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Estimation of Service Life & Optimum Maintenance Strategies for Urban Road Network of Rajkot city using HDM-4

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Abstract-*The purpose of the study was to develop a road maintenance management system (PMMS) for four sections of the urban road network (Rajkot, Gujarat, India) using the Highway Development and Management (HDM-4) model. The HDM-4 provides a deterministic approach to data input and process data consisting of existing road conditions, traffic and pavement composition to predict road degradation based on the International Roughness Index (IRI) value. This study proposes the use of the HDM-4 model to determination of Remaining Service Life (RSL) of Pavement section of Rajkot city and the optimum maintenance and Rehabilitation (M & R) strategy for each section of Rajkot city. The results of this study will help to better provide decision makers with adequate and timely allocation of funds to maintain urban roads.*

Keywords: *Pavement, management, maintenance, HDM-4, urban road, predict, road deterioration.*

I. INTRODUCTION

India has a road network of more than 5,472,144 kilometers, the world's second largest road network. Among them, the district, city road network accounted for nearly 14.1% of the total road network. About 65% of the cargo and 80% of the passenger transport by road. Road networks are essential for economic development, trade and social integration. To facilitate the smooth transport of people and goods. The size of the road network, its quality and access have an impact on transport costs. In addition, the road network to promote professional, extend the market, so as to carry out economies of scale. Easy road transport, flexible operation, door-to-door service and reliability make the passenger and cargo volume of road transport higher and higher relative to other modes of transport. India's transport demand has been growing rapidly. In recent years, this demand has largely shifted to the advantages of road transport, accounting for 87% and 61% of land passenger transport and freight demand respectively.

II. MATERIALS AND METHODS

A.Selection of Urban Road Sections

The very first step in developing the Pavement Maintenance Management System (PMMS) is to identify the road network and select the road sections based upon the homogeneity properties. In the present study, Rajkot city road network has been identified and four road sections comprising of total length 4 km have been selected for developing Pavement Maintenance Management System. The details of selected road section shown in table 1.

Table 1 : Section ID and Name of Selected Road Section

Section ID	Section Name	Description	Classification of Road
UR-01	Kuwadava Road	**From** Viral Agriculture Warehouse **To** Shree Yogkrupa Industries	Arterial Road
UR-02	150ft.Ring Road	**From** Near Madhapar Chowk**To** Gandhigram	Sub-arterial Road
UR-03	Kalawad Road	**From**Dr.B.R.Ambedkar girls hostel **To** YagnavalkyaVrukshMandirSwadhyayaParivar	Collector Street
UR-04	Dhebar Road	**From**Bhutkhana Chowk **To** Nagarik Bank	Collector Street

B.Road Network Data

Road Inventory Data:- Road inventory data collection consists of road length (m), lane width (m), shoulder width (m),traffic flow pattern, design speed (km/h), flow direction. Road sections have been visually inspected to get relevant information. Details of road section inventory data has been presented in Table 2.

Table 2 : Inventory Data of Selected Road Section

Section ID	Section Length (km)	Carriageway Width (m)	Shoulder Width (m)	Speed Flow Type	Flow Direction	Design Speed (km/hr)
UR-01	1.000	7.5	1.2	Four Lane Divided Road	Two-way	80
UR-02	1.000	6.6	1.4	Four Lane Divided Road	Two-way	60
UR-03	1.000	5.8	1.2	Four Lane Divided Road	Two-way	50
UR-04	1.000	5.2	1.0	Four Lane Divided Road	Two-way	50

Pavement History Data*:* -Pavement history data (type of pavement, year of last construction, surfacing and maintenance has been collected from Public Works Department (PWD) office and Municipal Corporation of Rajkot, Government of Gujarat. Details of pavement history data of road are presented in Table 3.

Table 3 : Pavement History Data

Section ID	Surfacing Material Type	Current Surface Thickness (mm)	Previous Surface Thickness (mm)	Last Construction Year	Last Rehabilitation Year	Last Surfacing Year	Last Preventive Treatment Year
UR-01	Bituminous Concrete(BC)	75	50	2004	2009	2014	2015
UR-02	Bituminous Concrete(BC)	75	50	2004	2010	2014	2015
UR-03	Bituminous Concrete(BC)	75	50	2005	2011	2015	2016
UR-04	Bituminous Concrete(BC)	75	50	2005	2010	2012	2015

C.Functional and Structural Evaluation of Road Pavements

The functional evaluation like roughness measurement survey has been conducted to assess the riding comfort and safety over the pavement section as experienced by road users. Road roughness refers to surface irregularities in the longitudinal direction and has been measured with fifth wheel bump integrator or simply known as 'Roughometer'. The equipment has been towed by pick-up and operated with speed of 30 kmph. Accumulated bumps (in cms) has been noted down corresponding to length travelled (in km).Shown table 4.

Unevenness Index (UI) = Bumps in cm/ Length travelled in km

UI value has been converted into International Roughness Index (IRI in m/km) [MORTH]

The structural evaluation has been carried out to assess the pavement's structural ability to receive wheel loads plying over it using rebound deflection measurements with the help of 'Benkelman Beam Defection Test'. The test was conducted as per IRC: 81-1997 guidelines. The Adjusted Structural Number (SNP) was calculated from deflection values by using the following equation given by Odoki and Kerali and Table 5.Presents calibration factors for HDM-4 deterioration models.

Table 4 : Determination of UI and IRI values for all Section

Section ID	Bumps (cm)	Length Travelled (km)	Unevenness Index in (cm/km)	International Roughness Index(IRI) *UI=630*IRI^1.12*
UR-01	250	1.000	250	3.42
UR-02	141	1.000	141	2.05
UR-03	174	1.000	174	2.47
UR-04	167	1.000	167	2.39

Table 5 : BBdef Value and SNP value for all Road section

Section ID	Benkelman Beam Deflection value(BB_{def})	Adjusted Structural Number(SNP)
UR-01	1.17	2.94
UR-02	1.05	3.16
UR-03	2.25	1.95
UR-04	0.73	3.95

D.Traffic Volume and Vehicle Composition Data

Traffic volume counts are conducted manually for 72 hours consecutively by engaging adequate number of enumerators in individual road section. In the present study, traffic volume data and vehicular composition data have been collected from Municipal Corporation, Rajkot. Annual Average Daily Traffic (AADT) for each section has been calculated by summing up the products of number of individual vehicle and its Passenger Car Space Equivalent (PCSE) factor. Table 6 presents the traffic volume of each section. Rajkot road traffic comprises of both Motorized (MT) and Non-Motorized (NMT) vehicles.

Table 6 : Traffic Volume Data of Road Sections

Section ID	Motorized AADT (In PCSE)	Non-Motorized AADT	AADT year	Traffic Volume
UR-01	9322	40	2017	Medium
UR-02	27938	1479	2017	High
UR-03	23878	2277	2017	High
UR-04	17583	1987	2017	High

E.Maintenance and Rehabilitation Works Data

Maintenance serviceability levels for urban roads are suggested by Ministry of Road Transport and Highways (MORT&H). The suggested serviceability levels and the limiting levels of surface defects based on measurement of roughness, cracking, rutting *etc*. as per, (MORT&H), are given in Table 7.

Table 7 : Maintenance serviceability levels for urban roads

Sr. No.	Serviceability Indicator	Serviceability Levels		
		Level 1	Level 2	Level 3
1.	Roughness by Bump Integrator (max. permissible) Equivalent IRI	2000mm/km 2.8 m/km	3000 mm/km 4.0 m/km	4000 mm/km 5.2 m/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 (max. permissible)	5mm	5-10 mm	10-20 mm
5.	Skid number (min. desirable)	50 SN	40 SN	35 SN

For the present study, maintenance standard has been formed with basic design details and intervention criteria. The maintenance work standard for all road sections for reconstruction is condition responsive work *i.e.,* 200mm wet mix macadam, 75mm dense bituminous macadam and 40mm bituminous concrete with the intervention criteria of 'roughness >= 8 IRI'.

F.Cost Data of M&R Works

The Indian Road Maintenance Code Committee recommends that the total cost of maintenance and restoration (M & R) projects for asphalt pavements located in national price areas. This division is done on the basis of the cost of stone (stone) in the area. For this study, since all road sections in the selected expressway network are located in the area, In addition, the fourth area is also considered the national average representative area. [MoRT& H, 2001a].

Table 8 : Updated economic cost data of M&R works for year 2017

Sr. No.	Type of M&R Work	Cost per sq. m of Surface Area, Rs.
Routine Maintenance		
1.	Crack Sealing (All Cracks)	66.4
2.	Pothole Patching	84.7
3.	Patch Repair	84.7
4.	Rutting and Undulation Repair	117.7
5.	Tack Coat	13.5
6.	Liquid Seal Coat	68.8
Periodic Maintenance		
1.	Single Bituminous Surface Dressing (SBSD)	178.5

2.	Double Bituminous Surface Dressing (DBSD)	282.7
3.	Premix Carpet (20mm PC)	223.2
4.	Mix Seal Surfacing (20 mm MSS)	230.6
5.	Semi Dense Bituminous Concrete (25mm SDBC)	208.3
6.	Bituminous Concrete (25mm BC)	230.6
7.	Bituminous Concrete (40mm BC)	369.0
8.	Bituminous Macadam (50mm BM)	370.5
9.	Dense Bituminous Macadam (75mm DBM)	614.5
10.	Mill 90mm and Replace with (BM 50mm + BC 40mm)	739.4
11.	200 mm Wet Mix Macadam + 75 mm Dense Bituminous Macadam + 40mm Bituminous Concrete	1429.8

G.Road User Cost (RUC) Data

Road User Cost (RUC) consists of three components *i.e.*, Vehicle Operating Costs (VOC), Travel Time Costs (TTC) and Accident Costs (AC). VOC is the dominating component in RUC. In present study, VOC component has been considered and has been calculated as per Clause 6.6 (Annexure C) and Clause 6.9 of IRC SP: 30.. Table 9 shows vehicle operating cost data input per 1000 vehicles-km and economic cost (exclusive of tax) has been considered here.

Table 9 : Vehicle operating costs data input per 1,000 vehicle-km

Parameter	Two-wheeler	Car/ Jeep/ Van	Bus (Medium)	Mini Bus	Trucks (Medium)	Mini Truck	Tractor/Trolley
Cost of Fuel (Rs/ litre)	620	1400	5530	4570	5730	4570	4570
Cost of Lubricants (Rs/litre)	4	16	13	13	20	13	13
Maintenance Labour (Rs/hr)	4.06	6.40	25.5	9.22	28.27	9.22	9.22
Crew Wages (Rs/hr)	-	-	1.17	4.08	2.20	4.08	4.08
Annual Overhead	0.25	0.91	0.84	4.67	2.60	4.67	4.67
Annual Interest (In %)	8	8	8	8	8	8	8

III. Determination of Remaining Service Life (RSL) of Road Sections

The aim of the very first objective was to compute Remaining Serviceable Life (RSL) of each road section. Remaining Serviceable Life (RSL) of road section means the time left in years, till it becomes necessary to reconstruct the road

pavement, providing no Maintenance and Rehabilitation (M&R) works throughout the intervening period (Gupta and Kumar, 2015). 'Project Analysis' in HDM-4 has been selected for determining this parameter.

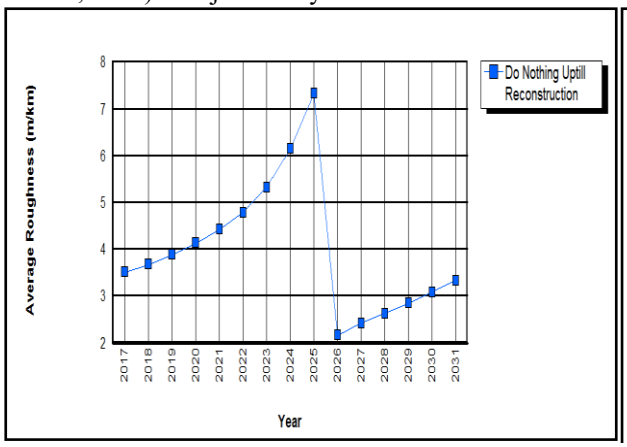

Figure 1: UR-01(Kuwadava Road)

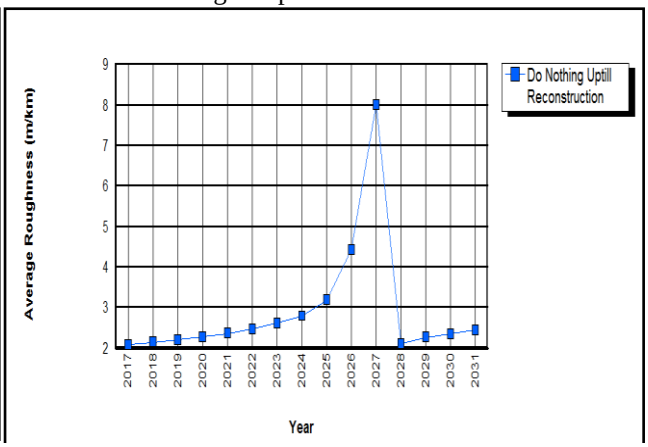

Figure 2: UR-02 (150ft Ring Road)

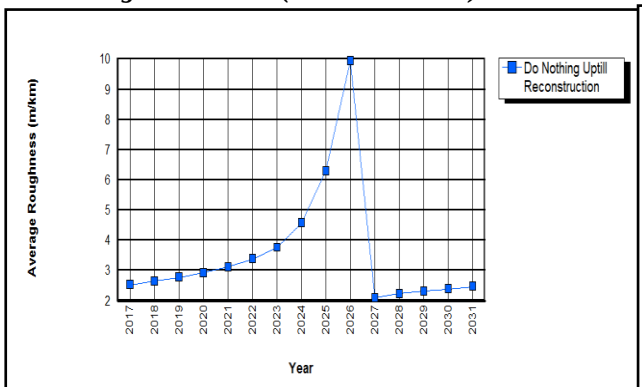

Figure 3: UR-03(Kalawad Road)

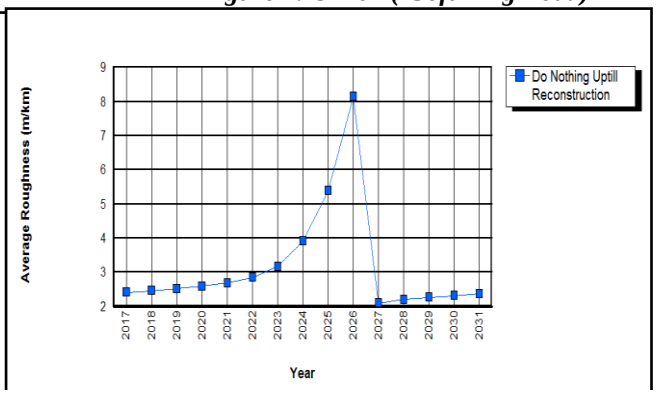

Figure 4: UR-04 (Dhebar Road)

Table 10: Remaining Service Life of Each Road Section

Section ID	Section Name	Reconstruction Year	Remaining Service Life (RSL), in years
UR-01	Kuwadava Road	2025	8
UR-02	150ft. Ring Road	2027	10
UR-03	Kalawad Road	2026	9
UR-04	Dhebar Road	2026	9

IV. Estimation of Optimum Maintenance Strategies for Road Section

Maintenance service level is the qualitative rating of expressway performance under the operating conditions such as traffic volume, speed, comfort and safety. Therefore, for maintenance purposes, it is recommended that the maintenance program be divided into three levels of maintenance, which are identified as Level 1, Level 2 and Level 3. Level 1 is the required level to provide the highest level of comfort, convenience and safety. Before the implementation of the new maintenance, the secondary use of two or three years later, the degree of road degradation from level 1. Level 3 represents the minimum level required to protect the investment and provides a reasonable level of safety. Table [MORT & H, 2001a17] gives a suggested level of usability and surface defects based on measurements of roughness, cracking, rutting, and the like.

Table 11: Maintenance serviceability levels for urban roads

Sr. No.	Serviceability Indicator	Serviceability Levels		
		Level 1	Level 2	Level 3
1.	Roughness by Bump Integrator (max. permissible) Equivalent IRI	2000mm/km 2.8 m/km	3000 mm/km 4.0 m/km	4000 mm/km 5.2 m/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 (max. permissible)	5mm	5-10 mm	10-20 mm
5.	Skid number (min. desirable)	50 SN	40 SN	35 SN

V. Proposed M&R alternatives

Table12: Proposed M&R alternatives

M&R Strategy	Works Standard	Serviceability Level	Traffic Level	Description of Work	Intervention Level
Base Alternative	Routine Maintenance	High	All	Crack Sealing and Pothole Patching	Scheduled annually
		Medium			
		Low			
M&R Alternative	Resealing/ Overlay/Reconstruction	High	>10000	Provide 25 mm DBSD	Total damage area > 5% of total area
				Provide 40 mm BC	Roughness >=3, <= 6 IRI
				Provide (200 mm Wet Mix Macadam + 75 mm Dense Bituminous Macadam + 40mm Bituminous Concrete)	Roughness >=6 IRI
		Medium	6000 to 10000	Crack Sealing	Wide Structural Cracking >=10%
				Provide 25 mm BC	Roughness >=4 IRI

				Provide (200 mm Wet Mix Macadam + 75 mm Dense Bituminous Macadam + 40mm Bituminous Concrete)	Roughness >=5 IRI

VI. Roughness progression

The Roughness progression graphs of all the four alternatives for all the four road sections are shown individually from Figure 5 to Figure 8. The roughness progression has been traced to know whether the works have been correctly triggered according to the specified intervention criteria or not.

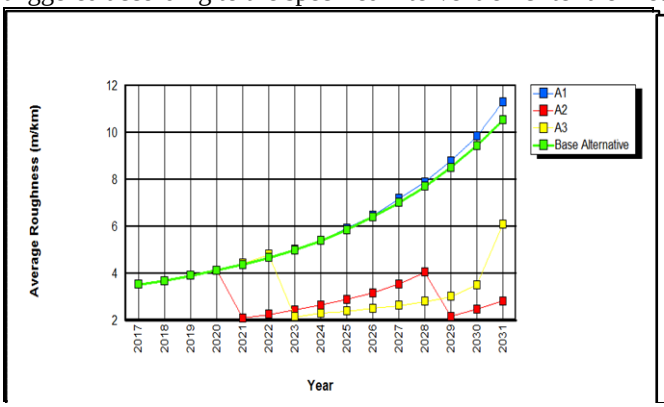

Figure 5: UR-01(Kuwadava Road)

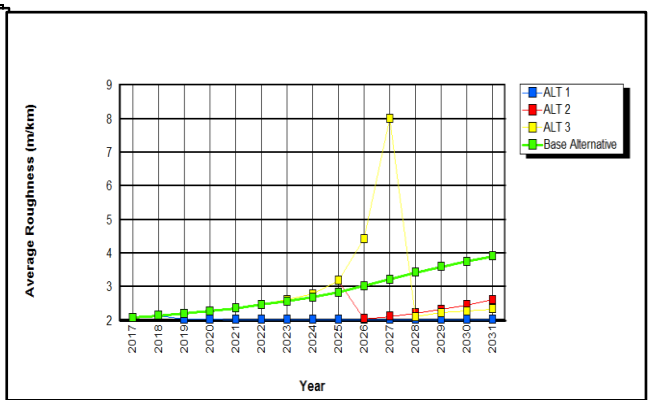

Figure 6: UR-02 (150ft Ring Road)

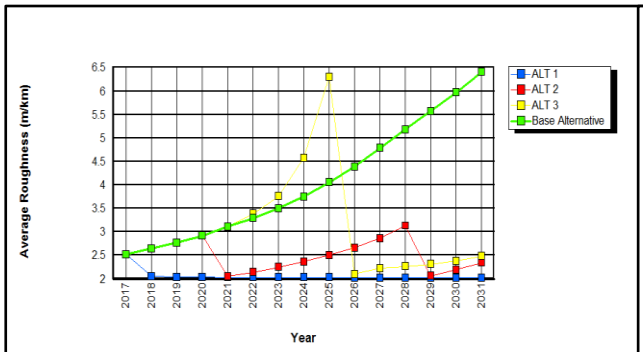

Figure 7: UR-03(Kalawad Road)

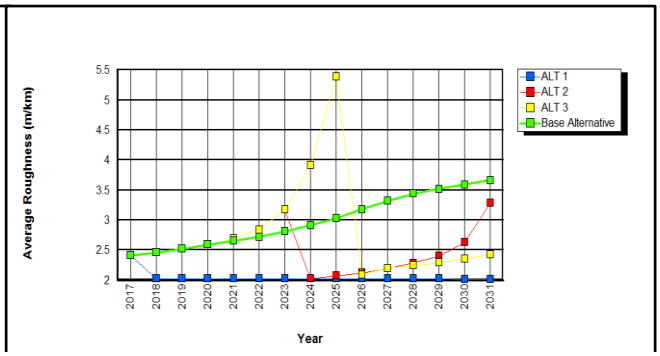

Figure 8: UR-04 (Dhebar Road)

On the basis of economic analysis of each alternative for all the road sections, optimum M&R strategy has been selected. The alternative which has higher NPV/Cost ratio for any road section compared to the other predefined alternatives, is selected as optimum M&R strategy for that section. Table 14 shows the optimum M&R alternative selected for each road section.

Table 13: Different alternative with section wise

Section/Alternative	Alternative 1	Alternative 2	Alternative 3
UR-01	2028	2028	2031
UR-02	2018	2025	2027
UR-03	2017	2020	2025
UR-04	2023	2023	2025

Table 14:Optimum M&R Alternative for each road section

Section ID	Section Name	Optimum M&R Strategy
UR-01	Kuwadva Road	Alternative 1
UR-02	150ft. Ring Road	Alternative 1
UR-03	Kalawad Road	Alternative 2
UR-04	Dhebar Road	Alternative 1

VII. Conclusions

- HDM-4 software is a future decision-making tool for Rajkot Road Network Management.
- Provides a common framework for the analysis of road management programs.
- The HDM-4 offers a wider range of upgrade options, road type, seal type and other maintenance options.
- The Remaining Service Life (RSL) for a number of pavement sections for Rajkot city has been determined which varies from 8 to 9 years, indicating that reconstruction on most of the pavement sections would be inevitable in the near future, in the absence of any sound maintenance management policy.
- In the project-level PMMS analysis of Rajkot, the best M & R pavement division strategy has been determined in a series of predefined M & R strategies based on the highest NPV / cost ratio.

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