Pavement Maintenance Management System for state Highway- A Case Study of Gujarat State

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Abstract: Gujarat state has 19761 km length of state highway which is 35% of total length of roads in Gujarat. The state highway are primary routes of a state that provides access to district headquarters, important towns within state and connecting them to national highways or state highways of neighbor states. Managing to this road network is also challenging because of lack of systematic approach for maintenance of roads. Pavement deterioration rate has been increased due to lack of proper maintenance approach and increase in number of vehicles as well as axle loads. There is a need of developing scientific and systematic approach towards developing the maintenance and rehabilitation requirements of road. To justify Pavement Maintenance Management System (PMMS), A 10 kilometer stretch of State Highway-151 (Dakor – Kapadvanj Road) has been selected and divided into 10 sections. Road inventory, Classified Volume Count Survey and pavement condition survey has been performed on the same stretch. Structural evaluation of pavement has been carried out by Benkelman Beam Deflection survey and other necessary data are collected from R & B Department, Government of Gujarat. These data have been incorporated into HDM-4 system. Various maintenance and rehabilitation alternatives have been assigned to these road sections and one having highest NPV/CAP ratio has been selected as optimum maintenance alternative. Life cycle cost analysis has been performed under all alternatives and economic analysis has been carried out for optimum maintenance alternative to check economic viability. This study concluded that proper maintenance technique helps to achieve service life of pavement and restricts pavement to fail before its service life.

Index Terms **- HDM-4, M&R alternatives, PMMS, Optimum Maintenance, Pavement Condition Survey, IRI.**

1) INTRODUCTION

Roads are a plentiful national investment and require maintenance to keep them in satisfactory condition and ensure safe movement at considerable speed with low road user cost (RUC). When pavements are not timely maintained, they deteriorate at faster rate compared to well-maintained pavements. Without timely maintenance may lead to higher vehicle operating cost (VOC), increase in accidents and increase in travel time which reduces reliability of transportation. When timely maintenance is avoidable, there may chance that pavement would go in such condition that pavement reconstruction is only solution. Delay maintenance work will increase capital maintenance cost, discomfort to road users and lack of safety. Therefore, road maintenance plays essential role and should be carried out periodically.

1.1) BACKGROUND

State Highways provide linkages with national highway, district headquarters of state, important towns and tourist centres. These are major carriers of traffic within the state. It is assessed that although these roads are only 4% of the total highway network but still carry about 40% of the total road traffic. As per NHAI, the share of road transport in passenger movement and freight movement has increased by 20% to 85% and 20% to 70% respectively during last 50 years. It indicates that as number of commercial vehicles increased, axle load has also increased which deteriorates pavement faster than before. Mainly State Highways are carried by two axle trucks which are generally overloaded and cause significantly damage than vehicles with more axles having better load distribution and under loading capacity. This is the main problem behind maintenance of roads because of overloaded and heavy commercial vehicles movement. There should be scientific and systematic approach like Pavement Maintenance Management System (PMMS). The main objective of PMMS is to develop database that will allow for scientific assessment of maintenance and rehabilitation needs of roads and implement system having capability of evaluating the economic effects of various levels of intervention and optimizing the maintenance treatments within the given budget scenario.

1.2) LITERATURE REVIEW

HDM-4 system consists of mainly three types of data: Road Network Data which includes basic road details, geometries, pavement history, pavement condition, etc. Vehicle Fleet Data which includes basic characteristics of vehicle fleet, economical and financial costs, etc. Work Standards which include specifications for maintenance and improvement works. HDM-4 system is helpful to determine optimum maintenance strategy of road network (Sudhakar, 2009). HDM-4 System contains pavement performance prediction models which is very useful for forecasting pavement performance (Fuentes, Goenaga, Reyes, & Alvarez, 2014). HDM-4 system includes pavement deterioration models that can be used for local conditions after derivation of calibration factors. Time series data of pavement condition are required to obtain calibration factors (Jain, Aggarwal, & Parida, 2005). PMMS helps the decision makers such as pavement engineers and highway authorities to apply the best technique for pavement rehabilitation at perfect time so that maximal use of available funds can be done. PMMS is considered as a systematic method that aids in assessing the pavement performance and condition of existing as well as future improvements on pavement (Al-Ajami, 2015). PMMS are designed to manage maintenance and rehabilitation activities to optimize pavement condition with available funds. The use of PMMS is becoming increasingly due to scientific and systematic approach (Sarsam, 2008). Strategic analysis of HDM-4 system is very much useful to plan long-term budget planning and maintenance planning. HDM-4 system allows customized economic analysis in forecasting budget requirements and compare with base alternative (Shah, Jain, & Tiwari , 2016). Life cycle cost analysis has been performed in HDM-4 which gives access to compare life cycle of various M&R alternatives and unconstrained programme which is useful to estimate total budget requirement for optimum maintenance strategy (Aggarwal, Jain, & Parida, 2004).

1.3) OBJECTIVES OF THE STUDY:

- To apply project analysis and strategic analysis to selected road sections of SH-151
- To determine total budget requirement for adopted maintenance strategy
- To study effect of various M&R alternatives on pavement condition
- To carry out life cycle cost analysis of road sections

2) METHODOLOGY

The methodology in this study involves five stages. In the first stage, the road stretches were identified and the primary data were collected. In the second stage, classified volume count survey was conducted. The traffic data were converted in to Annual Average Daily Traffic (AADT) for the analysis. In the third stage, pavement structural evaluation was carried out by measuring deflection with the help of Benkelman Beam Deflection. Pavement Condition survey has been carried out to measure present condition of pavement. In the fourth stage, the secondary data like history of road maintenance, the maintenance strategies existing in the study area, the cost data for maintenance of study stretches and periodicity interval of maintenance were collected Road & Building Department, Government of Gujarat. In the last stage, cost of various M&R activities and vehicle fleet has been calculated for present year by data of base year (MoRTH, 2001). The analysis was carried out using HDM – 4 and optimum maintenance and rehabilitation alternative has been obtained and life cycle cost has been performed for the same.

3) BACKGROUND OF HDM-4

The Highway Development and Management System (HDM-4) system has been developed after a series of studies carried out in different countries of the world. Though initiated by World Bank in the late sixties, many leading research institutions of the world have contributed immensely in its development during last three decades. Following are the three main areas of analysis in HDM-4 which can be undertaken using the following applications (Henry , 2000): Project analysis, Programme analysis and Strategy analysis:

1) *Project Analysis:* Project analysis is concerned with the evaluation of one or more road projects or investment options. It includes the appraisal of M&R options for existing roads, widening or geometric improvement schemes, pavement upgrading, new road construction, etc.
2) *Programme Analysis*: Programme analysis is concerned with the preparation of work programmes in which candidate investment options are identified and selected, subject to resource constraints. Road networks are analyzed section by section and estimates are produced of road works and expenditure requirements for each section over a funding period. Programme analysis may be used to prepare multiyear rolling work programmes.
3) *Network Strategy Analysis*: Strategic planning is concerned with the analysis of a chosen network as a whole. 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 between 5 to 40 years.

4) STUDY AREA AND FIELD STUDIES

4.1) PRIMARY DATA COLLECTION

10 kilometre stretch of SH-151 (Dakor - Kapadvanj road) has been selected as a study area. The road network of study area consisted of 10 sections of total 10 km length.

Field surveys

Various data collected for analysis are discussed in the following sections.

Pavement Condition Survey

It includes measurement of distresses in pavement like ravelling, cracking, rutting and potholes. The summary of data collected for every section considered as a study area.

Bump Integrator Survey

Bump integrator survey has been performed to measure roughness of road sections. Roughness values are converted into International Roughness Index (IRI).

Road Inventory data

The inventory data include the following details about selected pavement sections: section ID, category of road, carriageway width road geometrics, surface type, details regarding the history of maintenance and construction of these roads, etc. are given in Table-1

Table 1:-Road Inventory Data

Chainage		Section ID	Formation Width (m)	Carriageway Width (m)	Shoulder Width (m)		Type of Surface	Length (m)	AADT	
From	To				LHS	RHS			MT	NMT
00+00	01+00	H1	17	14	1.5	1.5	BT	1	26023	627
01+00	02+00	H2	17	14	1.5	1.5	BT	1	26023	627
02+00	03+00	H3	17	14	1.5	1.5	BT	1	26023	627
03+00	04+00	H4	13	10	1.5	1.5	BT	1	26023	627
04+00	05+00	H5	13	10	1.5	1.5	BT	1	26023	627
05+00	06+00	H6	13	10	1.5	1.5	BT	1	26023	627
06+00	07+00	H7	13	10	1.5	1.5	BT	1	26023	627
07+00	08+00	H8	13	10	1.5	1.5	BT	1	26023	627
08+00	09+00	H9	13	10	1.5	1.5	BT	1	26023	627
09+00	10+00	H10	13	10	1.5	1.5	BT	1	26023	627

Note: BT= Bituminous, MT= Motorized Vehicles, NMT= Nonmotorized Vehicles, AADT= Annual Average Daily Traffic

Cost of Maintenance treatments

The unit rates of road construction/maintenance activities were calculated for present year with the help of base year (MoRTH, 2001) and intervention criteria are in Table-4 that are applied to road sections and HDM-4 system analysis has been carried out.

Table 2:- Cost of various Maintenance treatments (In Rupees)

Sr. No.	Name of Work	Financial Cost (Rs. /sq.m)	Type of Work
1	Crack Sealing	90.47894884	Routine Maintenance
2	Pothole Patching	114.0034755	Routine Maintenance
3	Edge Repair	104.4428666	Routine Maintenance
4	Double Bituminous Surface Dressing (DBSD)	225.3908059	Periodic Maintenance
5	25 mm BC	367.5479775	Periodic Maintenance
6	40 mm BC	588.0767639	Periodic Maintenance
7	50 mm DBM	935.162881	Periodic Maintenance
8	Mill and Overlay 90 mm (50 mm BM+ 40 mm BC)	1377.254926	Periodic Maintenance
9	200 mm WMM+50 mm BM+ 25 mm BC	1839.043322	Pavement Reconstruction
10	200 mm WMM+50 mm BM+ 40 mm SDBC	2145.53675	Pavement Reconstruction

Note- DBSD- Double Bituminous Surface Dressing, BC- Bituminous Concrete, DBM- Dense Graded Bituminous Macadam, BM- Bituminous Macadam, WMM- Wet Mix Macadam

Vehicle Operating Cost

Vehicle fleet data includes basic vehicular characteristics and economic unit cost of vehicle operation like cost of new vehicles, cost of new tyre, cost of lubricating oil, etc. The cost is calculated for present year 2019 by using data of base year 2009 (IRC:SP:30, 2009).

Structural evaluation by Benkelman Beam Deflection method

To assess the structural condition of 10 road sections selected, Benkelman Beam rebound deflection method was used which is a non-destructive method. The deflection measurements were taken as per the standard procedure (IRC, 1997).

Table 3:- Vehicle Operating Cost (in Rupees)

Vehicle Type	New Vehicle	Tyre Cost	Fuel	oil cost	Labour	Crew Wage	Annual cost	Passenger working time*	Passenger non-working time*	Cargo*
2W	54090	993	28.3	86.7	6	0	5000	40	2	-
3W	230257	1673	27.8	86.7	3	50	10000	30	3	-
CAR	763226	2951	27.8	86.7	6	0	20000	65	4.5	-
LCV	652752	4617	27.8	86.7	3	30	120000	-	-	1
HCV	1141896	9357	27.8	179.5	4	52	400000	-	-	3
MAV	1287959	9357	27.8	179.5	4	52	400000	-	-	5
BUS	1102523	9977	27.8	179.5	6	80	200000	40	5	2
TRACTOR	616000	11400	27.8	86.7	3	30	120000	-	–	–

*As Per (IRC:SP:30, 2009)

Traffic volume count

In order to find the composition and volume of traffic, the road traffic volume surveys for period of 72 hour were carried out including non-motorized traffic. The traffic count was represented in terms of commercial vehicles per day (CVPD). The traffic data were collected manually and converted into Annual Average Daily Traffic (AADT) for further analysis process.

4.2) Secondary Data Collection

4.2.1) Pavement History Data

Secondary data collection was taken from R&B department, Government of Gujarat. It includes pavement layer composition, history of maintenance treatments provided and year of application.

5) Project Analysis

Project analysis application of HDM-4 system has been run to obtained optimum Maintenance and Rehabilitation (M&R) strategy. To justify selected M&R strategies by financial point of view, economic analysis has been performed so that maximum benefits can be gain by road users and optimum investment can be done by concerned authority. Project analysis has been performed for analysis period of 12 years and economic analysis has been carried out at discount rate of 12%. M&R Strategy having maximum NPV/CAP ratio is selected as an optimum M&R Strategy for particular road section. Table-5 gives economic analysis summary.

Table 4: Various M&R Strategy with their Intervention Criteria

Alternatives	M&R Strategy	Description of work	Intervention Level*
ALT-1	Base Alternative	Do Nothing	
ALT-2	Routine Maintenance	Crack Sealing, Patch work	Scheduled Annually
ALT-3	Overlay	25 mm SDBC	IRI > 2
ALT-4	Overlay	25 mm BC	IRI > 2.8
ALT-5	Overlay	40 mm BC	IRI > 4
ALT-6	Resealing	DBSD	TDA > 5%
ALT-7	Resealing + Overlay	DBSD + 40 mm BC	IRI > 4 & TDA > 5%
ALT-8	Strengthening	50 mm DBM + 40 mm BC	TDA > 3%, IRI > 4
ALT-9	Mill & Overlay	Mill 90 mm and replace with 50 mm BM + 40 mm BC	IRI > 4, TCC > 5%
ALT-10	Pavement Reconstruction	200 mm WMM + 50 mm BM + 25 mm BC	IRI > 8, TDA > 10%

*Decided as per (MoRTH G. o., 2004) & (Wightman, Stannard, & Dakin, 2000)

Table 5: Summary of Economic Analysis Summary

Section	Optimum Alternative	Description of work	NPV/CAP
H1	ALT-5	40 mm BC	39.11
H2	ALT-5	40 mm BC	32.43
H3	ALT-5	40 mm BC	28.84
H4	ALT-5	40 mm BC	38.56
H5	ALT-5	40 mm BC	29.06
H6	ALT-5	40 mm BC	29.07
H7	ALT-5	40 mm BC	38.80
H8	ALT-5	40 mm BC	34.52
H9	ALT-5	40 mm BC	35.53
H10	ALT-5	40 mm BC	37.59

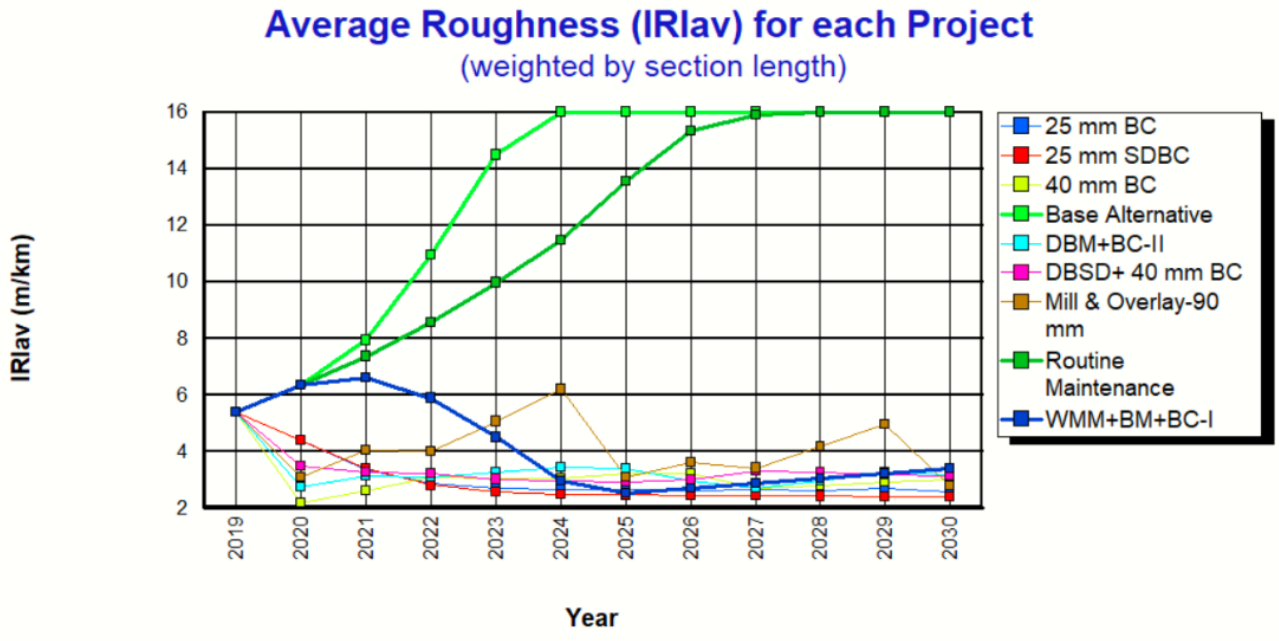

Figure 1: Roughness Progression under Various M&R Strategy

6) STRATEGY ANALYSIS (LIFE CYCLE COST ANALYSIS)

Life cycle cost analysis has been performed with taking various M&R strategy indicated in Table-4 by strategy analysis application of HDM-4 system. Life cycle cost analysis has been indicated by performing unconstrained works programme. As optimum M&R Strategy by project analysis and strategy analysis is found to be same so that Life cycle cost analysis of Optimum M&R strategy is given in Table-6 by unconstrained works programme. Total budget requirements to keep road sections in good condition is obtained by unconstrained work programme. When there is availability of budget, it is advisable to follow unconstrained work plan because it suggests best maintenance and rehabilitation strategy that is optimum for road sections.

Table 6: Life Cycle Cost Analysis for Optimum M&R Strategy

Section	Year of Application	Work Description	NPV/CAP	Cumulative Cost (Million Rupees)
H1	2019	40 mm BC	39.11	5.88
	2027	40 mm BC	39.11	11.76
H2	2019	40 mm BC	32.43	17.64
	2025	40 mm BC	32.43	23.52
H3	2019	40 mm BC	28.84	29.4
	2023	40 mm BC	28.84	35.28
	2028	40 mm BC	28.84	41.16
H4	2019	40 mm BC	38.56	47.04
	2027	40 mm BC	38.56	52.92
H5	2019	40 mm BC	29.06	58.8
	2023	40 mm BC	29.06	64.68
	2028	40 mm BC	29.06	70.56
H6	2019	40 mm BC	29.07	76.44
	2024	40 mm BC	29.07	82.33
	2030	40 mm BC	29.07	88.21
H7	2019	40 mm BC	38.8	94.09
	2029	40 mm BC	38.8	99.97
H8	2019	40 mm BC	34.52	105.85
	2025	40 mm BC	34.52	111.73
H9	2019	40 mm BC	35.53	117.61
	2027	40 mm BC	35.53	123.5
H10	2019	40 mm BC	37.59	129.37
	2027	40 mm BC	37.59	135.25
Total Budget Requirements			135.25 Million Rs. *	

*Cost is including Routine Maintenance works and up to analysis period

7) CONCLUSION

1) HDM-4 system has low distress acceptance criteria than IRC provision which keeps pavement at considerably condition.
2) Optimum M&R Strategy is much useful for highway engineer, concerned authorities and consultants in order to achieve maximum benefits from optimum investment.
3) Average condition of pavement reaches to 16 m/km IRI in year 2024 if no maintenance is applied while in case of routine maintenance, Average condition of pavement reaches to 16 m/km in year 2027.
4) PMMS is scientific tool which is helpful to achieve fully service life of pavement.
5) Strategy analysis helpful for long term budget planning so that necessary steps can be taken.
6) It is recommended that optimum M&R Strategy can be use rather than fixed cycle maintenance in order to avoid over maintenance.

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