PAVEMENT DETERIORATION MODELLING OF URBAN ROADS IN BANGALORE CITY

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Abstract - *An The present study of Development of Pavement Deterioration Models has been undertaken to develop models and to determine the factors influencing the rate of deterioration, Relative Deterioration Index was being evolved , validated and presented, Using the developed Relative Deterioration Index the Pavement Deterioration Models were developed and the progression models for each type of distress was developed.*

The Major initiative of the project is to develop multiple regression based on a large volume of field data collected from both the methods of distress data collection viz., Automated as well as Manual Method of Field Evaluation. Under the present study the Bangalore city roads were selected and short listed based on the uniformity of the construction date, vehicle type and linking of traffic from one road to another. Ten stretches five each from Arterial and Sub – Arterial totalling nearly 100 kms length of with variations in distress were studied. The selected stretches over a period of 54 months were evaluated for five cycles. The automated evaluation was carried out for three cycles and manual method of data collection was performed for two cycles.. Based on the field studies of Relative Deterioration Index was developed. The Relative Deterioration Models indicate that the Roughness has a dominant effect in the selected categories of road.

***Key Words*: Pavement Deterioration Modelling, Roughness Modelling.**

1. INTRODUCTION

The main objective of the study is to develop Pavement Deterioration Models for an identified Network of Urban Roads to assist the engineers responsible for maintaining the road network as well as the authorities responsible for allocating funds, in making consistent and cost effective decisions, related to maintenance and rehabilitation of pavements. This requires development of a systematic database so that it would assist in the prediction of models developed over this robust database. The most economical maintenance strategy for a particular pavement section and prioritization of such maintenance activities in the event of a constrained budget should be planned and executed based on this model.

The existing road condition in Bangalore is studied in this project, the surface deterioration parameters such as Roughness, Patching, Potholes, Cracking, Rut ting etc., are collected and analysed for the development of database over a time period of nearly 4 years

2. SCOPE OF THE PRESENT STUDY

The study was planned to cover for a time period of five years for a stretch of 100 kms of road length in Bangalore city taken under the urban infrastructure for Indian Scenario. The deteriorating pavement condition variables such as rebound deflection, roughness, rut depth, crack area, ravelling all were measured and collected through both visual and automated means of data collection. The Relative Deterioration Index was developed, validated based on the studies conducted on the selected stretches of road pavements in Bangalore city during different time periods of the year over a period of five years. The periodic structural evaluations were conducted using Benkelman Beam method and one time data regarding pavement section soil parameters and the pre-monsoon and post-monsoon performance data over a period of time was collected and finally Pavement Deterioration Models were developed based on the RDI developed.

3. LITERATURE REVIEW

Pavement Management Methodologies

The performance of the roads has a wider aspect of influence that extends to cover even the quality of life. The failure of road pavements occurs due to the improper maintenance and over use of the roads. It is necessary to maintain and safeguard the road pavements to improve the quality of life. Pavement maintenance management system is one such system to scientifically regulate the pavement maintenance (Maher, 2004).

3.2 Pavement Management Components

The pavement management system is implemented to improve the decision making regarding the pavement maintenance, to report the feedback of the decisions taken, and to regulate the consistency of the decisions at various stages. These needs are completed by various methods which include collection and storage of data, the analysis of the data, recovery of the data in a proper format, decision making based on the data collected and analyzed, updating of the database etc.

All most all the definition of PMS have consensus on the five components, which are critical to its success (Peterson, 1987). They include Pavement condition surveys, Database containing all related pavement information, Analysis scheme, Decision criteria, and Implementation procedures.

3.3 Pavement Condition Indicators

The pavement condition indicators are highly associated with distresses manifested on the pavement surface (Figure 2.3), which are generally classified into Operational surface indicators, Structural indicators and other indicators (Shahin et al, 1987).

Operational surface indicators: roughness, skid resistance, rutting, raveling, hydroplaning potential, potholing and loss of camber.

Structural indicators: rutting, fatigue and thermal cracking, distortion and disintegration.

Other indicators: rate of deterioration is to the M&R work done

3.4 Pavement Performance Models

The deterioration process is a gradual process. In order to maintain and manage a pavement, a model which determines the performance of a pavement and also estimates the prediction error is necessary (Prozzi & Madanat). Thus, the performance of a road pavement can be defined as the ability of a pavement to sustain the deterioration factors. According to Ferreiraa, et al. (2011), the pavement performance models are the fundamental modules of a pavement management system.

3.5 Pavement Prediction Model

In any pavement management system, prediction of pavement condition is critical. The pavement prediction performance models are developed to examine the condition of the pavement and evaluate the maintenance and rehabilitation requirement both at the network and project level. In the case of network level, they are mainly applied to forecast conditions, plan, budget, schedule inspection, and plan implementation. On the other hand, at the project level, they are mainly applied to choose rehabilitation alternatives to address the expected traffic and climate condition, evaluate life-cycle cost, in addition to comparing the maintenance and rehabilitation alternatives (Ismail, et al., 2009).

3.6 Structure Condition Deterioration Models

3.6.1 Deflection Growth Models

Deflection is a measure of pavement behaviour that signifies an immediate response to load. Researchers have shown that deflection influences the rate of pavement deterioration, although it cannot be used as a parameter to measure pavement deterioration. Reddy and Raghavan (1997) attempted to find a relationship between rebound deflection and cumulative standard axle load repetitions. Based on the initial deflection ranges, the rebound deflection data were collected at different ages and classified into four categories. They calculated cumulative standard axles at the corresponding ages. Reddy et al., (2004) developed deflection growth charts to determine the deflection value of overlaid flexible pavements after any anticipated traffic loading and ageRut Depth Progression Models

3.7 Crack Area Progression Models

Crack is a defect in the bituminous pavement surface that weakens the pavement structure. Further, deterioration of the flexible pavement surface occurs as water ingress from the surface during rains. As a result, the combined action of traffic and water weakens the pavement condition. Structural failure is indicated by the development of alligator crack at the top of the bituminous surface. Reddy and Veeraragavan (1997) found a significant correlation between crack area with cumulative standard axle repetitions.

4. FIELD STUDY AND DATA COLLECTION

4.1 Overview

4.1.1 Pavement Evaluation

The Performance of a Pavement is a function of relative ability to serve traffic over a time period. Initially the pavement's relative ability is to cater to the traffic and it is derived that quite subjectively by doing visual inspection and by rater's experience. The history has shown that the transfer of knowledge is difficult from one person to another, whereas the implementations or decisions which are made by each individual are also inconsistent even though they are actually made from the same set of data collected over a period of time. Earlier the surface measurements such as Roughness, Skid, Deflection studies were used to quantify the Pavement Condition and Pavement Performance.

The following are the Criteria based on which the whole study stretches were selected and Surveys were conducted.

i. The Selected Pavement sections were only Flexible Pavement. The Underpass and Flyovers are neglected while surveying for pavement distress.

ii. The Selected sections were mostly fairly level roads without steep gradients, and with no curves as the area was Urban i.e., Bangalore city roads.

iii. The stretches had variable to slightly uniform composition and had been overlaid at same time and no maintenance work was involved during the study period.

iv. The selection has taken both Arterial and Sub Arterial traffic into consideration, which carries both commercial traffic as well as regular urban traffic.

4.2 Description of Some of the Stretches Undertaken For Study.

Pavement Surface evaluation has been carried out on all the selected road stretches starting from the month of Feb 2011 till June 2015. The stretches description is as follows

4.2.1 SB-NDH

Hosur Road Junction Silk Board to Nayandanahalli denoted as SB-NDH is 11.7 kms long stretch which connects the east of Bangalore which is a software hub to the west of Bangalore comprising more of residential plots. The commercial traffic is not allowed during peak hours i.e., from morning 8:00 am till 8:00 pm. The Relative Deterioration Index was 2.01. The commercial Vehicles Per Day was 200 and the Cumulative standard axle was found to be 3.3 msa. The volume count of the stretch yielded 25474 PCU for a 12 hour value.

The cracking ranged from 0.53 in the first cycle to 2.57 % per km for the final cycle, Rutting from 3 mm to 5.00 mm, patching from 0.88 to 1.76 %, Ravelling from 0.30 to 0.86.

SB-NDH @ CH 11+0 (LWP)

	BC, 90mm Thickness
	BC, 25mm Thickness
	BC, 25mm Thickness
	WMM, 250mm Thickness
	Granular Sub Base 250mm Thickness

Figure 3 – Crust Thickness and Composition SB-NDH

4.2.2 SMF-KS

The stretch runs for around 3.9 kms in length connection west of Bangalore i.e., Magadi Road with NH-4 Tumkur Road of Bangalore. It falls under the category of Arterial road, has 4-lane divided carriage way. It has regular traffic of two wheeler and Cars along with truck traffic. The Roughness also increased from 2201 to 2927 which indicates the decrease of acceptability level from good to average.

The crust thickness for the arterial road is 740mm, out of which 190mm is bituminous surface course and 250mm WMM base is provided along with 300mm GSB is provided, The CBR value of the subgrade soil is 4.13 and the structural number being 2.84. During the initial study during Feb-2011 and final study during June-2015 the Benkelman beam study deflection value ranged from 0.95 to 1.24 mm. The Relative Deterioration Index was 14.18. The commercial Vehicles Per Day was 250 and the Cumulative standard axle was found to be 4.3 msa. The volume count of the stretch yielded 20071 PCU for a 12 hour period.

The cracking ranged from 6.57 in the first cycle to 18.57 % per km, Rutting from 5 mm to 12.05 mm, patching from 0.94 to 9.36 %, Ravelling from 0.10 to 6.83.

SMF-KS @ CH 1+0.7 Km (LWP)

	BC-90mm, Thickness
	BM,100mm Thickness
	WMM,250mm Thickness
	Granular Sub Base, 300mm Thickness

Figure 4 Crust Thickness and Composition – SMF-KS

5. DEVELOPMENT OF PAVEMENT RELATIVE DETERIORATION INDEX-RDI

5.1 Development of Relative Deterioration Model

5.1.1 Analysis of the Pavement Deterioration Data

The field data collection was organised for five cycles starting from February 2011 till June 2015 spanning over 54 months. In the year 2006 there was an overlay layer as a preventive treatment. The age of pavement is 15 years. The data collection was based on three cycles of automated data collection and also two cycles of visual data collection by individual rater system over 5 cycles alternatively.

5.1.2 RDI model for Pavement Deterioration

To develop a model for pavement deterioration, the multiple Linear Regression modelling techniques was applied. It is presented for relation for combined data of both Visual and Automated Data collection

$RDI_{Combined}$ = 0.16(IRI) + 0.37 (C+P) +0.62 (RD) + 3.98 RV +0.84 PH - 8.58

Where

$RDI_{Combined}$ = Relative Deterioration Index for the range of 0.33 to 9.7

IRI = International Roughness Index m/km in the range of 3.02 – 4.00

RD = Rut Depth ,mm for the range of 2.14 – 7.16

C +P = Cracking % area 1.24- 10.37

PH = Pothole in number 0 – 9

RV = Ravelling in % 0.37- 1.69

The results of the Statistical analysis is as shown in the table 4.1 , the value of the coefficients of Regression is 0.91 (91%) which indicates that there is a good correlation between the dependent variable RDI and independent variables like IRI, Cracking and Patching, Rutting, Ravelling, Potholes.

5.1.3 Development of RDI model for Visual Data Collection

The Linear Multiple Regression model for the data collected only for visual raters is as follows

RDI_{visual} = 1.29 (IRI) + 0.81 (C+P) +0.84 (RD) + 0.96 RV +0.80 PH – 11.92

Where

RDI_{visual} = Relative Deterioration Index for visual observation for the range of 0.03 to 29.4

IRI = International Roughness Index m/km in the range of 2.48 – 4.98

RD = Rut Depth, mm for the range of 1.95 – 10.06

C +P = Cracking % area 0.29- 7.37

PH = Pothole in number 0 – 8

RV = Ravelling in % 0.05- 16.61

The value of the coefficients of Regression is 0.64 (64%)

5.1.4 Development of RDI model for Automated Data Collection

The Linear Multiple Regression model for the data collected by Automated Data Collection Mechanism by uisng IRSM Survey Vehicle is as follows.

$RDI_{Automated}$ = -0.47 (IRI) + 0.31 (C+P) +1.35 (RD) + 2.62 RV +0.95 PH – 8.74

Where

$RDI_{Automated}$ = Relative Deterioration Index for visual observation for the range of 0.03 to 14.48

IRI = International Roughness Index m/km in the range of 2.55 – 4.71

RD = Rut Depth mm for the range of 2.41 – 5.71

C +P = Cracking % area 1.38- 17.50

PH = Pothole in number 1 – 10

RV = Ravelling in % 0.13- 1.69

The value of the coefficients of Regression is 0.77 (77%)

5.1.5 Validation of RDI model for both the Data Collection Methods

The three models that are being developed are being recalculated by substituting with the original values and the error in the prediction in present condition is calculated. The computed RDI values and the Predicted RDI values are as shown in table 5.1. A scatter plot correlating the Computed and Predicted Values are as shown in Figure 5.1, Figure 5.2, and Figure 5.3. The trend line is drawn and R^2 values indicated a good correlation between the computed and predicted values respectively for each of the method followed in collection of pavement distress data.

Table 5.1 Comparative values of RDI-Predicted V/s RDI Computed from Field Values

Sl No	Type	Linear Equation	R^2
1	RDI-Combined	y = 0.92x + 0.24	0.91
2	RDI-Visual	y = 0.63x + 1.25	0.63
3	RDI-Automated	y = 0.77x + 0.59	0.77

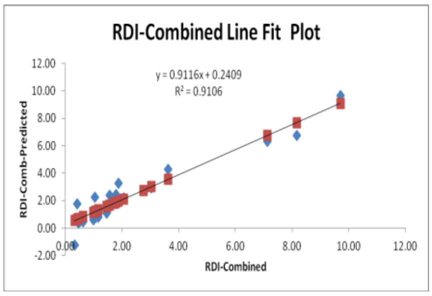

Figure 5.1 RDI-$_{\text{Combined}}$-field and RDI-$_{\text{Combined}}$-Computed

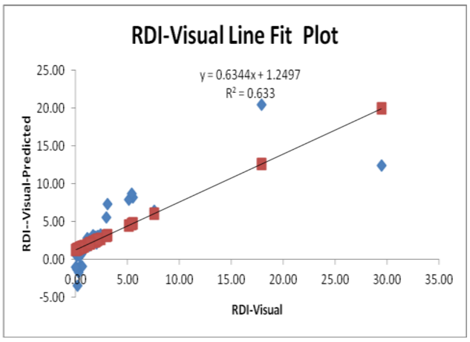

Figure 5.2 RDI-$_{\text{Visual}}$-field and RDI-$_{\text{Visual}}$-Computed

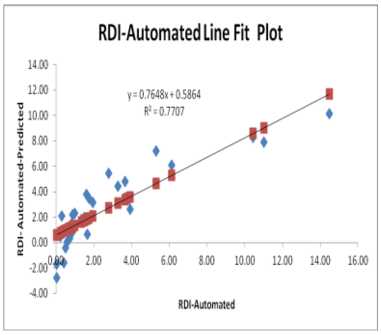

Figure 5.3 RDI-$_{\text{Auto}}$-Field and RDI-$_{\text{Auto}}$-Computed

5.5 Discussions of Development of RDI model- Arterial Roads

Research around the globe carried on Pavement Management Systems been mostly for rural road scenario and very less research work has been carried out to understand the pavement deterioration especially in urban scenario, where high volume of light traffic flows and the pavement deteriorates with respect to age than extensive load being the reason for pavement deterioration. The RDI models have been developed on the basis of PSI models as per the original serviceability equation developed by Walker and Yoder et al... For AASHO road Test in 1959. The model was developed based on the slope variance. Cracks, patching =, rut depth mainly.

The RDI Combined stands out as the best predictor with a high R^2 value of 0.91 and scores well above the other RDI's.

5.8 Discussions on Relative Deterioration Index

The present study aims at developing Relative Deterioration Index for two types of road categories namely, Arterial and Sub-Arterial, 10 Stretches which are selected for the present study are studied for over a period of 54 months in 5 cycle analysis using both the methods of collection of surface distress and also Structural Distress parameter. The RDI model for Arterial Roads is as follows

RDI $_{\text{Com-Arterial}}$ = 0.16(IRI) + 0.37 (C+P) +0.62 (RD) + 3.98 RV +0.84 PH - 8.58

6. DEVELOPMENT OF PAVEMENT DETERIORATION MODEL

Pavement Deterioration Models are most important assets in Pavement management Systems, they help in managing the network of roads and timely maintenance. The deterioration of pavement is mainly due to aging of pavement and other factors contributing to the pavement deterioration are mainly pavement materials, strength, Traffic and other conditions.

A pavement deterioration model are generated by correlating the Relative Deterioration Index (RDI) with strength of pavement, age of pavement, CSA, Subgrade Strength of soil and other conditions.

6.1 Development of Attributes for the Model Development

The combined Relative Deterioration Index is used to develop the pavement Deterioration Model. The attributes required to be attached to development of model are developed in the subsequent paragraphs.

6.1.1 Development of RDI

Developing a Relative Deterioration Index is the first step in development of pavement deterioration modelling. The RDI values for the selected pavements are computed and tabulated. The RDI values are based on the measurements of distress with respect to the surface the parameters of surface distress are Cracking, Patching, Rutting, Ravelling, Potholes, IRI etc., The RDI is based on the functional performance of the urban roads under due consideration.

$RDI_{Com\text{-}Arterial}$ = 0.16(IRI) + 0.37 (C+P) +0.62 (RD) + 3.98 RV +0.84 PH - 8.58

Where

$RDI_{Com\text{-}Arterial}$ = Relative Deterioration Index for the range of 0.33 to 9.7

IRI = International Roughness Index m/km in the range of 3.02 – 4.00

RD = Rut Depth ,mm for the range of 2.14 – 7.16

C +P = Cracking % area 1.24- 10.37

PH = Pothole in number 0 – 9

RV = Ravelling in % 0.37- 1.69

Development of Pavement Deterioration Model –Arterial Roads

A pavement deterioration model has to be developed by correlating the Relative Deterioration Index RDI values with the Deflection values, Cumulative Standard Axle, SNC value, Age of pavement in years.

$RDI_{PDM\text{-}Arterial}$ = 2.90 (BBD/CSA) + 9.79 (CSA/SNC) + 0.56 (P_{age}) - 13.42

Where

$RDI_{PDM\text{-}Arterial}$ = Pavement Deterioration Model- RDI

CSA = Standard Axles in million

SNC = Modified Structural Number

BBD = Benkelman Beam Deflection value in mm

P_{age} = Pavement Age in years

The Multiple Linear Regression has indicated R^2 value of nearly equal to 0.56

Variation in RDI-Pavement Deterioration Model and Computed RDI values- Arterial Roads

The RDI-PDM of the selected pavement stretches, were checked for validation using computed RDI values with Predicted RDI values using the Pavement Deterioration models are as shown in table 6.1

Table 6.1 Variation of Computed and Predicted RDI-PDM

RDI -PDM-Computed	RDI-PDM-Predicted	Difference	% Variation in RDI Values
2.32	1.12	1.20	51.77
2.01	2.77	0.76	27.43
14.18	9.93	4.25	29.99
2.01	5.68	3.67	64.64
1.79	4.70	2.91	61.89
Mean variation in %			47.15

The RDI-computed is based on the field measurements of surface distress parameters for the selected urban roads were compared with the predicted RDI-PDM values using the Pavement Deterioration model. The difference in RDI values are in the range of 0.76 to 4.25. The percentage variation in the RDI values by both the methods are in the range of 29.99 to 64.64 % , the mean variation of the model is 47 % when compared with actual field measurements. The results of the comparison indicate that the RDI values predicted by the Pavement Deterioration Model are comparable with the RDI values computed based on the engineering measurements of surface distress parameters. The computed and Predicted RDI values for all the selected stretches are as shown in Table 6.2

Table 6.2 RDI-computed and RDI-PDM values

Section Name	DI-PDM-Computed	RDI-PDM-Predicted
KS-AIT	2.32	1.12
AIT-MRJ	2.01	2.77
SMF-KS	14.18	9.93
SB-NDH	2.01	5.68
BEL-HBL	1.79	4.70

The pavement stretches selected for the computation studies and their RDI values are represented in X axis and the Predicted Pavement Deterioration Modelling values obtained from RDI-PDM are plotted on Y axis. The close proximity of the two series indicates describes that the model predicted values and field observed values are in good agreement.

6.4 Statistical tests for the Variation in RDI-Pavement Deterioration Model and Computed RDI values

The RDI values obtained from Field Surface Distress measurements are plotted against the predicted RDI -PDM values are as shown in the figure 6.1.

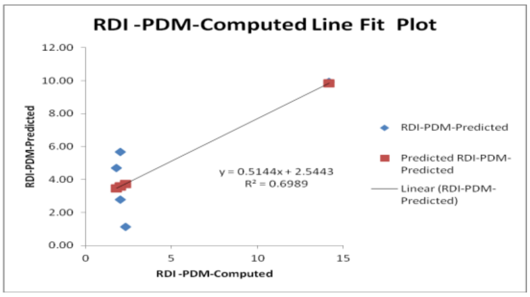

Figure 6.1 Correlation between the field Value and Predicted Value of RDI for the selected pavement stretches.

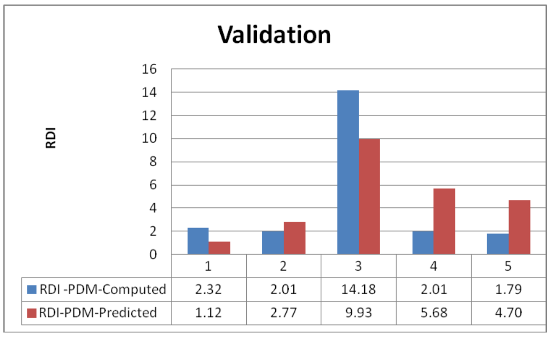

Figure 6.2 Plot between the field Value and Predicted Value of RDI for the selected pavement stretches.

$y = 0.51x + 2.54$, $R^2 = 0.70$ the co-efficient of determination R^2 was found to be 0.70

6.5 Individual Pavement Deterioration Models- Arterial Roads

6.5.1 Roughness Distress Pavement Deterioration Models-Arterial Roads

The roughness expressed in terms of IRI in m/km is an important and necessary factor depicting the existing condition or riding comfort is directly affected with increase in IRI and also it a basic measure of surface distress parameter. Every Economic analysis of the pavement involving any maintenance strategy or rehabilitation work the pavement unevenness is the key in deciding the strategy to be adopted. There is need to develop a Roughness Progression Model to exactly predict the trend of the progression of the unevenness.

$$\mathbf{IRI_t = 5.36 + 0.18\, IRI_{initial} + 0.56\, (CSA_t / SNC) - 0.14\, P_{age}}$$

Where

IRI_t = International Roughness Index in m/km at time 't'

$IRI_{initial}$ = Initial International Roughness Index in m/km

CSA_t = Cumulative Standard Axles in millions at time 't'

SNC = Modified Structural Number

BBD = Benkelman Beam Deflection value in mm

P_{age} = Pavement Age in Years

Rut Depth - Pavement Deterioration Models-Arterial Roads

The rut depth is the measure of pavement distress which is due to the deformation on the pavement surface which is permanent in nature caused by the repetitive application of wheel load in the same path of wheel, mostly concentrated on the wheel paths. Normally the measure of the rut depth is considered to represent the extent of structural deterioration of the flexible pavements. The extent of rut depth is a deciding factor in the decision making ability of pavement engineers to envisage the terminal condition of pavement before any strengthening of pavement is resorted.

$$\mathbf{RD = 8.25 + 0.61\, (BBD/CSA_t) + 3.46\, (CSA_t/SNC) - 0.48\, P_{age}}$$

Where,

RD = Rut Depth in mm

CSA_t = Cumulative Standard Axles in millions at time 't'

SNC = Modified Structural Number

BBD = Benkelman Beam Deflection value in mm

P_{age} = Pavement Age in Years

Cracking and Patching - Pavement Deterioration Models-Arterial Roads

Cracking is a Surface Defect on the flexible pavement surface course layer. The initiation of cracks on the top surface layer indicates structural failure of the pavement. In the present study the cracks are measured in terms of area in sq.mt and the total area of crack in converted into percentage of cracks with respect to the total surface area of the pavement under consideration. Patching is applied over the crack surface to prevent further disintegration of the flexible pavement and also is considered as a surface distress parameter, the presence of patching indicates the presence of crack in earlier stage and further has been modified as patching, the terms used for cracking is similar to patching, hence normally both the cracking and patching are combined and the progression model is developed using the pavement strength, subgrade strength of soil and also Structural

Number along with the Benkelman Beam Deflection value with the cumulative number of axles being considered.

(C+P) = 4.08 (CSA/SNC) + 1.84 (BBD/CSA) + 0.59 Page – 5.62

Where,

C+P = Crack + Patch in %

CSA_t = Cumulative Standard Axles in millions at time 't'

SNC = Modified Structural Number

BBD = Benkelman Beam Deflection value in mm

P_{age} = Pavement Age in Years

Ravelling - Pavement Deterioration Models- Arterial

Ravelling is a surface defect on a flexible pavement. It indicates a the severity of loss of binder and aggregate which is rated based on the degree of degradation. It is measured similar to cracking in terms of sq.mt and later converted into percentage of Ravelling (RV) with respect to the total surface area of the pavement under consideration. The Ravelling Progression Model is developed using Multiple Linear Regression analysis and is as presented below.

RV = 0.01 - 0.35 (CSA/SNC) - 0.23 (BBD/CSA) + 0.08 P_{age}

Where,

RV = Ravelling in %

CSA_t = Cumulative Standard Axles in millions at time 't'

SNC = Modified Structural Number

BBD = Benkelman Beam Deflection value in mm

P_{age} = Pavement Age in Years

7.0 DISCUSSIONS AND RECOMMENDATIONS

7.1 Discussions

The following discussions can be inferred upon the pavement performance models derived from the selected roads on Urban Scenario.

1. The Pavement Condition survey was conducted by IRSM survey vehicle for the initial two cycles and third cycle was conducted by manual means of measurement and the fourth cycle was conducted by IRSM survey vehicle, Final and Fifth cycle of survey was conducted by manual means.
2. The Relative Deterioration Index was first developed, validated by comparing with combined, visual and automated, the combined RDI gave better Linear regression value R^2 being 0.91 , which indicates 91 % reliability of results. The RDI model gave an impression that IRI plays one of the significant role in calculation of RDI value with Rut depth and potholes being of similar contribution, The Ravelling also plays the role in calculation of RDI.
3. A Pavement Deterioration Model was developed and validated by correlating with predicted values and observed values with R^2 being almost nearing 1 with a value of 0.99 indicating high correlation and fitting of data with the predicted values. The Model indicated a higher significance to the Cumulative standard axles, soil Strength and not much significance to age parameter.
4. The RDI values for the selected test stretches were evaluated and were in the range of 1.79 to 14.18 directly the value of RDI – Pavement Deterioration Model is linked to the increase in ESAL applications.
5. The RDI-PDM values obtained from the Pavement Deterioration Model and direct distress measurements for the selected stretches have given clear indication that even though age is one of the parameter to increase in distress, it is not the only contributing factor for major pavement deterioration. The other pavement distress such as Roughness, Rutting, Ravelling, Cracking and Patching contribute significantly to the increase in distress rapidly and the Pavement Prediction Modelling for evaluation of the same has been developed in this study.
6. The Progression models for Roughness, Rutting, Cracking and Patching, Ravelling have been evaluated in the present study and the factors contributing to the increase in pavement distress values in the Distress Factor Prediction Models have also shown an importance to the Cumulative standard axles, Benkelman Beam Deflection value, Modified Structural Number of the layers rather than only age being the predominant factor in deciding the distress value.

7.2 Recommendations

The following Recommendations have been identified based on the Pavement Deterioration Models generated from the present study.

1. The Pavement Deterioration Models for urban roads for the Arterial Sub-Arterial roads are to be used to arrive at the exact deterioration stage of pavement distress with respect to time, it is useful in arriving at the maintenance strategies.

2. The Relative Deterioration Index was developed and can be effectively to be used in arriving at the exact condition of the pavement and pavement distress using present condition with effect of time, other distress and structural parameters.

3. The Pavement Deterioration Models suggest that the pavement distress models happens due to the reduction of strength of pavement, traffic, age, etc., not one parameter has direct influence but it is the combined effect of all these parameters which has a cumulative effect on the performance of pavement.

4. The present condition of the pavement distress is evaluated and the future condition can be evaluated using the models developed in the research work.

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