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Adaptation of HDM-4 Tool for Strategic Analysis of Urban Roads Network

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Abstract

The Urban roads constitute about 9.0 % (4.11 lakh kms) of the total road length in India. The urban roads especially in metropolitan cities carry a huge traffic volume which affects the road condition adversely. The other factors responsible for poor roads in urban areas are the problem of overloading, encroachment on the road land and ribbon development along road side, lack of attention to drainage which may lead to failure of pavement, and various utility services which necessitate frequent digging thereby disturbing homogeneity of pavement. Therefore, there is a need of an efficient Urban Pavement Maintenance Management System (UPMMS) which would be useful to the highway agencies in planning pavement maintenance strategies in a scientific manner for urban cities, to ensure rational utilization of limited maintenance funds.

This paper describes the adaptation of the World Bank's highway development and management model HDM-4 at the strategic level. Urban road network of 21 sections, consisting of total 60 km road length of Noida city, near New Delhi, capital of India, were analyzed. The analysis was carried out to maximize the net present value (NPV) and minimize the costs to achieve a desirable target international roughness index (IRI). The analysis results presented the need for the optimal capital and recurrent maintenance required to maintain the urban road network in serviceable condition. The urban roads can be managed and maintained effectively using the strategy application of HDM-4.

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Keywords: Urban roads; HDM-4; Strategic analysis; international roughness index.

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1. Introduction

Pavement management systems have improved significantly and implemented effectively in developed countries, but developing countries like India still needs a systematic approach to implement PMS efficiently. Today, highway administrators have number of tools or mechanisms that allow them to make a better use of the available resources for the M&R of highway pavements but are not acceptable globally. Hence, these tools are lacking in universal acceptance and implementation. The World Bank has developed Highway Development and Management System (HDM-4) which is an internationally recognized tool available for making timely and cost effective maintenance management decisions for urban road network. HDM-4 system could be implemented to assist the highway agencies for establishing realistic levels of funding, and to set levels and priorities to maximize the effectiveness of expenditure on pavement maintenance activities. Therefore, HDM-4 system has been selected and used in this study due to the wider international acceptance.

2. Overview 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 (Morosiuk et al. 2006): Project analysis, Programme analysis and Strategy analysis:

i. *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.
ii. *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.
iii. *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.

3. Literature Review

Urban maintenance management system has been developed at network-level and project level for urban cities in developed countries *(Battiato et al. 1994, Chen et al. 1994 & Sohail et al. 1996)*. At a later stage, Highway Development and Management (HDM-4) analysis tool, developed by the International Study of Highway Development and Management (ISOHDM), was available which was a comprehensive package used to evaluate pavement condition, to suggest optimum M&R strategies, to prepare road maintenance investment plan, and to carry out economic appraisals of road projects. The budget requirements and prediction of pavement performance by applying the strategy analysis of HDM-4 has been presented for low-volume roads (*Veeraragavan & Reddy 2003*). The relationship between optimal pavement design and maintenance strategy and the level of economic development (LED) were investigated using HDM-4 *(Tsunokawa & Ul-Islam, 2003)*. The 'Project Analysis' and 'Programme Analysis' applications of HDM-4 has been used to develop the Pavement Maintenance System (PMS) for Indian National highways after due calibration of the deterioration models *(Aggarwal et al. 2004 & Jain el al. 2004)*. The HDM-4 tool was also applied after due calibration to develop maintenance plan for the Washington State Department of Transportation's (WSDOT's) road network (*Li et al. 2005*) and for Iran *(Fakhri & Rooeinbakht 2004)*. A web-based tool for The Western Cape Provincial Administration (WCPA) in South Africa was developed that allowed a user to obtain an HDM4 Version 2 workspace that is to be used in the LCCA *(Burger & Gryp 2008)*. Strategic analysis application of HDM-4 was adapted to derive optimal capital and recurrent maintenance needs to

clear existing maintenance backlogs and thereafter keep the local road network of UK in good condition on a sustainable basis *(Odoki et al. 2012).* The prioritization of pavement sections for maintenance, a key component of PMS, can be done using HDM-4 on the basis of Net Present Value by Agency Capital Cost (NPV/CAP) value *(Shah et al 2014).*

4. Objectives of the study

The main objectives of this study are:

i. To apply HDM-4 strategic analysis to a network of selected urban roads of Noida City, and
ii. To determine the required funding levels for the defined maintenance and improvement standards on the basis of two criteria: (i) maximizing the NPV and (ii) minimization of the costs to achieve target international roughness index (IRI).

5. Illustrations

NOIDA city is considered to be one of the most modern cities of Uttar Pradesh state of India, located about 20-kilometre southeast of New Delhi. The study area included 21 urban pavement sections, constituting a total length of 60 km of NOIDA city. The details of these road sections are given in Table 1.

Table 1. Details of selected urban road sections.

Sr. No.	Name of the Road	Section ID	Length (km)
1	Noida Link Road	UR 01	3.8
2	Jamnalal Bajaj Marg (MP Road No 1)	UR 02	3.5
3	Maharaja Agrasen Marg & Ashok Marg (MP Road No 2)	UR 03	6.0
4	Amrapali Marg & Golf Marg (MP Road No 3)	UR 04	7.5
5	Udhyog Marg	UR 05	3.2
6	Vindayachal Marg & Shivalik Marg	UR 06	2.2
7	Nithari Road	UR 07	2.4
8	Kamal Marg	UR 08	3.0
9	Khoda Village Road	UR 09	2.2
10	Sector - 62 Road Along NH-24	UR 10	2.0
11	Sector - 62 Road (Rajat Vihar to Mamura crossing)	UR 11	3.3
12	Kakral Road (60M) (Phase – II)	UR 12	1.8
13	Mahamaya Balika Inter college Road (60M)	UR 13	4.0
14	Panchsheel Bal Inter College Road (45M)	UR 14	2.3
15	45M Peripheral Road in Sector - 88	UR 15	2.5
16	24M Road in Sector - 88	UR 16	3.0
17	Amity University Road (Between Sector 125 & 126)	UR 17	0.7
18	Lotus Valley Inter School Road (Between Sector 126 &127)	UR 18	0.7
19	Road along NGN Expressway (45M) (Connecting Sector 126 & 127)	UR 19	2.0
20	Harsing Nagar Marg	UR 20	3.2
21	Road between Sector 7 & 8 (Near Vasundhara Enclave)	UR 21	0.7

Note: MP – Master Plan; DSC -Dadri-Surajpur-Chalera; NITHE –National Institute of Training of Highway Engineers; NGN – Noida Greater Noida.

Data collection for all pavement sections was aimed to meet the requirements of HDM-4 input system. The process of data collection was classified under following three categories:

(i) Road Network Data: The road network data collection in the field included road Inventory data and road geometric details, structural evaluation (structural capacity), functional evaluation (pavement condition and riding quality) and evaluation of pavement material. The characteristics of selected road sections are presented in Table 2.

(ii) Vehicle Fleet Data: The vehicle fleet data included the collection of basic vehicle characteristics, economic cost details of vehicles and traffic volume count & growth factors. The vehicle fleet characteristics are presented in Table 3 for motorized vehicles and in Table 4 for non motorized vehicles considered in this study. Table 5 presents the economic cost details for the selected vehicle categories.

Maintenance and Rehabilitation Works History: This includes collecting the information about current surface thickness (mm) & Base thickness (mm), last reconstruction or new construction year, and last rehabilitation/resurfacing/preventive treatment year.

Table 2. Road network data.

Section ID	Length (km)	Carriage-way Width (m)	Current Surface Thickness (mm)	Last Resurfacing/ Strengthening Year	Pavement Type	MT AADT	NMT AADT	DCTS (mm)	Roughness (IRI m/km)
UR 01	3.8	10.5	40.0	2006-07	AMAP	54476	1602	1.354	3.43
UR 02	3.5	10.5	40.0	2006-07	AMAP	35807	3073	1.435	5.16
UR 03	6.0	10.5	40.0	2008-09	AMAP	35707	5073	1.563	3.41
UR 04	7.5	10.5	50.0	2008-09 2009-10	AMAP	33381	1587	1.298	4.89
UR 05	3.2	10.5	40.0	2002-03	AMAP	24912	1707	1.342	4.85
UR 06	2.2	10.5	50.0	--	AMAP	20332	3814	1.287	4.77
UR 07	2.4	10.5	40.0	2008-09	AMAP	16804	3924	1.189	3.21
UR 08	3.0	10.5	40.0	2009-10	AMAP	19930	3709	1.989	5.65
UR 09	2.2	10.5	40.0	2006-07	AMAP	18450	4178	1.231	4.39
UR 10	2.0	10.5	40.0	2006-07	AMAP	10637	982	1.42	4.45
UR 11	3.3	7.0	50.0	2007	AMAP	12686	3960	2.378	4.67
UR 12	1.8	10.5	40.0	2006-07	AMAP	7961	1523	1.543	4.57
UR 13	4.0	10.5	40.0	2008-09	AMAP	2290	252	2.453	3.57
UR 14	2.3	10.5	40.0	2008-09	AMAP	6114	538	2.533	3.89
UR 15	2.5	10.5	40.0	2005-06	AMAP	1324	302	2.873	4.67
UR 16	3.0	7.0	40.0	2005-06	AMAP	3660	631	2.313	3.98
UR 17	0.7	7.0	50.0	2005-06	AMAP	3279	415	1.724	5.27
UR 18	0.7	7.0	40.0	2005-06	AMAP	6066	893	1.597	5.39
UR 19	2.0	10.5	40.0	2005-06	AMAP	3373	367	1.783	4.86
UR 20	3.2	10.5	40.0	2008	AMAP	18645	3423	1.829	3.87
UR 21	0.7	7.0	40.0	2006-07	AMAP	7286	3697	1.872	4.69

Note: IRI- International Roughness Index, MT-Motorized Traffic, NMT- Non Motorized Traffic, AADT-Annual Average Daily Traffic, AMAP – Asphaltic Mix on Asphaltic Pavement, DCTS – Characteristic Deflection

Table 3. Motorized vehicle fleet basic details.

Description	Motorized Vehicle Category							
	Scooter / M.C.	Car/Jeep / Van	Mini bus	Bus	Mini Truck	Truck	Tractor Trolley	Auto
PCSE	0.5	1	1.2	1.8	1.5	1.8	2.2	1
No. of wheels	2	4	4	6	4	6	4	3
No. of Axles	2	2	2	2	2	2	3	2
Tyre Type	Radial Ply	Radial Ply	Radial Ply	Radial Ply	Radial Ply	Radial Ply	Radial Ply	Radial Ply
Annual km	10000	30000	60000	85000	50000	90000	8000	35000
Annual Works Hour	500	600	3000	4000	2200	3000	500	800
Avg. Life (Years)	8	10	8	11	10	12	8	7

Private Use (%)	100	90	0	0	0	0	0	0
Passengers	1	3	20	50	0	0	0	3
Work related Trips (%)	75	75	75	75	0	0	0	75
ESALF	0	0	0.25	1.7	1.7	2.5	1.4	0
Oper. Weight in Tonnes	0.2	1.35	4	9	4	14	6	1

Note: M.C. – Motor Cycle, PCSE – Passenger Car Space Equivalency

Table 4. Non-motorized vehicle fleet basic details.

	Description								
NMT Vehicle Category	**Wheel Type**	**No. of wheels**	**Wheel Diameter (m)**	**Passen-gers**	**Works Hour**	**Annual km**	**Avg. Life (Years)**	**Pay Load (kg)**	**Oper. Weight (kg)**
Bicycle	Pneumatic	2	0.7	1	150	2500	8	35	80
Cycle Rickshaw	Pneumatic	3	0.7	3	500	6000	6	235	250

Table 5. Road user economic cost data for representative vehicles.

Description	**Motorized Vehicle Category (Cost in Rs.)**									
	Scooter /M.C.	**Car/Jeep /Van**	**Mini bus**	**Bus**	**Mini Truck**	**Truck**	**Tractor/ Trolley**	**Auto**	**Bicycle**	**Cycle Rickshaw**
Purchase Cost (New Veh.)	40000	500000	1000000	2000000	1200000	1500000	1600000	200000	3000	7000
Replace Tyre (per No.)	500	2000	5000	7000	7000	7000	7000	1000	100	100
Fuel (per litre)	70	70	50	50	50	50	50	50	0	0
Lubr. Oil (per litre)	250	280	280	280	280	280	280	280	0	0
Maint. Labour (per hr)	15	15	20	30	20	30	20	15	0	0
Crew Wages (per h)	0	20	80	80	80	80	50	30	0	20
Passenger Work Time (per h)	40	80	50	50	0	0	0	40	20	20
Passenger Non-work time (per hr)	20	75	25	25	0	0	0	20	0	0
Cargo Holding (per h)	0	0	0	0	20	55	60	0	0	0

6. 'Strategy Analysis' Application of HDM-4

Considering the prevailing maintenance strategies, various maintenance and rehabilitation (M&R) alternatives proposed for this study with their intervention criteria's are given in Table 6. The 21 representative sections are analyzed for the investment alternatives given in Table 6.The routine maintenance has been considered as a base alternative for the analysis. The total damage area, which comprise of total area of cracking, raveling and pothole has been considered to be the primary controlling factor for activating resealing of pavement surface. Roughness has

been considered to be the primary controlling factor for activating provision of overlays and strengthening of the pavement.

Table 6. Proposed M&R strategies and intervention criteria.

Sr. No.	Alternatives	Work Standard / Type of Maintenance	Description of Work	Intervention Level For Arterial Roads	For Sub arterial Roads
1	Base Alternative	Routine Maintenance	Crack Sealing	> 5 %	> 10 %
			Patching	> 5 %	> 10 %
			Pothole Repair	> 1 No.	> 3 No.
			Ravel Repair	> 5 %	> 10 %
			Side Drain Cleaning	Scheduled annually	Scheduled annually
2	Alternative 1	Resealing	25 mm SBSD	Total damage area > 5% of total area	Total damage area > 10% of total area
3	Alternative 2	Thin Overlay	Overlay 25 mm SDBC	Roughness > 2.8 m/km IRI	Roughness > 4 m/km IRI
4	Alternative 3	Thick Overlay	Overlay 40 mm BC	Roughness > 2.8 m/km IRI	Roughness > 4 m/km IRI
5	Alternative 4	Resealing + Overlay	25 mm SBSD + Overlay 40 mm BC	Total damage area > 5% of total area, and Roughness > 2.8 m/km IRI	Total damage area > 10% of total area, and Roughness > 4 m/km IRI
6	Alternative 5	Strengthening	50 mm DBM + 40 mm BC	Roughness > 5 m/km IRI and Carriageway cracked area > 10% of total area	Roughness > 6 m/km IRI and Carriageway cracked area > 15% of total area

Note: IRI – International Roughness Index, SBSD – Single Bituminous Surface Dressing, SDBC – Semi Dense Bituminous Concrete, BC – Bituminous Concrete, DBM – Dense Graded Bituminous Macadam

The strategic analysis has been carried out for the selected urban road network. The analysis is carried out to maximize the NPV or minimize the costs to achieve a desirable target IRI, which means the maximum IRI at or below which the network is to be kept. The project period has been considered to commence from the year 2014. The economic analysis has been carried out for a design period of 10 years considering a discount rate of 12%. The analysis has been done using the M&R standards same as that used for LCCA.

6.1. Maximize NPV

On analyzing the sections under strategy analysis to maximize the NPV, an unconstrained work program has been generated through HDM-4. Table 7 shows the results of the strategy analysis to maximize NPV with the total cumulative cost for maintenance and the alternatives with the highest NPV. From Table 7 it is seen that the investment alternative that maximizes the NPV for sections UR 09, UR 10, UR 13, UR 17 & UR 19 is 'Thin Overlay of 25 mm SDBC' and for section UR 06 & UR 20 is 'Thick Overlay of 40 mm BC'. For remaining 13 sections the 'Strengthening with 50 mm DBM + 40 mm BC' was the one that maximizes the NPV. The total capital cost required has been estimated as Rs. 643.96 million.

Table 7. Unconstrained work programme of strategy analysis considering maximizing NPV.

Section	Length (KM)	Year	Work Description	NPV/ CAP	Financial Cost	Cumulative Cost
UR 01	3.80	2014	Strengthening	12.28	29.89	29.89
	3.80	2021	Strengthening	12.28	29.89	59.77
UR 02	3.50	2014	Strengthening	16.53	27.53	87.30
	3.50	2021	Strengthening	16.53	27.53	114.82
UR 03	6.00	2014	Strengthening	18.67	47.19	162.01
	6.00	2021	Strengthening	18.67	47.19	209.20

UR 04	7.50	2014	Strengthening	17.76	58.98	268.18
	7.50	2021	Strengthening	17.76	58.98	327.16
UR 05	3.20	2014	Strengthening	17.15	16.78	343.94
	3.20	2022	Strengthening	17.15	16.78	360.72
UR 06	2.20	2014	Thick Overlay	11.50	8.27	368.99
	2.20	2015	Thick Overlay	11.50	8.27	377.26
	2.20	2020	Thick Overlay	11.50	8.27	385.53
UR 07	2.40	2014	Strengthening	6.17	18.87	404.40
UR 08	3.00	2014	Strengthening	16.70	23.59	428.00
	3.00	2021	Strengthening	16.70	23.59	451.59
UR 09	2.20	2014	Thin Overlay	9.16	5.15	456.74
	2.20	2015	Thin Overlay	9.16	5.15	461.89
	2.20	2018	Thin Overlay	9.16	5.15	467.04
	2.20	2022	Thin Overlay	9.16	5.15	472.19
UR 10	2.00	2014	Thin Overlay	4.75	4.68	476.88
	2.00	2015	Thin Overlay	4.75	4.68	481.56
	2.00	2017	Thin Overlay	4.75	4.68	486.24
	2.00	2020	Thin Overlay	4.75	4.68	490.93
UR 11	3.30	2014	Strengthening	41.45	17.30	508.23
UR 12	1.80	2014	Strengthening	3.65	14.16	522.38
UR 13	4.00	2014	Thin Overlay	0.26	9.37	531.75
	4.00	2017	Thin Overlay	0.26	9.37	541.12
	4.00	2021	Thin Overlay	0.26	9.37	550.48
UR 14	2.30	2014	Strengthening	2.62	18.09	568.57
UR 16	3.00	2014	Strengthening	3.34	15.73	584.30
UR 17	0.70	2014	Thin Overlay	5.43	1.09	585.39
	0.70	2015	Thin Overlay	5.43	1.09	586.49
UR 18	0.70	2014	Strengthening	7.34	3.67	590.16
UR 19	2.00	2014	Thin Overlay	1.56	4.68	594.84
	2.00	2015	Thin Overlay	1.56	4.68	599.52
	2.00	2019	Thin Overlay	1.56	4.68	604.20
UR 20	3.20	2014	Thick Overlay	11.52	12.03	616.23
	3.20	2016	Thick Overlay	11.52	12.03	628.26
	3.20	2020	Thick Overlay	11.52	12.03	640.29
UR 21	0.70	2014	Strengthening	12.37	3.67	643.96

All costs are expressed in Million Indian Rupees

NOTE: i. Thin overlay = 25 mm SDBC, ii. Thick overlay = 40 mm BC, iii. Strengthening = 50 mm DBM + 40 mm BC

6.2. Minimization of costs to achieve target IRI

On analyzing the urban road network with the criteria of minimizing costs for a target IRI, HDM-4 produced a constrained program as given in Table 8. From Table 8 it is seen that for all 21 sections, the 'Strengthening with 50 mm DBM + 40 mm BC' is the best investment alternative because it keeps the entire road network at an acceptable condition, as shown in Figure 1. The total capital cost for this option is estimated as Rs. 720.91 million.

Table 8. Constrained program to minimize costs for target IRI.

Section	Length (KM)	Year	Work Description	NPV/ CAP	Financial Cost	Cumulative Cost
UR 01	3.80	2014	Strengthening	12.28	29.89	29.89
	3.80	2021	Strengthening	12.28	29.89	59.77
UR 02	3.50	2014	Strengthening	16.53	27.53	87.30
	3.50	2021	Strengthening	16.53	27.53	114.82
UR 03	6.00	2014	Strengthening	18.67	47.19	162.01
	6.00	2021	Strengthening	18.67	47.19	209.20
UR 04	7.50	2014	Strengthening	17.76	58.98	268.18
	7.50	2021	Strengthening	17.76	58.98	327.16
UR 05	3.20	2014	Strengthening	17.15	16.78	343.94
	3.20	2022	Strengthening	17.15	16.78	360.72
UR 06	2.20	2014	Strengthening	8.24	17.30	378.02
	2.20	2023	Strengthening	8.24	17.30	395.32
UR 07	2.40	2014	Strengthening	6.17	18.87	414.20
UR 08	3.00	2014	Strengthening	16.70	23.59	437.79
	3.00	2021	Strengthening	16.70	23.59	461.38
UR 09	2.20	2014	Strengthening	5.42	17.30	478.69
	2.20	2023	Strengthening	5.42	17.30	495.99
UR 10	2.00	2014	Strengthening	2.62	15.73	511.72
	2.00	2023	Strengthening	2.62	15.73	527.45
UR 11	3.30	2014	Strengthening	41.45	17.30	544.75
UR 12	1.80	2014	Strengthening	3.65	14.16	558.90
UR 13	4.00	2014	Strengthening	0.15	31.46	590.36
UR 14	2.30	2014	Strengthening	2.62	18.09	608.45
UR 15	2.50	2014	Strengthening	0.06	19.66	628.11
UR 16	3.00	2014	Strengthening	3.34	15.73	643.84
UR 17	0.70	2014	Strengthening	3.13	3.67	647.51
UR 18	0.70	2014	Strengthening	7.34	3.67	651.18
UR 19	2.00	2014	Strengthening	1.34	15.73	666.91
UR 20	3.20	2014	Strengthening	8.19	25.17	692.08
	3.20	2023	Strengthening	8.19	25.17	717.24
UR 21	0.70	2014	Strengthening	12.37	3.67	720.91

All costs are expressed in Million Indian Rupees

NOTE: Strengthening = 50 mm DBM + 40 mm BC

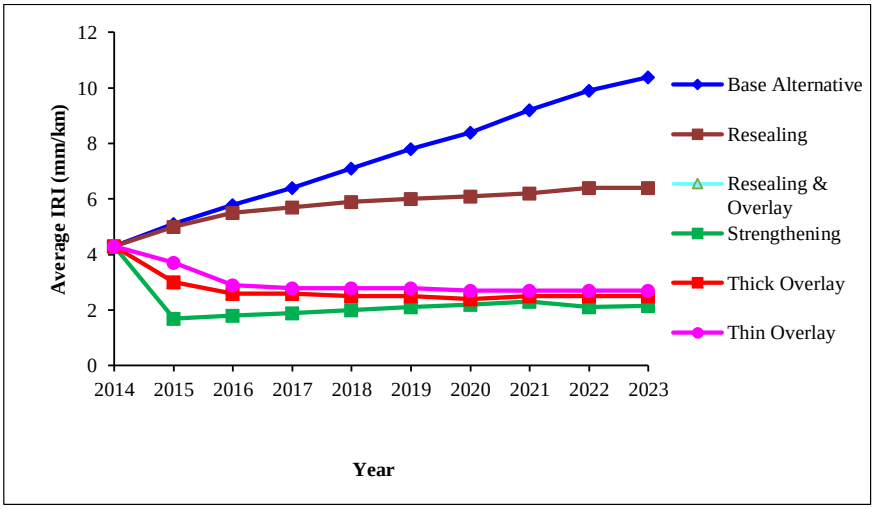

Fig. 1. Average IRI for urban road network under strategy analysis.

7. Conclusions

The selection of the best maintenance alternative and forecasting the maintenance budget requirement for a selected road network depend on the criteria that a planner adopts. The planning criteria may be maximizing the NPV or keeping the average road network in an acceptable condition. The following conclusions have been drawn from the analysis:

- When the criterion of maximizing NPV has been used, the 'Thin Overlay of 25 mm SDBC' maintenance results in maximum (NPV) for sections UR 09, UR 10, UR 13, UR 17 & UR 19 and for section UR 06 & UR 20 is 'Thick Overlay of 40 mm BC'. For remaining 13 sections the 'Strengthening with 50 mm DBM + 40 mm BC' was the one that maximizes the NPV.
- When the criterion of minimizing costs for target IRI was considered, the 'Strengthening with 50 mm DBM + 40 mm BC' is the best investment alternative because it keeps the entire road network at an acceptable condition.

The HDM-4 strategic analysis can serve as a customized economic evaluation tool in forecasting budget requirements and network condition and can be used for managing urban roads on the basis of sound engineering principles.

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