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Modeling the Pavement Serviceability Index for Urban Roads in Noida

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Abstract: The concept of "serviceability" of roads and its evolution through time is widely accepted by pavement engineers and professionals as a way to evaluate road quality and conditions. Both the Present Serviceability Index (*PSI*) and International Roughness Index (*IRI*) can be used as indicators of road riding quality and serviceability.

The objective of the present study was to develop realistic models for estimating PSI for asphalt pavement sections located in the urban city of Noida, near Delhi, the capital of India. The PSI model was developed as a function of the pavement age. An attempt was made to calibrate the American Association of State Highway & Transportation Officials (AASHTO) equation for *PSI* and determine the suitability of this equation in Indian pavement conditions for selected urban roads. The developed models were also validated. Based on the developed *PSI* model, the maintenance alternatives have been suggested for the urban road sections in the study area.

***Key words**: AASHTO method, Maintenance strategies; Present serviceability index (PSI); Statistical analysis.*

Introduction

A road network is the backbone of land transportation and facilitates overall national development. Out of India's 3.3 million kilometers of roadways, urban roads constitute about 7.6% of the total road length. India has one of the largest road networks in the world, and a great amount of money has been spent on its maintenance. Due to poor road conditions, it is estimated that an annual loss of approximately over Rs. 6000 crores (1081 million USD) occurs in VOC (Vehicle Operating Cost) alone [1]. Before the maintenance process, the evaluation needs to measure the level of failure (service) of the pavement.

Serviceability is an indicator that represents the level of service a pavement provides to the users. This subjective opinion is closely related to objective aspects that can be measured on the pavement's surface. Using the concept developed by AASHTO, this research aims to model pavement serviceability for 21 urban road sections of asphalt concrete pavement in Noida city. The objectives of this study are to determine:

i. The Pavement Serviceability Rating (*PSR*) on a scale of 0-5, by visually evaluating the pavement condition;
ii. The *PSI* of the road sections at the study area by using *PSR* and measuring the slope variance (*SV*), patching (*P*), cracking (*C*), and rut depth (*RD*) for the identified sections;
iii. The correlation between *PSI* and pavement age;
iv. Suggestions for the maintenance strategies based on the *PSI* models.

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Review of PSI Studies

Present Serviceability Index

Pavement serviceability represents the level of services that pavement structures offer users. This indicator first appeared as a rating made by users with respect to the state of the road, particularly the road's surface. This rating is represented by a subjective index called Present Serviceability Rating (*PSR*), and may be replaced by an objective index called Present Serviceability Index (*PSI*). The latter index is determined on a strictly objective basis by applying the users' rating scale to sections of roads featuring different states of distress. This scale enables users to rate the pavement's state in terms of its service quality. The scale rates pavements from 0 to 5, from an extreme state of distress to a new or almost new pavement, as shown in Table 1. Thus, a quantitative relationship is established between this serviceability rating and certain parameters that measure physical distress of pavement surface.

Studies on PSI/PSR

AASHTO has undertaken a pavement performance study for 123 test sections (including 74 flexible and 49 rigid pavement sections) to develop a *PSI* model based on subjective rating *PSR* and objective ground measurements. Through a multiple regression analysis, a mathematical index was derived and validated through which pavement ratings can be satisfactorily estimated from objective measurements taken on the pavements [2]. Eq. (1) was developed for flexible pavements.

$$PSI = 5.03 - 19.91 \times \log(1 + SV) - 1.38 \times RD^2 - 0.01 \times (C + P)^{0.5} \quad (1)$$

where, *PSI* = Present Serviceability Index, *SV* = Slope Variance × 10^{-6}, *RD* = Rut Depth in Inches, *C* + *P* = Total cracking and patching area in $ft^2/1000\ ft^2$.

In India, the Central Road Research Institute (CRRI) has developed a relationship between *PSI* and Unevenness Index (*R*) by British Towed Fifth Wheel Bump Integrator (*B.I.*) with total surface

Table 1. Present Serviceability Rating (PSR).

PSR	Pavement Condition	Description
4 - 5	Very Good	Only New (or Nearly New) Superior Pavements are Likely to be Smooth Enough and Distress Free (Sufficiently Free of Cracks and Patches) to Quality for this Category. Most Pavements Constructed or Resurfaced During the Data Year Would Normally be Rated in this Category.
3 - 4	Good	Pavements in This Category, Although not Quite as Smooth as Those Described Above, Give a First-class Ride and Exhibit Few, if Any, Visible Signs of Surface Deterioration. Flexible Pavements May be Beginning to Show Evidence of Rutting and Fine Random Cracks.
2 - 3	Fair	The Riding Qualities of Pavements in This Category are Noticeably Inferior to Those of The New Pavements and May be Barely Tolerable for High-speed Traffic. Surface Defects of Flexible Pavements May Include Rutting, Map Cracking and Extensive Patching.
1 - 2	Poor	Pavements have Deteriorated to Such an Extent that They Affect the Speed of Free-flow Traffic. Flexible Pavement May have Large Potholes and Deep Cracks. Distress Includes Ravelling, Cracking, and Rutting and Occurs over 50 Percent or More of the Surface.
0 - 1	Very Poor	Pavements are in Extremely Deteriorated Conditions. The Facility is Passable Only at Reduced Speed and Considerable Ride Discomfort. Large Potholes and Deep Cracks Exist. Distress Occurs Over 75 Percent or More of the Surface.

distress (*D*) of the pavement. The study was done to find out appropriate serviceability indices for Indian pavement conditions [3]. The general form of the *PSI* models was expressed as Eq. (2):

$$PSI = a - b \times f(R) - C \times f(D) \tag{2}$$

where, *PSI* = Present Serviceability Index of pavement on the 5 point Serviceability Scale, *R* = Unevenness Index of the pavement surface = *B/W* x *A* x 2.5 cm/km; where, *B* = Reading of the bump recording canter (at a speed of 30 km/h), *W* = Number of wheel revolutions, *A* = Number of revolutions of the wheel in 1 km length of travel, and it is 460 for the particular unit used in this study, *D* = Total Surface distress, comprising area cracked, area patched, and distressed area needing patching expressed as a percentage of total surface area ($m^2/100m^2$), *f(R)*, *f(D)* = Functions of *R* & *D* respectively; *a*, *b*, *c* = Constants.

Pavement performance evaluation of some typical highway road sections was studied to develop *PSI* models based on functional and structural aspects of pavements for the north zone by the parameters (i) *R* alone and (ii) *R* & *D*, and that *PSI* model was compared with those developed by the CRRI study [4]. The following Eqs. (3) and (4) were developed.

$$PSI = 13.0607 - 4.053 \times logR \tag{3}$$

$$PSI = 13.071 - 3.805\ logR - 0.0147D \tag{4}$$

The *PSR* was predicted using only knowledge of the pavement's age, cumulative equivalent single-axle loads, and a pavement structural number *(SN)* [5]. The following functional form of model, Eq. (5), was developed for predicting *PSR*.

$$PSR = PSR_i + a * STR^a * AGE^C * CESAL^d \tag{5}$$

where, PSR_i = initial value of *PSR* at construction (4.5 used in analysis); *STR* = existing pavement structure (structural number); *AGE* = age of pavement since construction or major rehabilitation (overlay) (years); and *CESAL* = cumulative 18-kip equivalent single-axle loads applied to pavement in the heaviest traffic lane (millions).

The *PSI* and *PCI* (Pavement Condition Index) based composite pavement deterioration models for low volume roads were developed for India [6, 7]. An artificial neural network (ANN) was used in modeling the present serviceability ratio (*PSR*) for the flexible pavements [8]. An ANN (5, 4, 1) model was developed with input variables as slope variance, rut depth, patches, cracking and longitudinal cracking, and output as panel data (*PSR*). The model was trained and tested using 74 samples of data taken from AASHTO test results.

Methodology

In order to achieve the objectives proposed in this paper, it was first necessary to select a sufficient number of urban pavement sections for study in Noida, India, covering the range of possible conditions (good, fair, poor, and new). The pavement condition survey was conducted to analyze the road sections. Fig. 1 shows the principal stages of the methodology.

Selection of Urban Pavement Sections

The study area consists of 21 major arterial/sub-arterial road sections of Noida, a prominent city in the National Capital Region (NCR) near Delhi, having 60 km (120 km both sides) of total road length with four & six lanes divided carriageway. All selected urban pavement sections were flexible pavements. The details of the 21 road sections are given in Table 2.

Pavement Inventory Survey

The inventory data includes the following details about selected pavement sections: name of road, category of road, carriageway width road geometrics, surface type and thickness, pavement layer details, details regarding the history of maintenance and construction of these roads (pavement age), etc. The same was collected from visual inspection of pavement sections, as well as from the construction and maintenance records of the highway division responsible for their maintenance.

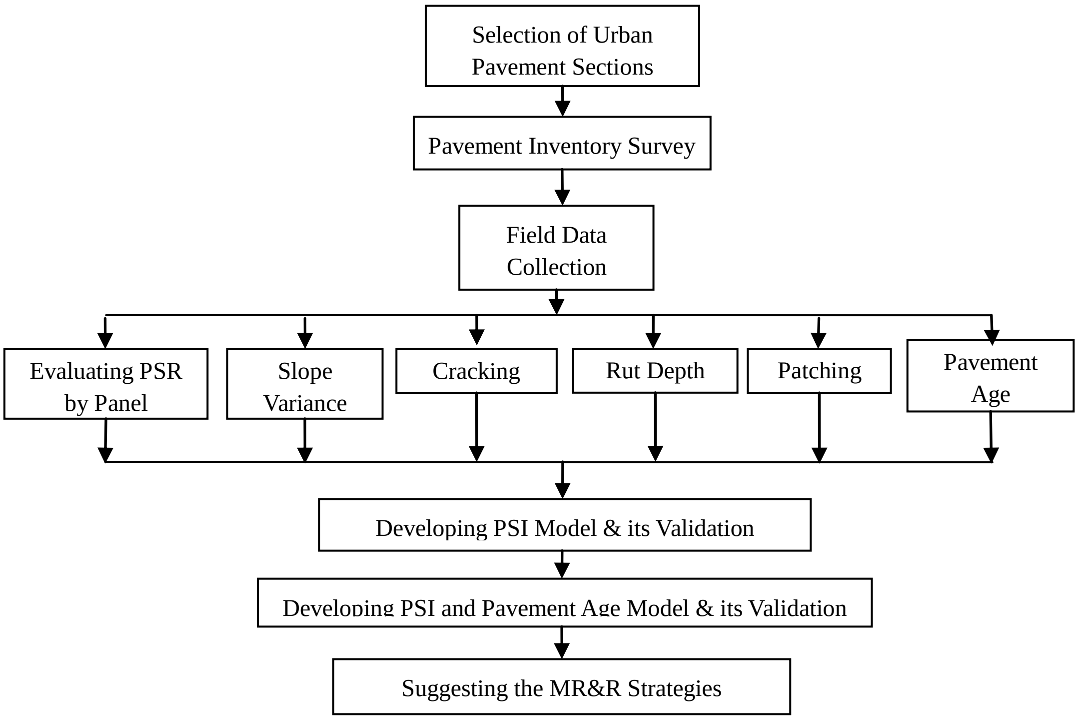

Fig. 1. Study Methodology**.**

Table 2. Details of Urban Road Sections Selected for Study Area.

S. N.	Name of Road	Section Code	Total No. of Lanes	Length in Meters
1	Express Highway from Sector – 14A to MP-3 Road	UR 1	6	3800
2	MP Road No 1 (from DND to T. Pint Sector -12, 22 & 56)	UR 2	6	3500
3	MP Road No 2 (from sector – 16A to Sector – 60)	UR 3	6	6000
4	MP Road No 3. (from Shahdra Drain to Sector – 60)	UR 4	6	7500
5	Udhyog Marg (Sector 14A T. Point to Jhundhupura)	UR 5	4	3200
6	Raghunath Pur Agahpur Road (Mp-1 to MP-3 Road)	UR 6	4	2200
7	Nithari Road (MP-2 to DSC Road)	UR 7	6	2400
8	Gihore Road (Khora Vill to MP-3)	UR 8	6	3000
9	Sector – 62 Road Along Khoda Village	UR 9	4	2200
10	Sector 62 Road Along NH-24	UR 10	4	2000
11	Sector – 62 Rajat Vihar to Mamura Singh	UR 11	4	3300
12	60M Kakral Road Ph.- II	UR 12	6	1800
13	60M Road from Mahamaya Fly Over to Sector – 97, 98	UR 13	6	4000
14	45M Road Wide Road from 93 A Fly Over to Punchsheel Inter College Sector – 91	UR 14	6	2300
15	45M Peripheral Road in Sector – 88	UR 15	6	2500
16	24M Wide Road in Sector – 88	UR 16	4	3000
17	Road bet Sector - 125-126	UR 17	4	700
18	Road bet Sector 126 – 127	UR 18	4	700
19	45M Road along Express Way to Sector – 126, 127	UR 19	6	2000
20	Z.R. No 8 (from Jhundhupura to MP-3)	UR 20	4	3200
21	Z.R. bet Sector – 7 & 8	UR 21	4	700

Field Data Collection

In order to develop *PSI* model, the various parameters observed in this study are: *PSR, SV, RD, C,* and *P*. The details about their measurements are given in following sections.

Evaluation of Serviceability by the Panel

The *PSR* evaluating panel consisted of three raters. To rate selected urban sections, each road section was divided into desirable length of 500 m. The driver of the jeep was asked to drive at a constant speed of 30 km per hour, and raters were asked to indicate their ratings in the prescribed form. Each pavement section was rated twice and the mean rating was calculated for each rater denoted as PSR_1, PSR_2 and PSR_3. The average of these three mean ratings as rated by each rater in the present study was termed as *PSR*.

Pavement Serviceability Measurement

Slope Variance Measurement

Slope variance is used as longitudinal profile measurement along the wheel path. To measure the slope variance, a 30 m road section was chosen, and the points were marked at a distance of 0.9 m from the edge of carriageway at an interval of 3 m along both the wheel paths. The elevation of all the points has been measured by a leveling instrument. Eq. (6) was used to calculate the slope variance.

$$SV = \frac{\sum Y^2 - \frac{1}{n}(\sum Y)^2}{n-1} \quad (6)$$

where, SV = Slope Variance, Y = Difference between two successive points at a constant distance of 3 m, and n = number of interval.

Rut Depth Measurement

The transverse deformation across the wheel path is defined as a rut. A 2-m straightedge and tape were used to measure the rutting depth. The rutting depth was measured every 10 m for each 100 m stretch of road. Therefore, the average of 10 value of rutting depth has been considered for 100 m stretch of road. The formula below, Eq. (7), summarizes the rutting depth calculation. The rutting depth was considered on whole of the 100 m of road section.

Rutting depth, $RD = (RD_1 + RD_2 + RD_3 + \ldots\ldots RD_{10})/10$ (7)

where, RD_1, RD_2, RD_3 …RD_{10} = Rut depth for each 10 m.

Cracking Measurement

Alligator, longitudinal, and transverse cracks, the typical flexible pavement cracks, were considered in the measurements. The affected area was marked in form of regular geometric shapes such as rectangles, triangles in case of interconnected cracks and alligator cracks. In the case of longitudinal and transverse cracks, the crack length was measured, and the affected width of the pavement surface across the length of the crack was taken as 30 cm for meaurement of cracking area. After calculaitng total cracked area for 100 m test section, it was expressed in terms of $m^2/1000m^2$.

Patching Measurement

Patching is the placing of asphaltic concrete in small isolated areas. The total patching area was measured by regular geometric pattern for the whole 100 m test section and expressed as $m^2/1000m^2$.

Development of Pavement Performance Model

Development of PSI Model

Statistical tools were used to model the *PSI* of the road section. Regression analysis was used in this context. For derivation of *PSI*, PSR was taken as dependent variable, and *SV, RD, C*, and *P* were taken as independent variables. Out of 21 urban road sections, 15 sections were considered for model development, and 6 sections for validation of the developed *PSI* model. The transformed data for independent variables was taken as per the *AASHTO* equation. The subjective rating, *PSR*, was correlated by multiple linear regression analysis with objective ground parameter measurements, i.e. log $(1+SV)$, RD^2, $(C+P)^{0.5}$. The regression statistics and coefficients of all the parameters were determined by multiple linear regression analysis and are tabulated in Tables 3 and 4, respectively. The value of coefficient of multiple correlation (R^2) and standard error of estimate (S) obtained for model indicate that the model is acceptable. The developed *PSI* model for urban roads section is presented in Eq. (8).

$$\begin{aligned} PSI &= 5.961 - 0.012 \times RD^2 - 0.405 \times \log(1+SV) \\ &\quad - 0.0029 \times \sqrt{(C+P)} \end{aligned} \quad (8)$$

where, SV = Slope Variance $\times 10^{-6}$, RD = Rut Depth in mm, $C + P$ = Total cracking and patching area in $m^2/1000\ m^2$.

Relationship between PSI & PSR

PSI values from the *PSI* model developed in Eq. (8) for the present study were calculated for all 15 urban sections. The relationship between *PSI* (calculated) and *PSR* (observed) is presented in Eq. (9). Fig. 2 shows the plot between *PSI* values calculated from these mathematical models and observed PSR values to justify the ability of *PSI* model.

$$PSI = 0.7471 \times PSR + 0.9313 \quad (9)$$

Validation of PSI Model

To validate the *PSI* model developed in the present study, 6 remaining test urban road sections were used. The relationship between *PSI* calculated using Eq. (8) and *PSR* observed was determined by regression analysis. The results show that R^2 = 0.7297, indicating that the developed model for urban road sections has been satisfied. Fig. 3 shows the relationship between *PSR* and

Table 3. Regression Statistics for Urban Road Sections.

Regression Statistics	
Multiple R	0.8773
R Square	0.7697
Adjusted R Square	0.7069
Standard Error	0.4034
Observations	15

Table 4. Coefficient of Parameters for Urban Road Sections.

Coefficient of Parameters	
Intercept	5.1607
Log (1+SV)	-0.4051
RD^2	-0.0124
$(C+P)^{0.5}$	-0.0029

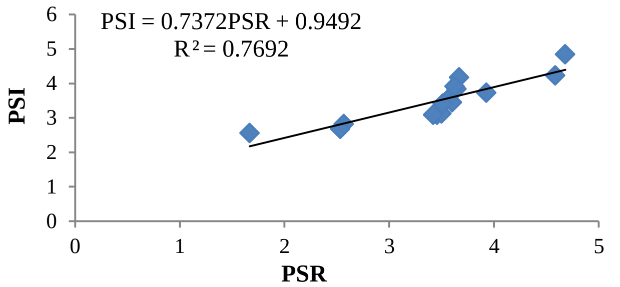

Fig. 2. Relationship between PSR & PSI for Urban Road Sections.

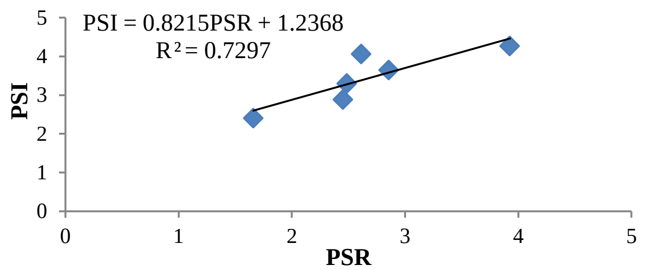

Fig. 3. Relationship between PSR and PSI for Validation of PSI Model.

Table 5. Paired T-test for Validation of Developed PSI Prediction Model.

Terms	Equation	Values
Sum of Difference ($\sum z$)	(Observed – Predicted) *PSI*	-5.154
Total no. of Observations (n)	-	21
Mean of (z)	$(\sum z)/n$	-0.245
Sum of Square of Difference	$\sum z^2$	6.114
Square of Sum of Difference	$(\sum z)^2$	26.561
	$(\sum z)^2/n$	1.265
$\sum dz^2$	$\sum z^2 - (\sum z)^2/n$	4.849
Variance (σ^2)		0.242
Square Root of Variance		0.492
$t_{calculated}$		-0.498

Table 6. Regression Analysis Results for Pavement Age Based PSI Model.

Model No.	Model Type	Model	R^2
1	Linear	$Y = -0.0282x+5.0243$	0.6898
2	Exponential	$Y = 5.3334e^{-0.008x}$	0.7015
3	Polynomial (2 order)	$Y = 4E\text{-}05x^2-0.0323x+5.1215$	0.6902
4	Logarithmic	$Y = 1.35\ln(x) + 8.8005$	0.6743

Where Y = PSI and X = Pavement age

PSI for validation of the *PSI* model.

The selected models' validity was further checked by performing a Paired t-test. However, the Paired t-test applies only to those data sets where both the observed and predicted data follow normal distribution. So, in this case, the Chi-square test is performed on both the data set to check the "goodness of fit". In Chi-square tests, two hypotheses are assumed:

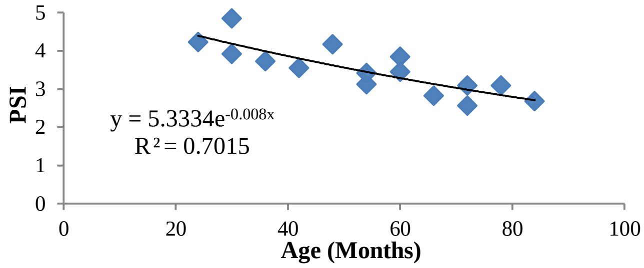

Fig. 4. Relationship between PSI and Pavement Age.

Null hypotheses = *PSR* data follows normal distribution

Alternative hypotheses = *PSR* data does not follow normal distribution

If Chi-square $_{calculated}$ < Chi-square $_{tabulated}$ then null hypotheses is accepted and vice-versa.

$$Chi-square\ value = \frac{(O_F - T_F)^2}{T_F} \qquad (10)$$

where, O_F = Observed Frequency, T_F = Theoretical Frequency.

Now Chi-square$_{calulated}$ = 1.63 and Chi-square$_{tabulated}$ = 11.07 (for, Degree of freedom (df) = 5 and Significance level $\alpha = 0.05$)

So, Chi-square$_{calulated}$ (1.63) < Chi-square$_{tabulated}$ (11.07)

Hence, in this case, null hypotheses can be accepted as the PSR dataset follows the normal distribution at 95% confidence level. Similarly, the same procedure is adopted for the predicted *PSI* data set and results obtained are given below.

Chi-square$_{calulated}$ (1.14) < Chi-square$_{tabulated}$ (11.07) (for, Degree of freedom (df) = 5 and Significance level $\alpha = 0.05$)

So, in this case also, null hypothesis can be accepted, and the predicted PSI dataset also follows normal distribution.

In the Paired t-test, the difference between two data sets is calculated, and the remaining process is given below in Table 5.

Now, $t_{calculated}$ = 0.498, which is less than the $t_{tabulated}$ = 2.09 (df = 20 and $\alpha = 0.05$).

So, it can be easily stated that there is no significant difference between observed and predicted PSI data at 95% confidence level.

Correlation between PSI and Pavement Age

In this section of the study, a correlation was developed between the *PSI* calculated using Eq. (8) and pavement age for the 15 urban road sections. The pavement age was estimated from the date of most recent rehabilitation for that particular urban road section. Regression analysis for different forms of models, such as linear, logarithmic, polynomial two degree, and exponential, were attempted and model parameters were estimated; the details are given in Table 6. The exponential equation with maximum goodness of fit ($R^2 = 0.702$) was suggested. Fig. 4 shows the scatter plot for *PSI* and pavement age.

Validation of Suggested PSI Based Pavement Condition Prediction Models

A total six urban road sections were selected for model validation. *PSI* were calculated for each selected urban road section, by using Eq. (8) . Similiarly, *PSI* values were determined for each urban road

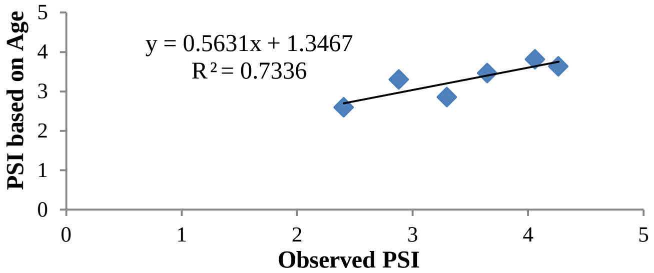

Fig. 5. Scatter Plot between Observed vs. Predicted PSI.

Table 7. Types of Maintenance Work Based on PSI Scale.

PSI	Pavement Condition	Types of Maintenance Work
4-5	Excellent (Pavement like New)	Routine Maintenance
3-4	Good (Several Years of Service Life Remaining)	Preventive Maintenance
2-3	Fair (Few Years of Service Life Remaining)	Deferred Action
1-2	Poor (Candidate for Rehabilitation)	Rehabilitation
0-1	Very Poor (Possible Replacement)	Reconstruction

Table 8. Age Triggering PSI and Corresponding MR&R Strategy.

MR&R Strategy	PSI	Age Triggering in Months
Routine Maintenance	4 - 5	Every Year
Preventive Maintenance	3 - 4	30
Deferred Action	2 - 3	55
Rehabilitation	1 - 2	85
Reconstruction	0 - 1	105

section by using the appropriate suggested *PSI* model as given in Table 6 (Exponential equation). Furthermore, a simple linear regression equation was developed between the observed *PSI* and the model-predicted *PSI* in order to check the signifiance of relationship between them. Fig. 5 shows the scatter plot. The goodness of fit value (R^2) is observed as 0.734, which shows a good agreement between observed and predicted *PCI* values and hence proves the adequacy of the "*PSI*" based pavement performance models for urban roads in the study area.

Selection of Maintenance Strategies Based on PSI

Maintenance can be defined as both preventive and corrective. Basically, maintenance consists of a set of activities directed toward keeping pavement in a serviceable state. The recommended alternative strategies for the pavement are based upon the pavement defect rating, pavement riding quality, pavement thickness design criteria, roadway traffic volume and truck percentage, and roadway functional classification. In addition, the overall rating, actual distresses and their causes, and performance of pavements over time should be analyzed to determine the most appropriate strategy to improve the roadway network.

The different types of Maintenance Rehabilitation and Reconstruction *(MR&R)* strategies on the basis of *PSI* scale suggested for urban sections in the study area are as shown in Table 7. The age (in months) triggering each level of the *PSI* scale was calculated for urban road sections, as shown in Fig. 4. The type of maintenance strategy needed for selected sections corresponding to triggered age are given in Table 8. The *PSI* of selected sections along with the required maintenance work alternatives are suggested in Table 9.

The operations of different types of maintenance work can be selected as per the Indian practices adopted for maintenance of flexible pavements [9, 10], depending on the magnitude of the problem and the availability of resources. More factors affecting maintenance action selection include level of concern, traffic level and characteristics, soil classification, cost of action, and available budget.

Conclusion

Pavement performance prediction is one of the most important components of the pavement management system. An accurate estimate directly affects the success of the entire pavement management system.

In the present study, the model for the pavement performance index, termed as *PSI*, as a function of pavement age was developed

Table 9. Suggested Maintenance Work for Urban Roads.

PSI Value	Urban Road (Section Code)	MR&R Strategy	Type of Maintenance Work
0-1	--	--	--
1-2	--	--	--
2-3	UR-03,04,15,16,21	Deferred Action	High Severity Pothole Patching Partial- depth Repair
3-4	UR-02,07,07,10, 11,12,14,17.18,19	Preventive Maintenance	Single Bituminous Surface Dressing Double Bituminous Surface Dressing Slurry Seal Chip Seal
4-5	UR-01,05,06,09,13	Routine Maintenance	Cleaning of Side Drains Crack Sealing Pothole patching Fog Seal Sand Seal Skin Patching

for 21 flexible pavement sections in the Noida urban area by measurement of various parameters. Statistical models were developed and results yielded better accuracy. The developed models were validated on the results of R^2, Chi-square, and Paired t-test. The *MR&R* strategies were suggested based on the predicted *PSI* for the pavement sections. However, this approach needs to be validated for other geographical locations in the country before the method is adopted at the national level.

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