUNCTIONAL CONDITION INDEX (OFCI) AND OVERALL STRUCTURAL CONDITION INDEX (OSCI)

The overall functional condition index (OFCI) is dependent on Functional Condition Total Pavement Distress Index (FCI_{TPD}), Roughness Index (FCI_{IRI}) and Skid Resistance Index (FCI_{SR}). In contrast, the overall structural condition index (OSCI) depends upon the Structural Condition MSN Index (SCI_{MSN}) and K-Value Index (SCI_{Kvalue}). Hence, weightages need to be determined for various parameters depending upon OFCI and OSCI to develop respective indexes. The same sample data of 92 responses have been used corresponding to the questionnaire given in Appendix-1 (part-B). Expert Choice 11 software has been used. The dynamic sensitivity of nodes has also been done using the software. The average weightage of 55%, 30% and 15% have been obtained for OFCI parameters of Total Pavement Distress Index (FCI_{TPD}), Roughness Index (FCI_{IRI}) and Skid Resistance Index (FCI_{SR}) respectively and the average weightage of 65% and 35% have been assigned to OSCI parameters of Structural Condition MSN Index (SCI_{MSN}) and K-Value Index ($SCI_{K\text{-value}}$) respectively. Hence, the Overall Functional Condition Index (OFCI) and Overall Structural Condition Index (OSCI) have been determined using equations (vii) and (viii), respectively.

$$OFCI = 0.55 * FCI_{TPD} + 0.30 * FCI_{IRI} + 0.15 * FCI_{SR} \quad \text{(vii)}$$

Where, FCI_{TPD} = Functional Condition Total Pavement Distress Index
FCI_{IRI} = Functional Condition Roughness Index
FCI_{SR} = Functional Condition Skid Resistance Index

$$OSCI = 0.65 * SCI_{MSN} + 0.35 * SCI_{K-value} \quad \text{(viii)}$$

Where, SCI_{MSN} = Structural Condition MSN Index
$SCI_{K\text{-value}}$ = Structural Condition K-Value Index

8. DEVELOPMENT OF RURAL ROAD MAINTENANCE PRIORITY INDEX (RRMPI)

The Rural Road Maintenance Priority Index (RRMPI) has been developed which is based on Overall Functional Condition Index (OFCI) and Overall Structural Condition Index (OSCI) which has been determined using equations (vii) and (viii) respectively. The weights have been assigned to functional parameters and structural parameters of pavement separately in order to articulate the final RRMPI for best results. The weights have been determined using Expert Choice 11 software based on the Analytical Hierarchy Process, as shown in **Fig. 2** using questionnaire given in Appendix-1 (PART-B). After processing 92 questionnaires, the average weightage of 60% has been assigned to functional parameters and 40% to structural parameters. Hence, the final RRMPI has been determined using equation (ix).

*RRMPI = 0.6 * (OFCI) + 0.4 * (OSCI)* *(ix)*

Where, OFCI and OSCI are overall functional condition index and overall structural condition index respectively.

8.1. Validation of Rural Road Maintenance Priority Index (RRMPI)

The developed RRMPI method of Prioritizing Rural Road Pavement sections has been validated after comparing it with the objective-based Analytical Hierarchy Process (AHP) method (Ahmed et al. 2017).

Priority Ranking using Objective based AHP method Analytical Hierarchy Process (AHP) is one of the simplest and most useful processes appropriate for approximate usages in decision making. This method has been a tool in the hands of decision-makers and researchers since its introduction. It is still one of the most widely used tools when assessing decisions in bridge and road construction.

AHP evaluation is based on the concept of paired comparisons. The elements in a level of the hierarchy are compared in relative terms as their importance or contribution to a given criterion that occupies the level immediately above the elements being compared. This process of comparison yields a relative scale of measurements of priorities or weights of the elements. These relative weights sum to unity.

In the objective-based AHP method (Ahmed et al. 2017), the pavement distresses were considered only in assessing the ranking of pavement sections. The weights to different categories of the AHP hierarchy were assigned by objective analysis compared to subjective analysis during the pair-wise comparison.

In the present study, criteria, sub-criteria, and alternatives in AHP were defined as Type of road, Pavement Distresses, and Pavement Sections, respectively. Since the entire selected pavement sections are Rural Road sections; hence Type of Road is indicated as Rural Road only, and the weightage of unity is shown in **Table 5.** Five Pavement Distresses were considered as sub-criteria including Cracking, Ravelling, Patching, Potholes, and Rutting.

After Pavement Inventory, the collected pavement distresses i.e., cracking, ravelling, patching, potholes were converted into a percentage of total pavement section area and rutting as a percentage of total pavement section length.

Table 5 Priority Weights for Objective Based AHP Method

Priority Weight of criteria				
Rural Road (criteria)= 1.0				
Priority Weight of sub criteria with respect to Rural Road (consistency ratio <0.1)				
Cracking	Ravelling	Patching	Potholes	Rutting
0.147	0.632	0.103	0.051	0.066
Priority Weight of Rural Road Sections with respect to Cracking				
RR1=0.352, RR2=0.066, RR3=0.043, RR4=0.031, RR5=0.062, RR6=0.176, RR7=0.039, RR8=0.028, RR9=0.021, RR10=0.035, RR11=0.122, RR12=0.025				
Priority Weight of Rural Road Sections with respect to Ravelling				
RR1=0.047, RR2=0.052, RR3=0.057, RR4=0.029, RR5=0.377, RR6=0.098, RR7=0.181, RR8=0.038, RR9=0.026, RR10=0.022, RR11=0.042, RR12=0.034				
Priority Weight of Rural Road Sections with respect to Patching				
RR1=0.198, RR2=0.040, RR3=0.033, RR4=0.018, RR5=0.069, RR6=0.340, RR7=0.021, RR8=0.024, RR9=0.079, RR10=0.106, RR11=0.044, RR12=0.028				
Priority Weight of Rural Road Sections with respect to Potholes				
RR1=0.011, RR2=0.031, RR3=0.044, RR4=0.062, RR5=0.153, RR6=0.027, RR7=0.304, RR8=0.019, RR9=0.103, RR10=0.150, RR11=0.014, RR12=0.083				
Priority Weight of Rural Road Sections with respect to Rutting				
RR1=0.286, RR2=0.180, RR3=0.050, RR4=0.024, RR5=0.109, RR6=0.024, RR7=0.040, RR8=0.013, RR9=0.011, RR10=0.071, RR11=0.050, RR12=0.142				

The weights to various alternatives i.e., selected 12 Rural Road sections and sub-criteria based on objective AHP analysis (Ahmed et al. 2017), are given in **Table 7** with Consistency Ratio less than 0.1. The overall priority weights (ranging from 0 to 1) of alternatives i.e., Rural Road sections, were computed using equation (x) and shown in **Table 6.** The priority rating was calculated for each rural road section by multiplying the corresponding priority weight with 100 **(Table 6).** The section having the highest priority rating is given the top priority for maintenance means worst pavement condition, and the section having the least priority rating is given the least maintenance priority suggesting best pavement condition as given in **Table 8.**

$$\text{Overall Priority Weight of Alternatives} = \sum \frac{W_i}{W_{imax}} \times F_i \qquad (x)$$

where, W_i = weight of each alternative related to sub-criteria of parameter i, W_{imax} = highest weight of alternative related to sub-criteria of parameter i, F_i = weight of related sub-criteria of parameter i

Table 6 Rural Road Section Rating and Ranking Value on the basis of Objective Based AHP

Rural Road ID	Priority Weight of Rural Road Sections	Priority Rating	Priority Ranking
RR1	0.354	35.4	3
RR2	0.173	17.3	5
RR3	0.142	14.2	7
RR4	0.084	08.4	12
RR5	0.730	73.0	1
RR6	0.350	35.0	4
RR7	0.386	38.6	2
RR8	0.089	08.9	11
RR9	0.096	09.6	10
RR10	0.125	12.5	8
RR11	0.148	14.8	6
RR12	0.122	12.2	9

Comparison of RRMPI and Objective based AHP Ranking

The final pavement prioritizing ranking of rural road sections determined by RRMPI and Objective-based AHP method is given in **Table 7.** It has been found that for few sections, the rankings are close enough to each other, and for other sections, there is a significant difference. It has also been found that both methods predicted the same results for RR4 as the best pavement section, which is at least priority of maintenance and RR5 as the worst pavement section, which is a top priority for maintenance. Apart from these two sections, there is a significant difference in priority rankings. The main drawback of the objective-based AHP method is that only pavement distresses were considered in the method; however, RRMPI also focused on overall evaluation parameters, which include skid resistance, road roughness, pavement deflection and modulus of subgrade reaction also, apart from pavement distresses only. Also, RRMPI utilizes an empirical approach and mathematical models depending on the functional and structural parameters, which depicts the actual condition of the pavement rather than solely on the AHP technique.

Table 7 Rural Road Section Maintenance Prioritization Ranking- RRMPI versus Objective Based AHP

Rural Road Section ID	RRMPI Ranking	Objective Based AHP
RR1	11	3
RR2	7	5
RR3	6	7
RR4	12	12
RR5	1	1
RR6	5	4
RR7	4	2
RR8	10	11
RR9	9	10
RR10	3	8
RR11	2	6
RR12	8	9

8.2 Statistical Analysis for Rank Correlation

The priority ranking assessment has been done using the Non-Parametric Spearman Rank correlation coefficient ρ that has been determined using equation (xi) and depicted in **Fig. 2**, which shows a positive rank correlation of 0.61 between rankings predicted using RRMPI and Objective based AHP method. It shows that RRMPI could determine priority ranking in the right consistency with the objective-based AHP method.

$$\rho = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} \quad \text{(xi)}$$

Where, d_i is the difference between ranks of rural road section i by using RRMPI and objective based AHP method, and n is the number of alternatives i.e. number of pavement sections.

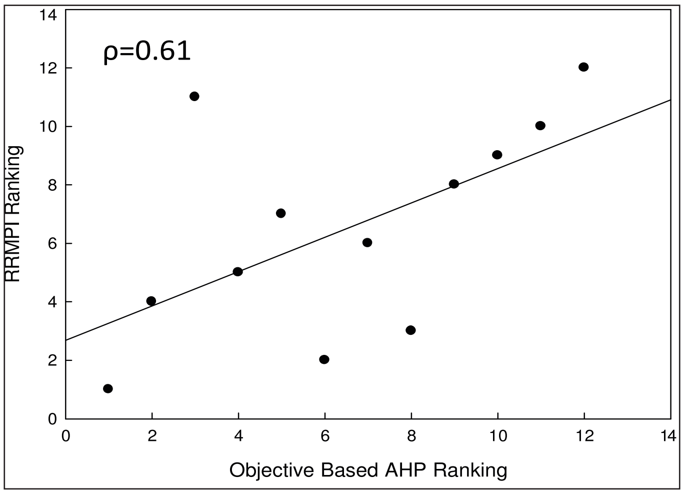

Fig. 2 Correlation between Objective Based AHP Ranking and RRMPI Ranking

Further, hypothesis testing was performed by Student's t-test to check the significance of the correlation relationship of obtained ρ value. The Null hypothesis of H_o: ρ=0 was tested against the alternate hypothesis H_1: ρ>0. As n is greater than 10, the significance of Spearman correlation was tested using equation (xii). The results obtained from the hypothesis test are given in Table 8, which shows that $t_{n-2} > t_{\alpha,n-2,}$ hence the null hypothesis is rejected, showing a non-zero correlation between RRMPI and objective-based AHP method.

$$t_{n-2} = \frac{\rho}{\sqrt{(1-\rho^2)/(n-2)}} \quad \text{(xii)}$$

Table 8 Analysis of Statistical Hypothesis Testing of Rank Correlation

Statistic	RRMPI versus Objective Based AHP
Observations	12
Degree of Freedom	10
Confidence Level	95%
Pearson Correlation	0.61
Student's t-test (t_{n-2} for n>10)	2.43
Critical one-sided T-value ($t_{\alpha, n-2}$)	1.78
Result	$t_{n-2} > t_{\alpha, n-2}$
Conclusion	Accept H_1 : ρ>0

9. MAINTENANCE AND REPAIR STRATEGIES BASED ON RRMPI

Some maintenance and repair strategies have been suggested in the present study for the preventive and corrective measures of rural road sections depending upon various ranges of Rural Road Maintenance Priority Index (RRMPI) values. Since, the Rural Road Maintenance Priority Index has been evolved considering the functional parameters and structural parameters of the rural roads; hence it is expected to be the best indicator of pavement condition. The Maintenance and Repair strategies corresponding to various ranges of RRMPI values have been recommended in **Table 9.**

Table 9 Maintenance and Repair strategies based on RRMPI Values

RRMPI Range	Pavement Rating	Maintenance and Repair Strategies
0-15	Very Poor	Full Depth Reconstruction, Reclaimed Asphalt Pavement Recycling
15-30	Poor	Thick overlays, Premix Carpet, Surface Dressing
30-50	Fair	Thick overlays, Full Depth Patching, Pothole filling
50-65	Good	Thin Overlays, patching, fog seal
65-80	Very Good	Thin Overlays, Chip Seal, Micro-surfacing
80-100	Excellent	Routine Maintenance that includes micro crack sealing, patching

10. RESULTS

The individual functional condition indexes of total pavement distress, International Roughness Index, Skid Resistance and structural condition indexes of Modified structural number and K-value parameter has been shown in **Fig. 3**. It can be seen from **Fig. 3** that the functional condition index of skid resistance of all the selected rural road sections lies in a range of 60-75, which indicates good skid resistance. Also, the functional condition index of international roughness index of all the selected rural road sections lies in a range of 20-75, in which lowest FCI_{IRI} of 22 and highest FCI_{IRI} of 71 corresponds to RR5 and RR4 respectively which indicates the worst and good roughness condition of the sections respectively. Similarly, the functional condition index of total pavement distress represents the worst and good distress condition for RR5 (FCI_{TPD} = 42) and RR4 (FCI_{TPD} = 82) respectively.

Also, it can be seen from **Fig. 3** that the structural condition index of K-value for all the selected rural roads is more than 80 which signifies the robust structural condition of all the rural road sections. However, on the other side, the structural condition index of Modified Structural Number is more than 80 for all roads except RR3, RR5 and RR11. Hence, the structural condition of pavement in case of rural roads RR3, RR5 and RR11 are contradictory.

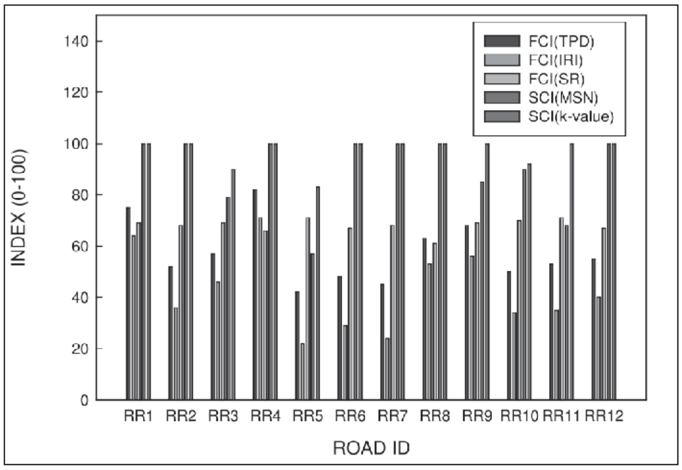

Fig. 3 Individual Functional and Structural Indexes

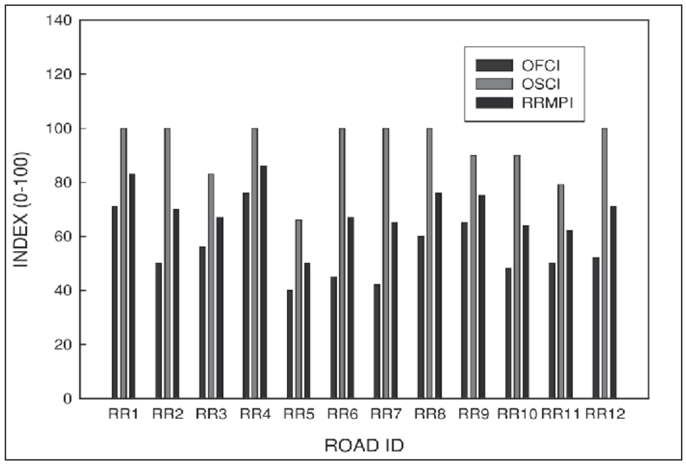

Fig. 4 OFCI, OSCI and RRMPI Indexes of selected Rural Roads

Table 10. Various Indexes and Maintenance Prioritization Ranking

Rural Road ID	FCI_{TPD}	FCI_{IRI}	FCI_{SR}	SCI_{MSN}	$SCI_{K\text{-}value}$	OFCI	OSCI	RRMPI	Ranking Based on IRI	Ranking Based on BBD Values	Ranking Based on RRMPI
RR1	75	64	69	100	100	71	100	83	11	7	11
RR2	52	36	68	100	100	50	100	70	6	11	7
RR3	57	46	69	79	90	56	83	68	8	4	6
RR4	82	71	66	100	100	76	100	86	12	12	12
RR5	42	22	71	57	83	40	66	50	1	1	1
RR6	48	29	67	100	100	45	100	67	3	9	5
RR7	45	24	68	100	100	42	100	65	2	6	4
RR8	63	53	61	100	100	60	100	76	9	10	10
RR9	68	56	69	85	100	65	90	75	10	3	9
RR10	50	34	70	90	92	48	90	64	4	5	3
RR11	53	35	71	68	100	50	79	62	5	2	2
RR12	55	40	67	100	100	52	100	71	7	8	8

The Overall Functional Condition Index (OFCI), overall structural condition index (OSCI) and the Rural Road Maintenance Priority Index (RRMPI) has been determined for all the 12 selected rural road sections in the vicinity of Shimla and Solan districts, Himachal Pradesh, India which has been depicted in **Fig. 4.** Also, the various indexes and maintenance prioritization ranking concerning the International Roughness Index (IRI), Benkelman Beam Deflection (BBD) values and RRMPI are shown in **Table 10.** It can be seen from **Fig. 4** that prioritization ranking of maintenance for different rural road sections varies corresponding to individual OFCI, OSCI and RRMPI values which indicates that RRMPI can give a reliable and better representation of pavement condition both functionally and structurally. The prioritization ranking obtained from objective-based AHP method shows a positive correlation with the ranking obtained by the RRMPI method. The priority ranking of RR4 and RR5 is found to be same by both the methods; however there is a significant difference in ranking of other rural road sections.

11. CONCLUSIONS

The Rural Road Maintenance Priority Index (RRMPI) can prove to be a powerful and handy tool for the highway engineers and road agencies, especially for the rural road sections of Himachal Pradesh in order to prioritize the various pavement sections for their maintenance strategies. It also helps in the appropriate allocation of road maintenance fund strategically without any economic loss. Following conclusions can be drawn from the present study-

i. It has been found that RR1 and RR4 have RRMPI in range 80-100 hence pavement rating is excellent, and RR5, RR7, RR10, RR11 are in the range of 50-65 which are in good condition corresponding to **Table 9.**

ii. It can be found from **Fig. 3** that prioritization with respect to different parameters is different as distinct indexes have been determined in a scale of 0-100 which do not give a clear picture which can signify the worst or best condition of any road.

iii. Also, it can be clearly understood from **Table 10** that prioritization cannot be done by merely considering the International Roughness value or Benkelman

Beam deflection value alone as it gives haphazard results and the maintenance fund is not used appropriately.

iv. It has been found from Table 10 that RR5 has the top priority ranking and needs to be maintained first and RR4 is the best road and needs the least priority in maintenance with respect to IRI ranking, BBD ranking and RRMPI ranking.

v. However, RR6 is considered at third, ninth and fifth priority in maintenance corresponding to ranking based on IRI, BBD values and RRMPI method. Hence, it shows that RRMPI signifies a clear and lucid condition of different roads.

vi. The RRMPI method utilizes mathematical models and empirical relations to determine the priority ranking of the rural road sections, which gives more accurate results as compared to an objective-based AHP method, which solely depends on the AHP technique.

vii. The RRMPI method predicts the maintenance ranking while considering both functional and structural parameters; however, objective-based AHP utilizes only pavement distress parameters in determining the pavement maintenance rank.

viii. Himachal Pradesh Public Works Department (HPPWD) is repairing/maintaining the rural roads after visual inspection only as they do not have any scientific method available with them. Also, in this regard, the maintenance budget has not been used appropriately. Hence, the proposed methodology presents a precise scientific method to prioritize the rural road sections in order of requirement and to utilize the road maintenance budget properly.

ix. Proposed method of Rural Road Maintenance Priority Index (RRMPI) can be applied to any rural roads which have similar climatic, geological and traffic conditions.

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APPENDIX-1

QUESTIONNAIRE

Relative Importance of Parameters Corresponding to Pavement Performance & Maintenance

	Fundamental Scale
Intensity of Importance	**Definition**
1	Equal Importance
3	Somewhat more Important
5	Much More Important
7	Very Much More Important
9	Absolutely More Important
2,4,6,8	Intermediate Value when compromise is required between above
PART-A	
Please check the box with a tick (✓) for the relative importance between Group 1 & Group 2 parameters.	

SAMPLE

For Example : If you think that road rutting is 5 times more important than road ravelling then put (✓) under 5 on left side towards cracking

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Rutting					✓													Ravelling

For Example : If you think that road rutting is 5 times more important than road cracking then put (✓) under 5 on right side towards ravelling

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Rutting													✓					Ravelling

For Example : If you think that road rutting has equal importance to road ravelling then put (✓) under 1 in the centre

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Rutting									✓									Ravelling

Start the Survey

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Longitudinal Cracking																		Ravelling
Longitudinal Cracking																		Patching
Longitudinal Cracking																		Potholes
Longitudinal Cracking																		Rutting
Longitudinal Cracking																		Mean Texture Depth
Longitudinal Cracking																		Transverse Cracking
Longitudinal Cracking																		Alligator Cracking
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Ravelling																		Patching
Ravelling																		Potholes
Ravelling																		Rutting
Ravelling																		Mean Texture Depth
Ravelling																		Transverse Cracking
Ravelling																		Alligator Cracking
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Patching																		Potholes
Patching																		Rutting
Patching																		Mean Texture Depth
Patching																		Transverse Cracking
Patching																		Alligator Cracking
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Potholes																		Rutting
Potholes																		Mean Texture Depth
Potholes																		Transverse Cracking
Potholes																		Alligator Cracking
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Rutting																		Mean Texture Depth
Rutting																		Transverse Cracking
Rutting																		Alligator Cracking
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Mean Texture Depth																		Transverse Cracking
Mean Texture Depth																		Alligator Cracking
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Transverse Cracking																		Alligator Cracking
	PART-B																	
	LEVEL-1																	
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Functional Condition																		Structural Condition
	LEVEL-2																	
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Pavement Distresses																		Pavement Roughness
Pavement Distresses																		Pavement Skid Resistance
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Pavement Roughness																		Pavement Skid Resistance
	LEVEL-3																	
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Pavement Modified Structural Number																		Pavement K-Value