Pavement Roughness Modelling on Arterial roads in Bangalore City

Dr. H. S. Jagadeesh[1] M. K. Harikeerthan[2]
[1]Professor [2]Associate Professor
[1,2]Department of Civil Engineering
[1]BMS College of Engineering, Bangalore- 560019, India [2]Dayananda Sagar Academy of Technology & Management, Bangalore- 560082, India

Abstract— The main objective of the study is to develop Pavement Deterioration Models based on Roughness 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.

Key words: Pavement Modelling, Roughness, Pavement Surface Evaluation

I. Introduction

The major concentration of this research is in urban roads deterioration, contributing factors and determining deterioration models to evolve maintenance strategies. The total road length in Bangalore city alone is 10,200 kms, worth in thousand crores of rupees by having a simple estimate of 1 million per km length for maintenance. The incharge agencies like BDA and BBMP alongwith urban development ministries both state and centre spend a lot of financial resources , so as to achieve economy in maintenance and rehabilitation program and also to conserve natural resources, there is urgent need for development of Pavement Deterioration Models.

The main objectives of the present study are

- To collect the data about pavement condition periodically and in a systematic way for over a period of atleast five years.
- To develop a Relative Deterioration Index - RDI as a measure of present condition of pavement.
- To develop a suitable Model of Pavement Deterioration which predicts to sufficient amount of accuracy based on field collection of data and also statistical analysis of data collected.

The study was planned to cover for a time period of five years for a stretch of 56 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, etc., all were measured, 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.

Pavement Performance Management is a process of maintaining the network of roads to ensure that the pavement conditions are maintained over the entire network. Although started as a design approach, later pavement management system encompassed all the activities that were included in providing the smooth and safe pavement for the road users as well as the goods that are being carried through it. When the network of roads were minimal, they were maintained in a non-systematic methods which was able to cover the burden, but as the network of roads have increased insurmountably, maintenance of these roads have also become complex, cumbersome, especially within a tight budget. Before moving to the different models of maintaining the roads, this chapter has discussed the various components of PMS, which throws light on how the system works. Flexible and rigid pavements are the two important types of pavements.

As this study is concerned with flexible pavement, further discussion is restricted to flexible pavements. Different conditions of the pavements have been described in detail to understand what are the criteria used to maintain the roads. Further, the pavement condition rating, which is based on visual inspection of pavement distress, is explained in detail. The pavement performance models have been described in terms empirical models and mechanistic models. In addition, the combination of these two models gave rise to mechanistic-empirical models. Pavement prediction models are developed to investigate the condition of the pavements with a goal to maintaining and rehabilitating the pavements.

A. *Field Study and Data Collection*

Pavement Evaluation is performed based on the criteria listed below.

- Functional Evaluation.
- Structural Evaluation.

1) *Functional Evaluation*

The Bump Integrator Study provides the unevenness value of pavement surface, it actually measures the driver or passenger’s comfort and riding quality. Along with Bump integrator there are other methods such as Dipstick Profiler is also used to collect the pavement surface

2) *Structural Evaluation*

Benkelman Beam (BBD) and Falling Weight Deflection(FWD) Studies are most common methods, but BBD studies are most cost effective measure and widely used, the shape of deflection and magnitude of the deflection is essentially function of traffic, the temperature of pavement, moisture, structural section affects the deflection value. Both the Functional and Structural Evaluations performed are Non-Destructive Techniques and hardly affect the day –to-day traffic.

The Surface distress data for the present study was collected by two methodologies, they are enlisted as below

- Automated Method of Data Collection of Pavement Information.
- Manual Method of Collection of Pavement Information.

B. *Pavement Roughness*

Pavement Roughness is a phenomenon experienced by the user on the pavement surface while operating in a vehicle over that surface. The rider sensation is a mixture of feeling of speed of the vehicle combined with profile of the road. The roughness affects the total vehicle operation cost, Fifth wheel Bump Integrator was used for the present study of manual evaluation while IRSM integrated vehicle had in built roughness evaluator.

The Pavement Roughness directly affects the VOC and has a major impact in any deterioration models. Simple devices like MERLIN were earlier used, but for long stretches, fifth wheel bump integrator or vehicle mounted is preferred.

The IRI or International Roughness Index is normally used to define the exact characteristics of longitudinal profile of a travelled wheel track ad it emerges as standardised roughness measurements. The common unit usually referred to are m/km and mm/km i.e., meter per kilometre or millimetre per kilometre. The IRI is a ratio of the total accumulation of vehicle's movement denoted either by millimetre or meter with total distance travelled by the vehicle during the measurement

The data from the bump integrator is converted to IRI which is International Roughness Index, expressed as m/km, the values of IRI ranges from 1 to 20, high value indicating extreme rough roads.

As per the intervention levels by MORTH-2004 for Primary corridors consisting of arterial roads and important roads in urban scenario the IRI value should be less than 2.7 to be classified as good roads and less than 5.7 to be termed as acceptable stage.

C. *Stretches adopted for the present Study*

For the present study the stretches were selected based on certain criteria mainly Arterial Roads around Bangalore city were selected. The stretches selected are being built in the same year and overlaid around same time, so as to ensure uniformity in assessment of condition while analysing the data and to achieve ease of data collection. The arterial roads were dual carriageway lanes with median and fair to good drainage facility as the present study was predominantly to assess the surface distress by the effects of traffic, subgrade, structural strength rather than being concentrated only on environmental conditions. In urban scenario the commercial vehicles are hardly 2-5 % of volume of traffic and the major traffic composed of two wheeler and Cars. The age of pavement and years after overlay are the most important factor in pavement deterioration and hence sufficient time gap has been allowed between study cycles.

Sl. No	Stretch Code	Road Stretches	Road Length in Km	Category of Road	No. of Lanes	combined LWP and RWP
1	SB-NDH	Hosur Road Junction Silk Board to Nayandanahalli	11.7	Arterial/ ORR	4	23.4
2	SMF-KS	Sumanahally flyover Junction to Kanteerava Studio gate	3.9	Arterial/ ORR	4	7.8
3	AIT-MRJ	Dr AIT College gate to Magadi Road junction	3.1	Arterial/ ORR	4	6.2
4	KS-AIT	Mysore Road junction (Kengeri Satellite town) to Dr AIT College Signal	5.5	Arterial/ ORR	4	11
5	BEL-HBL	BEL Circle to Hebbal Flyover signal	3.5	Arterial/ ORR	4	7
		TOTAL in Kms	27.7 kms			55.5 kms

Table 1: List of test Stretches

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

D. *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 two wheeler population is 69 % and cars are 21 % traffic volume which forms the major chunk of traffic composition whereas the truck forms 2- 4 % of the traffic composition.

The crust thickness for the arterial road is 540mm, out of which 140mm is bituminous surface course and 250mm WMM base is provided along with 250mm GSB is provided, The CBR value of the subgrade soil is 8.51 and the structural number being 3.37. During the initial study during Feb-2011 and final study during June-2015 the Benkelman beam study deflection value ranged from 0.52 to 0.99 mm. 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.

The drainage and other parameters ranged from good to fair on the stretch. The camber was good except in small parts on the stretch. The sand loaded trucks are the main reason for the deterioration near entrance of the stretch and apart from that not much of loaded trucks travel on the full stretch of the Arterial Road, Starting from Nayandanahalli till Silk Board Junction.

E. SB-NDH @ CH 11+0 (LWP)

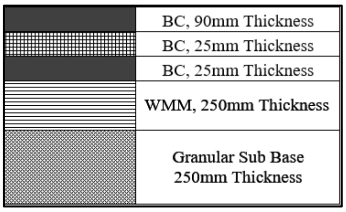

Fig. 1: Crust Thickness and Composition SB-NDH

The Pavement Surface data was collected over a period of Five years (05 Years) starting the year 2011 as the base year, the table 3.3 Indicates the time period of data collected from 2011 till June 2015.

Sl. No.	Date of Survey	Cycle	Method	Number of Months
1	Feb 2011	I	IRSM	Base Year 0 months
2	Dec 2011	II	IRSM	10 Months
3	May 2012	III	Manual	16 months
4	Feb 2013	IV	IRSM	26 Months
5	June 2015	V	Manual	54 Months

Table 2: Survey Cycle Dates and Number of Months

F. Development of Pavement Relative Deterioration Index-RDI

The Relative Deterioration Index (RDI) was calculated on the lines of PSI or PSR correlating with the field measurements such as Cracking, Patching, Ravelling, Rutting, Potholes, Roughness etc., The Relative Deterioration Index was obtained as a Product of all the distress parameters divided by the sum of total area of Stretch under consideration. The regression analysis of the RDI values with the pavement distress will result in the Pavement Deterioration models also known as RDI models. The RDI models help the pavement engineers in evaluation of the pavement serviceability by able to make the measurements of distress using various regression analysis packages.

G. RDI model for Pavement Deterioration-Arterial Roads

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 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 .

H. Development of Pavement Deterioration Models

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.

I. 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. The multiple linear regression analysis of the Pavement Deterioration Model is given in the form as below.

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

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

J. 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.

Predicting the progression of unevenness is an important part in the pavement performance predictions. In the present study IRI is measured using fifth wheel Bump integrator for manual data collection whereas vehicle mounted unevenness indicator is used by IRSM survey vehicle.

A Roughness Progression Model is developed using the Multiple Linear Regression Analysis. The Roughness Progression Model is as below.

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

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

The co-efficient of determination R^2 was found to be 0.96

K. Discussion on Pavement Deterioration Models

In the present research work of Development of Pavement Deterioration Models , all the models which are being developed are analysed by correlating the Relative Deterioration Index values with the Benkelman Beam Deflection, Cumulative Standard Axle, Modified Structural Number, Age of Pavement and other conditions to predict the serviceability of the urban roads under due consideration.

The major attributes in a Deterioration model developed is not only based on the age the pavement as in most of urban roads, the other parameters also decisively contribute to the further deterioration of the pavement surface.

The Pavement Deterioration models for Roughness is the most useful parameters of distress which are to be used in predicting the amount of distress at given time t. The values generated by using these models can be used by the authorities in urban road management so accurately program the need of maintenance and rehabilitation of roads and to achieve good performance of pavements.

II. DISCUSSIONS AND RECOMMENDATIONS

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

1) The traffic studies conducted on all the stretches revealed the Urban Traffic scenario where the two wheeler and cars dominate the vehicle composition nearly 80 % of whereas the truck traffic constitutes a mere 3-5 % of the total traffic flow.
2) The Crust thickness analysis revealed a base course of WMM ranged from 150mm till 250mm and Subbase course of GSB varied from 200mm thick in certain sections to 300 mm.
3) The CBR values of Subgrade soil evaluated during the course of study revealed the CBR ranged from 1.4 to 9.5, for the purpose of getting the best results the CBR tests were conducted carefully and care was taken to get the soil type, LL, PL, PI and other parameters.
4) The Rebound Deflection Studies were performed using the Benkelman Beam Method for all the stretches for all 5 cycles, the progression of decrease of strength from Feb 2011 till June 2015 is linear and is almost double within 54 months of evaluation.
5) 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.

A. 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 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.

III. SCOPE FOR FURTHER STUDIES

1) The Pavement Deterioration Models developed for the urban roads can be much more improved by suitably modifying the SNC and BBD for any type of pavement and further new models can be developed.
2) The present road length in Bangalore City alone is 10, 200kms of Flexible pavement, requiring huge amount of resources and also money to maintain and rehabilitate the pavement for effective performance. There is a urgent need for to develop cost effective and timely pavement management.
3) The models which are developed based on certain pavement distress should be made much more universal and applicability should be verified.

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