A Framework to Develop a Long-term Maintenance Plan Using HDM-4 for the Developing Countries

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Abstract: A road structure deteriorates with time under the combined effect of vehicular load and environment. To derive optimum performance adoption of a long-term comprehensive maintenance plan by the road agency is mandatory. This paper aims at presenting a framework for developing a comprehensive maintenance plan for the major road networks in a developing country, taking Bangladesh as a case using HDM 4 Program. The findings reveal substantial demand for periodic maintenance (650 million USD), partial reconstruction (501 million USD) and full reconstruction (383 million USD) for the first year (2016). However, the periodic maintenance demand falls sharply in the next year, vacillates slightly throughout the rest of the period to finally reach a value of 100 million USD in 2035. In contrast, partial and full reconstruction requirement diminishes almost to zero in future. Routine maintenance requirement increases consistently from 48 million USD in 2016 to 227 million USD in 2035.

Keywords: HDM 4, Program analysis, maintenance plan

1. INTRODUCTION

In order to achieve maximum performance from a road network, and to ensure that traffic can continue to travel in a safe, efficient, and reliable manner, it is imperative to adopt an effective pavement management system coupled with a long-term maintenance plan. An efficient maintenance plan provides necessary information to formulate a policy framework with a view to ensuring timely allocation of adequate budget to address the wear and tear of the road structure caused by traffic loading and adverse weather condition. It usually defines the serviceability of the existing road network, uses data and information to determine the maintenance requirements and adjusts maintenance needs to available funding by prioritizing the investment options to attain the best overall network outcomes. The absence of a long-term and appropriate maintenance strategy might lead to an inefficient and underfunded maintenance regime and accumulation of maintenance backlog creating immense pressure on existing budget allocation for road maintenance. Deferred maintenance might result in failure of pavement structure; requiring rehabilitation or full reconstruction at a much higher cost than the cost of preventive or corrective maintenance (Annual Report, 2004). Hence, a long term forecast of maintenance requirement and investment priorities may serve as a useful source of information for the road agency managers and the policy makers to devise an appropriate strategy to optimize their limited resources for the proper management of their road asset.

Like other developing countries, the road network of Bangladesh has experienced a massive expansion in the last couple of decades owing to a significant modal shift from other modes of transport like water and rail to road transport (TSC, 2006). As per the latest gazette published by the Planning Commission of Bangladesh, total length of arterial road network of the country is around 21,302 km of which 3,813 km are national highways (roads connecting the capital with the divisional headquarters, sea port and land port) , 4,247 km are regional highways (roads connecting a district with the divisional headquarters and other district) and the rest 13,242 km are the district roads (roads connecting district headquarters with the upazila headquarters and one upazila with other upazilas). The maintenance of this huge road asset is pivotal for the economic development of the country and understandably maintenance has been viewed with the highest priority in the National Integrated Multimodal Transport Policy (IMTP, 2013) In Bangladesh, however, the issue of road maintenance had always been underemphasized and insufficient maintenance budget allocation coupled with frequent occurrence of natural disaster have seriously degraded the serviceability of the road network to a sub-standard level. The absence of a long-term and appropriate maintenance strategy has led to an inefficient and underfunded maintenance regime and accumulation of huge maintenance backlog creating immense pressure on existing budget allocation for road maintenance. Hence, Roads and Highways Department (RHD), the major road agency in Bangladesh responsible for the management of this road network, is currently in need of an effective, efficient, long-term and sustainable Pavement Asset Maintenance Plan to preserve their existing valuable road asset as well as to wipe out the maintenance backlog.

Addressing this issue, this paper aims at developing a comprehensive maintenance plan for the major road network of Bangladesh for the next twenty years using HDM 4 Program Analysis that uses a life cycle cost-benefit approach. Even though, it is developed in the context of Bangladesh, the methodology and findings of this study can be useful for the other developing countries with similar geographical features and socio-economic condition. This study essentially includes the identification of the road segments that require maintenance, rehabilitation or reconstruction (where?), the time of maintenance intervention (when?), the appropriate maintenance option (what) and the priorities of maintenance works (order of preference). The main objectives of this analysis are:

- To perform a HDM 4 program analysis over the major road network of Bangladesh using a life cycle cost-benefit approach
- To select the road sections those require maintenance intervention and suggest the type of maintenance treatment
- To assess the priority of maintenance works on the basis of IRR, NPV and other economic indicators
- To make a future prediction of maintenance requirement for the next twenty years

2 METHODOLOGY

The historical data stored in road database of Roads and Highways Department (RHD) known as Road Maintenance and Management System (RMMS) which is a SQL server database, served as the fundamental input of this analysis. The data bank consists of pavement inventory data, traffic data (AADT), pavement roughness data (IRI), road condition data, Benkelman Beam deflection data, road user cost data, construction type and quality data, pavement history data etc., which are collected and updated in regular intervals. The latest updating was done by conducting a comprehensive field survey in the year 2016 by the Data Collection Division of RHD.

HDM 4 export tool, developed earlier by RHD, was used to extract data from the existing

RMMS database and produce a program file and as well as a road network comprising of all the 159 fields that correspond to HDM 4 input road network. The road network consists of several homogenous sections of similar attributes and is created by a process known as dynamic segmentation. A total of 20 road networks and 20 program files were created by the HDM-4 export tool for the purpose of this analysis.

The Vehicle fleet developed earlier by the Roads and Highways Department was used in this analysis. This vehicle fleet consists of 10 classes of motorized (heavy truck, medium truck, small truck, large bus, minibus, microbus, utilities, car, baby-taxi, motor cycle) and 3 classes of non-motorized vehicles (rickshaw, bi-cycle, cart). The different components of Vehicle Operating Costs such as fuel cost, lubricating oil cost, tire replacement cost, overhead maintenance cost and the travel time cost data were collected by road user cost (RUC) survey conducted by economist circle of RHD. The basic characteristics of each type of vehicle were also calibrated and adapted to develop a realistic road user effects (RUE) model.

The maintenance intervention matrix that determines the type of maintenance works for a specific road condition parameter (or a combination of parameters) were developed earlier based on field experience research undertaken by the officials of Roads and Highways Department, Bangladesh. A total of eight maintenance intervention matrices were used in this analysis. The financial and economic cost of all work items under each maintenance intervention matrix were calculated using RHD Schedule of Rates, 2015.

The aforesaid road networks, the program files, the vehicle fleet, the maintenance intervention matrices and other relevant data were imported in the HDM 4 workspace to make the environment for analysis. Level 1 calibration and configuration was performed to adapt different models used in HDM 4 to Bangladesh condition and finally the program analysis was carried out for each network for 20-year life cycle. The program analysis automatically identifies the road sections requiring maintenance, the optimum maintenance option and priorities of the works.

Using the result of the program analysis maintenance requirement along with priorities of the woks with respect to Net Present Value over cost were projected for the next twenty years. Figure 1 outlines the overall approach adopted by this study:

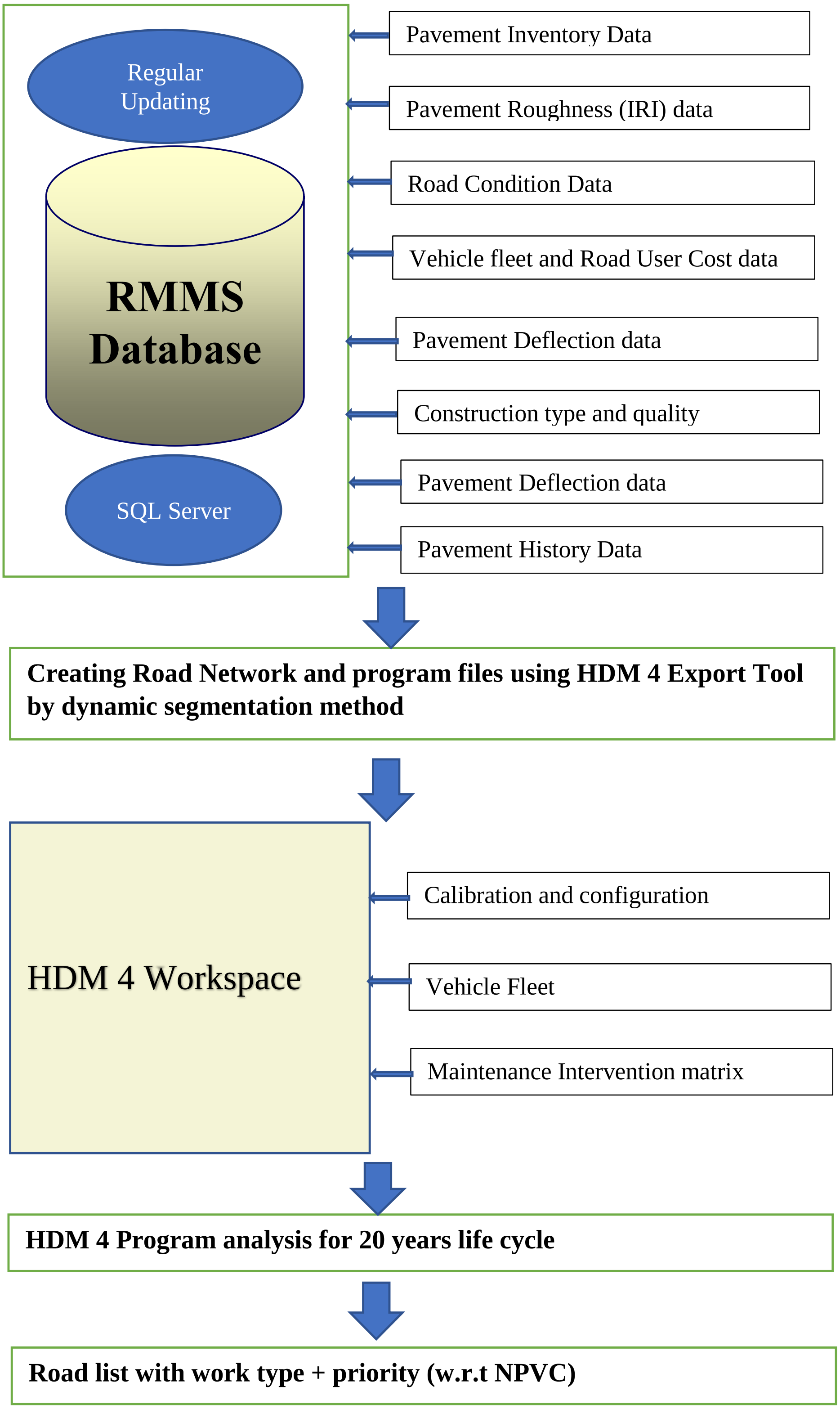

Figure 1. Overall Methodological Approach

2.1 The RHD Road Network

Table 1 shows the length of the 3 major classes of roads in Bangladesh belonging to Roads and Highways Department (RHD) and their present condition based on the field survey carried out in 2016. The road condition is grossly categorized into descriptive bands based on roughness (Table 2). Different ranges are adopted for each road class to reflect their relative importance.

Table 1: Overall Condition of RHD roads

Road	Length (km)	Good%	Fair%	Poor %	Bad %	Very bad %
National	3813	54.05	25.56	13.39	4.36	2.64
Regional	4247	42.82	26.39	20.23	6.25	4.32
District	13242	31.53	21.39	24.15	16.56	6.36
Total	21302	39.16	23.49	20.85	11.43	5.06

Table 2: Qualitative descriptors of IRI value

	National Highway	Regional Highway	Zila Road
IRI Values			
Good	0 – 3.9	0 – 4.9	0 – 5.9
Fair	4.0 – 5.9	5.0 – 6.9	6.0 – 7.9
Poor	6.0 – 7.9	7.0 – 8.9	8.0 – 9.9
Bad	8.0 – 9.9	9.0 – 10.9	10.0 – 11.9
Very Bad	≥10.0	≥11.0	≥12.0

2.2 Calibration and Configuration of HDM 4

One of the most important prerequisite of analyzing this road network by HDM 4 is calibration of the software itself. The main objective of calibration is to adjust the calibration coefficients so that the predicted performance compares well with the observed performance (Henning *et al.*, 2006). HDM 4 uses a number of models and sub models such as road deterioration model, road works effect model, road user effects model, Vehicular emission model and so on. These models require to be suitably calibrated in order to make sure that the output produced by the HDM 4 model represents the local condition (Bennett and Paterson, 2000).For the purpose of this study, level 1 calibration of different model parameters were done by determining the values of required basic input parameters, adopting many default values, and calibrating the most sensitive parameters with best estimates, desk studies or minimal field surveys as suggested by Bennett and Paterson (2000) in their book “A guide to Calibration and Adaptation”.

Level-1 calibration gave us the following three factors which have high impact on Road Deterioration and Works Effects model (RDWE) and are highly sensitive. These are:

- Roughness-age-environment factor
- Cracking initiation factor
- Cracking progression factor

The other factors, which have low impact and sensitivity, are as follows:

- Rut depth progression factor
- Roughness progression factor
- Pothole progression factor
- Raveling initiation factor.

Table 3. RDWE Calibration Parameters

Items	Calibration Factors
Roughness-age-environment factor	1.1
Cracking initiation factor	0.800
Cracking progression factor	1.250
Rut depth progression factor	1.500
Roughness progression factor	1.00
Pothole progression factor	1.000
Raveling initiation factor	1.000

2.3 Maintenance Intervention Matrix

The Maintenance Intervention Matrix specifies the optimum maintenance treatment option in response to a combination of pavement condition parameters (such as IRI, rutting depth, nature and extent of cracking, number of potholes) and traffic (AADT). These standards are based primarily on the research outcomes of two ex-officials of RHD; Khan and Odoki (2008). "Establishing optimal pavement maintenance standards using the HDM-4 Model for Bangladesh") and Hoque (1998). "Optimum Maintenance Standards for Feeder Road Type-B (FRB) and Rural Road Class-1 (R1) in Bangladesh". However, some modifications were brought into the compound maintenance standards taking into account the experience and analysis of road deterioration and road works effect mechanism in Bangladesh.
While developing the maintenance intervention matrix, Corridor roads (roads connecting the capital with the Divisional headquarters, i.e. N1, N2, N3, N4, N5, N6, N7 and N8) were given the highest priority as they carry a substantial portion of traffic and will be the part of the Asian Highway Network defined by ESCAP in the near future. Hence periodic maintenance is considered for these categories of roads at relatively low level of IRI (IRI=4). In contrast, for the other National highways, Regional highways and District roads periodic maintenance are suggested at higher value of IRI; 5, 5.5 and 6 IRI respectively. "Holding maintenance strategy" (mainly DBST) was considered to prevent the road from further deterioration in the case of inadequacy of maintenance budget allocation. Tables 4-11 provide details of the maintenance standards for all categories of roads of Bangladesh:

Table 4. Holding standard without reconstruction for national and regional roads

<table>
<tr><th rowspan="2">Roughness Range (IRI)</th><th rowspan="2">All Damage (%)</th><th colspan="5">Traffic Range (MT-AADT)</th></tr>
<tr><th>100 - 1999</th><th>2000 - 3999</th><th>4000 - 5999</th><th>6000 - 9999</th><th>> 10000</th></tr>
<tr><td rowspan="5"><12</td><td><5%</td><td colspan="5">Routine</td></tr>
<tr><td>5 - 10%</td><td colspan="3">Routine</td><td colspan="2" rowspan="4">DBST (DBST-A)</td></tr>
<tr><td>10 - 20%</td><td colspan="2">Routine</td><td rowspan="3">DBST (DBST-B)</td></tr>
<tr><td>20 - 30%</td><td>Routine</td><td rowspan="2">DBST (DBST-C)</td></tr>
<tr><td>> 30%</td><td>DBST (DBST-D)</td></tr>
<tr><td>> 12.00</td><td>All</td><td colspan="5">DBST (DBST-E)</td></tr>
</table>

Table 5. Holding standard with reconstruction for national and regional roads

<table>
<tr><th rowspan="2">Roughness Range (IRI)</th><th rowspan="2">All Damage (%)</th><th colspan="5">Traffic Range (MT-AADT)</th></tr>
<tr><th>100 - 1999</th><th>2000 - 3999</th><th>4000 - 5999</th><th>6000 - 9999</th><th>> 10000</th></tr>
<tr><td rowspan="5"><12</td><td><5%</td><td colspan="5">Routine</td></tr>
<tr><td>5 - 10%</td><td colspan="3">Routine</td><td colspan="2" rowspan="4">DBST (DBST-F)</td></tr>
<tr><td>10 - 20%</td><td colspan="2">Routine</td><td rowspan="3">DBST (DBST-G)</td></tr>
<tr><td>20 - 30%</td><td>Routine</td><td rowspan="2">DBST (DBST-H)</td></tr>
<tr><td>> 30%</td><td>DBST (DBST-I)</td></tr>
<tr><td>> 12.00</td><td>All</td><td>Full Recon 110mm (FR110A)</td><td>Full Recon 135mm (FR135A)</td><td>Full Recon 150mm (FR150A)</td><td>Full Recon 180mm (FR180A)</td><td>Full Recon 195mm (FR195A)</td></tr>
</table>

Table 6: Holding standard without reconstruction for District roads

<table>
<tr><th rowspan="2">Roughness Range (IRI)</th><th rowspan="2">All Damage (%)</th><th colspan="5">Traffic Range (MT-AADT)</th></tr>
<tr><th>100 - 999</th><th>1000-1999</th><th>2000-2999</th><th>3000-3999</th><th>>4000</th></tr>
<tr><td rowspan="4"><12</td><td>0 -10%</td><td colspan="5">Routine</td></tr>
<tr><td>10-20%</td><td colspan="2">Routine</td><td colspan="3" rowspan="3">Overlay 40mm (OV40A)</td></tr>
<tr><td>20-30%</td><td>Routine</td><td rowspan="2">Overlay 40mm (OV40B)</td></tr>
<tr><td>>30%</td><td></td></tr>
<tr><td>> 12.00</td><td>All</td><td colspan="5">Overlay 40mm (OV40D)</td></tr>
</table>

Table 7. Holding standard with reconstruction for District roads

<table>
<tr><th rowspan="2">Roughness Range (IRI)</th><th rowspan="2">All Damage (%)</th><th colspan="5">Traffic Range (MT-AADT)</th></tr>
<tr><th>100 - 999</th><th>1000-1999</th><th>2000-2999</th><th>3000-3999</th><th>>4000</th></tr>
<tr><td rowspan="4"><12</td><td>0 -10%</td><td colspan="5">Routine</td></tr>
<tr><td>10-20%</td><td colspan="2">Routine</td><td colspan="3" rowspan="3">Overlay 40mm (OV40E)</td></tr>
<tr><td>20-30%</td><td>Routine</td><td rowspan="2">Overlay 40mm (OV40F)</td></tr>
<tr><td>>30%</td><td>Overlay 40mm (OV40G)</td></tr>
<tr><td>> 12.00</td><td>All</td><td colspan="5">Full Rec 75mm (FR75A)</td></tr>
</table>

Table 8. Compound maintenance standard for national corridor roads

<table>
<tr><th rowspan="2">Roughness Range (IRI)</th><th rowspan="2">Cracking Range (%)</th><th colspan="5">Traffic Range (MT-AADT)</th></tr>
<tr><th>100 - 1999</th><th>2000 - 3999</th><th>4000 - 5999</th><th>6000 - 9999</th><th>> 10000</th></tr>
<tr><td rowspan="2">< 4.0</td><td>< 25%</td><td colspan="5">Routine</td></tr>
<tr><td>>= 25%</td><td colspan="4">DBST (DBST-J)</td><td>Overlay 50mm (OV50A)</td></tr>
<tr><td>4.00 - < 7.00</td><td>All</td><td colspan="3" rowspan="2">Overlay 50mm (OV50C)</td><td>Overlay 50mm (OV50B)</td><td rowspan="2">Overlay 80mm (OV80A)</td></tr>
<tr><td>7.00 - < 9.00</td><td>All</td><td>Overlay 60mm (OV60A)</td></tr>
<tr><td>9.00 - < 12.00</td><td>All</td><td>Rehab 120mm (RH120A)</td><td>Rehab 140mm (RH140A)</td><td>Rehab 150mm (RH150A)</td><td>Rehab 180 (RH180A)</td><td>Rehab 195mm (RH195A)</td></tr>
<tr><td>> 12.00</td><td>All</td><td>Full Rec 120mm (FR120A)</td><td>Full Rec 140mm (FR140A)</td><td>Full Recon 150mm (FR150B)</td><td>Full Recon 180mm (FR180B)</td><td>Full Recon 195mm (FR195B)</td></tr>
</table>

Table 9. Compound maintenance standard for other national roads

<table>
<tr><th rowspan="2">Roughness Range (IRI)</th><th rowspan="2">Cracking Range (%)</th><th colspan="5">Traffic Range (MT-AADT)</th></tr>
<tr><th>100 - 1999</th><th>2000 - 3999</th><th>4000 - 5999</th><th>6000 - 9999</th><th>> 10000</th></tr>
<tr><td rowspan="2">< 5.0</td><td>< 25%</td><td colspan="5">Routine</td></tr>
<tr><td>>= 25%</td><td colspan="4">DBST (DBST-K)</td><td>Overlay 50mm (OV50D)</td></tr>
<tr><td>5.00 - < 7.00</td><td>All</td><td colspan="3" rowspan="2">Overlay 50mm (OV50F)</td><td>Overlay 50mm (OV50E)</td><td rowspan="2">Overlay 80mm (OV80B)</td></tr>
<tr><td>7.00 - < 9.00</td><td>All</td><td>Overlay 60mm (OV60B)</td></tr>
<tr><td>9.00 - < 12.00</td><td>All</td><td>Rehab 110mm (RH110A)</td><td>Rehab 135mm (RH135A)</td><td>Rehab 150mm (RH150B)</td><td>Rehab 180 (RH180B)</td><td>Rehab 195mm (RH195B)</td></tr>
<tr><td>> 12.00</td><td>All</td><td>Full Recon 110mm (FR110B)</td><td>Full Recon 135mm (FR135B)</td><td>Full Recon 150mm (FR150C)</td><td>Full Recon 180mm (FR180C)</td><td>Full Recon 195mm (FR195C)</td></tr>
</table>

Table 10. Compound maintenance standard for other regional roads

<table>
<tr><th rowspan="2">Roughness Range (IRI)</th><th rowspan="2">Cracking Range (%)</th><th colspan="5">Traffic Range (MT-AADT)</th></tr>
<tr><th>100 - 1999</th><th>2000 - 2999</th><th>3000 - 3999</th><th>4000 - 4999</th><th>> 5000</th></tr>
<tr><td rowspan="2">< 5.5.0</td><td>< 25%</td><td colspan="5">Routine</td></tr>
<tr><td>>= 25%</td><td colspan="5">DBST (DBST-L)</td></tr>
<tr><td>5.50 - < 7.00</td><td>All</td><td colspan="4">Overlay 50mm (OV50G)</td><td rowspan="2">Overlay 60mm (OV60C)</td></tr>
<tr><td>7.00 - < 9.00</td><td>All</td><td colspan="3">Overlay 50mm (OV50H)</td><td>Overlay 60mm (OV60D)</td></tr>
<tr><td>9.00 - < 12.00</td><td>All</td><td>Rehab 110mm (RH110B)</td><td colspan="2">Rehab 135mm (RH135B)</td><td colspan="2">Rehab 150mm (RH150C)</td></tr>
<tr><td>> 12.00</td><td>All</td><td>Full Recon 110mm (FR110C)</td><td colspan="2">Full Recon 135mm (FR135C)</td><td colspan="2">Full Recon 150mm (FR150D)</td></tr>
</table>

Table 11. Compound maintenance standard for other regional roads

<table>
<tr><th rowspan="2">Roughness Range (IRI)</th><th rowspan="2">Cracking Range (%)</th><th colspan="5">Traffic Range (MT-AADT)</th></tr>
<tr><th>100-999</th><th>1000-1999</th><th>2000-2999</th><th>3000-3999</th><th>>4000</th></tr>
<tr><td rowspan="2">< 6.0</td><td>< 25%</td><td colspan="5">Routine</td></tr>
<tr><td>>= 25%</td><td colspan="3">Seal 15mm (SEALA)</td><td>Overlay 40mm (OV40H)</td><td>Overlay 50mm (OV50I)</td></tr>
<tr><td>6.0 - < 7.00</td><td>All</td><td colspan="4" rowspan="2">Overlay 40mm (OV40I)</td><td rowspan="2">Overlay 50mm (OV50J)</td></tr>
<tr><td>7.00 - < 9.00</td><td>All</td></tr>
<tr><td>9.00 - < 12.00</td><td>All</td><td colspan="5">Rehab- 75mm (RH75A)</td></tr>
<tr><td>> 12.00</td><td>All</td><td colspan="5">Full Rec 75mm (FR75B)</td></tr>
</table>

2.4 Maintenance and Rehabilitation Treatments

Program analysis of HDM 4 considers varieties of routine maintenance, periodic maintenance, rehabilitation and reconstruction treatment options that correspond to the commonly used maintenance works by the Roads and Highways Department, Bangladesh. Table 12 provides details of these treatments and the assumptions made for HDM.

Table 12. Maintenance and rehabilitation treatments and assumptions used in HDM (Source: Annual Maintenance and rehabilitation Needs Report (AMRNR) 2016-17, Roads and Highways Department, Bangladesh)

Periodic Maintenance	Preparatory Patching	Patching potholes and regulating surface irregularities prior to undertaking the treatments like DBST or DBS Overlay. Should not be more than 2% of the total quantity of overlay for National roads and maximum of 5% for Regional roads.
	Preparatory Edge Repair	Allows for restoring pavement edges that have been damaged by vehicles leaving the road to drive onto the shoulder prior to undertaking the treatments like DBST or DBS Overlay.
	DBST	Applying two layers of surface treatments on the prepared road surface. The total thickness has been specified as 25mm. This is applied in medium to highly trafficked road. Life expectancy assumed to be 3 years.
	Bituminous Carpeting	This is a 40-mm thick manual overlay used in low trafficked roads in place of dense bituminous overlay. Life expectancy has been taken as 2 to 4 years.
	Overlay	Machine laid premixed dense bituminous surfacing overlay 50 – 80 mm thick used in medium to highly trafficked roads. Carefully controlled overlay may be applied in response to badly damaged road surface or high roughness so as to obtain a predefined roughness level (2.5 to 3 IRI). Life expectancy assumed to be 5 years.
Rehabilitation	Partial Reconstruction	Reconstruction of the upper pavement layers following scarification of the existing damaged surface and re-compaction. Normally a 150-200 mm crushed aggregate base with a dense bituminous surfacing of between 75 and 195mm, depending on traffic level. This is a treatment to overcome higher roughness or higher levels of surface cracking resulting from delayed maintenance. Life expectancy should be 10 years prior to major periodic maintenance. Full design of the pavement must be undertaken prior to treatment. Shoulder rehabilitation would also be provided where necessary.
	Complete Reconstruction	A major reconstruction on the existing alignment and within the same overall dimension limits. The road is not widened. The pavement must be fully designed prior to construction and shoulder rehabilitation provided where necessary. Life expectancy should be 10 years before major periodic maintenance. Applied where there are extremely high levels of roughness and extensive cracking.
Holding Treatment		DBST triggered when rehabilitation is required but budget constraints do not permit the preferred treatment. Expected to last for 3 years
Routine Maintenance	Off-pavement works:	Includes all regular works along a road such as maintaining shoulders, roadside vegetation control, cleaning side drains and pipe culverts, maintenance of signs and signals.
	Patching	Repair of potholes based on a standard pothole unit of 0.01m3 per pothole. The quantity of pothole repairing shall not be more than 1% of the total surface.
	Crack Sealing	Sealing to cracks using Seal Coat/Fog Seal. It assumes a maximum in any one kilometer of 5% area affected.

2.5 Unit cost of Treatments

The unit costs of each maintenance treatment option were calculated using RHD schedule of 2015 and presented in table 13.

Table 13. Unit cost of treatment

Work Description	Financial Costs(USD)	Economic Costs (USD)
Routine (/km/year)	1,010	909
Patching (per m^2)	20	18
Edge Repair (per m^2)	20	18
Crack Sealing (per m^2)	3	3
Seal Coat (per m^2)	3	3
DBST 25 mm (per m^2)	6	6
Carpeting 40mm (per m^2)	10	9
Overlay 40mm (per m^2)	11	10
Overlay 50mm (per m^2)	13	12
Overlay 60mm (per m^2)	16	14
Overlay 80mm (per m^2)	21	19
Overlay 100mm (per m^2)	26	23
Overlay 120mm (per m^2)	31	28
Partial Recon 75mm (per m^2)	38	34
Partial Recon 100mm (per m^2)	44	40
Partial Recon 110mm (per m^2)	47	42
Partial Recon 120mm (per m^2)	49	44
Partial Recon 135mm (per m^2)	57	51
Partial Recon 140mm (per m^2)	58	53
Partial Recon 150mm (per m^2)	61	55
Partial Recon 180mm (per m^2)	73	65
Partial Recon 195mm (per m^2)	77	69
Full Recon 75mm (per m^2)	55	49
Full Recon 100mm (per m^2)	60	54
Full Recon 110mm (per m^2)	62	56
Full Recon 120mm (per m^2)	65	58
Full Recon 135mm (per m^2)	69	62
Full Recon 140mm (per m^2)	74	67
Full Recon 150mm (per m^2)	77	69
Full Recon 180mm (per m^2)	88	80
Full Recon 195mm (per m^2)	92	83

2.6 Program Analysis

For the purpose of program analysis, each road segment under a road network is assigned several alternatives so that comparative economic cost-benefit analysis can be done over a specified period (20 years in this case) and the optimum maintenance option can be determined. These section alternatives were developed by combining the different maintenance strategies (or intervention matrices) for each category of road and are as follows:

- Holding Treatment of the road
- Maintaining the road from 1st year (2016)
- Holding the road for 1st year (2016) and maintaining from 2nd year (2017)
- Holding the road for 1st 2 years (2016,17) and maintaining from 3rd year (2018)
- Holding the road for 1st 3 (2016,17,18) years and maintaining from 4th year (2019)
- Holding the road for 1st 4 years (2016,17,18,19) and maintaining from 5th year (2020)

In HDM 4 Program analysis, a road segment having certain condition parameters and traffic volume has been analyzed for each alternative for a life cycle of 20 years. Under this analysis, different maintenance treatments over the life cycle of the road are identified from the appropriate maintenance intervention matrix using the calibrated road deterioration and road works model and the year wise cost/ benefit streams, Net Present Value (NPV), Internal Rate of Return (IRR) and Net Present Value over Cost (NPV/C) are computed. For example, let us consider a National road with IRI=8, cracking=35% and AADT=3000. For alternative 1, the corresponding maintenance intervention matrix is table 4: Holding standard without reconstruction for national and regional roads and the maintenance treatment option is DBST. Assuming this treatment being provided, the after works road condition parameters are determined from the calibrated built-in HDM 4 road works effect model (RWEM). Then the road is allowed to deteriorate in accordance with the HDM 4 Road Deterioration Model (RDM) till a second intervention is required and this process continues for a period of 20 years (Figure 2). The cost (maintenance intervention cost) and benefit (savings from vehicle operating cost, travel time cost, accident cost and other exogenous cost) for each year is automatically calculated by HDM 4 software and the economic indicators like NPV, IRR, NPV/C are computed for a user defined discount rate (12% in our case) (Figure 2). In a similar manner, NPV is calculated for all the six alternatives and the alternative yielding maximum NPV has been chosen as the optimum alternative. The modelling logic and calculation process of HDM 4 is elaborately described in Odoki, J. B., Kerali, H. G. R. (2000) ‘Analytical Framework and Model Description. *Highway Development and Management Series*, HDM- 4, Vol. 4, SOHDM, PIARC, Paris’.

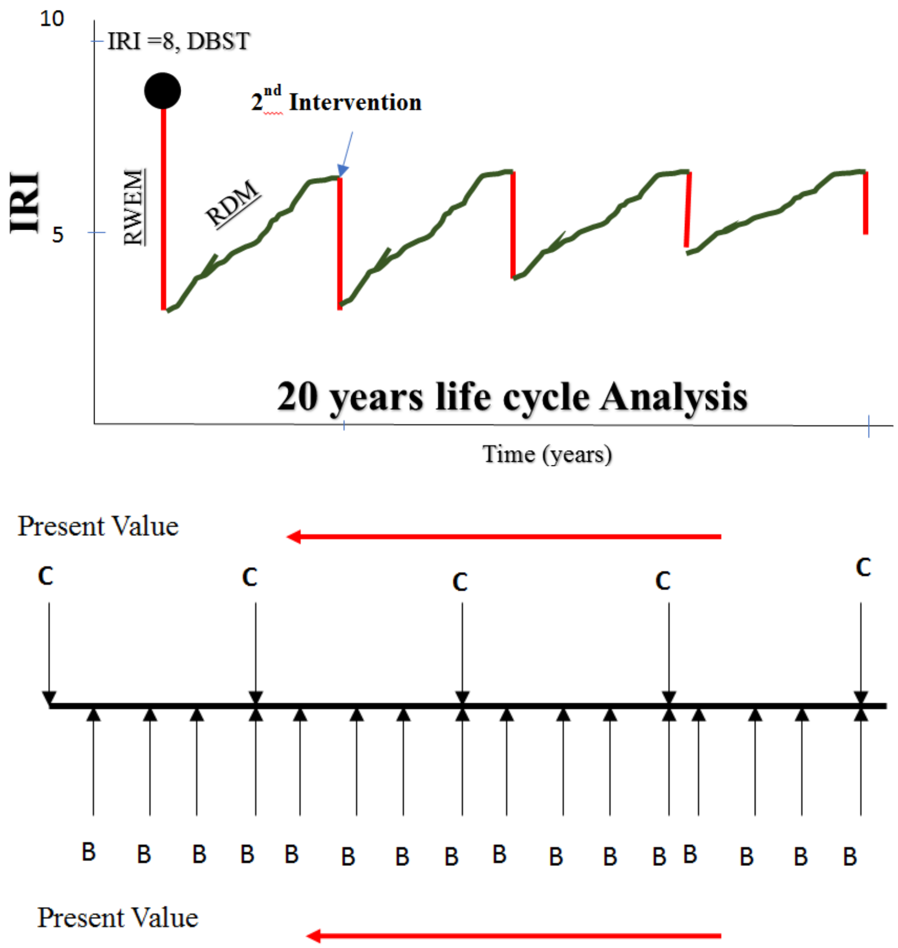

Figure 2. Life cycle analysis by HDM 4

Thus, by running the HDM 4 program analysis certain maintenance treatments for all the road segment under this study were identified and corresponding NPV, IRR and NPV/C were calculated. The parameter NPV over cost was used to determine the priority of the segments under maintenance and finally a road segment list with maintenance treatment and priority could be generated (table 14).

Table 14: Sample road list with work priority

Road No.	Road name	Chainage	Treatment	year	Financial cost	NPV/C
N2	Dhaka-Bhairab-Sylhet-Tamabil	Km 068.79-070.10	Overlay 80mm @ IRI 4-9	2016	18.54269	18.647
N2	Dhaka-Bhairab-Sylhet-Tamabil	Km 070.14-070.85	Full Recon 195mm	2016	41.23604	6.393
N2	Dhaka-Bhairab-Sylhet-Tamabil	Km 070.14-070.85	Full Recon 195mm	2016	41.23604	6.39
N2	Dhaka-Bhairab-Sylhet-Tamabil	Km 070.85-071.08	Overlay 80mm @ IRI 4-9	2016	4.601952	15.826
R211	Itakhola-Motkhola-Kotiadi Road	Km 035.34-035.54	Rehab 135mm @ IRI 9-12	2016	5.035136	0.932

R211	Itakhola-Motkhola-Kotiadi Road	Km 035.54-036.44	Overlay 50mm @ IRI 5-7	2016	5.32035	2.355
R211	Itakhola-Motkhola-Kotiadi Road	Km 036.44-036.54	Rehab 135mm @ IRI 9-12	2016	2.67152	1.015
R211	Itakhola-Motkhola-Kotiadi Road	Km 036.54-037.64	Overlay 50mm @ IRI 5-7	2016	6.8145	2.295
R211	Itakhola-Motkhola-Kotiadi Road	Km 037.64-037.74	Full Recon 135mm	2016	3.22376	1.562
R211	Itakhola-Motkhola-Kotiadi Road	Km 037.74-040.84	DBST @ Traff 2000-4000	2016	8.468642	1.875
R211	Itakhola-Motkhola-Kotiadi Road	Km 040.84-041.44	Overlay 50mm @ IRI 7-9	2016	3.465	3.233
R211	Itakhola-Motkhola-Kotiadi Road	Km 041.44-041.54	DBST @ Traff 2000-4000	2016	0.2717	3.316

3 ANALYSIS AND RESULTS

HDM-4 analysis was carried out for all road networks of Bangladesh that will be open to public use in future to have a general picture of upcoming maintenance budget requirement. The software generated a detailed work program for the whole network (Table 14) for a full 20-years analysis period. Figure 3 illustrates year wise periodic maintenance requirement in terms of different types of treatment such as overlay, double bituminous surface treatment (DBST) and seal coat. Figure 4 provides information on the total length of road over which periodic maintenance is suggested.

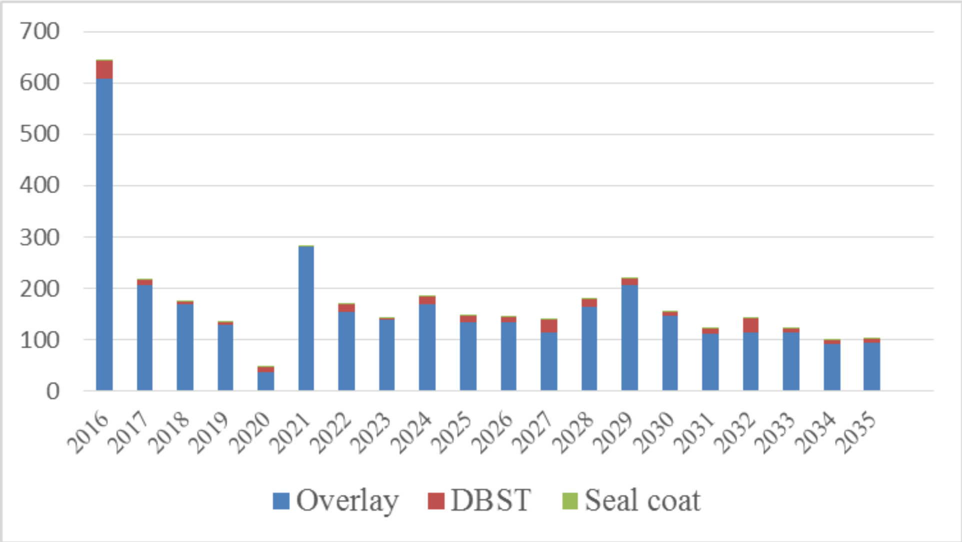

Figure 3. Total periodic maintenance requirement in million USD

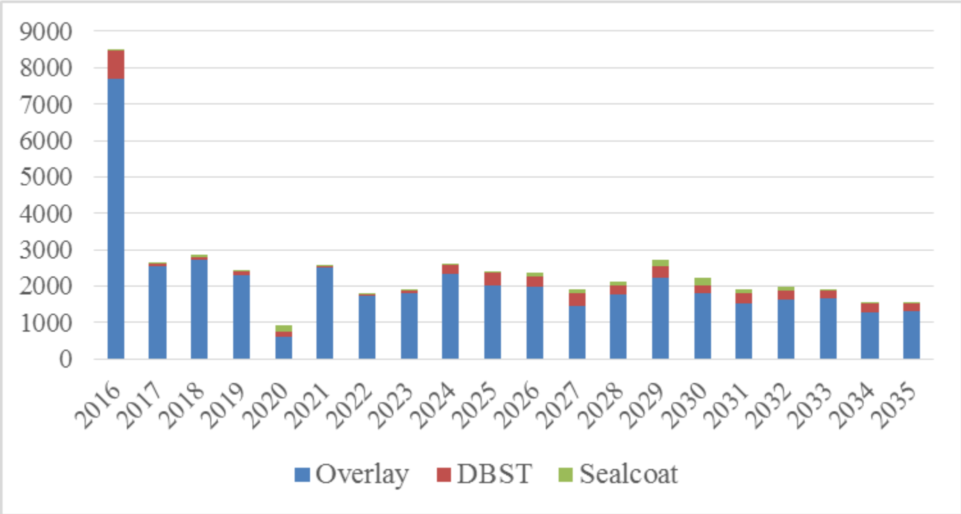

Figure 4. Total road length of periodic maintenance in km

The analysis reveals an enormous demand for periodic maintenance for the first year (2016), requiring nearly 650 million USD for treating over 8000 km of paved roads. This can be attributed to the fact that currently a major portion of road (nearly 40%) is in sub-standard condition (table 2), and providing a major maintenance treatment is a must to bring back the pavement to an acceptable level of service and rideability. The demand, however, declines quite dramatically in the next year, fluctuates slightly over the span of time to finally reach to a value of 100 million USD in 2035.This projection essentially assumes that the first-year maintenance requirement is fulfilled. On the other hand, overlay that comprises almost 95% of the periodic maintenance treatments cost and road length was found to be the most preferred periodic maintenance option compared to DBST and Overlay.
Figure 5 depicts backlog maintenance requirements in terms of partial reconstruction (rehabilitation) and full reconstruction. Predictably, the requirement is huge (almost 501 million USD for partial reconstruction and 383 million USD for full construction) in Bangladesh due to regular accumulation of maintenance works that were required to be carried out but postponed for insufficient budget allocation leading to structural failure of the pavement. Figure 5 gives information about total length of the road suggested by HDM 4 to be partially or fully reconstructed.

Figure 5. Trend of length of road in km requiring partial and full reconstruction

Interesting to note that even though the demand for partial and full reconstruction is massive at the first year, it falls sharply and diminishes almost to zero in the next couple of years. It is due to the fact that, the backlog maintenance once wiped out, would not come back, if appropriate preventive and periodic maintenance is carried out regularly and no pavement work is deferred to a future time.

Routine maintenance includes all regular works along the road length such as repairing potholes, sealing cracks, maintaining shoulders, removing vegetation etc. Routine maintenance is, in fact, a type of regulation maintenance work and the yearly budget requirement for this type of work remains more or less same over the pavement life cycle. In this analysis, however, a clearly upward trend in the requirement of routine maintenance budget was observed, increasing consistently from 48 million USD in 2016 to reach a value of 227 million USD in 2035. Figure 6 shows the trend of routine maintenance demand for the road network under this analysis.

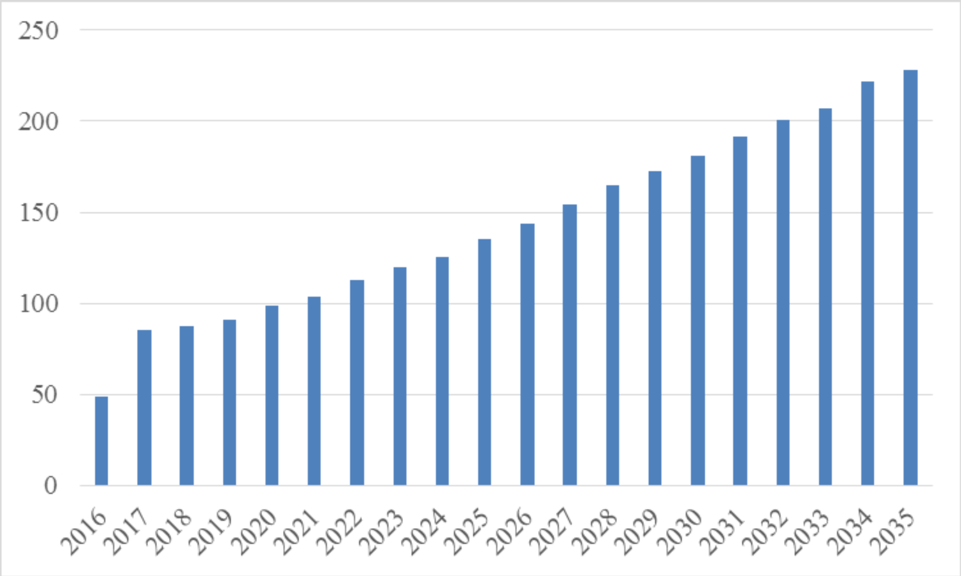

Figure 6. Trend of routine maintenance demand in million USD

The steady increase in the budget requirement for routine maintenance can be explained by the fact that, during the initial years more length of the network is suggested for periodic maintenance and reconstruction leaving less area for routine maintenance, whereas during the latter years comparatively greater portion of the network will be maintained by preventive and corrective maintenance resulting in declining periodic maintenance requirement.

Finally Figure 7 illustrates the trend of total maintenance budget requirement (periodic + partial reconstruction + full reconstruction + routine maintenance) over the next twenty years and Figure 8 shows the average roughness (IRI) of different categories of road, if this level of budget is maintained. From Figure 8, it is evident that majority of the road network will be in good or fair condition (defined in Table 3) under this suggested budget regime.

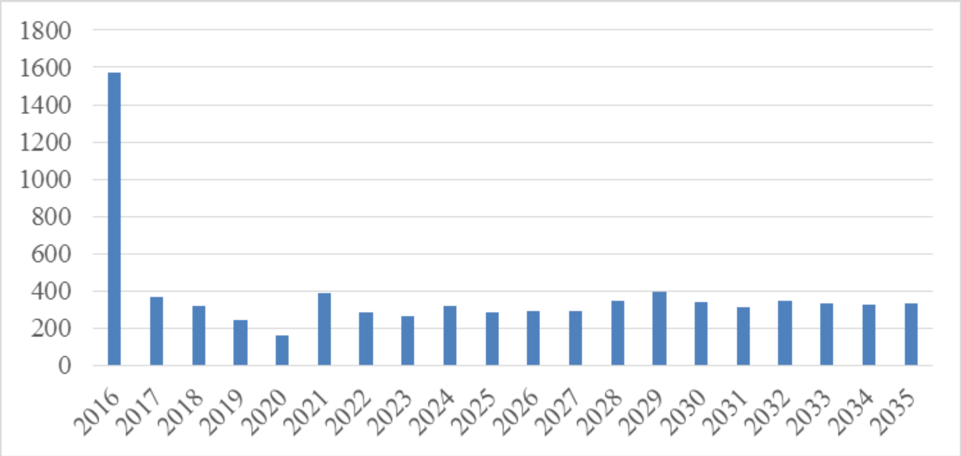

Figure 7. Trend of maintenance budget requirement in million USD for the next 20 years

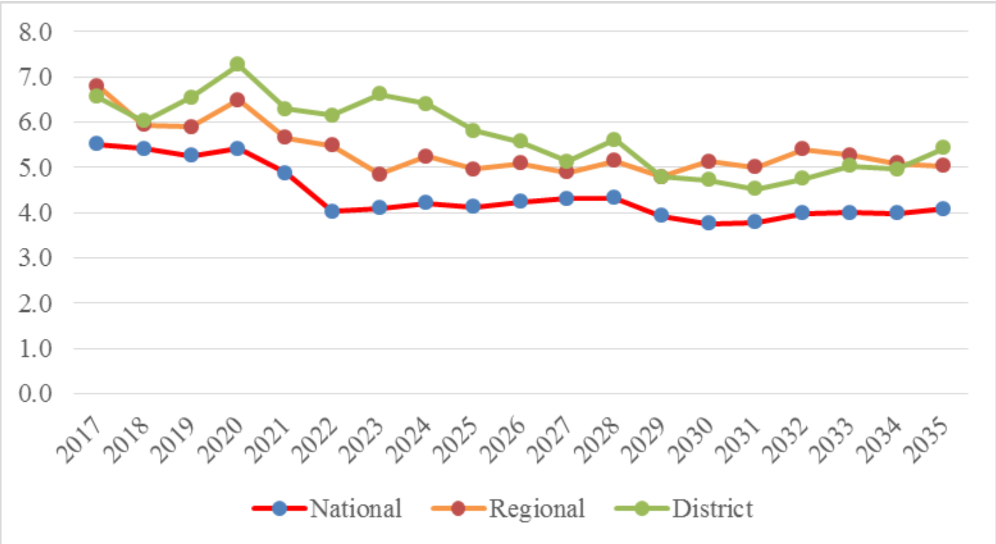

Figure 8. Average Predicted IRI of National, Regional and District Highways for the next 20 years

4 CONCLUSIONS AND DISCUSSION

This paper provides a framework for the policy makers to allocate their limited resources in an economically beneficial way and to make a master plan to maintain their road network efficiently by forecasting the future budget and identifying the portion of the network that requires maintenance in the coming years. The analysis reveals that, if the backlogs are eliminated and the initial huge requirement of periodic maintenance is addressed properly by allocating adequate budget, the yearly maintenance requirement will be brought down considerably and pavement condition will improve. So, an effective strategy should be adopted to wipe out the maintenance backlog as soon as possible. However, it should be kept in mind that the treatments suggested by the maintenance intervention matrices are indicative only and field visits and detail design verification must be undertaken before finalizing any treatment option.

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