LIFE CYCLE COST ANALYSIS COMPARISON OF FLEXIBLE AND RIGID PAVEMENT

[1]Pankaj Singh Rajawat, [2]Prof. Kapil Soni
[1]Scholar M.Tech (Structure) Department of Civil Engineering, RNTU, Bhopal (M.P).
[2]Guide &HOD, Department of Civil Engineering, RNTU, Bhopal (M.P).

Abstract: - The methodology described here attempts to take advantage of all the capabilities of HDM-4, deal with the limitations of HDM-4, and produce usable results. The examples presented are actual HDM-4 inputs and results obtained from applying the model in many road stretches in the Bhopal city. The examples, which were selected from different evaluations performed on different roads to best illustrate a given evaluation step, do not otherwise reflect a particular pattern or relationship. The methodology used by the author calls for HDM-4 analysts to first identify the possible road works and then determine which road works to evaluate for each road class as a function of the traffic and other characteristics of the road class. For example, the works selected could be: (i) preventive treatment or surface treatment works for roads in good condition, (ii) surface treatment or asphalt concrete resurfacing works for roads in fair condition, and (iii) strengthening or reconstruction works for road in poor condition. It is important that the selected road works per road class be feasible from a purely technical point of view to produce realistic results.

The Pavement Management System methodology, developed in this study would be useful for the highway agencies in planning pavement maintenance strategies in a scientific manner and ensuring rational utilization of limited maintenance funds. Graphical presentations of PMS results will also be useful for gaining better support from decision-makers, for adequate and timely fund allocations for preservation of the highway network. This methodology may be used for preparing the maintenance management Programme for the National Highways covered under the prestigious National Highway Development Programme (NHDP) of India. Once this PMS methodology for National Highway network is implemented and made operational for a few years; this would serve as a window to State Governments, particularly for State Highways and Major District Roads. Thereafter, similar kind of PMS may be developed for other categories of roads such as State Highways and Major District Roads, using the inputs of PMS methodology presented in this study.

Life Cycle Cost Analysis of Bhopal Urban City Network

This study demonstrates the development of a pavement maintenance management programme for 10 no. selected urban city network of Bhopal, and budget forecasting for an analysis period of 15 years. The main objective of this study is to prepare an unconstrained works programme, to determine the required funding levels for defined network performance standards, and to prepare an optimized and prioritized works programme for reduced budget allocation.

Input data - The selection of databases and other input data for this study is shown in Figure 5.1. All 10-pavement sections included in the 'Bhopal City Network' database have been selected for this study, as shown in Figure 5.2. All 17 classes of vehicles included in the 'Bhopal Vehicle Fleet' database have been selected for this study as shown in Figure 5.3.

Defining alternative maintenance strategies – The life cycle cost analysis requires a comparison to be made between a Base alternative and one or more alternatives. For this study, eight alternatives have been defined for each pavement section, namely; a Base Alternative, ST 20mm PC, ST 25mm SDBC, ST 40mm BC, Overlay 20mm PC + 50mm BC, Overlay 20mm PC + 50mm DBM, Overlay 25mm SDBC + 75mm DBM and Reconstruction . The Base Alternative comprise of routine pavement maintenance activities in terms of Drainage cleaning, edge repair, pothole repair, crack seal and shoulder make-up. The other alternative includes surface treatments, overlays and reconstruction work activities. The maintenance works included in the Base Alternative are the same for all pavement sections. But in case of other alternatives, the applicable maintenance works for each pavement section will vary depending upon the Maintenance Serviceability Level. The selected maintenance strategies and the corresponding intervention criteria are given in Table 5.1 and are shown in Figure 5.4 to 5.6.

Table 5.1 Details of Selected maintenance Strategies for Program Analysis

Alternative Strategies	Works Standard	Maintenance Works	Intervention Criteria
Base Alternative	Routine Maintenance	Drainage cleaning, edge repair, pothole repair, crack seal and shoulder make-up	Scheduled Annually
Surface treatment 20mm PC	Periodic Maintenance	Overlay 20 mm Premix Carpet	Roughness >= 2.5 <3 IRI
Surface treatment 25mm SDBC	Periodic Maintenance	Overlay 25 mm SDBC	Roughness >= 3 <4 IRI
Surface treatment 40mm BC	Periodic Maintenance	Overlay 40 mm BC	Roughness >= 4 < 4.5 IRI

Overlay 20mm PC + 50 mm BM	Strengthening	Overlay 20 mm Premix Carpet + Overlay 50 mm BC	Roughness >= 4.5 < 5.0IRI
Overlay 25mm BC + 50 mm DBM	Strengthening	Overlay 25 mm BC + Overlay 50 mm DBM	Roughness >= 5< 5.5 IRI
Overlay 25mm SDBC + 75 mm DBM	Strengthening	Overlay 25 mm SDBC + Overlay 75 mm DBM	Roughness >= 5.5< 6.5 IRI
Reconstruction	Reconstruction	Reconstruction	Roughness >= 6.5 IRI

Life-cycle cost analysis - After selection of the alternative maintenance strategies, the Program Analysis application module of HDM-4 has been used to compare the total life-cycle costs, including the highway agency costs and road user costs, predicted under the Base Alternative of scheduled routine maintenance, against those predicted for the condition responsive maintenance alternative. The program application is run, as shown in Figure 5.7, for life cycle cost analysis of the whole Bhopal city network comprising of 10 pavement sections.

Summary of Life-cycle cost analysis – As a result of this analysis, the alternatives with the highest NPV are assigned for each pavement section. A summary of the life-cycle cost analysis, showing the increase in road agency costs and decrease in road user costs, as a result of selecting the maintenance alternative in comparison to the base alternative, is given in Table 5.2. All these costs have been discounted to the base year 2013, with a discount rate of 12%.

Unconstrained works programme – The life-cycle cost analysis of pavement sections results in a tentative unconstrained works programme determined by the specified maintenance work standards. The unconstrained works programme list, as shown in Table 5.2, gives details of the optimum maintenance work activities for the candidate pavement sections, year of their application, corresponding financial costs involved, and the cumulative budget requirements. The total agency cost required for maintenance management of the whole highway network for the analysis period of 10 years comes out to be 1014.20 million Indian Rupees. If sufficient budget is available, this unconstrained works programme can be taken up for final application on the highway network.

Table 5.2 Summary of Life Cycle Cost Analysis

Pavement Section	Traffic (AADT)	Year	Maintenance Work	B/C Ratio	Financial Cost*	Cumulative Cost*
45 M Road from Mahamaya Fly Over to Sector - 97, 98	8953	2013	ST 40 mm BC	4.89	66.00	66.00
	14140	2022	ST 40 mm BC	4.89	66.00	132.00
Gijhor road (Khora Vill. to MP - 3)	10492	2013	ST 40 mm BC	6.27	54.00	186.00
	16571	2022	ST 40 mm BC	6.27	54.00	240.00
MP Road No. 1 (From DND to T. Point Sector 12,22,56)	8124	2015	ST 40 mm BC	2.38	49.00	289.00
	14975	2027	ST 40 mm BC	2.38	49.00	338.00
MP road No. 2 (from sector 16 A to Sector 60)	9909	2013	ST 40 mm BC	4.55	120.00	458.00
	16468	2023	ST 40 mm BC	4.55	120.00	578.00
MP Road No. 3 (From Shahdra Drain to Sector - 60)	11247	2020	Reconstruction	7.15	90.00	668.00
Raghunathpur Agahpur Road (MP - 1 to MP - 3 Road)	11087	2013	ST 40 mm BC	5.76	30.80	698.80
	21482	2026	ST 40 mm BC	5.76	30.80	729.60
Sector - 62 Road along Khora Village	10430	2015	ST 40 mm BC	3.97	35.20	764.80
Sector - 62 road along NH – 24	8983	2013	ST 40 mm BC	3.81	34.00	798.80
	15713	2024	ST 40 mm BC	3.81	34.00	832.80
Sector -62 Rajat Vihar to Mamura Xing	10441	2013	ST 40 mm BC	9.19	36.30	869.10
	16489	2022	ST 40 mm BC	9.19	36.30	905.40
Udhyog Marg (Sector - 14 A T. Point to Jhundhpura)	9324	2013	ST 40 mm BC	3.22	54.40	959.80
	17165	2025	ST 40 mm BC	3.22	54.40	1014.20

* All costs are expressed in million Indian Rupees

Budget requirements - the year-wise budget requirements for the Bhopal City network under the Maintenance Alternatives are shown in Figure 5.8 and the Section wise budget requirements for the Bhopal City network under the Maintenance Alternatives are shown in Figure 5.9. It is quite clear from this figure that more than 39% (Rs. 395.50

million) of the total budget requirements need to be met with in the very first year (2013) of the analysis period itself, as majority of the pavement sections (7 sections) become candidate sections for maintenance works to be undertaken in this year itself. The remaining two pavement sections will become candidates in the third year (2015) and one pavement in the eighth year (2020) of the analysis period. Thereafter, there will be no immediate budget requirements for carrying out maintenance works. However, the need for maintenance works on most of the sections appears again in the following years, i.e. 2022 and 2023, as indicated by almost 27% (Rs. 276.30 million) of the total fund requirements during these two years. Some leftover pavement sections become candidates for maintenance works in the next year 2024. Thereafter, from year 2025 onwards, the yearly fund requirements show a variable trend till the end of the analysis period, depending upon the number of pavement sections becoming candidate sections for maintenance in a particular year.

Condition of the Bhopal city network

As a result of the above analysis, the predicted average roughness progression of the city network as a whole, under the Base Alternative and the Maintenance Alternative is shown in Figure 5.10 and the average roughness progression by each section is shown in Figure 5.11 to 5.20. The average roughness keep on increasing in case of Base Alternative because the routine maintenance operations do not help in reducing roughness, though it retards the rate of progression of roughness to some extent. However, in case of maintenance alternative, the average roughness value for the city road network decreases because of timely application of maintenance works.

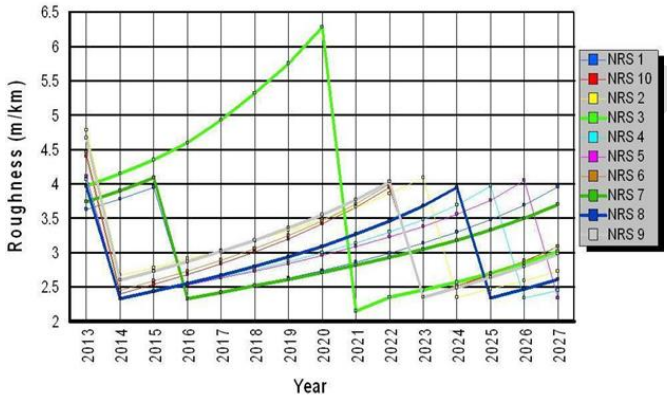

Figure 5.10 Average Roughness Value for the Bhopal City Network

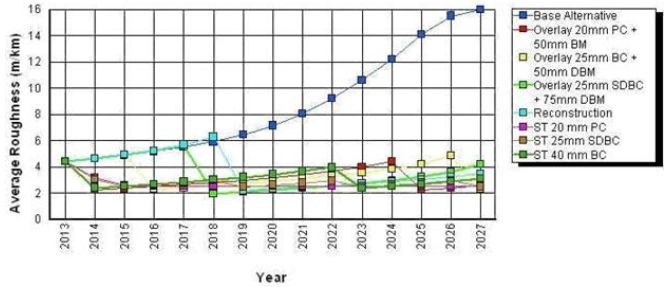

Figure 5.11 Average Roughness Value for the 45 M Road from Mahamaya Fly over to Sector - 97, 98

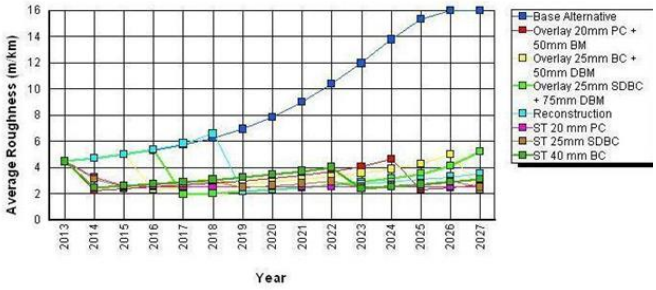

Figure 5.12 Average Roughness Value for the 45 M Road from Gijhor road (Khora Vill. to MP - 3)

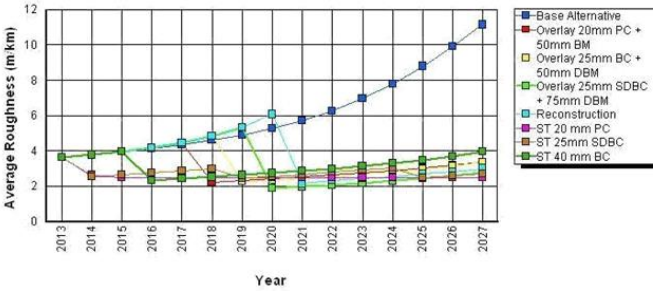

Figure 5.13 Average Roughness Value for the 45 M Road from MP Road No. 1 (From DND to T. Point Sector 12, 22, 56)

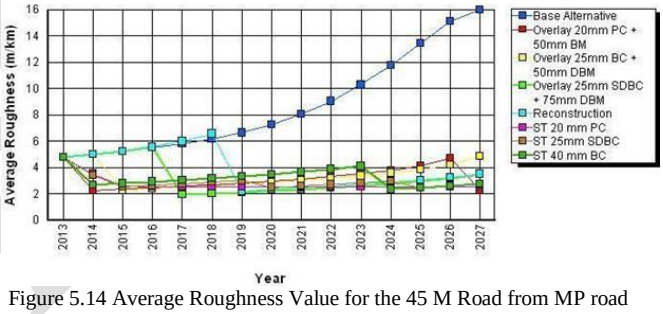

Figure 5.14 Average Roughness Value for the 45 M Road from MP road No. 2 (from sector 16 A to Sector 60)

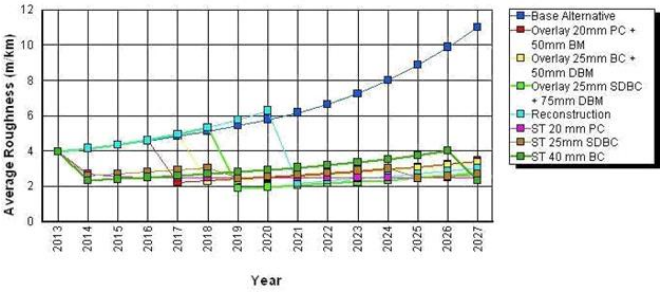

Figure 5.15 Average Roughness Value for the 45 M Road from MP Road No. 3 (From Shahdra Drain to Sector - 60)

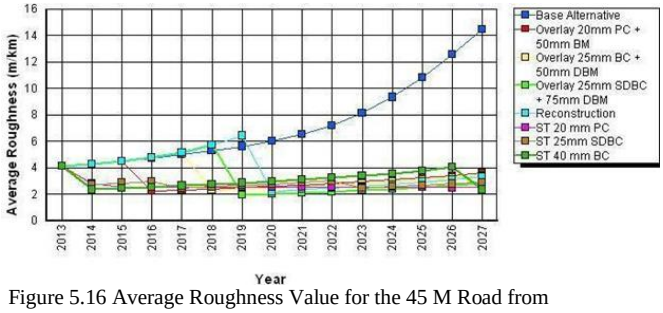

Figure 5.16 Average Roughness Value for the 45 M Road from Raghunathpur Agahpur Road (MP - 1 to MP - 3 Road)

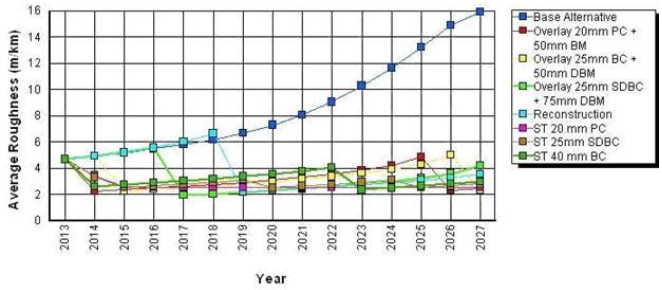

Figure 5.17 Average Roughness Value for the 45 M Road from Sector - 62 Road along Khora Village

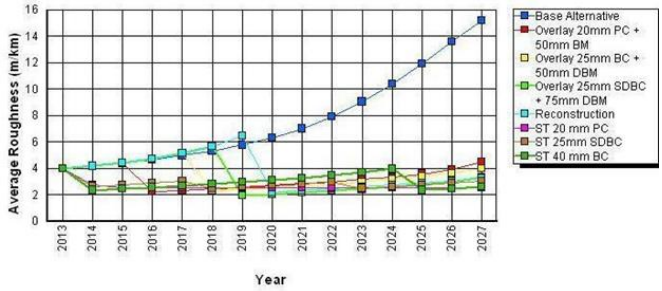

Figure 5.18 Average Roughness Value for the 45 M Road from Sector - 62 road along NH – 24

Budget optimization – In the unconstrained works programme, if the budget required for each period is below the available budget, no further economic analysis is necessary, and the unconstrained works programme can be adopted as such. However, if the budget needs are higher than the available budget, the following two options may be considered:

1. Revise maintenance standards and run the life-cycle analysis again
2. Execute budget optimization

Since the maintenance standards have already been fixed, keeping in view the minimum requirements of the candidate pavement sections, very little scope exists for their revision. Hence, under most of the circumstances, the second option of budget optimisation would usually be selected. The budget optimisation provides a facility to select road sections that can be included within a specified budget in order to maximize the economic benefits. After performing the budget optimisation, a revised work programme is worked out. This works programme has a total cost requirement that is within the specified budget.

Optimized works programme - In case, sufficient funds are not available to carry out all the maintenance activities, as obtained for the unconstrained works programme, the works programme need to be optimized depending upon the available budget. The budget optimisation process is performed with Rs. 800 million budget availability, as against the requirement of Rs. 1014.20 million, over the analysis period of 15 years. The optimisation process is set up by specifying the minimum incremental value for NPV and the budget optimisation is performed using the 'Incremental Analysis Method', as shown in Figure 5.21 and 5.22. This process results in an optimized works programme list, as given in Table 5.3. This optimized works programme has total budget requirements of Rs. 790.20 million, which is almost equal to the available budget of Rs. 800 million.

Table 5.3 Section-wise Optimized Works Programme List

Pavement Section	Traffic (AADT)	Year	Maintenance Work	B/C Ratio	Financial Cost*	Cumulative Cost*
45 M Road from Mahamaya Fly Over to Sector - 97, 98	8953	2013	ST 40 mm BC	4.89	66.00	66.00
	14140	2022	ST 40 mm BC	4.89	66.00	132.00
Gijhor road (Khora Vill. to MP - 3)	10492	2013	ST 40 mm BC	6.27	54.00	186.00
	16571	2022	ST 40 mm BC	6.27	54.00	240.00
MP Road No. 1 (From DND to T. Point Sector 12,22,56)	10472	2020	Reconstruction	6.31	62.00	282.00
MP road No. 2 (from sector 16 A to Sector 60)	12765	2018	Reconstruction	18.82	142.00	354.00
MP Road No. 3 (From Shahdra Drain to Sector - 60)	11247	2020	Reconstruction	7.15	90.00	444.00
Raghunathpur Agahpur Road (MP - 1 to MP - 3 Road)	11087	2013	ST 40 mm BC	5.76	30.80	474.80
	21482	2026	ST 40 mm BC	5.76	30.80	505.60
Sector - 62 Road along Sector - 62 road along NH - 24	10430	2015	ST 40 mm BC	3.97	35.20	540.80
	8983	2013	ST 40 mm BC	3.81	34.00	574.80
	15713	2024	ST 40 mm BC	3.81	34.00	608.80
Sector -62 Rajat Vihar to Mamura Xing	10441	2013	ST 40 mm BC	9.19	36.30	645.10
	16489	2022	ST 40 mm BC	9.19	36.30	681.40
Udhyog Marg (Sector - 14 A T. Point to Jhundhpura)	9324	2013	ST 40 mm BC	3.22	54.40	735.80
	17165	2025	ST 40 mm BC	3.22	54.40	790.20

* Cost is expressed in million Indian Rupees

Comparison of HDM4 output with experimental result

The data collection of a pavement section at Patiala City was done and analysis on HDM-4 was performed. The following data has been collected for roughness, cracking, pot holes and Rut depth. The comparison is performed in HDM-4. Following are the results of the comparison.

Table 5.5 Roughness values of actual and results from HDM-4 in IRI m/Km

Section ID UR-04	July 2012	April 2013	Dec 2013
Actual	2.50	2.54	2.63
HDM4	2.50	2.60	2.72

CONCLUSIONS

(i) The network level pavement management analysis has been carried out using the Program Analysis' application module of HDM-4. The life-cycle cost analysis of the selected urban city network has been carried out, and an unconstrained works programme has been prepared for the defined analysis period of 15 years. The total budget requirements for maintenance management of the whole city network at a pre-defined, optimum serviceability level have been determined, which comes out to be equal to Rs. 1014.20 million. The budget optimisation process is performed with Rs. 800 million budget availability. The Comparison of Unconstrained and Constrained Budget Analysis is presented in the Table 7.1. It is observed that in the section 'NRS3', in Unconstrained Budget Analysis strengthening alternative 'ST 40mm BC' is applied two times in years 2015 and 2027 respectively. When the Constrained Budget Analysis is performed, then only Reconstruction alternative is applied in the year 2020 at roughness greater than 6.5 IRI value. Similar is in the case of Section 'NRS4'.

(ii) The motorized vehicles have higher growth rates, which cause the increase in volume of traffic and the pavement condition gets deteriorated. Hence require a large amount of funds to maintain such urban roads. When the funds are limited, the PMMS can be used to optimize the budget for the urban roads as per the available amount of resources.

(iii) The average roughness value of the city network will not change much if the maintenance is delayed by one year, but in case the application of maintenance activities is deferred by two years, the roughness value will rise very sharply to 7.57 m/km IRI in the year 2020. A further delay of one year will cause rise in roughness value up to 8.65 m/km IRI in the year 2021. This will result in very high vehicle operation cost for the road users. Therefore, the maintenance activities should be carried out as and when they become due as per the unconstrained works programme.

(iv) The HDM-4 makes provision for a much wider range of upgrading options, pavement types, seal types and other maintenance options.

(v) All three alternatives of pavement maintenance are compared to each other on economic analysis. The Alternative of providing 40 mm BC has been found as the optimum pavement maintenance management strategy.

(vi) The scope of present study may be extended for the development of PMMS methodology for the urban city network having rigid pavements.

(vii) The life cycle approach requires not only an in-depth evaluation of the pavement under consideration, but also prediction of its future condition

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