MAINTENANCE STRATEGY AND BUDGETING FOR ROAD NETWORK IN KARNATAKA STATE USING HDM-4

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Abstract

The Public Works, Ports, and Inland Water Transport Department of Karnataka, India, oversees a diverse road network. This network spans approximately 76,060 km and includes 6,572 km of National Highways, 19,587 km of State Highways, and 49,910 km of Major District Roads. The variety of road types presents a unique challenge in developing a comprehensive maintenance strategy and budgeting plan.

This study, of significant importance, focuses on developing an optimal maintenance strategy for 17,472 km of State Highways (SH) and Major District Roads (MDRs) within the Core Road Network (CRN) of Karnataka. The data collection process was thorough, ensuring the accuracy and reliability of the results. Functional condition data, such as roughness, rut depth, surface distress (cracking, ravelling, patching), and geometric characteristics, were collected using a laser-based Road Condition Data Collection Vehicle (RCDCV). Structural pavement conditions were assessed using a Falling Weight Deflectometer (FWD), and maintenance and rehabilitation history was obtained from the Department's Road Information System.

The collected data were used for program-level analysis to generate the Annual Works Program (AWP) and optimize budgets for various alternatives over a 10-year analysis period using HDM-4. The findings of this study have direct and practical implications, as they demonstrate the impact of different maintenance and rehabilitation strategies on pavement deterioration under varying budget constraints. One budget alternative could reduce the International Roughness Index (IRI) from 6.3 to around 3.5 within four years, with an average annual budget of 35,000 million INR. Maintaining the network at an average IRI of 3.5 for the subsequent six years would require an average annual budget of 5,000 million INR.

1 Introduction

The road transport system plays a vital role in the economic and social progress of the nation. India has the second largest road network in the world, covering about 63.32 lakh miles. This encompasses National Highways, Motorways, State Highways, Major District Roads, Other District Roads, and Village Roads.

The road transport system accounts for approximately 3.12% of the country's Gross Value Addition (GVA).

The Ministry of Road Transport and Highways (MoRTH) was allocated INR 2.17 lakh crores in the Union Budget of India. (Ministry of Finance 2023) for the fiscal year 2023-2024.

The Indian government has allocated 5.95 Lakh Crores to the Ministry of Road Transport and Highways to develop Road Infrastructure from 2019 to 2023. During the fiscal year 2019-23, the roads sector will be estimated to represent 18 per cent of the total capital spending.

Hence, ensuring that the road infrastructure is adequately maintained during its designated lifespan is imperative. The criteria for selecting the frequency and kind of maintenance jobs for rural roads, as specified in the Indian Roads Congress Guidelines for Maintenance Management or Primary, Secondary and Urban Roads (Indian Road Congress 2004), are mainly based on subjective judgment and substantially depend on the practical expertise of field engineers. These guidelines do not incorporate any economic analysis.

The allocation of financing for the maintenance of the Highway Network in India is determined through established guidelines, the expertise of the Engineer in charge, and data derived from current road information. Nevertheless, this system's precision diminishes when there are constraints on the accessibility of funds. Consequently, they searched for pragmatic ways to tackle road maintenance and rehabilitation challenges, considering the limitations on the resources at hand. One element in this process entails creating a Pavement Management System (PMS) to handle the various conditions observed around the country effectively. Pavement management systems (PMS) commonly incorporate a specific component focused on pavement maintenance (PMMS). This section frequently contains models that can be utilised to ascertain the treatment that will produce the most cost-effectiveness. Several variables, including surface features, pavement type, and other significant criteria, generally influence them. Ensuring that the necessary maintenance treatment is implemented promptly is essential for the pavement to operate at its best and for the maintenance schedule to be cost-effective. Progress in information technology has resulted in significant enhancements in Pavement Management Systems (PMS) and Pavement Maintenance Management Systems (PMMS) in the last twenty years. Transportation agencies nowadays possess a range of technologies and methods that they can utilise to enhance the efficiency of the construction, upkeep, and restoration services offered for roadways. The Highway Development and Management (HDM-4) tool is a widely recognised and influential analytical tool.

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1.1 Highway Development and Management System

The Highway Development and Management Model – 4 (HDM-4) is a widely acknowledged model that assists pavement managers in assessing road maintenance, improvements, and investment choices at all levels of management. HDM-4 is mostly utilized in strategic planning, road work programming, project analysis, and research and policy analysis(Kerali et al. 2006; Morosiuk et al. 2006; Odoki and Kerali 2006)

Strategic planning is concerned with analyzing a chosen network. A typical application is the preparation of long-range planning estimates of expenditure needs for road network development and maintenance under different budget scenarios. Estimates are produced for expenditure requirements for medium to long-term periods of 5 to 40 years.

These applications are utilized to predict yearly road conditions and assess highway construction and maintenance strategies. The HDM-4 road deterioration models are designed to replicate the complex interplay among vehicles, the environment, pavement design, and surface characteristics.

The data needed for Network Analysis with HDM-4 include details such as Vehicle Fleet Data, Maintenance and Rehabilitation Data, and Road Network Data containing Functional Data like Roughness, extent of distress, rutting, etc. Structural Condition data is gathered using tools like Road Condition Data Collection Vehicle (RCDCV), Benkelman Beam / Falling Weight Deflectometer, and other secondary sources.

1.2 Pavement Deterioration Models

Deterioration models play a crucial role within the domain of Pavement management systems. Pavement degradation constitutes a multifaceted and ever-changing phenomenon influenced by various elements such as material properties, environmental conditions, design specifications, and additional latent variables. Precise forecasts regarding pavement conditions can potentially optimise resource utilisation for pavement management entities by enhancing the efficiency of preservation and maintenance endeavours.

2 Literature Review

The calibration of the HDM–4 models play a vital role in obtaining accurate results that depict the field conditions in future years. The authors have tried calibrating the HDM–4 models using the CRRI deterioration models (Jain et al. 2005)**.** The analysis conducted to maximize the net present value (NPV) and minimize the costs to achieve a desirable target international roughness index (IRI). Urban roads can be managed and maintained effectively using the HDM-4 strategy. (Yogesh et al. 2016). Researchers used the HDM-4 tool to model different road distresses, such as potholes, for newly constructed flexible pavements with modified bitumen, comparing

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observed conditions with predictions to validate the models (Deori et al. 2018). Researchers applied statistical analysis to the data collected, using equations from the HDM-4 models, and performed linear regression to compare predicted values against observed values for calibration (Bannour et al. 2019). The paper affirms that utilizing the HDM-4 approach can greatly assist road agencies in effectively preserving road assets, enhancing service for users, and making well-informed decisions regarding maintenance strategies. (Bannour et al. 2022). HDM-4 in pavement management offers valuable insights into budget projection, investment alternatives, and the enduring maintenance necessities of urban road networks (Rejani et al. 2023).

3 Objectives

The objective of the study is mainly focused on

- Develop an optimal maintenance and rehabilitation strategy for a part of the Core Road Network of 17,472 km.
- Compare different maintenance and rehabilitation treatment alternatives for different budget conditions by optimising NPV in achieving the targe IRI

4 Analysis

Program Level analysis uses HDM–4 Software based on a well-established economic analysis framework. The Road Network consists of State Highways and Major District Roads of length 17,472 Km, a part of Karnataka's Core Road Network. Economic evaluation of the road network compares the benefits and costs to the country's economy. Thus, economic analysis uses the economic prices computed from the market prices, excluding taxes, duties, profits, sundries, etc., to measure the legitimacy of using national resources for the improvement and maintenance programme.

4.1 Road Network

The road network of 17,472 km was divided into 2863 homogenous sections based on carriageway width, road roughness traffic volume and geographical condition.

The road data was collected by the Planning and Road Asset Management Center (PRAMC) of Karnataka Public Works, Ports & Inland Water Transport Department (KPWP&IWTD) using a laser-based Road Condition Data Collection Vehicle (RCDCV). The functional data used in this analysis includes the International Roughness Index (IRI), rut depth, type, and extent of distress, with a sample interval of 100m. The structural condition was collected using a vehicle-mounted Falling Weight Deflectometer (FWD) with a sampling interval of 500m. Secondary data, such as earlier maintenance and rehabilitation details, were obtained from the department's road information system. The summary of the road network condition is shown in Table 1.

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Table 1. Summary of Road Network Condition

Road Class	IRI Range(m/km)				
	Good (< 4)	Fair (4 - 6)	Poor (6 - 9)	Bad (> 9)	Total
State Highway	3,346.4	5,430.5	5,518.7	2,037.9	**16,333.5**
Major District Road	132.5	340.5	463.2	202.3	**1,138.5**
Total	3,478.9	5,771	5,981.9	2,240.2	**1,7472**
Percentage (%)	**19.91%**	**33.03%**	**34.24%**	**12.82%**	

4.2 Vehicle Fleet Data

The representative vehicles for the road network were considered based on the 7-day classified traffic volume count. The economic cost of the car and the new tyres were worked out by considering the average market price of the product based on the vehicular type, and the various taxes were deducted to obtain the economic cost. Fuel and lubricant costs were obtained from the annual report of the Petroleum & Natural Gas Department. (*Indian Petroleum & Natural Gas Statistics 2022-23* 2023).The wages for the drivers of the vehicle are considered based on the standard wages fixed for each type of driver for different vehicular categories. The annual overheads are calculated based on the yearly cost spent on the maintenance of the vehicles. The cargo cost is calculated based on the prevailing rates for cargo transportation. (Government of Karnataka 2023a)

4.3 Road Widening Cost

The capital costs in financial terms are worked out based on cost estimates based on the Common Schedule of Rates published by KPWP&IWTD for 2023-24 (Government of Karnataka 2023b) . If there is a requirement for widening in the next 10 years, road widening has been proposed. The cost of the widening has been considered for the base year 2023-24 and is shown in Table 2.

Table 2. List of Widening Standards

Widening Proposals	Criteria	Crust Composition	Financial Cost	Economic Cost
			(In Million INR)	
Single Lane to Two Lane	Two Way AADT between 2000 - 15000; Roughness between 4-6 m/km	40mm AC + 50mm DBM + 250mm WMM +	14.35	12.91
Single Lane to Two Lane - 1	Two Way AADT between 2000 - 15000; Roughness between 6-8 m/km		17.22	15.50

Widening Proposals	Criteria	Crust Composition	Financial Cost	Economic Cost
			(In Million INR)	
Single Lane to Two Lane - 2	Two Way AADT between 2000 - 15000; Roughness greater than 8 m/km	250 mm GSB + 500mm Subgrade	21.61	19.45
Intermediate Lane to Two Lane	Two Way AADT between 6000 - 15000; Roughness between 4-6 m/km		11.53	10.38
Intermediate Lane to Two Lane - 1	Two Way AADT between 6000 - 15000; Roughness between 6-8 m/km		13.84	12.45
Intermediate Lane to Two Lane - 2	Two Way AADT between 6000 - 15000; Roughness greater than 8 m/km	40mm AC + 50mm DBM + 250mm WMM + 250 mm GSB + 500mm Subgrade	17.30	15.57
Intermediate Lane to Two Lane with Paved Shoulder	Two Way AADT between 6000 - 15000; Roughness between 4-6 m/km		20.44	18.40
Intermediate Lane to Two Lane with Paved Shoulder - 1	Two Way AADT between 6000 - 15000; Roughness between 6-8 m/km		24.53	22.08
Intermediate Lane to Two Lane with Paved Shoulder - 2	Two Way AADT between 6000 - 15000; Roughness greater than 8 m/km		29.30	26.37

Note: AADT is presented in Number of Vehicles.
DBM: Dense Bituminous Macadam (Binder Layer)
WMM: Wet Mix Macadam (Granular Base Layer)
GSB: Granular Sub-Base

4.4 Routine and Periodic Maintenance Costs

Routine and Periodic maintenance alternatives are worked out based on the departmental practices and costs are estimated based on the Common Schedule of Rates published by KPWP&IWTD for 2023-24 (Government of Karnataka 2023b) and are presented in Table 3 and Table 4 Respectively.

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Table 3. Cost of Routine Maintenance

Type of maintenance	Unit	Composition	Criteria for Selection	Financial Cost	Economic cost
				(In INR)	
Thin overlay	Sq.m	AC – 40 mm	Roughness (4 - 6 m / km)	533	480
Structural	Sq.m	AC – 40 mm	Roughness (6 - 8 m / km)	925	833
Reconstruction	Sq.m	AC – 40 mm DBM – 50 mm	Roughness >= 8 IRI, AND Cumulative ESAL	2,314	2,083

Table 4. Cost of Periodic Maintenance

Type of Maintenance	Unit	Criteria	Financial	Economic
			(In INR)	
Patching	Per sq. m	Potholes >=5, <=500 No./Km, OR	426	384
Shoulder Repair	Per km	Every year	14,753	13,278
Jungle clearance	Per km	Every year	11,220	10,098
Drain Maintenance	Per km	Every year	33,860	30,474

4.5 Budget Analysis

Programme-level analysis was conducted using the HDM-4 to prioritise road improvement and maintenance works for different budget scenarios. A discount rate of 12% is adopted for the analysis. Five different budget scenarios are considered for optimisation. The constrained budget scenarios considered are increments of 10%, 15%, 20% and 25% of Year-1 budget allocation for State Highways and Major District Roads in Karnataka and a 10% increment on the overall PWD Budget.

The 10% increment on the overall PWD Budget scenario is proposed based on the practical consideration that, in the unconstrained budget scenario, the first-year investment requirement is 89,409 million INR, which is an ideal objective and very unlikely to be obtained in any case. Instead of this huge investment in the first year, it could be distributed in the first three years with a static budget of 30,000 million INR to clear all backlog maintenance on the road network and bring the roughness at the desired level of around IRI value of 4. The year-wise cost and length of the road network Improved for different budget Scenarios are indicated in Table 5.

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Table 5. Year-wise Capital Cost and Road Lengths for Budget Scenarios

Year	Budget Scenarios (In Million INR) (Annual Works Programme Road Length in KM)					
	Unconstrained Budget Scenario	**10% Incremental Budget Scenario**	**15% Incremental Budget Scenario**	**20% Incremental Budget Scenario**	**25% Incremental Budget Scenario**	**10% Increment on Overall PWD Budget Scenario**
Year -1	89,409 (12324 KM)	4,950 (537 KM)	5,170 (560 KM)	5,400 (590 KM)	5,620 (613 KM)	30,000 (3078 KM)
Year -2	9,693 (2936 KM)	5,440 (493 KM)	5,950 (557 KM)	6,480 (589 KM)	7,030 (638 KM)	30,000 (3402 KM)
Year -3	9,184 (1715 KM)	5,990 (560 KM)	6,840 (620 KM)	7,780 (720 KM)	8,790 (819 KM)	29,990 (4432 KM)
Year -4	10,871 (1716 KM)	6,590 (662 KM)	7,870 (788 KM)	9,330 (921 KM)	10,990 (1090 KM)	16,360 (5784 KM)
Year -5	7,702 (1135 KM)	7,250 (687 KM)	9,050 (847 KM)	11,190 (1107 KM)	13,730 (1398 KM)	10,050 (1473 KM)
Year -6	9,111 (1065 KM)	7,970 (753 KM)	10,410 (1025 KM)	13,440 (1390 KM)	17,170 (1836 KM)	12,120 (1035 KM)
Year -7	12,087 (901 KM)	8,770 (803 KM)	11,970 (1295 KM)	16,120 (1840 KM)	21,450 (2444 KM)	15,910 (1221 KM)
Year -8	12,069 (975 KM)	9,640 (1020 KM)	13,760 (1577 KM)	19,350 (2239 KM)	26,820 (3423 KM)	13,160 (983 KM)
Year -9	8,583 (1596 KM)	10,610 (1301 KM)	15,830 (1884 KM)	23,220 (2924 KM)	33,530 (1694 KM)	8,310 (1020 KM)
	12,567	11,670	18,210	27,860	41,910	12,580

Year	Budget Scenarios (In Million INR) (Annual Works Programme Road Length in KM)					
	Unconstrained Budget Scenario	10% Incremental Budget Scenario	15% Incremental Budget Scenario	20% Incremental Budget Scenario	25% Incremental Budget Scenario	10% Increment on Overall PWD Budget Scenario
Year -10	(2451 KM)	(387 KM)	(643 KM)	(620 KM)	(482 KM)	(1272 KM)

The Predicted IRI Values for the Road network are indicated in Table 6 and

Table 7. It is observed that for the Unconstrained Budget scenario, the roughness values reduce to less than 4 in one year (2019), and for the 10% Increment on the Overall PWD Budget Scenario, the roughness value will reduce to less than 4.5 IRI after the fourth year. The predicted IRI for State Highways and Major District Roads for the different budget alternatives are shown in Figure 1.

Table 6. Predicted IRI values on State Highways of Total Road Network

Year	10% Incremental Budget	15% Incremental Budget	20% Incremental Budget	25% Incremental Budget	10% Increment on Overall PWD	Unconstrained Budget
Year-1	6.3	6.3	6.3	6.3	6.3	6.3
Year-2	6.3	6.3	6.3	6.3	5.6	3.6
Year-3	6.4	6.4	6.4	6.3	5.1	3.5
Year-4	6.5	6.5	6.4	6.4	4.4	3.4
Year-5	6.5	6.5	6.4	6.3	3.4	3.4
Year-6	6.6	6.5	6.4	6.2	3.3	3.3
Year-7	6.6	6.4	6.1	5.9	3.3	3.3
Year-8	6.5	6.2	5.8	5.4	3.3	3.4
Year-9	6.3	5.9	5.4	4.7	3.3	3.4
Year-10	6.2	5.6	4.8	4.5	3.3	3.4

Table 7. Predicted IRI Values on Major District Roads of Total Road Network

Year	10% Incremental Budget	15% Incremental Budget	20% Incremental Budget	25% Incremental Budget	10% Increment on Overall PWD	Unconstrained Budget
Year-1	6.8	6.8	6.8	6.8	6.8	6.8
Year-2	6.8	6.8	6.8	6.8	5.8	3.1

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Year	10% Incremental Budget	15% Incremental Budget	20% Incremental Budget	25% Incremental Budget	10% Increment on Overall PWD	Unconstrained Budget
Year-3	6.6	6.5	6.5	6.5	4.7	3.1
Year-4	6.7	6.6	6.6	6.5	4.0	3.1
Year-5	6.9	6.8	6.7	6.5	3.1	3.1
Year-6	6.9	6.6	6.2	5.9	3.1	3.1
Year-7	7.1	6.3	5.9	5.8	3.1	3.1
Year-8	6.6	5.7	5.3	4.5	3.1	3.1
Year-9	6.1	5.6	4.5	4.1	3.2	3.2
Year-10	5.8	4.7	4.2	4.1	3.3	3.3

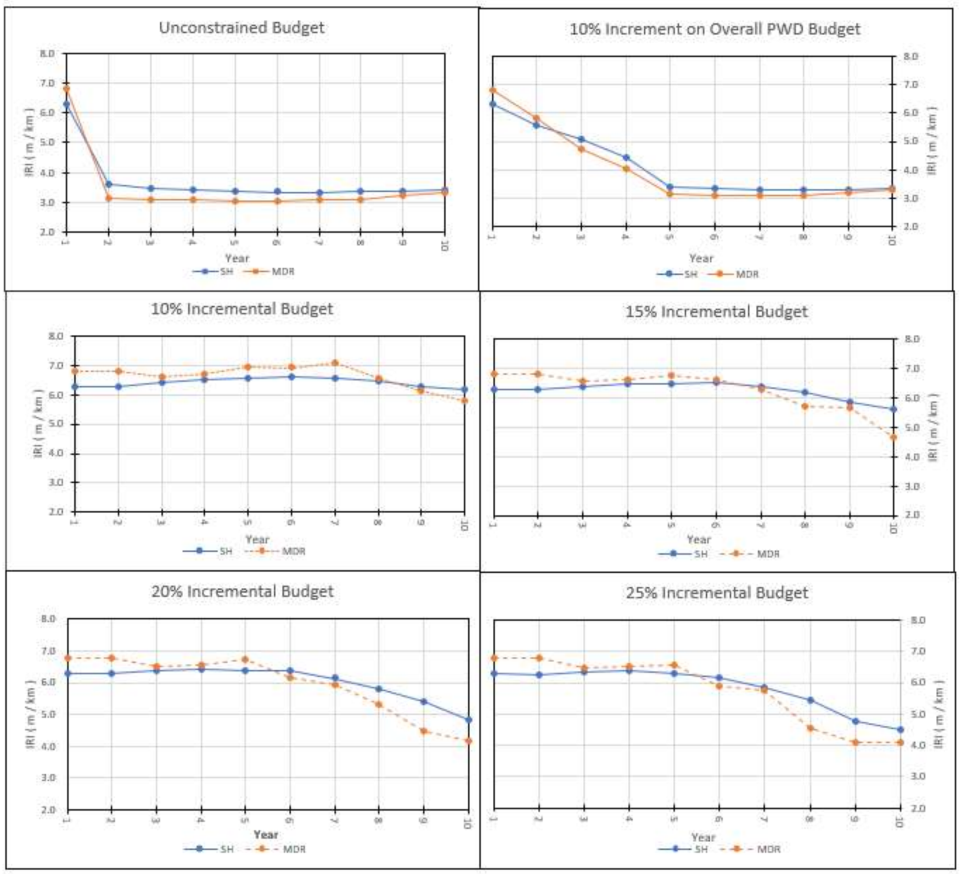

Figure 1. IRI Progression during the Analysis Period for Budget Alternatives

From the above data, it can be concluded that the "10% Increment on Overall PWD Budget" Scenario predicts the road network IRI at about 3.3 m/km at the end of ten years, close to the Unconstrained Budget scenario. Thus, the "10% Increment on Overall PWD Budget" Scenario is the most economical.

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4.6 Annual Works Program

The Capital Cost and Recurrent Cost for the "10% Increment on Overall PWD Budget" scenario year-wise are indicated in Table 8.

Table 8. Capital and Recurrent Cost Year Wise

Year	Improvement	Capital Cost (in Million	Maintenance	Recurrent Cost (in Million INR)
Year-1	3078	29997	14393	1321
Year-2	3402	29999	14069	1305
Year-3	4432	29999	13040	1049
Year-4	5784	36363	11688	736
Year-5	1473	8510	15999	936
Year-6	1035	6668	16436	951
Year-7	1221	6545	16251	942
Year-8	983	6005	16488	951
Year-9	1020	7751	16452	951
Year-10	1272	7401	16200	941

5 Conclusion

The main findings of this study are

- The unconstrained budget scenario predicted a sustainable investment in the first year itself, indicating a huge backlog in maintenance that must be taken care of in the first instance. Otherwise, relatively low investments will not affect reducing current roughness, which has already reached an average value of 6.2 IRI, which should not be ignored. In summarising the above results, it is noted that due to budgetary constraints, the unconstrained scenario is not a feasible option at this juncture.
- In the budget scenarios, such as 10%, 15%, 20% and 25% incremental of the current year budget, the IRI value does not fall below 4.0, meaning that the road condition will not come to the desired level of IRI with those levels of funding and is not recommended.
- In the case of a 25% incremental budget scenario, the IRI level will come to the desired level in the 10th year, which is also undesirable.
- In the case of "10% Increment on the overall PWD Budget Scenario", the IRI values can be brought down to around 3.5 from the present level of 6.3 within four years. This results in an average annual budget of 35,000 million INR for four years and an average budget of 500 million INR for the remaining six years to maintain the network at an average IRI of 3.5.
- The 10% increment on the overall PWD budget scenario" is the most economical and gives the maximum reduction in VOC and maintains the entire network at a serviceable roughness of IRI 3.3 m/km

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