A REVIEW OF HDM-4 OUTPUTS IN BANGLADESH

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ABSTRACT

Roads and Highways Department (RHD) of Bangladesh uses the Highway Development and Management Model (HDM-4) to determine its Annual Maintenance and Rehabilitation Needs for Periodic Maintenance Program (PMP) and to maintain its assets. Some of the HDM-4 outputs in 2005 were initially found inconsistent from field observations and video data. It was observed that data quality and mismatch of yearly data provided wrong outputs. As a result, several HDM-4 reruns were made to obtain better results. Paved roads asset valuation, current backlog, RHD's recent and 5-years maintenance demand were derived in the analysis. It is recommended to analyze the database for reliability before use, to collect data on time, to change treatment intervention criteria and to set calibration parameters of the HDM-4 model appropriately to obtain better HDM-4 outputs. Field visits are suggested to finalize treatment selection. It was observed that maintenance overlay would not sustain long if pavements are structurally weak, and rehabilitation design is suggested for those cases.

1. INTRODUCTION

Roads and Highways Department (RHD) of Bangladesh has the prime responsibility to construct and maintain major roads, bridges and ferries in the main road network of Bangladesh. RHD's objective is to provide safe, cost effective and well-maintained roads at the satisfaction of road users. RHD has about 20,800 km of roads and about 15,000 bridges and culverts [1]. The replacement value of RHD road-related assets is valued at approximately US $7,400 million [2].

RHD has a comprehensive Pavement Management System (PMS), which is currently being upgraded and its scope extended. It contains a Road Maintenance and Management System (RMMS) database at its core, a Geographical Information System (GIS) and the Highway Development and Management Model (HDM-4) for decision-making purposes [3]. RHD-PMS has the following components [4]:

- Data collection system,
- Database (the RMMS database),
- Decision making tool (the HDM-4 model),
- Programming,
- Implementation, and
- Monitoring.

Generally, to maintain the road network properly, road condition, pavement inventory, traffic and roughness data are collected each year for each paved road and entered into the RMMS database [5]. In 2004, Road Measurement Data Acquisition System (ROMDAS) was used in RHD to measure roughness data at different speeds, and traffic, road condition, deflection and pavement inventory data were collected through out-sourced contracts [5]. However, in 2005, only roughness data were fed into the RMMS database. No traffic, road condition and pavement inventory data were collected in 2005 for the latest HDM-4 analysis [1]. It should be mentioned here that complete and timely data are required in the analysis year for a justifiable HDM-4 run.

HDM-4 model is a well-known economic tool [6]. It is observed in RHD that appropriate inputs are essential to obtain sound results for a justifiable HDM-4 run, which are [4]:

- Reliable data,
- Treatment intervention criteria, and
- Calibration parameters.

In a recent study [3], it was observed that less than 5% of the RMMS database of RHD is reliable, which considered 1996-2002 data. However, the 2004 outsourced data are quite all right [4]. Data reliability can be checked by field visits, and using statistical and range check methods before use [3].

Treatment intervention criteria are the trigger levels of a treatment, based mainly on ranges of roughness, road condition and traffic volume [7]. Intervention levels are usually chosen in relation to road importance and road use on the basis of technical and economic criteria. Set treatment intervention criteria for all treatments in Bangladesh can be seen elsewhere [1] [3] [4].

Several studies developed Road Deterioration (RD) and Work Effects (WE) models' calibration factors for Bangladesh [3]. However, a recalibration is required for some of the factors [4].

2. ANNUAL MAINTENANCE AND REHABILITATION NEEDS REPORT

RHD produces the Annual Maintenance and Rehabilitation Needs Report using the HDM-4 model to maintain its asset and the current report of 2006-2007 is the seventh one [1]. The report provides guidelines to managers and engineers in RHD to improve the road network in a cost effective manner. The outputs from HDM-4 program analysis are based on the RMMS database of RHD [1].

2.1 Assumptions

The HDM-4 predicts the life cycle pavement conditions (performance) and costs over a specified analysis period (in this case 20 years) under a user-specified set of circumstances. The costs used in the analysis include cost of capital investment, maintenance costs and Vehicle Operating Costs (VOC). The costs of two scenarios are compared [1]:

- The “do minimum maintenance" scenario (patching and resealing of cracks every year, Double Bituminous Surface Treatment (DBST) when treatment is deferred due to lack of funding and total reconstruction at International Roughness Index (IRI) =12 from year six onwards).

- The "with maintenance" scenario.

In the current analysis, holding maintenance strategy has been considered, which means that DBST has to be provided instead of higher treatment if there is shortage of funding. It can keep a road, as it is as much as possible until funding is ensured. This approach was considered to manage the road network at least in a maintainable condition [1]. For the acceptance of any maintenance option, only the actions with positive "Net Present Value (NPV)/Cost" value (at a 12 % discount rate) were considered as viable. NPV/cost was chosen to obtain maximum benefits as it produces highest benefits when there is crisis in funding [1].

Initially, the project-alternative, per road category, with highest NPV/cost was found, which represents a theoretical optimal solution that concentrates most of the road works in year 1, and then the resulting theoretical optimal road works programme was evenly distributed over years 1 to 5 without budget constraint. It should be mentioned here that the Periodic Maintenance Programme (PMP) is undertaken from the HDM-4 outputs [1].

2.2 Results on Maintenance Demand

The unconstrained and average cost needed for periodic maintenance and rehabilitation for the first 5 years of the analysis period is shown in Figure 1 and in Table 1, which shows that on an average about US$ 777 million is required for the next 5 years for PMP and to remove backlog for the 14,940 km of analyzed roads [1]. Table 1 reveals that current RHD backlog is US$ 214 million for the analyzed roads, which is below than previous estimation. It was decreased due to considering holding maintenance strategy instead of higher treatments, and having reliable and precious roughness data in 2005 [1].

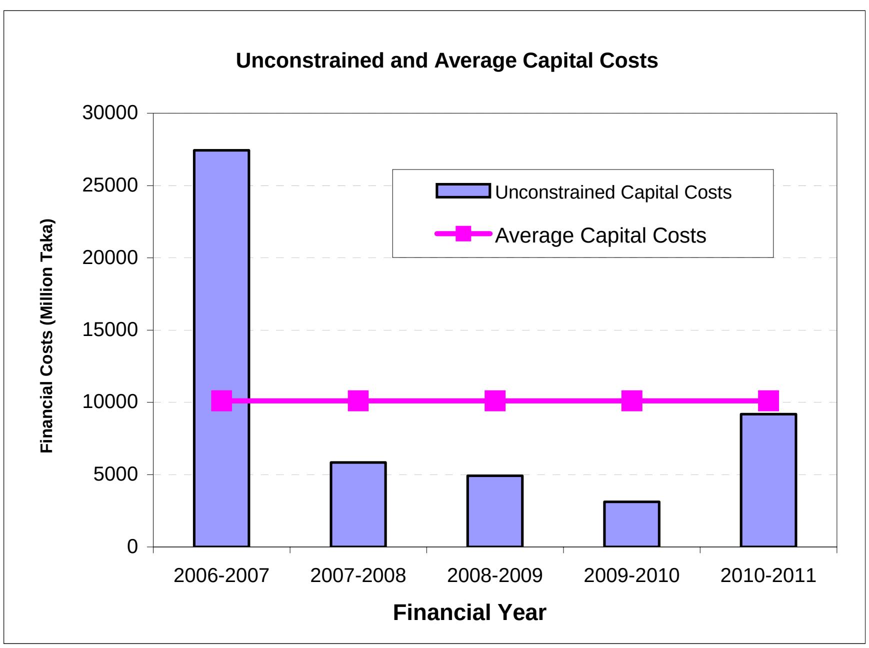

Figure 1 - Unconstrained and average costs of actual periodic maintenance and rehabilitation needs for the period 2006 – 2010 (US$ 1 million = 65 million taka) [1]

Table 1 - Unconstrained periodic and rehabilitation costs (US$ million) [1]

Work name	Year					Total
	2006	2007	2008	2009	2010	
Periodic maintenance	263.71	53.17	66.38	44.36	135.05	562.67
Rehabilitation	158.30	36.65	9.23	3.61	6.27	214.06
Total	422.01	89.82	75.61	47.97	141.32	776.73

The current analysis shows that 72.4% of the expenditures should be for periodic maintenance and 27.6% for rehabilitation works. National Highways (NH) (primary roads), Regional Highways (RH) (secondary roads) and Zilla Roads (ZR) (tertiary roads) require 31.10%, 25.86% and 43.04% respectively of the total expenditure [1]. Details of these roads can be seen elsewhere [3].

The results show that about 2.5% works can provide high economic benefits (NPV/Cost $\geq$ 5), which are generally periodic maintenance works. About 31% works can give moderate benefits (NPV/Cost: 1 to 5), which are also mainly periodic maintenance works. However, the results reveal that two-third of the road works might not be economical, as they produce NPV/Cost $\leq$ 1 [1].

The above discussions show that PMP is necessary to maintain the road assets, which has been identified in the HDM-4 outputs. Timely data collection, data reliability, appropriate treatment intervention criteria and proper calibration factors of the HDM-4 model are necessary to obtain sound results [4].

2.3 Road Asset Management System (RAMS)

RHD has developed Road Asset Management System (RAMS) maps for all the field divisions to show the HDM-4 outputs easily for the decision makers, and to undertake maintenance program efficiently. However, filed visits are necessary to finalize a PMP works [1]. It is observed that data quality, time gap in HDM-4 run and treatment selection may affect on treatment finalization.

2.4 RHD Paved Roads Demand

Table 1 shows RHD's maintenance demand for 14,940 km of roads. However, a simple analysis was done to determine demand for the whole network, which shows that RHD requires US$ 208 million for its total paved road network maintenance per year for the next 5-year program [1].

2.5 Backlog Estimation

Table 1 reveals that RHD has about US$ 214 million backlog at the moment for 14,940 km roads [1]. An extrapolation was made to forecast backlog for the whole network, which would be US$ 250 million [1].

2.6 RHD Paved Roads Asset Valuation

In the current analysis, depreciation of 14,940 km roads was determined, which was then calculated for the whole paved road network. Again, construction costs were also estimated for paved roads to derive its asset value by deducting depreciation cost from construction cost. It shows that RHD has now about US$ 3,700 million road assets. Land and bridges costs were not included in the analysis [1].

3. PROBLEM OF THE HDM-4 OUTPUTS

It was observed that the previous Annual Maintenance and Rehabilitation Needs analysis was not always consistent [4]. Hence, field visits and video data checking were conducted for some roads to assess the current report [1], which results can be seen in Table 2 (as summary) and in Table 3 (as sample).

Table 2 - HDM-4 outputs situation for some zones of Bangladesh

Name of the zone	Type of roads	Classification	Consistency in HDM-4 results (%)	Comment
Dhaka	National Highway (NH)	Primary roads	30%	A rerun is required to obtain better HDM-4 outputs.
	Regional Highway (RH)	Secondary roads	23%	
	Zilla Roads (ZR)	Tertiary roads	80%	
Comilla	National Highway (NH)	Primary roads	50%	
	Regional Highway (RH)	Secondary roads	60%	
	Zilla Roads (ZR)	Tertiary roads	70%	
Chittagong	National Highway (NH)	Primary roads	100%	
	Regional Highway (RH)	Secondary roads	100%	

Table 3 - Comparison between HDM-4 outputs, field visits and video checking

Road no.	Chainage (km)	HDM-4 results	Field observations and video checking	Comment on the results between HDM-4 outputs and field visits and video checking
N8	0.0-1.5 1.5-2.0	50 mm overlay Part Recon 100 mm	RM and drainage improvement is required	Not consistent
R810	0.2-6.3 6.3-6.9 6.9-9.7 9.7-10.2 10.2-10.6	DBST Overlay 60 mm Overlay 50 mm Overlay 60 mm Part Recon 100 mm	HDM-4 results are consistent between 8-10.6 km. DBST can be given, but drainage improvement is required.	Not always consistent
R110	0.0-0.2 0.2-0.7 0.7-0.9 0.9-3.9 4.0-6.5 6.5-6.6 6.6-6.9 6.9-7.0 7.0-9.0	Part Recon 110 mm Overlay 50 mm Overlay 60 mm Overlay 50 mm RM Part Recon 110 mm RM Part Recon 110 mm RM	RM is all right for all through the road. Otherwise, localized reconstruction is required.	Not consistent
N1	0.0-8.9 8.9-9.3	RM Overlay 60 mm	RM Overlay 60 mm	Consistent Consistent
R111	0.0-7.4 7.4-8.0	DBST Overlay 60 mm	The result is all right. However, drainage and shoulder improvement is required at 6-8 km.	Consistent

Note: RM = Routine Maintenance, DBST = Double Bituminous Surface Treatment, Part Recon 110 = Partial Reconstruction of 110 mm [1]

Tables 2 and 3 reveal that HDM-4 results were not always reliable in the current year's analysis. The reasons may be as follows:

- Lack of a complete reliable data set, and
- Mismatch of data.

About 37% of the RMMS data of 2004 are reliable at the moment [4], which might impact on results. It was mentioned in Section 1 that in the current analysis, traffic, road condition and pavement inventory data were of 2004 and roughness data used were of 2005, as a results, mismatch of data was found, which might select wrong treatments. For example, overlay 50 mm is required for N302 (a NH) at 8.10 to 17.44 km, but in reality it requires routine works. It was because of using 2004 bad conditioned data; a treatment was given in this section in 2005, which was not reflected in the RMMS database. It also reveals that there is lack of treatment history data in the RMMS database.

4. OBJECTIVES OF THE ANALYSIS

Section 3 shows that HDM-4 results were not always consistent due to data quality and mismatch of data. The objective of the analysis was to improve HDM-4 results through reruns. It was understood that data quality could not be improved in a short period, which requires timely and accurate data collection in future. Hence, to improve the current results, HDM-4 reruns were made by improving treatment intervention criteria.

5. METHODOLOGY OF THE ANALYSIS

Approaches considered to improve the HDM-4 outputs through reruns can be seen in Table 4 and the overall process of the current analysis can be seen in Figure 2.

Table 4 - Assumptions made for the HDM- 4 reruns

Issues considered	**Run-1 (original run)**	**Run-2 (rerun 1)**	**Run-3 (rerun 2)**
1. Set treatment intervention criteria 2. DBST as holding strategy for all roads	✓	-	-
1. Modify intervention criteria (RM at low roughness and high traffic) 2. DBST for NH and RH, and carpeting for ZR as holding strategy	-	✓	-
1. Modify intervention criteria (DBST at low roughness, high traffic and at cracking ≥ 25%) 2. DBST for NH and RH, and carpeting for ZR as holding strategy 3. Carpeting as periodic maintenance for ZR instead of DBST and overlay	-	-	✓

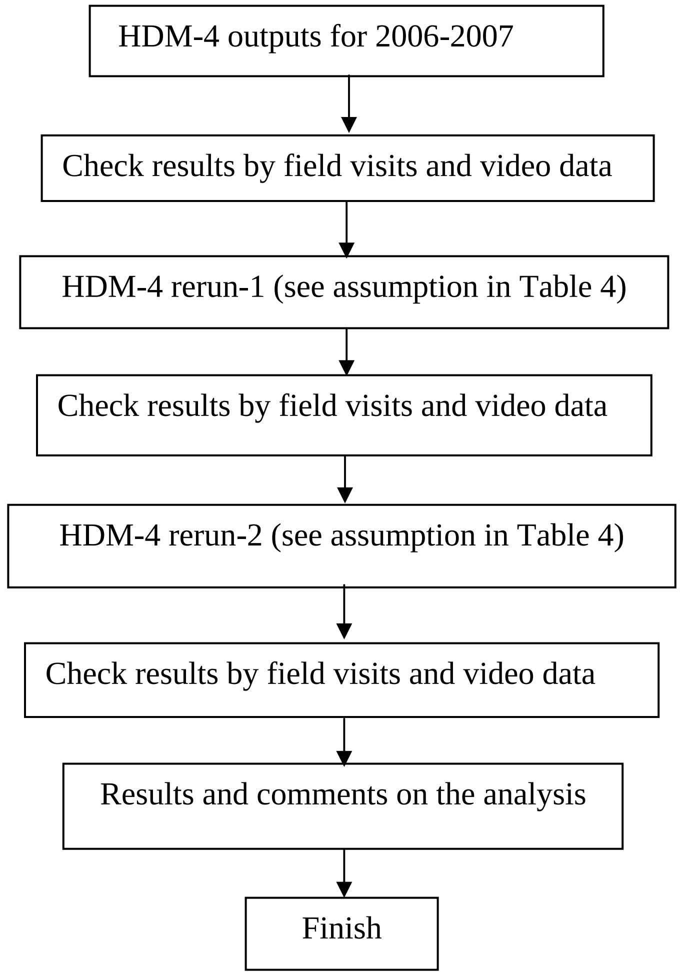

Figure 2 - Overall process of the current analysis

6. RESULTS OF THE HDM-4 RERUNS 1 AND 2

Results to obtain better HDM-4 outputs using the assumptions shown in Table 4 by reruns 1 and 2 are shown in Tables 5 and 6 respectively.

Table 5 - Comparison between HDM-4 outputs, field observations and video checking (rerun 1)

Road no.	Chainage (km)	HDM-4 original run results	Field observations and video data checking	HDM-4 rerun 1 results	Comment on the HDM-4 rerun 1 results
N4	0.00-21.00 114.00-121.00 123.84-126.44	Overlay 50 mm Part Recon 110 mm Part Recon 110 mm	RM Overlay 60 mm Overlay 60 mm	RM Part Recon 110 mm Part Recon 110 mm	Consistent Not consistent Not consistent
N401	0.00-6.90	Overlay 50 mm	Overlay 50 mm	Overlay 50 mm	Consistent
N5	15.00-21.00	DBST	DBST	DBST	Consistent
N503	1.58-3.25	Overlay 50 mm	Overlay 50 mm	Overlay 50 mm	Consistent
N3	0.00-7.10 7.40-8.60	Overlay 50 mm Overlay 50 mm	RM RM	RM Overlay 50 mm	Consistent Not consistent

Table 6 - Comparison between HDM-4 outputs, field observations and video checking (rerun 2)

Road no	Chainage (km)	Probable work needed as per video observation and field visits	HDM-4 rerun 2 results	Comment on the HDM-4 rerun 2 results	Possible reasons of difference
N4	0.00-21.00 114.00-121.00	RM Overlay 60 mm	DBST Part Recon 110 mm	Not consistent Not consistent	Due to cracks High traffic-2969 AADT, high roughness >9 IRI
N302	0.00-5.70 5.70-8.80	Overlay 50 mm Overlay 50 mm	Overlay 50 mm Part Recon 110 mm	Consistent Not always consistent	Work done from 8.10 km to 17.44 km, data mismatch
N5	15.00-21.00	DBST	DBST	Consistent	-
N503	1.58-3.25	Overlay 50	Overlay 50	Consistent	-
N3	0.00-7.10	RM	DBST	Not consistent	Traffic-88,188 AADT, roughness 2.81 IRI and crack 31%
R810	0.00-3.50 3.50-9.70 9.70-10.80	DBST DBST Partial Recon 110 mm	RM DBST Partial Recon 110 mm	Not consistent Consistent Consistent	- -
N1	0.00-8.9 0 8.90-9.30	RM Overlay 60 mm	RM Overlay 60 mm	Consistent Consistent	- -
R111	0.00-7.40 7.40-8.00	DBST Overlay 60 mm	DBST Overlay 60 mm	Consistent Consistent	- -

The above Tables 5 and 6 reveal that rerun 2 provided justified results as it considered DBST at high traffic, cracking ≥ 25% and at low roughness. However, rerun 1 omitted any provision of DBST at high traffic and low roughness, which is not accepted. Though rerun 1 solved the problem of data mismatch much better than rerun 2 (see 0.00-21.00 km results for N4 in Tables 5 and 6), it might not be a good solution in practical. Hence, rerun 2 results were finally accepted.

7. LIMITATIONS OF THE ANALYSIS

The major limitations observed in the analysis were:

- Data quality was not satisfactory,
- Mismatch of road condition, pavement inventory and traffic data of 2004 and roughness data of 2005,
- RHD has limitation of treatment history data, and
- Rerun 1 was not considered though it gave better results in some cases.

It was mentioned earlier that rerun 2 considered DBST at low roughness, high traffic and cracking ≥ 25%, which is more acceptable. Due to high traffic and cracking, DBST may be given to improve road functional condition even at low roughness. The current approach considered in Table 4 was tried to overcome data mismatch problem. However, no initiative was taken to improve data quality, as it would require time. RHD requires appropriate treatment history data in future.

8. REHABILITATION DESIGN

Generally, preventive maintenance is conducted as PMP in Bangladesh to manage assets. Successes of these treatments depend on the structural capacity of pavements. If a pavement is structurally sound to withstand loads, then preventive maintenance is all right. However, it is observed in Bangladesh that structural capacity using deflection data are very poor for GoB funded projects [8], which can be seen in Figure 3.

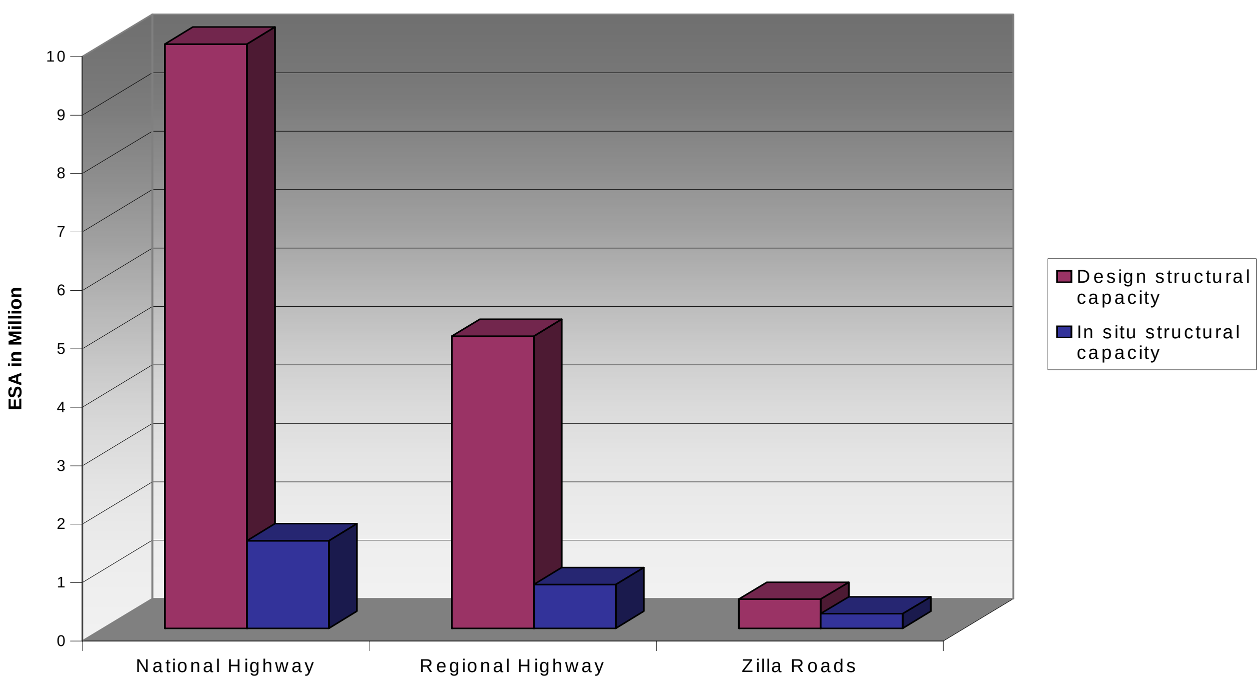

Figure 3: Design and in situ structural capacity of pavement [8]

Due to having insufficient load carrying capacity, routine and periodic maintenance do not last long and in reality rehabilitation and/or reconstruction are required to overcome this problem. Otherwise, preventive maintenance treatments suggested by the HDM-4 would not be useful. Generally, maintenance overlay are considered in the HDM run, where it is believed that pavements are well designed and structurally sound. Therefore, analyzed maintenance overlay between 40 and 80 mm are all right [8].

However, it is observed from the 2003-04 and 2004-05 PMP treatments that some of the roads could not sustain at the given maintenance overlay, which have structurally failed due to structural inadequacy. Recent HDM-4 results showed that some of them require overlay at the moment. In practical, overlay is required at every 8 to 10 years interval but performances of maintenance overlays for those roads were not acceptable.

Dhaka-Chittagong road (N1) of chainage 0-9 km can be considered as an example where 50 mm overlay given in 2004 did not last long. Fatigue cracking was found recently (within 2 years) (see Figure 4), as deflection data shows that 50 mm overlay was not sufficient for this road section. As a result of in proper treatment in 2004, HDM-4 suggested DBST/overlay 50 mm in 2006 due to fatigue failure at this section [8].

Figure 4: Fatigue cracking observed in Dhaka-Chittagong road (N1) (chainage 0-9 km) [8]

The above discussions clarify that rehabilitation design is required for roads where repeated overlays are observed. It can be done using Asphalt Institute's Rehabilitation Design Guide from deflection and design loading data [8]. An analysis was conducted to determine strengthening overlays for sample roads where repeated overlays were observed from HDM-4 results, details can be seen elsewhere [8]. These roads may require reconstruction, which can be done by detail investigation.

9. RECOMMENDATIONS

The current analysis provides the following suggestions.

- Timely survey on road condition, traffic, roughness and treatment history data are necessary.
- Roughness surveys may be done twice a year to obtain a good database.

- Time gap in data collection and HDM-4 analysis need to be reduced.
- Data quality has to be improved by field visits, video checking, analysis by statistical and range check methods.
- Field visits are necessary to finalize treatments, and
- Rehabilitation design and detail investigations are necessary for roads where repeated overlays are observed.

For future HDM-4 reruns and improvement, the analysis provides the following suggestions [3] [4] [8]:

- Data quality has to be checked for the whole RMMS database before use using range check and statistical methods. Captured video data should be reviewed to assess consistency. More field visits are required to cross check data quality.
- Treatment intervention criteria have to be changed for all treatments using sections optimization technique, which need to be validated with field condition.
- New set of calibration parameters of the HDM-4 model with reliable data is required.

For HDM-4 improvement in RHD, the following issues are required [4]:

- Introduction of HDM-4: Version 2 in RHD by 2007 for Multi Criteria Analysis (MCA).
- Inclusion of capacity improvements criteria in the HDM-4 analysis.
- Establishment of Long Term Pavement Performance (LTPP) sections to develop deterioration models of pavement for Bangladesh and to calibrate RD and WE models of the HDM-4.

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