Development of Pavement Maintenance Management System (PMMS) for an Urban Road in New Delhi, India

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Abstract Pavements must be well maintained with proper utilization of maintenance funds as they are valuable national assets. Deferring pavement maintenance causes enormous financial losses and has a negative impact on the nation's growth. Simultaneous maintenance of existing roads is necessary in a timely way in addition to rapid construction of new road networks. Therefore, it is necessary to assess the state of pavements before deciding the type of maintenance needed, in order to make effective use of road maintenance funds. In the present study an Urban Road in New Delhi was assessed for its structural and functional condition to develop PMMS. The condition of the pavement has been evaluated in terms of pavement indices, such as the Pavement Condition Rating (PCR), and the Structural Capacity Index (SCI).

The deterioration of pavement with time is calculated using the deterioration models developed by CRRI in the year 1994, for Asphalt Concrete Roads in Northern India. A 15-year maintenance plan has been proposed for the selected Urban roads. In addition, a life cycle cost analysis has been performed to compare the costs under periodic and condition responsive maintenance strategies. It has been found that the condition responsive maintenance can be carried out at a cost of 4.7% less than the cost of periodic maintenance. Even though the difference in life cycle costs between periodic maintenance and condition responsive maintenance is minimal, the pavement can be maintained at level-1 or good condition under condition responsive maintenance.

Keywords Maintenance · Life-cycle cost · Deterioration · Pavement condition

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1 Introduction

Due to the advancement in human civilization, there is an increased need for the movement of men and materials. Passenger and freight transportation has grown into a key industry that is the backbone of a society's and country's development in terms of economy, technology, security, and growth. Road transport is possibly the oldest and, without a doubt, the most widely recognized and used means of transportation in the world. It is essential to have an efficient road transportation infrastructure for a country's development and advancement. A well-developed and well-maintained road transport industry serves as a catalyst for the country's development.

The majority of pavements in India are Flexible Pavements, (about 95% of total pavements), which deteriorate due to increasing traffic, increasing load, high tyer pressure, adverse environmental conditions, etc. Distresses like rutting, cracking, potholes, ageing are most common in flexible pavements, which greatly affects the service life. As a result, methods for maintaining pavements are required, to ensure that they perform as expected during their service life. In order to maintain stable road condition and ride quality, maintenance and rehabilitation (M&R) operations should be undertaken as a part of the maintenance plan, which results in pavement design life being attained in a cost-effective manner.

The present pavement maintenance strategy involves doing routine maintenance as necessary and restoring or strengthening pavements every 5 years without taking into account their possible economic implications. This study focuses on the Life-Cycle Cost Analysis (LCCA) of periodic and condition responsive maintenance strategies. It gives an overview of the most appropriate and cost-effective pavement maintenance strategy as well as the Net Present Value (NPV) difference between periodic and condition responsive maintenance strategies. Net present value method of LCCA is an economic tool used for evaluating the pavements, which considers both initial construction cost, and maintenance cost during the analysis period. The total life cycle costs of condition responsive maintenance and periodic maintenance are compared based on NPV, and the optimum maintenance alternative is taken into consideration.

2 Literature Review

2.1 Road Asset Management

Shah et al. [1] worked diligently on prioritization methods for effective maintenance of urban roads. According to his study, the most significant components of PMMS are determining the appropriate maintenance technique and prioritizing the pavement portions for treatment, and this prioritization can be done using a subjective ranking method. Another researcher Mandapaka et al. [2] emphasizes traditional LCCA is the fundamental tool for economic comparisons, and it may be used to assess the present costs of various pavement alternatives. Ashok et al. [3] used net present value (NPV) technique to evaluate the cost efficiency of alternatives, which determines the total cost needed over the project's life cycle. The study examined the life cycle costs of bituminous and concrete pavements, as well as bituminous and concrete overlays. According to Jain k et al. [4] financing a project in a developing country like India is challenging, and the funds provided are insufficient to satisfy the maintenance requirements, and therefore the Maintenance and Rehabilitation (M&R) plan for a specific highway stretch might be planned based on pavement conditions.

Pavement maintenance. Jain et al. [5] stated that the existing pavement maintenance program is centered on doing routine repairs as needed and renewing every five years without taking into account the costs and effects. Despite the fact that most recently developed software packages, such as HDM-4, give time-bound maintenance intervention criteria, condition responsive maintenance intervention is recommended for Indian conditions, which is more advantageous than planned maintenance. According to Hashema et al. [6] in order to avoid complicated combinations of distress levels (types, amount, and severity) and feasible M&R options, a Maintenance Unit (MU) system was developed which employs a combined index to highlight maintenance needs. The main purpose of the MU system is to decrease the number of linkages between distress data (type, severity, and density) and M&R alternatives that are necessary. Another researcher Raof et al. [7] combines both structural and functional conditions of pavement for the selection of M/R strategies and recommends that the treatment should be chosen based on the current condition and anticipated future performance.

Pavement Performance Prediction Models

Sood et al. [8] state that the pavement deterioration models are based on the traffic, environmental, and pavement conditions. Roughness, cracking, and pothole prediction models were developed based on the above distress parameters for Indian condition, which could be used to design an appropriate pavement management system that allows for maintenance planning and prioritization. Further Rohde et al. [11] developed model to determine the Structural Condition Index of the pavement directly from the deflection values of the Pavement.

3 Research Objectives

- To quantify the functional and structural condition of the pavement which includes pavement roughness, distresses like cracking, raveling, potholes, and deflections
- To propose a maintenance plan for 15 years for the selected Urban roads.
- To perform life cycle cost analysis under periodic and condition responsive maintenance strategies

Table 1 Details of selected pavement sections

Road No	Terrain	Traffic (CVPD)	Length (km)
R-1	Plain	5650	5
R-2	Plain	9257	5
R-3	Plain	7150	3
R-4	Plain	6397	7
R-5	Plain	7890	9
R-6	Plain	7538	6
R-7	Plain	7184	5
R-8	Plain	6698	8

4 Road Network

Eight heavy traffic corridors in Delhi, India, with varied lengths and an average width of 7.5 m, were chosen, for collecting pavement functional and structural data. Each road section is representative of the whole length of the road in terms of traffic and climatic conditions. The selected roads were two-lane urban roads with Bituminous concrete surfacing. The details of the study roads are tabulated in Table 1.

5 Data Collection

The functional evaluation has been carried out on road sections in which functional parameters like distresses, pavement unevenness in terms of IRI have been quantified. NSV was employed to collect the functional data of pavements, Table 2 represents the average distress on each road section. The structural evaluation of the selected road sections has been carried out using Falling Weight Deflectometer (FWD) and Pavement deflection, a structural characteristic of pavement, has been calculated.

6 Maintenance of Pavements

Pavement preservation is defined as a long-term, approach for improving pavement performance by implementing an integrated, cost-effective set of activities that extend pavement life, improve safety, and provide required serviceability. Road maintenance is routine work that is done to keep the pavement, shoulders, and other amenities provided for road users as nearer to their original construction state as feasible under normal traffic and weather conditions. Maintenance is necessary to ensure that the pavement structure provides the best possible service over its lifetime. Because of the traffic and environmental effects, all pavements require care. Maintenance

Table 2 Pavement Distress Data

Roads	Average cracking	Average raveling	Average pothole	Average patching	Average rutting	IRI
	%/km	%/km	%/km	%/km	%/km	%/km
R-1	0.30	0.19	0.00	0.03	4.03	3.684
R-2	0.27	0.03	0.00	0.14	4.48	3.980
R-3	0.37	0.03	0.00	0.03	2.99	4.547
R-4	0.28	0.01	0.00	0.05	3.52	4.848
R-5	0.04	0.01	0.00	0.00	3.32	4.454
R-6	0.47	0.01	0.01	0.02	3.29	4.355
R-7	0.55	0.00	0.00	0.02	2.93	4.832
R-8	0.94	0.00	0.00	0.03	3.32	2.409

aids in the preservation of the pavement surface and avoids the need for premature reconstruction.

Periodic Maintenance: The current pavement maintenance plan focuses on doing routine maintenance as needed and repairing or reinforcing pavements every 5 years without considering their potential economic effects. The fundamental disadvantage of this method is that certain pavements, although being in good condition, are resurfaced in accordance with a time-specific renewal cycle, while other pavements swiftly deteriorate while needing replacement but not being included in the maintenance cycle.

Condition responsive maintenance: To provide maintenance based on certain intervention criteria. The proposed criteria are based on the frequently used performance indicators, such as roughness, cracks, rutting, skid, and potholes. As per IRC 82, when the condition rating of a rural road reaches a value of 2 to 1, periodic renewal treatments may be selected. In the case of highways and urban roads, however, periodic renewal at a serviceability level of 2 may be undertaken. Before the pavement rating decreases below 2, preventive maintenance must be performed. Structural Condition Index (SCI) as per Rohde's model between 80 and 100 indicate the pavement is structurally sound [11]. The maintenance phase of a Pavement Management System's major goal is to figure out how much it costs to provide various levels of serviceability for a specific pavement. Serviceability levels of primary roads as given in Table 3 The serviceability level considered for this study is Level 1.

6.1 Intervention Criteria

A layer of 25 mm BC must be provided once every five years as part of periodic maintenance, as per MoRT&H recommendations. For the purpose of reinforcing an existing pavement, a 75 mm DBM and 40 mm BC overlay must be provided every 10 years after construction. The intervention criteria for the study roads have been

Table 3 Levels of primary roads

No	Serviceability indicator	Level 1 (Good)	Level 2 (Average)	Level 3 (Acceptable)
1	Roughness by B.I (max. permissible)	2000 mm/km	3000 mm/km	4000 mm/km
2	Potholes per km (max. number)	Nil	2–3	4–8
3	Cracking and patching area (max. permissible)	5%	10%	10–15%
4	Rutting—20 mm (Maximum permissible)	5 mm	5–10 mm	10–20 mm
5	Skid Number (Minimum desirable)	50 SN	40 SN	35 SN

Source [9]

Table 4 Intervention criteria

No	Alternatives	Work type	Intervention criteria
1	Preventive maintenance	Crack repairs	>10%
		Pothole repairs	>1%
2	Thin overlay	25 mm BC	IRI >3000 mm/km'
3	Thick overlay	40 mm BC + 75 mm DBM or	IRI >3000 mm/km' After thin overlay is provided
		Recycling Of 40 mm bituminous layers and providing 100 mm DBM + 40 mmBC	

developed based on Table 5 and also on the opinion from the experts in the field. The preventive maintenance of pavement is carried out when cracking and pothole are greater than 10% and 1%, respectively. Thin overlay of 25 mm BC is given when the IRI of the road is more than 3000 mm/km. Thick overlay of 75DBM + 40BC is provided when the IRI increases more than 3000 mm/km even after providing a thin overlay (Table 4).

7 Deterioration of Pavements

The pavement deterioration models were developed by CRRI in 1994, under Pavement Performance Studies (PPS), for Indian roads, by considering the pavements with different wearing courses, viz., Asphalt Concrete, Semi Dense Carpet, and Premix Carpet in the states of Haryana, Gujarat and Rajasthan. 500 sections with traffic ranging between 1400 and 10,872 CVPD and length not less than 1 km were considered. Numerous time series data and correlations between pavement and pavement performance were included in the PPS. The study developed pavement performance prediction models for the major distresses, including cracking, potholes, Raveling, and roughness, which are most significant from road maintenance and road user cost considerations [10]. Since the models developed suited to the condition of selected roads of in terms of traffic, wearing course and the distresses were within the range as used in model development in the present study, these models were adopted for determining deterioration of selected roads during analysis period. The major distresses on study stretches were cracking and potholes; therefore, only cracking and pothole models were adopted to calculate the deterioration along with the roughness model.

8 Results

Both functional and structural evaluation of all the study stretches was carried out as mentioned in 5.1. The functional condition of the pavement is determined in terms of Pavement Condition Rating (PCR) as per IRC 82 2015 and structural condition in terms of Structural Condition Index (SCI) as per Rohde's model [11] (Figs. 1 and 2).

The deterioration of pavements is calculated for an analysis period of 15 years and the maintenance plan is shown in the table below. Since the study stretches were structurally adequate and the roughness of all the sections except section R-8 was more than 3000 mm/km a functional overlay of mixed seal surfacing is provided for R-1 to R-7 in the zeroth year (current Maintenance need) and then deterioration analysis is carried out and maintenance is provided based on intervention criteria. Table 5 shows the Maintenance Plan.

Economic Analysis

The life cycle cost analysis begins with the assumption of the analysis period. An analysis period of 15 years is assumed in the current study. Costs are calculated from the schedule of rates of the Public Works Department (PWD), Delhi region.

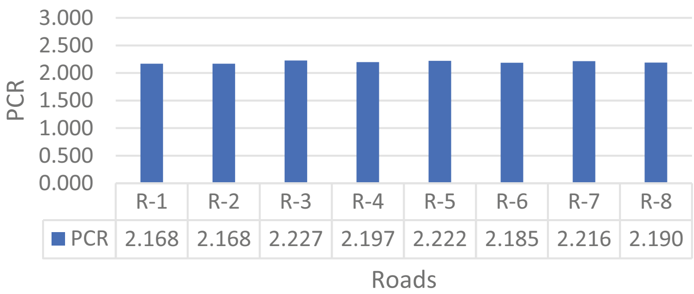

Fig. 1 Pavement condition rating

Fig. 2 Structural capacity index

Table 5 Maintenance plan

Road no year	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
0	FO	FO	FO	FO	FO	FO	FO	–
1	–	–	–	–	–	–	–	–
2	–	–	–	–	PM	–	–	FO
3	–	PM	PM	PM	–	PM	PM	–
4	PM	–	–	–	–	–	–	–
5	–	TO	TO	–	TO	TO	–	–
6	TO	–	–	TO	–	–	PM	PM
7	–	–	–	–	PM	–	–	–
8	–	PM	PM	–	–	PM	TO	TO
9	–	–	–	PM	–	–	–	–
10	PM	ST	ST	–	ST	ST	–	–
11	–	–	–	–	–	–	PM	–
12	ST	–	–	ST	PM	–	–	PM
13	–	PM	PM	–	–	PM	–	–
14	–	–	–	–	–	–	ST	ST
15	–	TO	TO	PM	TO	TO	–	–

FO: functional overlay of mixed seal surfacing, PM: Preventive Maintenance, TO: Thin Overlay of 25mm BC, ST: Strengthening of with 50mm BC + 75mm DBM

According to government policy, a discount rate of 12% and an inflation rate of 5.5% have been taken into account for future increases in material prices. The net Present Value of each of the alternatives is calculated. The alternative with the lowest NPV is selected as the best alternative. The comparison of NPV under periodic and condition responsive maintenance is presented in Tables 6 and 7.

Table 6 NPV comparison

Road no	Road length	NPV in crores		
	km	PM	CRM	CRMR
R-1	5	16.90	15.83	15.35
R-2	5	17.28	16.81	16.24
R-3	3	9.69	9.62	9.29
R-4	7	22.09	19.66	19.18
R-5	9	29.75	29.77	28.79
R-6	6	19.83	19.27	18.90
R-7	5	17.65	16.48	16.03
R-8	8	25.84	23.91	23.22

**PM: Periodic Maintenance; CRM: Condition Responsive Maintenance; CRMR: Condition Responsive Maintenance with Recycling

Table 7 D% Difference in NPV between PM and CRM

Road no	% Difference in NPV between PM and CRM	% Difference in NPV between PM and CRMR
R-1	6.33	9.17
R-2	2.72	6.02
R-3	0.72	4.13
R-4	11	13.17
R-5	0.07	3.23
R-6	2.82	4.69
R-7	6.63	9.18
R-8	7.47	10.14
Average	**4.7**	**7.47**

9 Pavement Performance

The pavement performance is calculated in terms of PCR as per IRC 82, 2015 under both periodic and condition responsive maintenance strategies. Figure 3 represents the performance of road R-1 under above-mentioned maintenance strategies.

10 Conclusions

The following conclusions have been drawn on the basis of this study:

- The economic analysis proves that condition responsive maintenance is more economical than periodic maintenance.

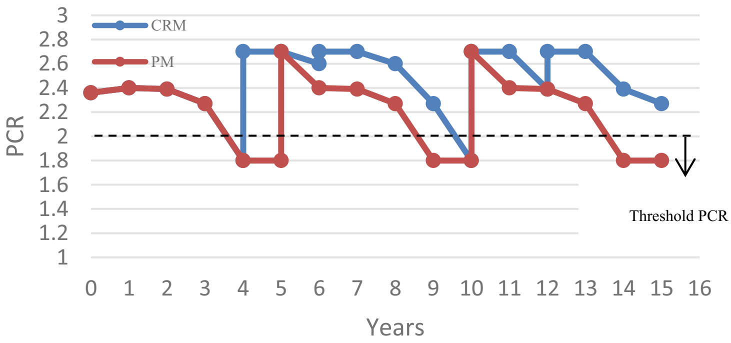

Fig. 3 Pavement Condition under periodic and condition responsive maintenance

- The condition responsive maintenance can be carried out at a cost of 4.7% less than the cost of periodic maintenance.
- Even though the difference in costs between periodic maintenance and condition responsive maintenance is minimal (around 1 crore on an average), the pavement can be maintained at level-1 or good condition under condition responsive maintenance as shown in Fig. 3.
- The condition responsive maintenance with recycling of the bituminous layer can be done at a cost of 7.47% less than the cost of periodic maintenance.

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