

PAVEMENT DETERIORATION ANALYSIS USING HDM-4 SOFTWARE

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Abstract - A well-developed transportation system plays a vital role in the economic development of a country. However, continuous growth in vehicular population and axle loads leads to accelerated pavement deterioration on major highways. The Pune to Satara section of NH-48, with an approximate length of 110 km, experiences significant distress in the form of rutting, cracking, and surface deformation due to heavy traffic movement. Therefore, timely assessment and maintenance planning are essential to ensure serviceability and safety of the pavement. The present study focuses on evaluating pavement deterioration and its impact on performance and economic feasibility of maintenance strategies. The analysis is carried out using HDM-4 software to assess deterioration trends, predict future conditions, and determine cost-effective rehabilitation measures. The economic evaluation is based on parameters such as vehicle operating cost, travel time savings, and Economic Internal Rate of Return (EIRR). The results indicate that appropriate maintenance and strengthening alternatives significantly reduce deterioration rate and are economically viable, ensuring improved riding quality and extended pavement life.

Keywords - Pavement deterioration; NH-48; HDM-4; Economic Internal Rate of Return (EIRR); Flexible pavement; Maintenance strategies; Highway performance; Economic viability.

I. INTRODUCTION

Highways are the dominant mode of transportation in India and play a crucial role in supporting economic growth and regional connectivity. The Pune to Satara section of NH-48, spanning approximately 110 km, is one of the important corridors that carries heavy traffic including commercial vehicles. Due to continuous increase in traffic volume and axle loads, this highway section is increasingly subjected to pavement deterioration in the form of cracking, rutting, potholes, and surface irregularities. Improvement and proper maintenance of highway infrastructure lead to reduction in travel time, decrease in vehicle operating costs, enhanced safety, and minimization of environmental impacts. If timely measures are not taken, pavement deterioration can significantly affect ride quality, increase maintenance costs, and reduce the overall efficiency of the transportation network. Therefore, systematic evaluation of pavement condition and planning of appropriate maintenance strategies are essential for sustainable highway performance. The decision-making process for selecting the most suitable maintenance and rehabilitation strategy often faces challenges due to the lack of reliable and customized economic evaluation tools.

II. OBJECTIVES OF PRESENT STUDY

- To Carry out an economic analysis using HDM - 4 software to identify economic conditions.
- To Study the pavement Deterioration analysis using HDM -4 software.
- To calculate important pavement performance metrics under various circumstances, such as rutting, cracking, and roughness

III. OVERVIEW OF HDM-4

HDM-4 is a computer-based tool used for highway development and maintenance management. It supports decision-making by evaluating both engineering performance and economic feasibility of road investment projects. The software was developed for global application with support from the World Bank. HDM-4 helps in analyzing pavement condition, predicting deterioration, estimating costs, and comparing different improvement alternatives. It mainly includes three types of analysis:

- **Project Analysis:**

Used to assess individual road projects by comparing different alternatives with a base case (do-nothing scenario). It helps in selecting the most suitable option for maintenance, rehabilitation, or construction.

- **Programme Analysis:**

Focuses on prioritizing multiple road projects within a limited budget. It selects the best combination of projects by

maximizing economic benefits such as NPV or cost-effectiveness.

- **Strategic Analysis:**

Involves long-term evaluation of the entire road network under different budget scenarios.

IV. STUDY AREA

The Pune to Satara section is located in western Maharashtra and forms part of NH-48. The study stretch is approximately 110 km long and carries heavy traffic.

The project road lies between about 18°31' to 17°41' North latitude and 73°51' to 74°00' East longitude.

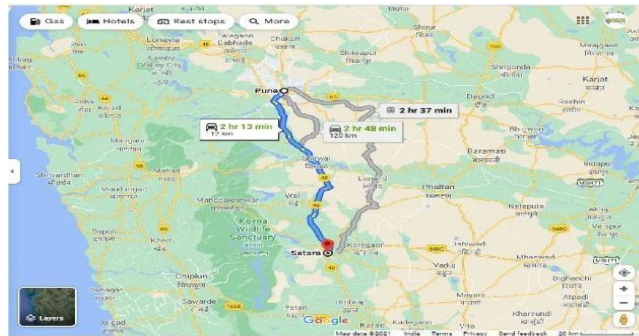


Fig. 1 Google Image of Study Area

V. INPUT DATA

The input data for HDM-4 Model consists of various parameters which are classified as below

- **Road Network**

Data The road network data included road Inventory data, road geometric details, structural evaluation, pavement condition and evaluation of pavement material as given in Table I

Table 1. Road Network

Parameter	Data
Section ID	NH48
Section Name	Pune to Satara
Section Length	110 Km
Terrian Type	Rolling (Mostly)
No.of Lanes	6 Lanes
Carriageway Width	21 m (6* 3.5)
Shoulder Type	Paved + Earthen
Shoulder Width	2.5 – 4.5 m
Pavement Type	Bituminous

- **Pavement Condition and Traffic Data**

Table 2. Pavement Condition and Traffic Data

Pavement condition (Initial)	Roughness	3 m /km
	Rut Depth	5 – 8 mm
	Cracking (%)	5%
	Edge Break	Negligible
	Skid Resistance	Good

	Ravelling (%)	Low
	Potholes (No/km	-2 per km
	Deflection	
Traffic Data	AADT	60,000 PCU/day
	Heavy Vehicle (%)	40%
	Axle Load	3
	Growth Rate	6%
	Directional Spilt	0.5
	Speed Flow Type	2
	Traffic Flow Pattern	Continuous Flow
	MTAADT (2024)	60,000 PCU/day
	NMTAADT (2025)	63,000PCU/day

VI. METHODOLOGY

In this study, pavement deterioration analysis is carried out using the HDM-4 model. The required road data such as traffic, pavement condition, and structural details are collected and prepared for analysis. Traffic data includes volume, composition, and growth rate, while pavement condition data includes roughness, cracking, and rutting.

The collected data is input into HDM-4 after proper processing and calibration to suit local conditions. The model uses its built-in deterioration models to predict yearly changes in pavement condition over the analysis period. Different maintenance and rehabilitation strategies, such as routine maintenance and overlays, are defined and analyzed in the model. HDM-4 evaluates these alternatives based on technical performance and economic parameters like vehicle operating cost and maintenance cost.

- RESULT OF PAVEMENT DETERIORATION

HDM - 4 **Pavement Condition Summary**
HIGHWAY DEVELOPMENT & MANAGEMENT Study Name: 48
Run Date: 19-04-2026 19-04-2026

Alternative: Base Alternative		Road Class: Primary or trunk														
Section: Pune to Satara		Surface Class: Bituminous														
Length: 110.00km		Width: 21.00m														
Average Annual Values																
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-ling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2026	50,030	3.56	3.90	3.70	4.67	4.80	2.20	6.34	12.00	3.41						
2027	50,045	3.56	4.21	4.05	5.20	5.30	2.50	6.70	30.00	3.60						
2028	50,060	3.56	4.47	4.40	5.90	5.80	2.80	7.10	90.00	3.80						
2029	50,075	3.56	4.71	4.75	6.80	6.40	3.20	7.60	260.00	4.00						
2030	50,090	3.57	4.88	5.20	7.80	7.20	3.60	8.20	820.00	4.20						

Fig.2 Pavement Condition Summary for Bituminous Pavement (Base Alternative, Pune-Satara Section)

HDM - 4 **Pavement Condition Summary**
HIGHWAY DEVELOPMENT & MANAGEMENT Study Name: 48
Run Date: 19-04-2026 19-04-2026

Alternative: Overlay 40mm		Road Class: Primary or trunk														
Section: Pune to Satara		Surface Class: Bituminous														
Length: 110.00km		Width: 21.00m														
Average Annual Values																
Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-ling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Struct. No.	Gravel Thick. mm	Avg. Faulting mm	Spalled Joints %	No. of Failures per km	Cracked Slabs %	Det. Cracks No/km
2026	50,030	3.56	3.20	3.00	2.50	2.80	0.80	5.50	5.00	4.20						
2027	50,045	3.56	3.40	3.20	3.00	3.20	1.00	5.80	10.00	4.15						
2028	50,060	3.56	3.70	3.50	3.80	3.70	1.30	6.20	40.00	4.05						
2029	50,075	3.56	4.10	3.90	4.80	4.30	1.70	6.70	150.00	3.95						
2030	50,090	3.57	4.50	4.30	5.90	5.10	2.20	7.20	500.00	3.85						

Fig.3 Pavement Condition Summary for Bituminous Pavement (Overlay 40 mm, Pune-Satara Section)

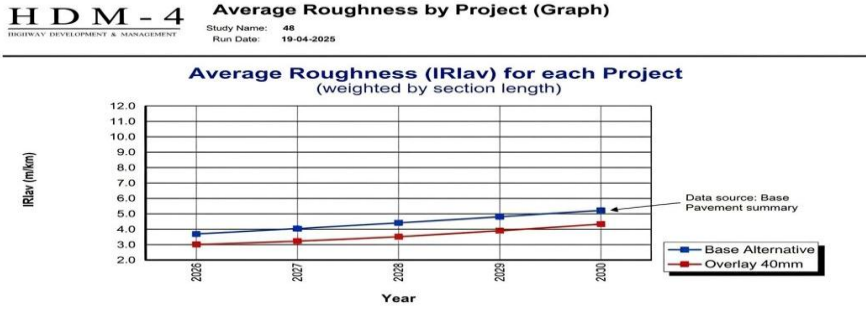


Fig.4 Average Roughness Graph

HDM - 4 Pavement Condition (Bituminous Pavements)
 Study Name: 48 Run Date: 19-04-2026

Section Details:
 ID: FH48 Description: Pune to Satara Road Class: Primary or trunk
 Length: 110.00km Width: 21.00m Rise + Fall: 25.00m/km Curvature: 45.00deg/km
 Alternative: Base Alternative

Year	MT AADT	ESAL (millions/one)	Pavement Type	End of Year Condition														
				Average Structural Number S/N _{SPC}	Roughness IRI (m/km)	All Structural ACA	Wido Structural ACW	Transvers Thermal ACT	Total Cracking ACRA	Ravelled Area (% ARV)	Potholes Number per km NPT	Area (% APOT)	Edge-break Area (m ² /km) AEB	Mean Rut Depth (mm)	Std Dev of Rut Depth	Texture Depth (mm) TD	Skid Resistance SFC50	
2026	50030	3.56	Before works	AMGB	3.41	3.90	4.67	2.80	1.87	4.67	4.90	12	0.50	4.67	6.34	4.10	0.50	0.49
			After works	STAP	3.41	3.90	4.67	2.80	1.87	4.67	4.90	12	0.50	4.67	6.34	4.10	0.50	0.49
2027	50045	3.56	Before works	STAP	3.66	4.21	5.20	3.10	2.10	5.20	5.30	30	1.00	5.20	6.70	4.22	0.60	0.49
			After works	STAP	3.66	4.21	5.20	3.10	2.10	5.20	5.30	30	1.00	5.20	6.70	4.22	0.60	0.49
2028	50060	3.56	Before works	STAP	3.85	4.47	5.60	3.60	2.30	5.60	5.80	90	2.50	5.60	7.10	4.33	0.75	0.49
			After works	STAP	3.85	4.47	5.60	3.60	2.30	5.60	5.80	90	2.50	5.60	7.10	4.33	0.75	0.49
2029	50075	3.56	Before works	STAP	4.04	4.71	6.00	4.30	2.60	6.00	6.40	260	6.50	6.00	7.60	4.42	0.90	0.49
			After works	STAP	4.04	4.71	6.00	4.30	2.60	6.00	6.40	260	6.50	6.00	7.60	4.42	0.90	0.49
2030	50090	3.57	Before works	STAP	4.20	4.88	7.80	4.90	2.90	7.80	7.20	820	10.00	7.80	8.20	4.51	1.10	0.49
			After works	STAP	4.20	4.88	7.80	4.90	2.90	7.80	7.20	820	10.00	7.80	8.20	4.51	1.10	0.49

Fig.5 Pavement Condition (Base Alternative, Pune- Satara Section)

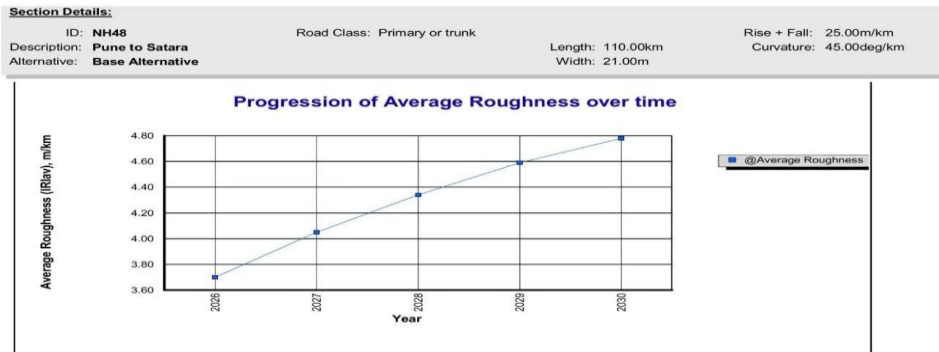


Fig.6 Bituminous Pavement Condition (Base Alternative)

HDM - 4 Pavement Condition (Bituminous Pavements)

Section Details:
 ID: NH48 Description: Pune to Satara Road Class: Primary or trunk
 Length: 110.00km Width: 21.00m Rise + Fall: 25.00m/km Curvature: 45.00deg/km
 Alternative: Overlay 40mm

Year	MT AADT	ESAL (millions/one)	Pavement Type	End of Year Condition														
				Average Structural Number S/N _{SPC}	Roughness IRI (m/km)	All Structural ACA	Wido Structural ACW	Transvers Thermal ACT	Total Cracking ACRA	Ravelled Area (% ARV)	Potholes Number per km NPT	Area (% APOT)	Edge-break Area (m ² /km) AEB	Mean Rut Depth (mm)	Std Dev of Rut Depth	Texture Depth (mm) TD	Skid Resistance SFC50	
2026	50030	3.56	Before works	AMGB	4.20	3.20	2.50	1.50	1.00	2.50	2.80	5	0.10	2.50	5.50	4.10	0.30	0.49
			After works	AMGB	4.20	3.20	2.50	1.50	1.00	2.50	2.80	5	0.10	2.50	5.50	4.10	0.30	0.49
2027	50045	3.56	Before works	AMGB	4.15	3.40	3.00	1.80	1.20	3.00	3.20	10	0.40	3.00	5.80	4.23	0.40	0.49
			After works	AMGB	4.15	3.40	3.00	1.80	1.20	3.00	3.20	10	0.40	3.00	5.80	4.23	0.40	0.49
2028	50060	3.56	Before works	AMGB	4.05	3.70	3.80	2.30	1.50	3.80	3.70	40	3.00	3.80	6.20	4.36	0.55	0.49
			After works	AMGB	4.05	3.70	3.80	2.30	1.50	3.80	3.70	40	3.00	3.80	6.20	4.36	0.55	0.49
2029	50075	3.56	Before works	AMGB	3.95	4.10	4.80	2.90	1.90	4.80	4.30	150	0.28	4.80	6.70	4.48	0.75	0.49
			After works	AMGB	3.95	4.10	4.80	2.90	1.90	4.80	4.30	150	0.28	4.80	6.70	4.48	0.75	0.49
2030	50090	3.57	Before works	AMGB	3.85	4.50	5.90	3.60	2.30	5.90	5.10	500	0.60	5.90	7.20	4.59	0.95	0.49
			After works	AMGB	3.85	4.50	5.90	3.60	2.30	5.90	5.10	500	0.60	5.90	7.20	4.59	0.95	0.49

Fig. 7 Pavement Condition (Overlay 40mm, Pune- Satara Section)

HDM - 4 Bituminous Pavement Condition (Graph)

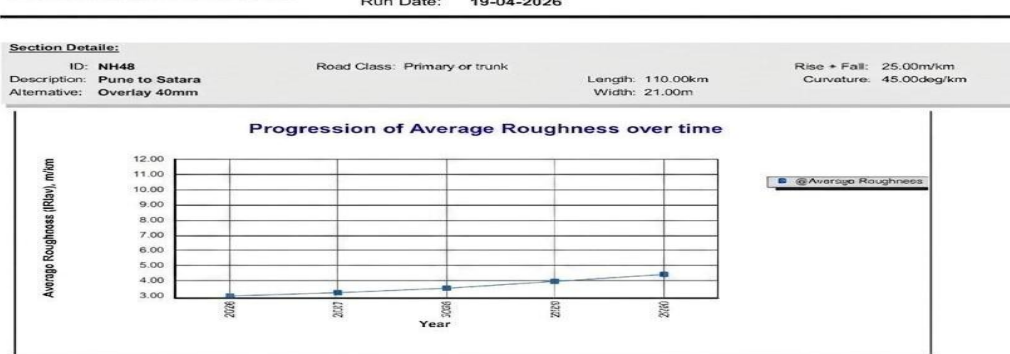


Fig.8 Bituminous Pavement Condition (Overlay 40mm)

VII. RESULTS & CONCLUSION

The pavement condition analysis of NH48 (Pune–Satara) for the period 2026 to 2030 indicates a consistent deterioration trend under the base scenario. Key parameters such as International Roughness Index (IRI), cracking, potholes, and rutting show gradual increase due to heavy traffic loading (AADT and ESAL) and continuous usage. This deterioration results in reduced riding comfort, increased vehicle operating costs, and decline in overall pavement performance and safety. If no major maintenance intervention is applied, the pavement condition is expected to worsen significantly over time.

In contrast, the improvement alternative involving a 40 mm bituminous overlay shows noticeable enhancement in pavement condition. The overlay reduces surface roughness, controls the development of cracks and potholes, and improves ride quality. It also helps in better load distribution, thereby reducing stress on underlying layers and slowing the rate of deterioration.

Overall, the comparative results suggest that the overlay option is more effective in maintaining both functional performance and structural integrity of the pavement. It ensures better serviceability, extends pavement life, and proves to be a practical and efficient maintenance strategy for the NH48 (Pune–Satara) section.

Table 3 Results of Economic Analysis

Section Name	Net Economic Benefit (12%) Discounted Rate	Economic Internal Rate of Return (EIRR)
Pune Satara Section of NH48	28,300.00	26%

HDM - 4 Economic Analysis Summary

Highway Development & Management Study Name: Widening of Pune - Satara Section of NH-48
 Run Date: 12-04-2026

This report shows total economic benefits using the following
 Currency: INR (millions).
 Discount rate: 12.00%.
 Analysis Mode: Analysis-by-Project

Alternative: With Project vs Alternative: Base Case

	Increase in Road Agency Costs			Saving in M VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction In Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	80000.00	6500.00	0.00	150,200.00	110,500.00	0.00	8200.00	0.00	172,400.00
Discounted	15500.00	2700.00	0.00	42,300.00	18,900.00	0.00	3200.00	0.00	28,300.00

Economic Internal Rate of Return (EIRR) = 26.8% (No. of solutions = 1)

As per the generated results, the economic returns for the selected road section are satisfactory and indicate strong feasibility. The Pune–Satara section of NH-48 shows a Net Economic Benefit of 28,300.00 at a 12% discount rate, reflecting the project's positive economic performance. The calculated Economic Internal Rate of Return (EIRR) is 26%, which is considerably higher than the standard benchmark value of 12%, confirming that the proposed improvement is economically viable and beneficial.

In addition to the direct economic gains, the project also contributes to reduced vehicle operating costs, savings in travel time, and improved riding comfort for road users. Better pavement condition leads to lower fuel consumption and reduced wear and tear of vehicles, which further enhances user benefits. The improvement in road quality also supports safer travel and increases overall efficiency of transportation along this important corridor.

Furthermore, the HDM-4 (Highway Development and Management) tool plays an important role in evaluating long-term pavement performance and estimating future budget requirements. It supports the selection of optimal maintenance strategies and ensures effective allocation of resources under budget constraints. Thus, the use of HDM-4 enables better decision-making, enhances sustainability, and ensures that the pavement remains in good condition throughout the analysis period

VIII. ACKNOWLEDGMENT

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