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# A CASE STUDY ON OVERLAY DESIGN USING HDM-4

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**Abstract**

Highway Development and Management tool, HDM-4 software, developed by the World Bank for global applications is utilized for identifying an optimum maintenance strategy for highway pavements. The study area selected was Seaport-Airport Road (SPAP Road), a two-lane, 11.47km long road at Cochin. Economic analyses of different overlay options were evaluated using HDM-4. The concept of Ultra-Thin Whitetopping has not yet introduced in Kerala. Hence a feasibility check for Ultra-Thin Whitetopping is done. It may be defined as a concrete overlay 50mm to 100mm thick, with closely spaced joints and bonded to an existing bituminous pavement. From the deterioration summary it is identified that even after 15 years, the riding quality of Ultra-Thin Whitetopping is the excellent and the most desirable one without any intervention. Ultra-Thin Whitetopping has the minimum rate of roughness progression which in turn may lead to very low Road User Cost values thus providing 46% increase in the Net Economic Benefits than that of Ordinary Bitumen overlay.

**Keywords**: Deterioration Model, Distress Progression, Economic Analysis, HDM-4, Ultra- Thin Whitetopping.

## 1. INTRODUCTION

For suggesting an efficient maintenance strategy, evaluation of pavement performance is very necessary. Pavement performance evaluation includes both structural and functional evaluation. The process of accumulation of damage is called deterioration and the failure of the pavement occurs at the limiting stage of serviceability level. Distresses like Cracking, Rutting, potholes etc are the basic indicators of pavement condition. Bituminous pavements are showing early sign of distresses worldwide, due to increasing loads,
intensity of traffic, high tyre pressure etc. The rutting, cracking and potholes etc are quite common. The current maintenance practice is to provide the rehabilitation strategies based on subjective judgment and

engineering experience.

Kerala has a tropical humid climatic condition. Due to rainfall and harsh climatic conditions, roads in Kerala often deteriorate in different ways to those in the more temperate regions of the world. Moreover Kerala roads often suffer from accelerated failures caused by variable quality control during construction, high axle loads and inadequate funding for maintenance. Maintenance and repair of the highway network system are major expenses in the state budget. So it is the duty of road engineers to suggest a scientific maintenance system for pavements which is both economical and sustainable. Bituminous pavements/overlays are relatively more sensitive to heavy loads. The advantage of Whitetopping is its longer life compared to bituminous overlay. Ultra-Thin Whitetopping may be defined as a concrete overlay 50mm to 100m thick, with closely spaced joints and bonded to an existing bituminous pavement. Ultra-Thin Whitetopping system consist of a thin layer of high strength ,fiber-reinforced concrete placed over a clean, milled surface of distressed bituminous concrete pavement, to achieve a full or partial bonding.

## 2. OBJECTIVES AND SCOPE OF THE STUDY

The main objectives of the present study are

1. To calibrate HDM-4 deterioration models for the existing pavement condition.

2. To determine the cost effectiveness and feasibility of Ultra-Thin Whitetopping with that of other overlay options.

The scope of this work is to compare the cost effectiveness and performance of alternate overlay options as maintenance treatment for Kerala Urban Road conditions, considering Seaport-Airport road, running between HMT Kalamasseri and Cochin Refineries Ltd. as the study area. The study stretch is a two-lane road of 11.370 km length by Roads and Bridges Development Corporation Kerala Ltd. Also, this work is to calibrate HDM-4 deterioration models for the existing pavement condition.

## 3. DATA COLLECTION

The data is collected under the following four categories
A. Pavement Condition Data
B. Vehicle Fleet Data
C. Maintenance and Rehabilitation Works Data
D. Cost Data

### A. Pavement Condition Data

The Pavement Condition data collection in the field was divided under the following heads:

1) Inventory data: The inventory data includes the details like Name of road, category of road, carriageway and shoulder width, drainage conditions, surface type and thickness, pavement layer details etc.
2) Pavement Evaluation: Pavement evaluation includes both structural and functional evaluation of pavements. Structural evaluation is done by Benkelman Beam Deflection method. Functional evaluation is by pavement condition survey, roughness survey and Skid resistance measurements.

### B. Vehicle Fleet Data

Midblock Counts were taken for seven days at the toll booth on Airport-Seaport road. Hourly traffic

counts were conducted simultaneously in both directions at survey location to obtain the traffic flow and the classified composition. It is obtained that Goods vehicle accounts for 17.78% and passenger vehicles accounts for 82.17% of total traffic. The values were taken from "IRC 106-1990: Guidelines for capacity of Urban Roads in Plain Areas".

### C. Maintenance and Rehabilitation Works Data

Maintenance and Rehabilitation strategy is a course of action to be taken over the analysis period in order to keep the road section in a good condition. . The maintenance has been categorized as Ordinary Repairs (Routine Maintenance) and Periodic Renewals (Periodic Maintenance) as per the "Report of the Committee on Norms for Maintenance of Roads in India" [MoRT&H 2001].

### D. Cost Data of M&R Works

The "Committee for Maintenance Norms for Roads in India, [MoRT&H 2001], has recommended the total costs for carrying out various types of Maintenance and Rehabilitation (M&R) works on bituminous pavements situated in various price zones of the country.

## 3. ANALYSIS OF PAVEMENT

### 3.1 DETERIORATION CONDITION

Highway Development and Management Tool (HDM-4) is designed to make comparative cost estimates and economic evaluations of different construction and maintenance options. HDM-4 includes relationships for modelling Road Deterioration (RD) and Road Works Effects (RWE). These are used for the purpose of predicting annual road condition and for evaluating road works strategies.

### A. Procedure for Project Analysis

The procedure for project analysis is summarized below.

1. Create the road project to be analyzed by giving it a title and specifying the road to be analyzed.
2. Define the project by specifying the following: General information about the project-Road Network data, Pavement Condition data, Vehicle fleet data and Traffic Volume data, Method of analysis, Road sections to be analyzed.
3. Specify maintenance and improvement standards to be analyzed for each selected road section. Set-up and run the analysis.
4. Generate the reports and print the required outputs.

## 4. CALIBRATION OF HDM-4 DETERIORATION MODELS

The HDM-4 was run for the same loading, Distress and structural condition as that of initial pavement condition. The distress progressions are then plotted on a graph to find the variations in the predictions made. The calibration factors for Initiation and Progression are altered and the model is run to obtain the progression of distresses. The obtained values are given in Table 1.

The four overlay options considered as M&R alternatives for this study are defined in the Table 2. The first alternative, Base alternative represents minimum routine maintenance in terms of crack sealing and pothole patching only, till such time when the reconstruction of the pavement section becomes inevitable.

TABLE 1. CALIBRATION OF HDM-4

| Sl No | Model Description | Calibration Factors | Sl No | Model Description | Calibration Factors |
|---|---|---|---|---|---|
| 1 | Cracking Initiation | $K_{cia}$=0.8 | 5 | Ravelling Progression | $K_{vp}$=0.42 |
| 2 | Cracking Progression | $K_{cpa}$=0.69 | 6 | Pothole Initiation | $K_{pi}$=0.45 |
| 3 | Ravelling Initiation | $K_{vi}$=0.27 | 7 | Roughness Progression | $K_{gm}$=0.4 |

TABLE 2. PROPOSED MAINTENANCE AND REHABILITATION ALTERNATIVES

| Alternatives | Works Standard | Description of Work |
|---|---|---|
| Base Alternative | Routine Maintenance | Crack Sealing<br>Pothole Patching<br>Drainage |
| Alternative 1 | Overlay | Provide 40mm Bituminous concrete + Routine maintenance |
| Alternative 2 | Overlay | Provide 40mm Natural Rubber Modified Bitumen+ Routine maintenance |
| Alternative 3 | Ultra-Thin Whitetopping | Provide 100mm thick Cement Concrete Slab |

The deterioration of the pavement section under various Maintenance &Rehabilitation Alternatives is analysed. Roughness is the most useful indicator of the pavement deterioration or average condition of the pavement section. Progression of roughness is shown in figure 1. The progression of roughness can be tracked to check that the works are correctly triggered according to the specified intervention criteria. From the deterioration summary shown in Table 3, it is identified that even after 15 years, the riding quality of Ultra-Thin Whitetopping is the excellent and the most desirable one without any intervention. So it eliminates the Routine maintenance cost.

## 5. ECONOMIC ANALYSIS

In set up to the analysis, the Base Alternative is confirmed and a discount rate of 10 per cent is specified. While running the project analysis, Alternatives 1 to 3 are compared against the Base Alternative. The analysis summary is given in Table 4. From the Economic analysis it is obtained that Ultra-Thin Whitetopping has the maximum Net Present Value/ cost ratio and Internal Rate of Return which clearly indicates that Ultra-Thin Whitetopping is the most economical

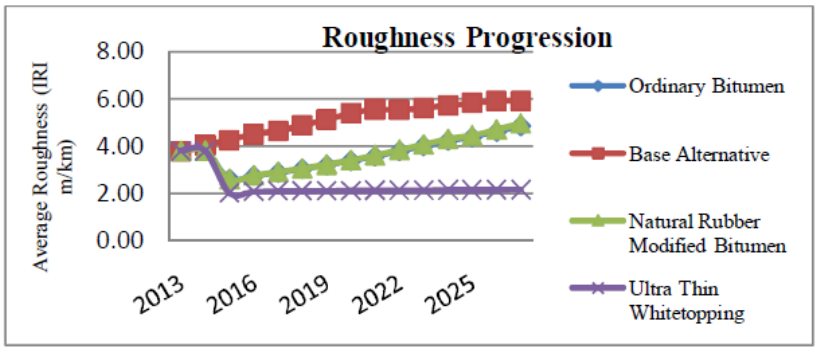


FIGURE 1. ROUGHNESS PROGRESSION

TABLE 3. PAVEMENT DISTRESS UNDER VARIOUS ALTERNATIVES

| Year | AADT | Base Alternative | | | | Alternative 1 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Average Roughness IRI m/km | All structural Cracks % | Ravelling % | No. of Potholes (No./km) | Average Roughness IRI m/km | All structural Cracks % | Ravelling % | No .of Potholes (No./km) |
| 2013 | 19,442 | 3.80 | 8.22 | 15.50 | 0 | 3.80 | 8.68 | 15.70 | 0 |
| 2014 | 20,790 | 4.03 | 11.07 | 28.25 | 0 | 3.80 | 4.34 | 7.85 | 0 |
| 2015 | 22,145 | 4.26 | 14.59 | 46.19 | 0 | 2.59 | 0.00 | 0.00 | 0 |
| 2016 | 23,592 | 4.51 | 11.30 | 60.28 | 20 | 2.74 | 0.00 | 0.00 | 0 |
| 2017 | 25,137 | 4.64 | 4.82 | 71.08 | 28 | 2.88 | 0.00 | 0.00 | 0 |
| 2018 | 26,788 | 4.88 | 7.73 | 78.73 | 35 | 3.03 | 0.50 | 0.00 | 0 |
| 2019 | 28,551 | 5.13 | 11.11 | 84.91 | 41 | 3.19 | 1.83 | 0.25 | 0 |
| 2020 | 30,310 | 5.39 | 14.77 | 84.50 | 47 | 3.37 | 4.01 | 2.33 | 0 |
| Year | AADT | Alternative 2 | | | | Alternative 3 | | | |
| | | Average Roughness IRI m/km | All structural Cracks % | Ravelling % | No of Potholes (No./km) | Average Roughness IRI m/km | Avg. Faulting mm | Spalled joints % | Cracked Slabs |
| 2013 | 19,442 | 3.80 | 8.68 | 15.70 | 0 | 3.80 | 0.00 | 0.00 | 0.00 |
| 2014 | 20,790 | 3.80 | 4.34 | 7.85 | 0 | 3.80 | 0.00 | 0.00 | 0.00 |
| 2015 | 22,145 | 2.59 | 0.00 | 0.00 | 0 | 2.03 | 0.08 | 0.02 | 0.01 |
| 2016 | 23,592 | 2.75 | 0.00 | 0.00 | 0 | 2.07 | 0.09 | 0.04 | 0.04 |
| 2017 | 25,137 | 2.90 | 0.00 | 0.00 | 0 | 2.09 | 0.10 | 0.07 | 0.09 |
| 2018 | 26,788 | 3.05 | 0.50 | 0.00 | 0 | 2.09 | 0.11 | 0.11 | 0.15 |
| 2019 | 28,551 | 3.21 | 1.83 | 0.25 | 0 | 2.10 | 0.12 | 0.16 | 0.23 |
| 2020 | 30,310 | 3.40 | 4.01 | 2.33 | 0 | 2.11 | 0.12 | 0.22 | 0.32 |

TABLE 4. ECONOMIC ANALYSIS SUMMARIES

| Alternative | Discounted Savings In Motorised Traffic Vehicle Operating Cost (Indian Rupees (Millions) | Discounted Savings In Motorized Traffic Travel Time Cost (Indian Rupees (Millions) | Discounted Net Economic Benefits, Net Present Value (Indian Rupees (Millions) | Net Present Value /Cost Ratio | Internal Rate Of Return |
|---|---|---|---|---|---|
| Base Alternative | 0 | 0 | 0 | 0 | 0 |
| 40mm Ordinary Bitumen | 173.94 | 977.16 | 822.93 | 2.508 | 40.4 |
| 40mm Natural Rubber Modified Bitumen | 158.75 | 1205.66 | 1019.81 | 2.959 | 47.5 |
| Ultra-Thin Whitetopping | 343.98 | 1235.28 | 1203.07 | 3.198 | 48.2 |

## 6. CONCLUSIONS

The present pavement performance and riding quality of the study road is analysed by both Structural and Functional evaluation. It is identified that the pavement is structurally good but riding quality is reduced due to lack of maintenance strategy. In order to improve the riding quality of the pavement, an overlay option is suggested.

For predicting the deterioration progress of the study road, the HDM-4 pavement deterioration models are calibrated for the Kerala urban road conditions. From the deterioration summary it is identified that even after 15 years, the riding quality of Ultra-Thin Whitetopping is the excellent and the most desirable one without any intervention. So it eliminates the Routine maintenance cost.

Due to the high increase in vehicular traffic and congestion, Level of Service of the study stretch is very low thus demanding a Partial Widening in addition to overlay. Pavement Upgradation with Ultra-Thin Whitetopping is found to be the most economical since it has the highest Internal Rate of Return of 48.2 which is 19% higher than that of Ordinary Bitumen overlay. Ultra-Thin Whitetopping has the minimum rate of roughness progression which in turn may lead to very low Road User Cost values thus providing 46% increase in the Net Economic Benefits than that of Ordinary Bitumen overlay. It also improves the functional efficiency of the pavement. Also there are other benefits which can be non-quantifiable like delays to traffic during maintenance of flexible pavement, increase in comfort and safety.

Ultra-Thin Whitetopping can be suggested as the most appropriate overlay option which reduces the Life Cycle cost of the pavement.

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