Development Of Optimum Maintenance & Rehabilitation Strategies For Urban Bituminous Concrete Surfaced Roads

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ABSTRACT: In India, the road traffic volume has increased manifolds during the post-independence period. The traffic axle loading may also in many cases be much heavier than the specified limit. As a result of which, the existing road network has been subjected to severe deterioration leading to premature failure of the pavements.In such a scenario, development of the effective pavement management strategies would furnish useful information to ensure the compatible and cost- effective decisions so as to keep the existing road network intact. The pavement deterioration models can prove to be an effective tool which can assist highway agencies to forecast economic and technical outcome of possible investment decisions regarding maintenance management of pavements. The optimum maintenance and rehabilitation strategies developed in this study would be useful in planning pavement maintenance strategies in a scientific manner and ensuring rational utilization of limited maintenance funds. Once this strategy for urban road network is implemented and made operational; this would serve as window to the other urban road network of different regions.

Key words: pavement, maintenance and rehabilitation, strategy, cost, benefits, deterioration

1. INTRODUCTION

1.1 BACKGROUND

Road Transport is vital to India's economy. The roads deteriorate significantly without the timely and proper maintenance which can lead to dwindled reliability of transport system and thereby increasing the number of accidents, increased travel time and increased user cost. The Rehabilitation and reconstruction cost will multiply to a great extent if maintenance work is not given proper heed at right time, road maintenance is, therefore, such a indispensable feature of transportation system, the absence of which will lead to ultimate repair cost, road user cost and a lot of discomfort to the road user. India has a road network of over 46, 89, 842 km in 2013, the second largest road network in the world. As of 2008, 49 percent i.e. about 2.1 million km Indian roads were paved.Total urban road length recorded in India is about 3, 04,327 km. Preservation of existing urban roads has become a major activity for all level of government. Deteriorating urban roads and reduced funding are a major problem for the local government. Funds designated for pavement must, therefore, be used as effectively as possible.

1.2 INADEQUACIES OF PRESENT ROAD INFRASTRUCTURE

The growth of road network, both in terms of capacity and quality has not kept pace with the significant growth in demand for transport in India. That is why the current road infrastructure of India has to cope with serious inadequacies as described below:

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1.2.1 Poor Quality of Roads

In spite of having such a big network of roads, the quality of roads is still not up to the mark. The existing road network has aged, leading to appearance of different kind of distresses viz. cracking, raveling and potholing on the surface. These distresses, under the combined action of traffic and environmental factors have been continuously growing to the extent of severity because of the inability to properly upkeep and maintain the road network within budgetary constraints.

1.2.2 Increased Traffic and Axle loads

Traffic on the Indian roads is increasing, with the annual growth rate estimated to be of the order of 5% [IRC, 2012]. The phenomenal growth in vehicle population and road usage has put a terrific strain on the existing road network. There has been significant increase in the axle loads carried by freight vehicles, but the regulations administered of axle weight limitations have not been changed tangibly for many years, thereby putting the negative effect on pavements in terms of fatigue and deterioration. The present spectrum of axle loads plying on the Indian roads shows that as against a prescribed legal limit of 10.2 tones axle load, commercial vehicles with much higher axle loads, even to the extent of 20-22 tonnes are plying on the roads. As per the 'Road Damage Formula', pavement that can last for 10 years without overloading will last only for 6.5 years, if there is 10 percent overloading on an average. With 30 percent overloading, the same pavement will last only for 3.5 years [CRRI 1994]. The situation has led to swift rate of deterioration, which warrants for timely additional maintenance inputs, for preserving and up keeping the roads to the minimum acceptable level of service.

1.3 ROAD MAINTENANCE MANAGEMENT

1.3.1 Necessity of Road Maintenance Management

The lack of road maintenance have caused irreparable damage to economic growth rate, since the poorly maintained roads cause delay, road accidents and higher vehicle operating costs. Any neglect of maintenance activity is self defeating as one Rupee spent on maintenance saves

2 to 3 Rupees in vehicle operating cost [MORT&H 2013e]. Also such neglect of maintenance accelerates the process of deterioration leading to the higher cost of rehabilitation and reconstruction.

1.3.2 Consequences of poor maintenance timings:
The consequences of poor maintenance timings are shown in Figure 1.1. If proper and timely maintenance measures are not taken, the pavement condition deteriorates very rapidly from 'good' to 'poor' during a very short period of pavement life, causing the requirement of 4-5 times more fund for rehabilitation of the pavement. If maintenance and rehabilitation is performed during the early stages of deterioration, before a sharp decline in pavement condition, over 75% of the maintenance costs can be avoided [shahin 1994].

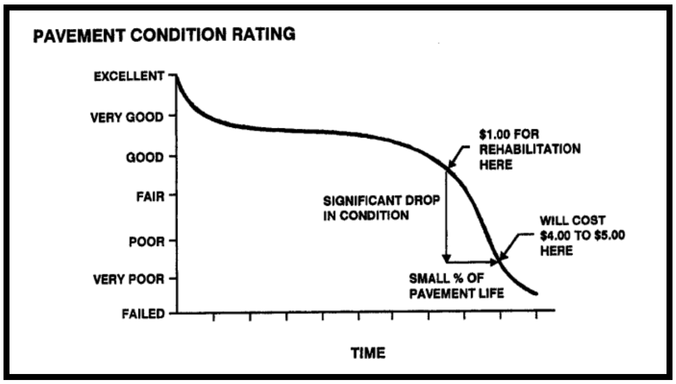

***Figure 1.1** Consequences of Poor Maintenance Timings [Shahin 1994]*

1.3.3 Scientific Approach Towards Maintenance Management of Roads
Initially for a few years after construction, the deterioration of road is trivial when it is subjected to gradual weakening process by traffic loading and climatic factors such as rain, temperature changes and solar radiation etc. The speed of deterioration also depends upon the quality and parameters of original construction. The neglect of maintenance is the key factor which accelerates the pace of deterioration and dwindles the design life significantly. The strengthening of pavement is imminent when the road enters the critical stage as the pavement structure loses its ability to withstand the load of traffic. Keeping in view the above scenario, it has been necessitated to formulate the effective strategies for Optimum Maintenance and Rehabilitation works to put the pavement in a best serviceable condition within the constraints of funds.

2. METHODOLOGY DEVELOPED FOR THE STUDY

2.1 Identification of Urban Road Network
The identification and selection of different categories of roads of various sectors of Panchkula Distt., Haryana has been made. The whole road network comes under the jurisdiction of HUDA (Haryana Urban Development Authority) which can exercise the good control over the whole activities of the study, being the only agency. The following urban road network of Panchkula has been considered for the study:

Bituminous Concrete (BC) Roads
- **Road-R1**: 9.7m wide road with 40mm BC top layer, from BEL factory to Amartex Chowk in sector 15, Panchkula.
- **Road-R2:**9.7m wide road with 40mm BC top layer, between sector 14 and 15, Panchkula.
- **Road-R3:**9.7m wide road with 40mm BC top layer, between sector 9 and 16, Panchkula.

2.2 Types of Data Collected
The process of data collection has been categorized into the following four types:
- Road Network Data
- Vehicle Fleet Data
- Maintenance and Rehabilitation Works Data
- Cost Data

Table 2.1 Details of Identified Urban Road Network

Name of Road	Description of Road	Soil Type	Terrain	Rainfall In mm (Annual)	Temp. In 0c	Traffic
Road-R1	40mm BC road from BEL factory to Amartex Chowk in Sector 15,PKL	Loamy Sand Soil	Plain	1057	-1to43	High
Road-R2	40mm BC road between sector 14 and 15,PKL	Loamy Sand Soil	Plain	1057	-1to43	High
Road-R3	40mm BC road between sector 9 and 16,PKL	Loamy Sand Soil	Plain	1057	-1to43	High

2.3 ROAD NETWORK DATA COLLECTION

2.3.1 General
Some of the data has been obtained from the secondary sources such as the past records of concerned division of Haryana Urban Development Authority (HUDA). The other part of data has been gathered from the selected pavement sections by carrying out the field studies. The data related to the type of soil, terrain, traffic (volume and axle load data), pavement composition and climate has also been gathered through field studies.

2.3.1.1 Road network surveys:
The road network surveys is categorized into the following two types
- Primary Survey -- Field data collection
- Secondary Survey – Inventory data collected from HUDA offices

The following secondary data has been obtained from various divisional offices of the HUDA in-charge of construction and maintenance of the respective sections of the selected roadway network.

- Year of original construction and its specification
- Crust thickness of each pavement layer
- Maintenance inputs and its norms
- Traffic details for the last 5 years
- Year of strengthening and its specification
- Year and specifications of last renewal course
- Temperature and rainfall data for the last 5 years

The road network data collection in the field is categorized under the following heads:

- Inventory data
- Structural evaluation/Structural capacity
- Functional evaluation
- Evaluation of pavement material

2.3.2 Inventory Data
The details of Inventory data about the selected pavement section is given below:

Name and Category of road
Carriageway width
Shoulder width
Surface type and thickness
Pavement layer details

The above data has been gathered from the visual inspection of the pavement section and from the in-charge of construction and maintenance records of the concerned highway division of HUDA (Haryana Urban Development Authority).

2.3.3 Calculation of Adjusted Structural Number (SNP):
The Adjusted Structural Number (SNP) for all the pavement section has been calculated from the Benkelman Beam deflection values by using the following equations [Odoki and Kerali 2000].

For granular base courses such as WBM/WMM

$$BBdef = 6.5 * (SNP)^{-1.6}$$

For bituminous base courses such as BM/BUSG

$$BBdef = 3.5 * (SNP)^{-1.6}$$

2.3.4 Functional Evaluation
Functional evaluation of pavements pertains to road data collection of surface distresses e.g. cracked area, pothole area, rut depth and surface roughness etc.

2.3.4.1 Surface distress measurements: The type and extent of distress developed at the surface were observed based on the visual inspection. The distresses developed were also measured in quantitative terms.

- **Measurement of cracked area:** The test sections of length 50m were selected for each pavement section to measure the cracked area. In case of interconnected cracks, the affected area was marked in the form of rectangle and measured. In case of single longitudinal/transverse cracks, the width of crack area was taken as 50cm and the consequent area was measured by multiplying it with actual length of crack. The cracked area was expressed as percentage of total pavement area.

- **Measurement of pothole area:**

One pothole Unit = 0.1sq.m

The minimum diameter 150mm and minimum depth of 25mm of pothole has been considered.

- **Rut depth measurements:**
  The rut depth was measured with at least 2m straight edge under the wheel path. The maximum value of rut depth was noted down at each observation.

2.3.4.2 Roughness measurements:
The pavement roughness was measured on each pavement section with the help of 'Fifth Wheel Bump Integrator' towed by the jeep as per the standard procedure. The instrument was made to run at a constant speed of 30kmph. The roughness values were obtained in terms of Unevenness Index using the following equation [Jain et al 1999].

$$UI = B/W * 460 * 25.4 \text{ mm/km}$$

Where,
UI = Unevenness Index, in mm/km
B = Bump Integrator reading
W = Number of Wheel revolutions

The above calculated Unevenness Index (measured in mm/km) has been converted into the universally acceptable International Roughness Index (IRI -measured in m/km) by using the following equation [Odoki and Kerali 2000].

$$UI = 630 \times IRI^{1.12}$$

2.3.5 Evaluation of Pavement Materials

3.3.5.1 Field evaluation: The test pits of suitable size were dug up at suitable locations in all pavement sections. The following tests were conducted and the observations were taken.

- Thickness of the most recent surfacing course and old surfacing courses
- Thickness of base and sub-base courses
- Field dry density and field moisture content of the soil subgrade

The representative subgrade soil samples were collected from the test pits for marking the characterization of materials in the laboratory.

2.3.5.2 Laboratory evaluation:
The evaluation of the subgrade soil samples collected from the field was done in laboratory conforming to the Indian Standard specifications.

Table 2.2 Laboratory Test Results of Collected Sub grade Soil Samples on AllPavement Sections of the Selected Roads

Name Of the Road	Optimum Moisture Content (%)	Atterberg Limits (%)			CBR In (%)	
		LL	PL	PI	Un-soaked	Soaked
Road-R1	13.0	15	12	3	6.96	4.66
Road-R2	15.0	17	12	5	6.07	4.09
Road-R3	14.0	14	10	4	5.97	4.01

2.3.6 Road Network Database
All road network data items which are required to be defined for each pavement section are given in the Table 2.3 and 2.4.

Table 2.3 Inventory Data of All Selected Urban Road Sections

Name of Road	Description of Road	Flow Type	Carriage -way Width	AADT	AADT Year	Length Of Road (km)
Road-R1	40mm BC road from BEL factory to Amartex Chowk in Sector 15,PKL	One way	9.7m	17140	2014	1.55
Road-R2	40mm BC road between sector 14 and 15,PKL	One Way	9.7m	15975	2014	1.10
Road-R3	40mm BC road between sector 9 and16,PKL	One Way	9.7m	22253	2014	0.96

Table 2.4 Observed Condition Data on All Pavement SectionsOf Urban Road Network

Name of the Road	Condition Year	Roughness IRI(m/km)	Cracking Area(%)	Benkelman Beam Deflection (mm)	Adjusted Structural Number of Pavements (SNP)
Road-R1	2013	2.23	3.04	0.42	3.76
Road-R2	2013	2.17	2.82	0.41	3.82
Road-R3	2013	2.68	3.56	0.44	3.65

2.4 VEHICLE FLEET DATA

2.4.1 Categories of Vehicle
A typical traffic flow on all types of urban road in India consists of both Motorized (MT) and Non-Motorized (NMT) vehicles. Both MT and NMT vehicles have been taken into account in this study.

2.4.2 Traffic Volume Counts
Traffic surveys were conducted manually for 24 hours round the clock for a week by engaging the sufficient number of enumerators. A separate count station was established for each individual road. The vehicles were classified as per the representative vehicles specified in the previous section. The vehicles not covered under the representative vehicles defined above were suitably clubbed with the vehicles similar to them in composition and speed.

2.4.3 Vehicle Growth Rate
The average annual growth rate of vehicles in India has been taken as per IRC-37, July2012.The traffic compositions and annual growth rates have been assumed to be applicable to all different roads in the urban road network under study.

2.5 MAINTENANCE AND REHABILITATION WORKS

2.5.1 Serviceability Levels for Maintenance
The attempts are being made all over the world to develop standards for maintenance quality level for which roads are to be maintained to achieve the requisite level of comfort, convenience and safety to the road users. The maintenance of roads should be kept up to such a level that the vehicle operating costs and accident costs are minimized. Environmental concerns are also being given due consideration to reduce the level of exhausts from road traffic. The measure of maintenance quality levels which have been accepted in most of the developed countries consists of measuring the service conditions of roads in terms of surface defects such as roughness, potholes, cracking and rutting etc. to determine a 'Serviceability Index' which varies from country to country.The suggested serviceability levels and the permissible levels of surface defects based on the measurement of roughness, cracking, rutting etc. are shown in Table 2.6 [MORT&H(2013)].

Table 2.5 Grouping of Roads as per Maintenance Serviceability level

Serviceability Level	Traffic Volume (AADT)	Name of Roads
High (Level 1)	More than 10000	Road-R1,Road-R2,Road-R3
Medium (Level 2)	5,000 – 10,000	**********************
Low (Level 3)	Less than 5,000	**********************

Table 2.6 Intervention Levels for Urban Roads

Sr.No	Serviceability Indicator	Serviceability Levels		
		Level 1 (Good)	Level 2 (Average)	Level 3 (Acceptable)
1	Roughness by Bump Integrator (max. permissible) Equivalent IRI*	2000mm/km 2.8m/km	3000mm/km 4.0m/km	4000mm/km 5.2m/km
2	Potholes per km (max. number)	Nil	2-3	4-8
3	Cracking and Patching Area(max.	5 percent	10 percent	10-15 Percent

	permissible)			
4	Rutting-20mm (max. permissible)	5mm	5-10mm	10-20mm

Source: MORT&H(2013)(OdokiKerali[2000]*

2.6 COST DATA

2.6.1 Cost of Maintenance and Rehabilitation Works

The cost of various items pertaining to Maintenance and Rehabilitation works has been considered as per HSR Item/Description (Haryana Schedule rates) of HUDA (Haryana Urban Development Authority) as shown in Table 2.7.

Table 2.7 Cost Data for Maintenance and Rehabilitation Works

Sr.No.	Type of Maintenance & Rehabilitation Work	*Cost per sq.m (2014-15)
1	Tack Coat	14.50
2	Crack sealing	140.00
3	Potholing patching for PC surface	210.00
4	Potholing patching for BC surface	245.00
5	Patch repair for PC surface	210.00
6	Patch repair for BC surface	245.00
7	Rutting and undulation repair	310.00
8	Single Bituminous Surface Dressing(25mmSBSD)	143.00
9	Double Bituminous Surface Dressing(25mmDBSD)	285.00
10	Premix carpet (25mmPC)	211.00
11	Semi Dense Bituminous Concrete (25mmSDBC)	228.20
12	Bituminous Concrete (40mm BC)	340.00
13	Dense Bituminous Macadam (50mmDBM)	392.00
14	Bituminous Macadam (50mmBM)	298.00
15	Mill and Replace with 50mmBM+25mmPC	584.00
16	Mill and Replace with 50mmBM+40mmBC	713.00

**All Costs are in Indian Rupees, Source: HSR Item/Description*

2.7PAVEMENT DETERIORATION MODELS

2.7.1Cracking Initiation Model (BC surfacing)

ICA = Kcia [CDS2 * 4.21 EXP {0.14 SNP – 17.1 (YE4/SNP2)} + CRTWhere,ICA = Time to initiation of all structural cracks, in years, CDS = Construction defects indicator for bituminous surfacing

Dry (brittle) = 0.5, Normal = 1.0, Rich (soft) =1.5

SNP = Average annual adjusted structural number of pavements

YE4 = Annual number of equivalent standard axles, in millions/lane

CRT = Crack retardation time due to maintenance, in years (default value = 1.5)

Kcia = Calibration factor

2.7.2 Cracking Progression Model (BC surfacing)

dACA = Kcpa (CRP/CDS) [(1.84 * 0.45 * δtA + SCA0.45)1/0.45 – SCA]

where,

dACA = Incremental change in area of all cracking during year, in percent of total carriageway area

CRP = Retardation of cracking progression due to preventive treatment

[CRP = 1 – 0.12 CRT]

SCA = Min { ACAa, (100 – ACAa)}

ACAa = Area of all cracking at the start of the analysis year, in %

δtA = Fraction of the analysis year in which all progression applies

CDS = Construction defect indicator for bituminous surfacing

Dry (brittle) = 0.5, Normal = 1.0, Rich (soft) =1.5

Kcpa = calibration factor

2.7.3 Roughness Progression Model (For BC surfacing)

ΔRI = Kgp [134 * EXP(m Kgm AGE3) * (1 + SNPKb)-5 YE4]

+ [0.0066 * ΔACRA] + [0.088 * ΔRDS]

+ [0.00019 (2 – FM) {((NPTa * TLF) + (ΔNPT * TLF/2))1.5 – (NPTa)1.5}]

+ [m Kgm RIa]

Where,

ΔRI = Total incremental change in roughness during analysis year, in m/km IRI

m = Environmental co-efficient (default value = 0.025)
(= 0.04 for Indian conditions)

Kgm = Calibration factor for the environmental component of roughness

(default value = 1.0)

AGE3 = Age since last overlay or reconstruction, in years

SNPKb = Adjusted structural number due to cracking at the end of the analysis yr.

YE4 = Annual number of equivalent standard axles, in millions/lane

ΔRDS = Incremental change in standard deviation of rut depth during analysis yr. in mm

FM = Freedom to maneuver index based on carriageway width in m and AADT

NPTa = Number of potholes per km at the start of the analysis year

TLF = Time lapse factor depending upon the frequency of pothole patching

(default value = 1.0)

∆NPT = Incremental change in number of potholes per km during the analysis yr.

RIa = Roughness at the start of the analysis year, in m/km IRI

Kgp = Calibration factor

Source: Odoki et al (2000)

2.8 CALIBRATION OF PAVEMENT DETERIORATION MODELS

The calibration of pavement deterioration models has been done with the help of actual field data taken by different methods and equipment used. The number of data setsas given in Table 2.8 has been considered for calibration purposes. All the data values are within the defined limits of respective distress model.

Table 2.8 Data Sets For Calibration of Pavement Deterioration Model

Types of Roads	YAX (millions)	YE4 (AMSA)	AGE 3 (Years)	SNP (mm)	NPTa (potholes)	RIa (m/km)	HS (mm)
Road-R1	6.99	0.209	4	3.75	1.85	2.10	40
Road-R2	6.39	0.198	4	3.80	2.27	2.21	40
Road-R3	9.27	0.263	4	3.85	2.1	2.28	40

The following assumptions have been made for calibration purposes

The traffic growth rate has been considered to be 5.0% uniformly and the change in cumulative standard axles and total number of vehicle axles over a time period of one year has been calculated accordingly.

- The adjusted structural number (SNP) of the pavement for the pavement deterioration models has been assumed to be the same.
- The pothole area in pothole model has been suitably converted into number of pothole units by considering the following relationship: [0.1 m2 pothole area = 1 pothole unit]
- The value of TLF has been fixed as 1, since the potholes occurring on the roads are usually not patched within 12 months of their occurrence.
- Freedom to maneuver index (FM) has been fixed as zero for carriageway width of 9.7m.
- The environmental coefficient ‘m’ in the Pavement Roughness model has been assumed as 0.025 considering the average climatic zone for India as Sub-humid/Sub-tropical hot. The environmental factor for BC pavements in Indian Roughness model is taken as 0.04.
- The relationship given by the following equation has been used to convert the Unevenness Index (UI in mm/km) into the universally acceptable International Roughness Index (IRI in m/km) [Odoki and Kerali 2000]
- UI = 630 × IRI1.120

Table 2.9Calibration Factors Obtained For Pavement Deterioration models

Model description	Road-R1	Road-R2	Road-R3
Cracking Initiation Model	0.230	0.214	0.200
Cracking Progression Model	0.410	0.465	0.490
Roughness Progression Model	0.680	1.23	0.710

The calibration factors obtained for various deterioration models are: Cracking Initiation (Kcia) = 0.215 (average), Cracking Progression (kcpa) = 0.455 (average), and Roughness Progression (Kgp) = 0.87 (average). It shows that the initiation of cracking start appearing on the pavement surface a lot earlier than what is predicted by the pavement deterioration model. In other words, the initiation of cracking is faster for urban road test stretch. The rate of cracking initiation (Kcia = 0.215) is faster by 78.5% on urban road test stretch. The rate of progression of cracking (Kcpa = 0.455) is slower by 54.5% on urban road test stretch.

2.9 VALIDATION OF PAVEMENT DETERIORATION MODELS

2.9.1 General

The validity of the calibrated pavement deterioration models has been checked to test the efficacy of these models. The distresses predicted by the calibrated deterioration models were compared with those actually observed on the selected pavement sections to prove the validity of these models.The pavement condition data on all sections of the road network was collected by the starting of the year 2013 with the help of various equipments and methods. The pavement condition data was once again collected in the same time period of the year 2014 with help of same equipment and methods so as to ascertain the status of the annual progression of distresses during the year 2013- 14. The two types of deterioration models which have been validated are

- Cracking progression model
- Roughness progression model

2.9.2 Cracking Progression Model

The observed values of cracking area around the starting of the year 2014 for the selected pavement section have been compared with those predicted by the cracking progression model as shown in the Table 2.10. These values have been plotted against each other as shown in figure 2.1 to determine the correlation between them.

Table 2.10 Variability between Observed and Predicted Cracking Values

Name of the Road	ObservedCracking Area in %	PredictedCracking Area in %	% Variability
Road-R1	2.43	2.84	16.8
Road-R2	4.89	5.91	21.0
Road-R3	7.23	8.13	12.5

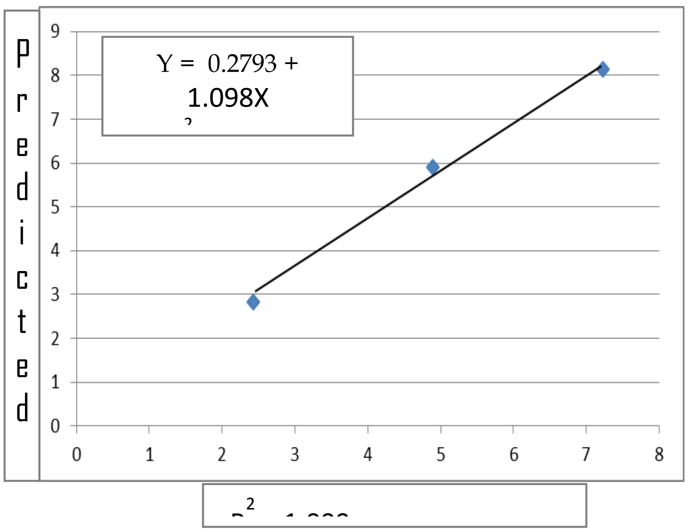

Figure 2.1 *Observed V/S Predicted Cracking (% Area)*

2.9.3 Roughness Progression Model

The observed values of roughness around the starting of the year 2014 for the selected pavement section have been compared with those predicted by the roughness progression model as shown in the Table 2.11. These values have been plotted against each other as shown in figure 2.2 to determine the correlation between them.

Table 2.11 Variability Between Observed and Predicted Roughness Values

Name of the Road	Observed Roughness (m/km IRI)	Predicted Roughness (m/km IRI)	% Variability
Road-R1	2.57	2.89	12.4
Road-R2	4.12	4.53	9.9
Road-R3	5.96	6.84	14.7

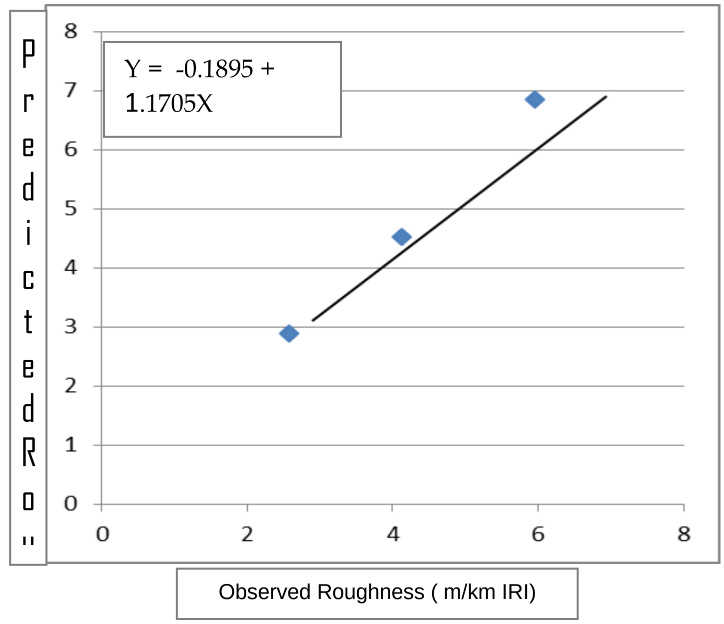

Figure 2.2 *Observed V/S Predicted Roughness Value (m/km IRI)*

2.9.4 The 't' Test

The 't' test has been performed to find out the significance of difference between the observed and predicted distress values in response to various deterioration models. The calculated't' values (tcal) for all deterioration models have been compared with tabulated 't' values for a level of significance of 5% (t0.05) as shown in the Table 2.12. From this test, it is inferred that tcal < t0.05 for boththe pavement deterioration models. Therefore, the difference between the observed and predicted distress values is not significant at 5% level of significance. Hence, it is maintained that both the pavement deterioration models can be used for prediction of distresses and for the development of maintenance management strategies for the selected urban road network.

Table 2.12 The 't' Test for Observed and Predicted Distress Values

Distress Modeled	Calculated 't' Value (tcal)	Degree of Freedom	Tabulated 't' Value (t0.05)	Comparison of tcal v/s t0.05
Cracking	0.45	4	2.776	tcal < t0.05
Roughness	0.24	4	2.776	tcal < t0.05

2.9.5 Conclusion on Validation of Models

The calibrated pavement deterioration models have been validated by comparing the value of distresses predicted by the respective model with those actually observed in the field. The variations of 12.5 to 15.1 percent for cracking area and 9.9 to 14.7 percent for roughness have been obtained. The above variations are bound to exist for such complex phenomena of pavement behaviour under varied conditions of traffic loading, climatic and other conditions. The regression analysis has been carried out correlation equations has been framed for the given distress parameters. The R2 (coefficient of determination) values for cracking and roughness have been obtained as 0.993 and

1.000 respectively. Since R2 values depict good agreement between observed and predicted distress values. Hence, it is concluded that the above models can be used for prediction of distresses and the development of maintenance management strategies for selected urban road network. The 't' test has been carried out to find out the difference between the observed and predicted distress values with regard to all deterioration models. The calculated 't' values (tcal) for all models have been compared with tabulated 't' values at 5% level of significance (t0.05). On the basis of comparison, the conclusion has been made that the difference between the observed and predicted distress values is not significant for both the deterioration models. The above statistical data justifies the efficacy of the calibrated pavement deterioration models for the urban road network. Hence, it is concluded that the above deterioration models can be used for prediction of distresses and the development of maintenance management strategies for the identified urban road network.

3. APPLICATION OF METHODOLOGY

This study includes the economic analysis of alternative maintenance and rehabilitation (M&R) strategies for the urban (Bituminous concrete) road. The main purpose of this study is to appraise the economic benefits arising out of investing in maintenance and rehabilitation of the road network at the appropriate time as compared with carrying out minimum routine maintenance annually. The optimum M&R strategy is finalized on the basis of economic indicator such as NPV.The analysis period is defined by a start year (i.e. current year 2015) and the duration of 8 years (i.e. 2015-2022).

3.1 Pavement Sections of Selected Roads:

The Road-R1 of the identified urban roads network Panchkula have been selected for this present study. The Road-R1 comprises of a Bituminous Concrete (BC) surface and is from BEL factory to Amartex Chowk in sector 15 of Panchkula. This road is considered as a very heavily trafficked road section and a busy route of Panchkula. The last reconstruction (50mm BM+40mmBC) of the pavement section of Road1 was done in Nov, 2009. The total traffic plying on the identified pavement section of the roads is collected in terms of AADT. The selected pavement section of Road-R1 belongs to high serviceability level (Level1). So, the applicable maintenance standards and the appropriate intervention level based on the **serviceability** indicators have been mentioned for this pavement section. All the maintenance standards mentioned here are applicable from the first year of the analysis period i.e. year 2015.

3.2 Proposed M&R strategies:

The maintenance and rehabilitation strategies applicable to the pavement section have to be put forward in advance. The five M&R strategies depicted in the Table 3.1 are considered for this study. The first strategy i.e. 'Base Alternative' makes the provision of minimum routine maintenance till up to the time when the reconstruction of the pavement section becomes inevitable. Four other alternative M&R strategies, namely Alternative 1, Alternative 2, Alternative 3, and Alternative 4, which comprehend resealing, resealing plus overlay, overlay, and mill & replace type of maintenance works respectively, have also been mentioned.

Table 3.1 Proposed M&R Strategies and Intervention Level of Road-R1

M&R Strategy	Works Standards	Description of Work	Intervention Level
Base Alternative	Routine Maintenance	Crack Sealing	Scheduled annually
		Patching	Scheduled annually
Alternative 1	Resealing	Provide 25mm DBSD	Total damaged area > 5% of the total area
Alternative 2	Resealing + Overlay	Provide 25mm DBSD	Total damaged area > 5% of the total area
		Provide 40 mm BC	Roughness > 2.8m/km IRI
Alternative 3	Overlay	Provide 40 mm BC	Roughness > 2.8m/km IRI
Alternative 4	Mill and Replace	Remove 90 mm Surfacing and provide 50 mm BM+40 mm BC	Roughness > 5 m/km IRI Carriageway cracked Area > 20% of total area

Total damaged area consists of cracked, raveled and potholed area

3.3 Project analysis:

During the set up of the project analysis, Base Alternative is established with respect to which the economic analysis is to be undertaken and a discount rate of 10% is specified. While doing execution of project analysis, Alternative1, Alternative2, Alternative3 and Alternative4 are compared with the Base Alternative. As a result of this operation, the pavement deterioration reports, and the maintenance & rehabilitation works reports are created for all M&R strategies considered above. These two types of reports are mentioned in the following sections.

3.4 Pavement deterioration:

The deterioration summary report of the pavement sections of Road-R1 as obtained under alternative M&R strategies over the analysis period of 8 years is shown in the Table 3.2,3.3,3.4 and 3.5.Pavement distresses such as cracking and roughness show annual progression over the analysis period, with respect to pavement deterioration models. These deterioration models have already been suitably calibrated as per the local conditions, as mentioned in the previous chapter. The annual progression of all types of distresses is varying under different M&R strategies.

3.5 Description of works:

The different work items resulting from application of all the defined M&R strategies (as triggered by the respective intervention parameters), and timings of their application, are given in the M&R works report in Table 3.6 and 3.7. This works report shows description of the works that would be implemented in each year of the analysis period (2015-2022), under each M&R strategy. The cost associated with each work item is also shown in this report. The total cost to be incurred by the highway agency on maintenance management of the pavement section under each alternative M&R strategy, is computed over the whole analysis period of 8 years, and the same is also shown in this works report.

Table 3.2 Deterioration Summary Report of the Pavement Sectionof Road-R1 forAlternative1

Year	AADT	ESAL Per Lane	Roughness (m/km IRI)	All Structural Cracks (% area)	Treatment Provided
2015	17997	0.219	2.40	5.15	DBSD(25mm)
2016	18897	0.230	2.10	0.00	*****
2017	19842	0.242	2.31	3.24	****
2018	20834	0.254	2.60	6.31	DBSD(25mm)
2019	21875	0.267	2.14	0.00	****
2020	22969	0.280	2.38	3.24	****
2021	24118	0.294	2.69	6.31	DBSD(25mm)
2022	25324	0.308	2.13	0.00	****

Table 3.3 Deterioration Summary Report of the Pavement Section of Road-R1 for Alternative2

Year	AADT	ESAL Per lane	Roughness (m/km IRI)	All Structural Cracks (% area)	Treatment Provided
2015	17997	0.219	2.40	5.15	BC(40mm)
2016	18897	0.230	2.05	0.00	****
2017	19842	0.242	2.12	1.83	****
2018	20834	0.254	2.47	4.17	****
2019	21875	0.267	3.18	7.60	DBSD(25mm)
2020	22969	0.280	2.25	0.00	****
2021	24118	0.294	2.42	3.24	****
2022	25324	0.308	3.26	6.31	DBSD(25mm)

Table 3.4 Deterioration Summary Report of the Pavement Section of Road-R1for Alternative3

Year	AADT	ESAL Per lane	Roughness (m/km IRI)	All Structural Cracks (% area)	Treatment Provided
2015	17997	0.219	2.40	5.15	BC(40mm)
2016	18897	0.230	1.92	0.00	****
2017	19842	0.242	2.12	1.83	****
2018	20834	0.254	2.47	4.17	****
2019	21875	0.267	3.10	7.60	BC(40mm)
2020	22969	0.280	1.98	0.00	****
2021	24118	0.294	2.10	1.83	****
2022	25324	0.308	2.40	4.17	****

Table 3.5 Deterioration Summary Report of the Pavement Section of Road-R1 for Alternative4

Year	AADT	ESAL Per lane	Roughness (m/km IRI)	All Structural Cracks (% area)	Treatment Provided
2015	17997	0.219	2.40	05.15	****
2016	18897	0.230	3.32	08.91	****
2017	19842	0.242	4.14	13.78	****
2018	20834	0.254	5.09	19.78	****
2019	21875	0.267	6.98	27.26	Mill&Replace
2020	22969	0.280	1.90	00.00	****
2021	24118	0.294	2.16	01.83	****
2022	25324	0.308	2.46	04.17	****

Table 3.6 M&R Works Report for Pavement Section of Road-R1

Year	M&R Works				
	Base Alt	Alt1	Alt2	Alt3	Alt4
2015	Patch & Crack Seal	DBSD 25 mm	BC (40 mm)	BC 40 mm	****
2016	Patch & Crack Seal	****	****	****	****
2017	Patch & Crack Seal	****	****	****	****
2018	Patch & Crack Seal	DBSD (25mm)	****	****	****
2019	Patch & Crack Seal	****	DBSD (25mm)	BC (40mm)	Mill & Replace
2020	Patch & Crack Seal	****	****	****	****
2021	Patch & Crack Seal	DBSD (25mm)	****	****	****
2022	Patch & Crack Seal	****	DBSD (25mm)	****	****

Table 3.7 Associated Costs for Pavement Section of Road-R1

Year	Cost of Works				
	Base Alt	Alt1	Alt2	Alt3	Alt4
2015	0.579	4.275	5.112	5.112	****
2016	0.579	****	****	****	****
2017	0.579	****	****	****	****
2018	0.579	5.700	****	****	****
2019	0.579	****	6.270	7.484	15.695
2020	0.579	****	****	****	****
2021	0.579	7.587	****	****	****
2022	0.579	****	8.346	****	****
Total Cost in Million Indian Rupees	4.632	17.562	19.728	12.596	15.695

3.6 Economic analysis summary for a pavement section of Road-R1:

The summary of the economic analysis is undertaken under the 'Project Analysis' is shown in the Table 3.8. This summary shows a comparison of the present value of the total agency costs and reduction in road user costs for each M&R strategy, when compared with the Base Alternative. The economic indicator NPV is also computed.

Table 3.8 Summary of Economic Analysis of Road-R1 for Project Analysis'

Alternative Strategies	Total Agency Costs	Increase In Agency Costs	Decrease In Road User Costs	Net Present Value (NPV)	NPV/Cost Ratio
Base Alternative	4.632	0.000	0.000	0.000	0.000
Alternative1	17.562	12.930	44.511	31.581	1.798
Alternative2	19.728	15.096	51.348	36.252	1.837
Alternative3	12.596	7.964	35.847	27.883	2.213
Alternative4	15.695	11.063	35.345	24.282	1.547

All Costs are expressed in Million Indian Rupees

3.7 Selection of optimum M&R strategy of a pavement section of Road-R1:

On the basis of the economic analysis summary shown in Table 3.8, Alternative3 has been selected as the optimum

M&R strategy, having the maximum NPV/cost ratio. Therefore, it has been concluded on the basis of above case study that Alternative3, which comprises of application of overlay (40mm Bituminous Concrete) at a pre defined intervention level (triggered when Structural Cracks > 5% of total area), is the optimum M&R strategy for the selected pavement section.

4. CONCLUSIONS AND RECOMMENDATIONS

The following inferences have been drawn on the basis of this study.

- An operational methodology in this study, aided by adequate indigenous tools is not popular in India for the development of Optimum Maintenance and Rehabilitation strategy urban road network. Therefore, the pavement deterioration models which are internationally recognized has been selected for use in this study. These models have been chosen because of its global acceptance and large applicability in a number of advanced countries.
- The methodology comprehends: identification and selection of the urban road network, data acquisition, and calibration, validation and activation of pavement deterioration models for Indian conditions.
- The urban road network selected for the present study consists of threeroads (Road-R1, Road-R2and Road-R3) of bituminous concrete type, which are located in different sectors of Panchkula. The BC roads (Road-R1, Road-R2 and Road-R3) are one way type.Since, this urban road network covers different types of traffic and pavement composition, therefore, this network may be considered as the representative for other urban road network in India and abroad.
- As per the current norms for maintenance of roads, all the selected pavement section of the roads need not to be maintained at the same level of serviceability due to functional requirements and funds constraints. Therefore, these three pavement sections of different roads have been categorized into High Maintenance Serviceability Levels as per the volume of traffic carried by them at present i.e.> 10000AADT.
- All the collected data have been utilized for time series prediction of pavement distresses by making use of pavement deterioration models.
- The calibration factors obtained in this study for various deterioration models are: Cracking Initiation (Kcia) = 0.215 (average), Cracking Progression (kcpa) = 0.455 (average) and Roughness Progression (Kgp) = 0.87 (average). It shows that the initiation of cracking start appearing on the pavement surface a lot earlier than what is predicted by the pavement deterioration model. In other words, the initiation of cracking distresses is faster for urban test stretch. The rate of cracking initiation (Kcia = 0.215) is faster by 78.5% on urban test stretch. The rate of progression of cracking (Kcpa = 0.455) is slower by 54.5% on urban test stretch.
- The validation has been undertaken through percentage variability in the observed and predicted values, coefficient of determination (R2), and 't' test. Variability of 12.5 to 21.0 percent for cracking area and 9.9 to 14.7 percent for roughness have been obtained. These variations are bound to occur for such complex phenomena of pavement behaviour under different conditions of soil type, pavement composition, traffic loading and climatic conditions. The correlation equations have been developed for these distress values and the regression analysis has been done. The Coefficient of Determination (R2) values for cracking and roughness have been obtained as 0.993, and 1.000 respectively.
- The calculated 't' values for cracking and roughness are 0.45 and 0.24 respectively. The tabulated 't' values for cracking and roughness at 5% level of significance are 2.776, and 2.776 respectively. All the calculated 't' values are less than their corresponding tabulated 't' values. This evinces that the difference between the observed and predicted distress values is not statistically significant at 5% level of significance. Therefore, it is inferred that these deterioration models can be used for prediction of distresses and the development of maintenance management strategies for the urban road network.
- An optimum maintenance and rehabilitation strategy for a pavement section has been determined on the basis of highest NPV/Cost ratio, amongst a number of pre-defined M&R strategies. The M&R strategy consists of application of overlay (40mm Bituminous Concrete) at a defined intervention level (activated when structural cracks > 5%).
- similar kind of Optimum Maintenance and Rehabilitation Strategy may be developed for different categories of urban road network.

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