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Establishing optimal pavement maintenance standards using the HDM-4 Model for Bangladesh

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Abstract

Roads and Highways Department (RHD) of Bangladesh does not have appropriate maintenance standards to maintain the road network efficiently. Therefore, a study was conducted to improve some important aspects of Pavement Management System (PMS) in Bangladesh, which dealt with analysis of road database of RHD for reliability, development of treatment intervention criteria and optimum maintenance standards using the Highway Development and Management (HDM-4) model. This paper discusses deriving optimum pavement maintenance standards using the HDM-4. All the road maintenance treatments used in Bangladesh were considered to determine optimum intervention levels for each treatment using different sections optimisation technique. The study divided the whole RHD road network into 48 groups of road based on surface type, traffic volume and pavement width to determine the optimum maintenance standard for each road group. It was observed that the derived optimum maintenance standards could be used for future decision-making purposes, as they were within the zones of optimum maintenance standards. Detail examples in deriving optimum pavement maintenance standards were given in this paper.

Keywords: Maintenance standard, pavement, road condition survey.

1. Introduction

A sound Pavement Management System (PMS) is a system that manages roads efficiently and it is a key requirement for any road authority. PMS can provide cost-effective decisions about the allocation of resources for maintenance, rehabilitation and new pavement construction due to shortage of funding in a planning period for any road authority (Hass, et al. 1994; Robinson, et al. 1998). Hence, it can reduce total transport cost (OECD, 1994). Therefore, PMS has been introduced in different road authorities.

A PMS consists of road condition surveys, database, decision-making tools, analysis scheme, decision criteria and implementation procedures (Paterson, 1987; Battiato, et al. 1994). Therefore, PMS is a complete mechanism for pavement maintenance management.

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. Its' vision is to provide safe, cost effective and well-maintained roads. RHD has about 20,800 km of roads, about 15,000 bridges and culverts (RHD, 2006). The total roads, bridges, land and other related assets value of RHD is about US $7,400 million (MoC, 2000). Recent estimation shows that it has about US$3,700 million paved road assets (RHD, 2006). This huge asset requires proper maintenance with an efficient management system (Robinson, 2004).

The current road condition of the RHD road network based on roughness reveals that only 40% roads are at good condition. Classifications of roads based on roughness ranges has been discussed elsewhere (Odoki and Kerali, 2000). Now RHD has backlog of US $250 million, and it requires US $208 million for the next 5 years for maintenance and backlog removal to bring the roads at good condition (RHD, 2006). It indicates that effective and timely maintenance of roads and bridges under budgetary constraint is necessary to keep the network at good condition. The current National Land Transport Policy (NLTP, 2004) and Road Master Plan (TSC, 2006) of Bangladesh emphasized on maintenance of roads and removal of backlog. Therefore, it requires an efficient PMS in RHD for effective maintenance of the road network and removal of backlog.

RHD has a PMS, which consists of the Road Maintenance and Management System (RMMS) database, Highway Development and Management Model (HDM-4) model, programming, implementation and monitoring (Khan, 2007).

The main purpose of the RMMS database is to develop the Annual Maintenance Plan (AMP) and Road Asset Management System (RAMS) maps using the HDM-4 model. RAMS maps are the outputs of the HDM-4 analysis to show the results in the Geographical Information System (GIS) map for each field unit. RHD has been using the Highway Design and Maintenance Standards (HDM-III) model since 1995, now HDM-4: version 1.3 is being used (Khan, 2004). The database is also used for GIS mapping and to determine Road Users Costs (RUC) for decision-making purposes. The RHD database is user friendly and can be used directly in the HDM-4 analysis. The HDM-4 outputs are used to determine yearly Periodic Maintenance Programme (PMP). Rehabilitation, reconstruction and widening works are done under the Annual Development Programme (ADP), funded by the Donours and Government. RHD has a Central Monitoring System (CMS) to monitor physical and financial progress of a project. As a result, this PMS helps RHD to maintain assets.

2. Lacking of the RHD-PMS

However, the RHD-PMS has some limitations, as it is still new. Previous studies show that the RMMS database is not always reliable (Khan, 2004 and ARRB, 2003), hence, it might affect on the HDM-4 outputs. There are not any scientifically set maintenance standards and treatment intervention criteria in Bangladesh, which are also essential to manage assets. These are at the moment prime need in RHD.

Maintenance standard is a set roughness for a road at its life cycle, which also represents the allowable limit for road deterioration (Odoki and Kerali, 2000). A standard is based on road surface class, characteristics of traffic and general operational practice (Odoki and Kerali, 2000). Generally, when roughness reaches close to the standard (fixed International Roughness Index, IRI), any treatment is required to restrain road roughness to go beyond the standard. Standards have to optimum considering cost and road condition, and should be set at network level.

It should be mentioned here that Hoque (1998) determined optimum maintenance standards for feeder and rural roads in Bangladesh. However, these standards are not suitable for major road network, e.g., National Highways (NH, primary roads), Regional Highways (RH, secondary roads) and Feeder Roads Type A (FRA, tertiary roads). Moreover, RHD does not have a maintenance standard for any road.

Therefore, a study (Khan, 2005) was conducted in the University of Birmingham, UK to analyze the RHD database to obtain high-quality data in future. Determination of treatment intervention criteria and maintenance standards were also the aims to make the decision-making tool, HDM-4 model, more effective for planning purposes in Bangladesh. Khan (2005) also aimed to investigate the “system loss” or increased unit costs of treatment of road works and to determine their effect on maintenance strategies and hence overall costs to the economy.

In that study, the HDM-4 model was used to develop optimum pavement maintenance standards for Bangladesh. Jain, et al (2007) mentioned that use of HDM-4 to develop standards is a scientific method. Again, HDM-4 was used to set standards elsewhere (Tsunokawa and Ul-Islam, 2003; Jain, et al, 2007; and Jain, et al. 2005).

The current paper emphasizes on deriving optimal maintenance standards and strategy for different roads. Analysis of data quality can be seen in Khan (2005), and the system loss and its effect was discussed elsewhere (Khan, 2005 and Khan and Snaith, 2008).

3. Methodology to derive maintenance standards

The overall methodology to develop optimal pavement maintenance standards using the HDM-4 model can be seen in Figure 1. Details are discussed below.

The RMMS database was used for reliability checking using statistical and range check methods. In statistical analysis, initially assumptions were made to determine which of the traffic data stored in the RMMS were valuable. Roughness data were then checked with treatment year for consistency. Similarly, trend analyses between roughness and different Road Condition Survey (RCS) parameters were used to show which of the RCS data were consistent. As a cross check, range check method based on engineering judgment was utilized. In this method, traffic, roughness and RCS data were analyzed sequentially like statistical method, which was based on IF-THEN rules. Different parameters, ranges and engineering rules were set logically to analyze these data using range check method. Details of the two methods can be seen in Khan (2005). The analysis revealed that less than 5% data were reliable (Khan, 2005). Hence, reliable, real and hypothetical data were considered for road groups as input for the HDM-4 to derive standards.

Generally, reliable data means when data are acceptable for a link, whereas, real data are not acceptable. However, hypothetical data were considered when there were no reliable and real data. The whole RHD road network was divided into 48 road groups so that they are manageable. These groups were set based on 3 categories of traffic volume (low, medium and high) that were developed in Khan (2005), 2 types of surface (surface treatment, ST and asphaltic concrete, AC) and 8 types of pavement width. The derived traffic volume ranges for Low Traffic (LT), Medium Traffic (MT) and High Traffic (HT) were <2050, 2050-4275 and >4275 AADT (Annual Average Daily Traffic)/lane (Khan, 2005). Pavements width is related to speed-flow, hence they were considered 8 types based on HDM series (Odoki and Kerali, 2000): ST: single lane two-way, IT: intermediate lane two-way, TT: two-lane two-way, WTT: wide two-lane two-way, FT: four-lane two-way, TO: two-lane one-way, FO: four-lane one-way and MO: multi-lane one-way. Hence, STMTTT means surface treatment type road with medium traffic and two lane two way.

It should be mentioned here that Jain, et al. (2007) considered terrain, design traffic loading and pavement age for road groups. Odoki and Kerali (2000) emphasized on surface, traffic and engineering judgment to set road groups. Hence, the 48 road groups selected in Khan (2005) satisfied the others' concepts in developing representative road groups for HDM-4 run.

It is necessary to calibrate and validate HDM-4 model for Bangladesh condition before use, which has been done earlier by Khan (2004) and Bari (1999). The parameter values chosen in the study can be seen in Khan (2005).

Khan (2005) determined treatment intervention levels for all the treatments used in Bangladesh using the HDM-4 model with "Net Present Value (NPV) maximization objective". These treatment intervention criteria can be used to obtain the AMP. Determination of treatment intervention criteria can be seen in Figure 2, which was based on section optimization techniques (to use several sections to get the optimum results). It was used to obtain the highest Net Present Value (NPV) from several HDM runs for several sections with different treatment intervention levels for a treatment. NPV maximization objective was considered for this analysis. Set treatment intervention levels were used as input in HDM for maintenance standards derivation.

Maintenance standards-treatments matrix was used for each road group. Different standards based on IRI were considered for a road group to obtain optimum standard, which may be achieved by routine and periodic maintenance. In a pavement life cycle, routine maintenance is needed each year and when necessary. Again, periodic maintenances are required based on road condition, traffic and roughness, or they may be scheduled. No rehabilitation and reconstruction are encouraged for pavement maintenance in its life cycle, as it means that they were not maintained earlier on time.

Generally, seal coat, Double Bituminous Surface Treatment (DBST), carpeting, overlay 40, 60 and 80 mm are considered as periodic maintenance in Bangladesh. Details of these treatments can be seen in Khan (2005). Standards were set as "Routine Maintenance (RM) + another periodic maintenance treatment at different realistic roughness values" in the life cycle of a pavement.

Finally, the following inputs for the HDM-4 strategy analysis were used to determine optimum maintenance standards for the road network (Khan, 2005). Generally, strategy analysis is used for representative road groups to obtain results that are valid for the whole road network (Odoki and Kerali, 2000).

- Weighted average representative road sections for selected 48 road groups,
- Calibration parameters of the HDM-4 model for Bangladesh,
- Treatment intervention levels for all treatments used in Bangladesh,
- Maintenance standards-treatments matrixes for all road groups, and
- Unit costs of treatments.

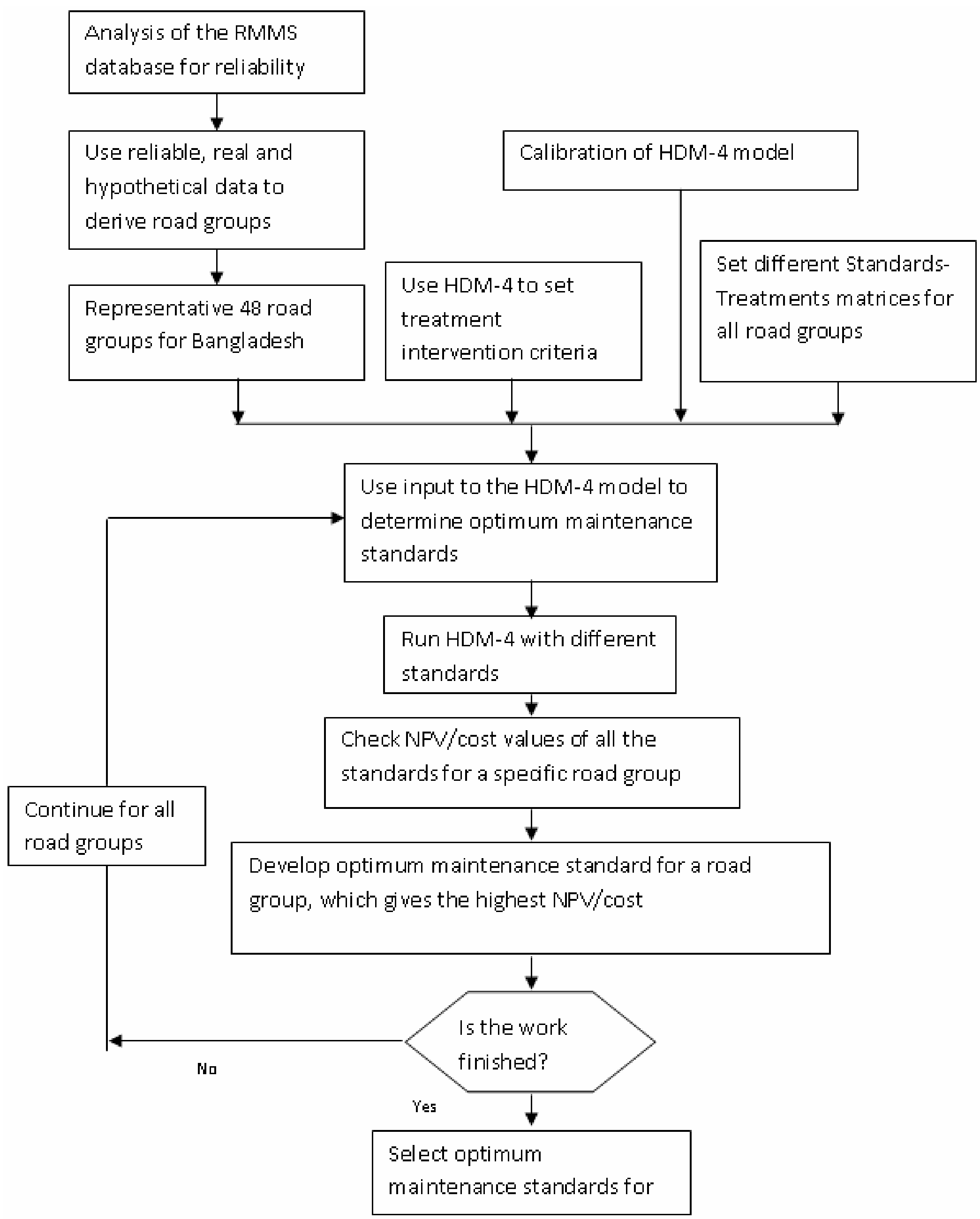

Figure 1. Overall methodology to derive optimum maintenance standards using the HDM-4 model (Khan, 2005)

4. Determination of optimum maintenance standards and treatment intervention criteria

Treatment intervention criteria were used in the HDM-4 strategy analysis as input to set maintenance standards. It was discussed earlier that in Bangladesh no maintenance standards were developed for different road groups. However, treatment intervention criteria were set for NH, RH and FRA in Bangladesh (see Khan, 2005), which are not based on proper study.

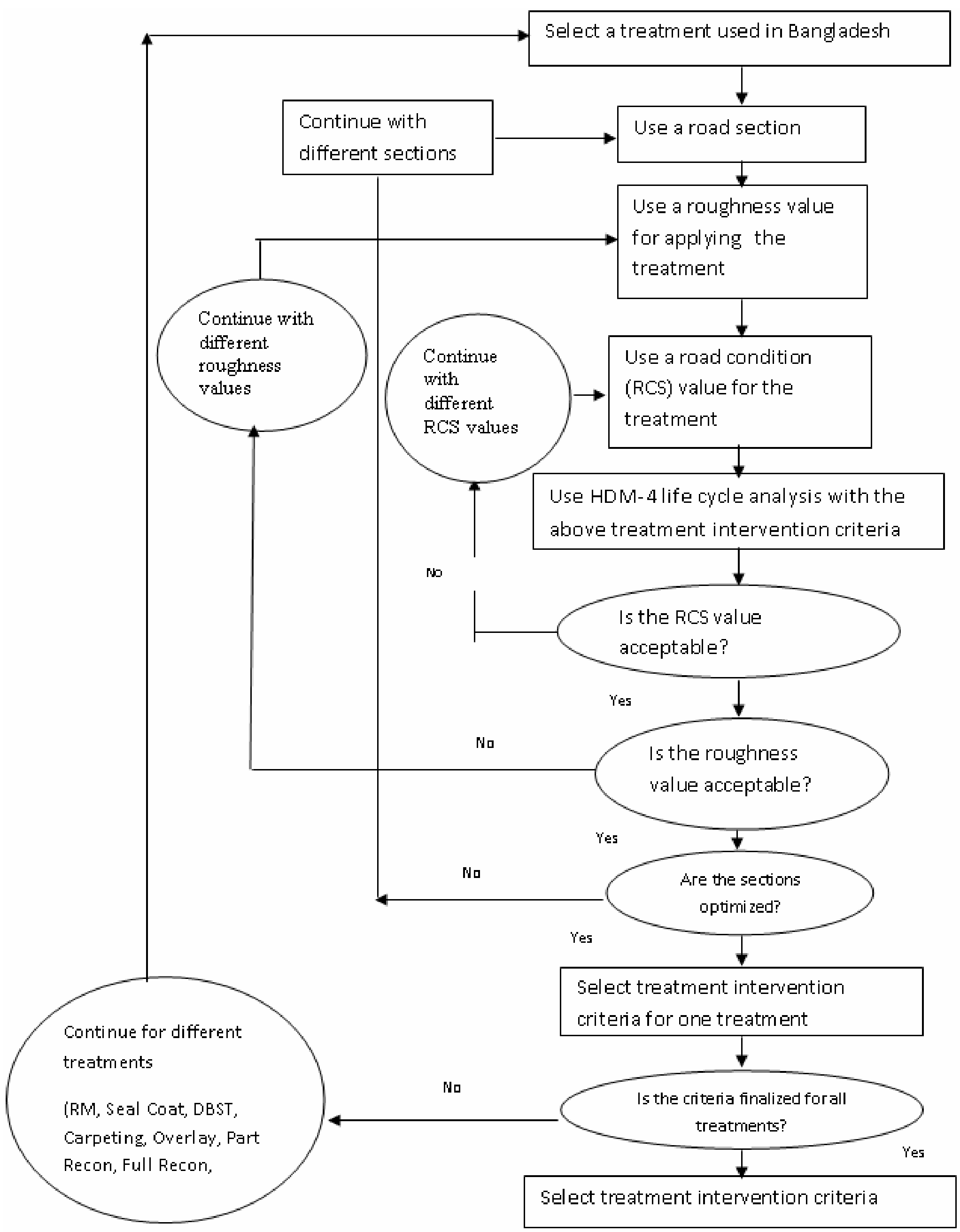

Figure 2. Finalisation of treatment intervention criteria (Khan, 2005)

Hence, Khan (2005) tried to determine optimum maintenance standards and treatment intervention criteria for Bangladesh.

Khan (2005) concentrated to determine optimum maintenance standards for Bangladesh using the HDM-4 strategy analysis with “NPV/cost” optimization objective due to budget constraints. It was mentioned earlier that to make the analysis manageable, the overall road network of RHD was divided into 48 road groups considering surface type, pavement width and traffic volume, details of these road groups data can be seen elsewhere (Khan, 2005).

Roughness, road condition, traffic volume and treatment interval were considered to determine trigger levels for each treatment at network level in the study (Khan, 2005). The life cycle cost analysis considering roughness and distress attributes, and selecting the most economic one is a realistic treatment intervention criteria selection method, which is used in the HDM model (Watanatada, et al. 1987). The optimization objective chosen for this purpose was “NPV (benefit) maximization” (Khan, 2005).

4.1 Treatment intervention criteria

One of the important parts of a PMS is to determine treatment intervention criteria properly, which can be determined using the Genetic Algorithm (GA) (Roberts, et al. 2003). The GA optimization approach is based on evaluation theory by rejecting weaker solutions and combining better solutions to obtain an optimal solution. Khan (2005) utilized the HDM-4 model to determine each treatment intervention criteria for Bangladesh using the GA based application. No GA was developed, but better solutions were considered to achieve the optimal result for a treatment.

To achieve each treatment optimum intervention criteria, several criteria were chosen for a treatment in HDM runs that were based on roughness, road condition and traffic volume (see Khan, 2005 for details). This approach was repeated for all the criteria for a section and then different road sections were used to obtain an optimal solution. In each HDM run, two alternative treatment intervention criteria were used for a section, and then two output NPV values were compared to achieve better solutions. Thus all the selected sections were optimized to obtain the best solution.

Any treatment intervention criteria analysis should be stopped when some sections are optimized and the optimal solution are sound (Roper, 2004). In real applications, there are several indicators to ensure the progress of optimization, e.g., number of trials, improvement in target value, number and frequency of progress steps, change of road agency costs (Roper, 2004). However, Khan (2005) considered NPV, agency cost and percentage of sections optimized as indicators to check the optimization progress for each treatment. Several sections are optimized using the minimum, maximum and increment values of all trigger parameters of a treatment to achieve the optimum solution with a number of trials by HDM-4 (see Khan, 2005).

4.2 Example of analysis: determination of overlay (40 mm) criteria

Generally, RHD considers 40, 60 and 80 mm overlay (MoC, 2002). The parameters considered and their trigger ranges to determine overlay 40 mm criteria have been shown in Khan (2005). A typical example of section optimization can be seen in Figure 3 for overlay 40 mm derived in Khan (2005), which shows that NPV values almost reached the target/highest NPV after a number of trials. The trend of NPV's from different sections optimization was asymptote. Target NPV can be considered as the ultimate NPV, which can be determined from optimization of all sections. Figure 3 also ensures that agency cost and percentage of sections optimized were also optimized, as they show asymptote trends. Figure 4 shows the optimum zone considered to determine overlay 40 mm treatment intervention criteria. The results of the analysis are shown in Table 1.

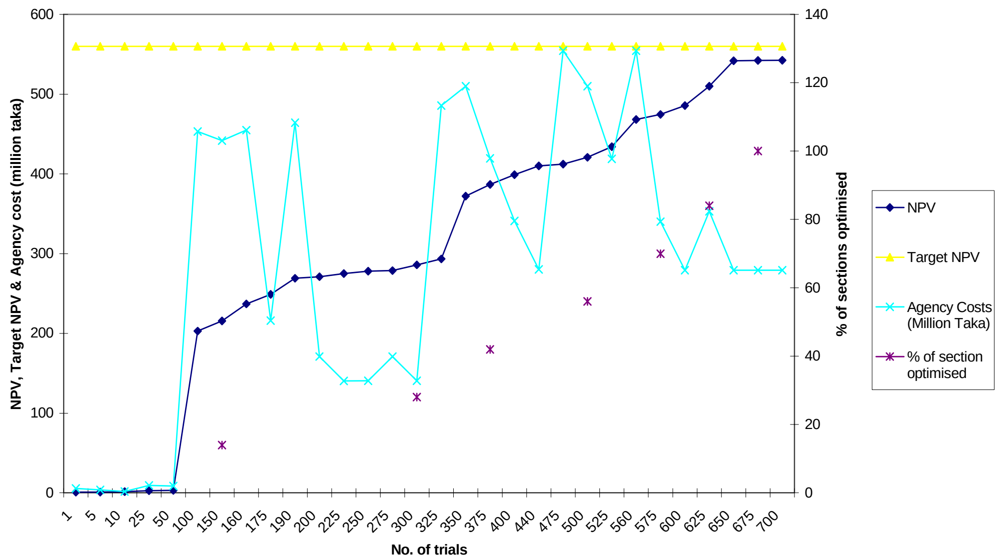

Figure 3. Optimization progress indicators for overlay 40 mm (Khan, 2005).
(US$ 1 million = 70 million taka)

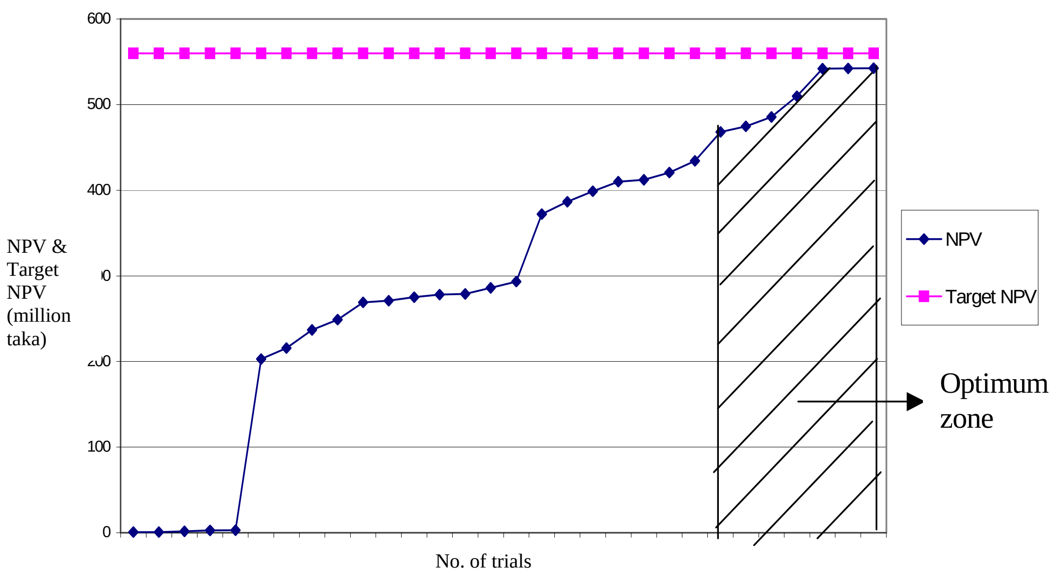

Figure 4. Selected optimum zone for overlay 40 mm (Khan, 2005)

Table 1
Results of the analysis to achieve optimum overlay 40 mm criteria (Khan, 2005)

Roughness range (IRI, m/km) (at ≥ 5% cracking area and 5900 AADT)	Corresponding NPV (million taka)	Maximum AADT (at 3-9 IRI and ≥ 5% cracking area)	Corresponding NPV (million taka)	Cracking area (%) (at 4-9 IRI and 5900 AADT)	Corresponding NPV (million taka)
3.0-9.0	541.83	5000	278.03	5	542.41
4.0-9.0	541.83	5200	278.03	10	272.72
4.5-9.0	541.83	5500	278.03	15	272.72
5.0-9.0	268.17	5800	278.03	20	1.25
5.5-9.0	268.17	5900	542.50	30	1.25
6.0-9.0	268.17	6000	542.50	40	1.25
4.0-8.0	277.68	6200	542.50	-	-
4.5-8.0	277.68	6500	542.50	-	-
7.0-9.0	268.17	7000	542.50	-	-
5.5-8.0	277.68	-	-	-	-
3.5-9.0	541.83	-	-	-	-
5.0-8.0	277.68	-	-	-	-
6.0-8.0	1.43	-	-	-	-

The above analysis shows that these results are acceptable (Khan, 2005). Table 2 reveals finally selected intervention levels for overlay 40 mm. Other results on different treatments' intervention criteria can be seen elsewhere (Khan, 2005).

Table 2
Selected intervention levels for overlay 40 mm (Khan, 2005)

Criteria 1	Criteria 2	Criteria 3
Roughness range = 4-9 IRI, 5-year interval, Maximum AADT = 5900, Cracking area ≥ 5%, Observed NPV = 542.41 million taka.	Roughness range = 4.5-9 IRI, 5-year interval, Maximum AADT = 5900, Cracking area ≥ 5%, Observed NPV = 542.41 million taka.	Roughness range = 4-9 IRI, 5-year interval, Maximum AADT = 5900, Cracking area ≥ 10%, Observed NPV = 272.72 million taka.

4.3 Optimum maintenance standards

The following approach has been considered to determine optimum maintenance standards and required treatments (Khan, 2005):

- Step 1: Determination of optimum maintenance standard among different standards for a road group using the HDM-4 strategy analysis where NPV/cost is the optimization objective (see Figure 1).
- Step 2: Selection of required treatments to maintain the road at its optimum maintenance standard.
- Step 3: Development of optimum maintenance standard zone for each road group.

However, engineering judgment was applied to select the optimum maintenance standard when NPV/cost was the same among some standards for a road group. The judgment was based on road classification (e.g., NH, RH and FRA) and their importance, optimum maintenance standard zones developed by statistical approach and pavement performance in their life cycles.

It is justified that NH, as they carry major and heavy traffic, should have maximum maintenance standard up to 5 IRI, as they are the main highways in Bangladesh. RH can have maximum standard up to 6 IRI. However, FRA can have maximum standard up to 8 IRI, as they are the tertiary roads of the road network in Bangladesh. Engineering judgment was applied considering maximum ranges of these standards for different road classes. For example, if the highest NPV/cost was the same at 3.5 IRI and 4 IRI for NH, then 3.5 IRI (the lower IRI) was selected as optimum maintenance standard. However, the higher IRI was chosen as optimum maintenance standard for RH and FRA (Khan, 2005). The statistical “t” distribution at 90% confidence interval was considered to determine optimum maintenance standard zone for each road group to obtain sound results. Any standard in this zone can be considered acceptable. Finally, pavement performance curve in its life cycle was compared at optimum maintenance for a road group to justify the selected optimum maintenance standard (Khan, 2005).

4.4 Maintenance standards-treatments matrices

Khan (2005) utilized several standards at different IRI for a road group to determine the optimum one. Same standards were also set with several treatment alternatives, e.g., Routine Maintenance (RM) with overlay 40 mm at 4 IRI, or RM with DBST at 4 IRI, etc. Generally, routine and periodic maintenance treatments are considered to achieve different maintenance standards at network level. Rehabilitation works (e.g. partial reconstruction, reconstruction and widening) are not preferred in a life cycle of a road for setting optimum maintenance standard. As a result, RM along with seal coat, DBST, carpeting, overlay 40, 60 and 80 mm were considered to develop different standards (Khan, 2005). The characteristics of the selected treatments are shown in Khan (2005).

Different standards were set for all the road groups considering road classification and engineering judgment, which can be seen in Table 3. It shows that NH, RH and FRA have standards range of 3-5 IRI, 3-6 IRI and 3-8 IRI respectively (Khan, 2005). Table 3 shows that road groups with single lane and intermediate lane roads have been considered as FRA and RH respectively. The other road groups were considered as NH.

Table 3
Standards considered for different road groups (Khan, 2005)

Road class	Pavement width (m)	Road groups based on pavement width for the corresponding road class	Maintenance standards considered
NH	*> 5.5 m*	TT, WTT, FT, TO, FO and MO	3, 3.5, 4, 4.5 and 5 IRI
RH	3.66-5.5 m	IT	3, 4, 5 and 6 IRI
FRA	≤ 3.66 m	ST	3, 4, 5, 6, 7 and 8 IRI

Note: SLT: single lane two-way, IT: intermediate lane two-way, TT: two-lane two-way, WTT: wide two-lane two-way, FT: four-lane two-way, TO: two-lane one-way, FO: four-lane one-way and MO: multi-lane one-way.

It is clear that each road group had different standards considered for analysis (see Table 3). Again, each standard set at fixed IRI had several alternatives based on different treatments. Standards and corresponding treatments were set using "RM + Any Periodic Maintenance Treatment at a fixed IRI" approach.

It was shown in Table 3 that 3, 3.5, 4, 4.5, 5, 6, 7 and 8 IRI were considered as standards for different roads. Khan (2005) coded these standards as A, B, C, D, E, F, G and H respectively. For example, standard at 3.5 IRI is "B". Again, RM + seal coat was considered as alternative (treatment) 1. In this way, DBST, carpeting, overlay 40, 60 and 80 mm with RM were coded as alternative 2, 3, 4, 5 and 6 respectively. Hence, C3 means standard at 4 IRI with alternative of RM + Carpeting, whereas, G5 means standard at 7 IRI with alternative of RM + Overlay 60 mm (Khan, 2005).

The developed standards-treatments matrices for NH, RH and FRA are shown in Tables 4, 5 and 6 respectively. These show the standards considered for each road group with all the treatment alternatives to obtain the optimum one using the HDM-4. For example, A1 to E6 were considered for NH's standards-treatments matrix (see Table 4).

Table 4
Standard-treatment matrix for NH (Khan, 2005)

Standards	Treatment alternatives					
	1	2	3	4	5	6
A	A1	A2	A3	A4	A5	A6
B	B1	B2	B3	B4	B5	B6
C	C1	C2	C3	C4	C5	C6
D	D1	D2	D3	D4	D5	D6
E	E1	E2	E3	E4	E5	E6

Table 5
Standard-treatment matrix for RH (Khan, 2005)

Standards	Treatment alternatives					
	1	2	3	4	5	6
A	A1	A2	A3	A4	A5	A6
C	C1	C2	C3	C4	C5	C6
E	E1	E2	E3	E4	E5	E6
F	F1	F2	F3	F4	F5	F6

Table 6
Standard-treatment matrix for FRA (Khan, 2005)

Standards	Treatment alternatives					
	1	2	3	4	5	6
A	A1	A2	A3	A4	A5	A6
C	C1	C2	C3	C4	C5	C6
E	E1	E2	E3	E4	E5	E6
F	F1	F2	F3	F4	F5	F6
G	G1	G2	G3	G4	G5	G6
H	H1	H2	H3	H4	H5	H6

4.5 Results of the HDM-4 analysis with example

It was mentioned earlier that HDM-4 strategy analysis was used to set optimum maintenance standards. For any road groups the entire set standards-treatments matrix was considered. For example, standards-treatments matrix of Table 4 was used for ACMTTT (Asphalt Concrete surface type, Medium Traffic and Two-lane Two-way road), as TT falls under NH. Results of all road groups are given in Appendix A, and details can be seen in Khan (2005). Here, as an example, the results of the HDM-4 strategy analysis for the road group ACMTTT are shown in Table 7, Figures 5 and 6. This road group is a very common in Bangladesh. Table 7 and Figure 5 show at 90% confidence interval that the derived optimum maintenance standard (3.5 IRI) was within the optimum maintenance standard zone. The treatments required to achieve the optimum maintenance standard was "RM + overlay 80 mm at 3.5 IRI" (Khan, 2005). Figure 6 shows the pavement performance at this optimum maintenance standard.

Table 7
Selection of optimum maintenance standard for road group ACMTTT (Khan, 2005)

Road group	Road class	Set optimum maintenance standard	Observed highest NPV/cost value	Selected treatments at optimum maintenance standard	Optimum maintenance standard zone (at 90% confidence interval)
ACMTTT	NH	3.5 IRI	5.201	RM + Overlay 80 mm at 3.5 IRI	3.49-5.01 IRI

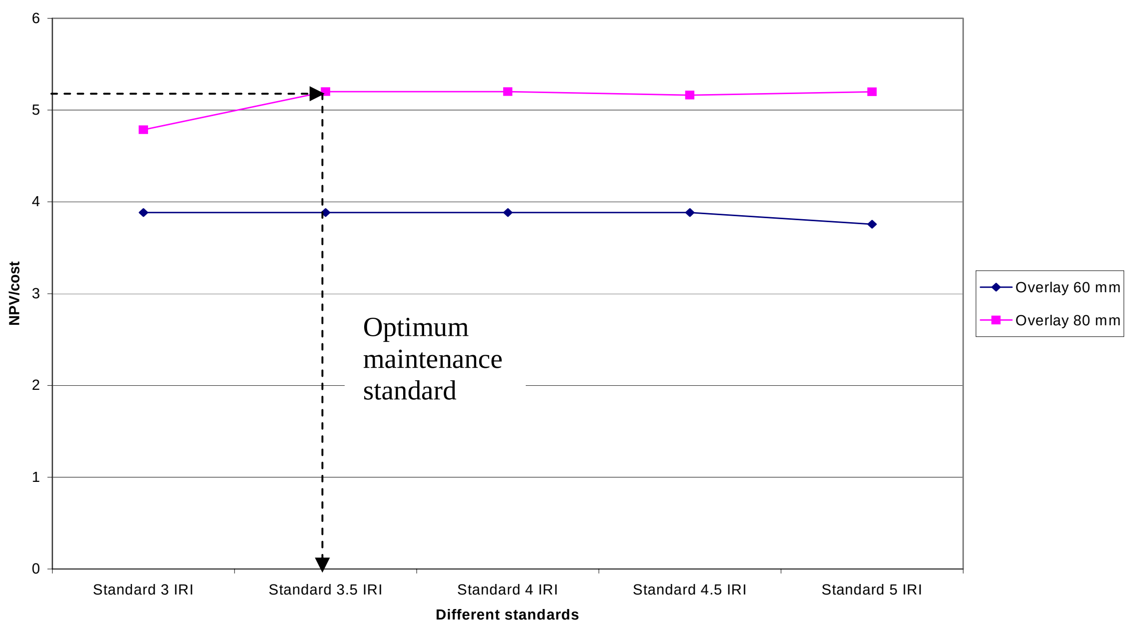

Figure 5. Determination of optimum maintenance standard for ACMTTT (Khan, 2005)

Figure 5 shows that NPV/cost (5.201 see Table 7) was the high at 3.5 IRI. Though 3.5 to 5 IRI had similar NPV/cost, but 3.5 IRI produced the highest NPV/cost. Again, engineering judgment and pavement performance (Figure 6) reveals that 3.5 IRI was justified.

Generally, optimum maintenance standards can be used for future budget forecasting. Set standards help to develop maintenance strategy for the network, and HDM-4 model can be used to determine long-term budget. A simple analysis has been conducted to show this idea (Khan, 2005), which can be seen in Table 8 for some road groups. It shows the budget required to maintain the roads at their maintenance standards. The optimisation objective function considered was “minimisation of agency cost for a target IRI”.

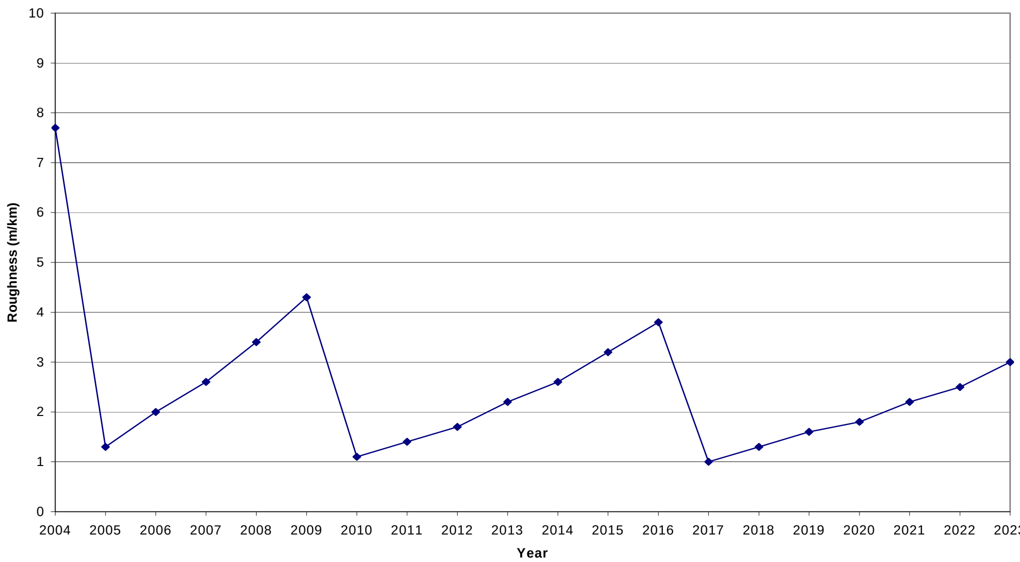

Figure 6. Pavement performance at optimum maintenance standard for ACMTTT (Khan, 2005)

Table 8
Budget forecasting to maintain different type of roads in Bangladesh (Khan, 2005)

Road group as example	Name of road group	Optimum maintenance standard	Treatments required to maintain the road at its standard	Budget required (million Taka)	Maintenance strategy (RM has to be conducted every year)
ACMTTT	Asphaltic Concrete, Medium Traffic and Two lane Two way road	4.39 IRI	RM + Overlay 80 mm at 4.39 IRI	19.50	2004: Overlay 80 mm 2009: Overlay 80 mm 2017: Overlay 80 mm
STLTST	Surface Treatment, Low Traffic and Single lane Two way road	5.50 IRI	RM + Overlay 40 mm at 5.5 IRI	8.70	2004: Overlay 40 mm 2009: Overlay 40 mm 2014: Overlay 40 mm 2020: Overlay 40 mm
STLTIT	Surface Treatment, Low Traffic and Intermediate lane Two way road	4.83 IRI	RM + Carpeting at 4.83 IRI	6.20	2004: Carpeting 2008: Carpeting 2012: Carpeting 2016: Carpeting 2021: Carpeting

5. Conclusions

This paper highlights the M.Phil. research carried out by Khan (2005) and it emphasizes on developing optimum pavement maintenance standards using the HDM-4 model for Bangladesh. It is believed that this could help RHD in planning, programming and efficient network maintenance.

For an efficient PMS, each road authority should have complete sets of treatment intervention criteria for all treatments, which were determined in Khan (2005) with the HDM-4 model using different sections optimization technique. NPV maximization objective was considered to obtain the optimum criteria from several HDM-4 runs for different sections (see Figure 2). Analysis, approach and results for overlay 40 mm were shown as example (see Section 4.2 Figures 3, 4 and Tables 1, 2). Detail results for all the treatments can be seen in Khan (2005).

Each road authority should have a set of proper maintenance standards to maintain their roads efficiently. This paper shows the method considered in Khan (2005) to develop optimum standards for Bangladesh. Optimum maintenance standards were determined for 48 road groups of RHD using the HDM-4 strategy analysis considering NPV/cost as optimization objective function (see Figure 1). It was observed that these derived optimum maintenance standards were within the zones of optimum maintenance standards, results for all road groups are given in Appendix A. Hence, it is safe to say that these optimum maintenance standards can be utilized for future budget forecasting and efficient network maintenance (see Section 4.5, Table 7 and Figures 5, 6 as an example). Treatments required at optimum maintenance standard for each road group to maintain the road properly were also determined (Khan, 2005). It was discussed earlier that engineering judgment was required when NPV/cost was the same for several standards that are applicable to a road group. This was based on road classification of Bangladesh and their importance, optimum maintenance standard zones and pavement performance (Khan, 2005).

Table 8, as an example, shows that developed optimum maintenance standards and required treatments can help budget forecasting for all road groups using the HDM-4 model.

Finally, it should be mentioned here optimum maintenance standards for 48 road groups would help to develop optimum road maintenance policy for Bangladesh. Again, it is clear that optimum budgets would be utilized in future to preserve huge road assets.

6. Recommendations

Generally, treatment intervention criteria and maintenance standards should be developed using field studies conducted on some selected sections (ASRA, 1980). However, derived treatment intervention criteria were based on HDM-4 analysis. A study could be conducted in future to check whether these criteria are consistent with the new set of criteria that may be developed from field studies using the Long Term Pavement Performance (LTPP) sections (Khan, 2005).

Khan (2005) proposed the following recommendations to determine optimum maintenance standards:

- Some road sections can be selected at random considering different road groups to check the performance of the developed optimum maintenance standards,
- The assumptions made in the HDM-4 analysis (see Khan, 2005) can be improved by using real values and can be checked to see whether there are any deviations in the results of the standards,
- Different hypothetical data (extremely good, moderate and extremely bad road and traffic conditions) for a road group can be used to check the set optimum maintenance standards,
- Design traffic loading may be considered to set road groups instead of AADT/lane,
- Multi-Criteria Analysis (MCA) using political pressure, funding, environment, construction quality, social acceptance, Road User Charges (RUC) and engineering judgment can be utilized to determine optimum maintenance standard when NPV/cost is the same among several standards for a road group, and
- Benefit (NPV/cost) and road condition maximization objectives can be chosen together to obtain the better optimum maintenance standards, which can be carried out using linear programming or GA.

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