SENSITIVITY ANALYSIS OF HDM-4 IN BANGLADESH

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ABSTRACT

HDM-4 is a computer software for highway development and maintenance management practices developed by World Bank. It can be used in any locality of the world with the calibration of the parameters of HDM-4. And calculating the sensitivity of the parameters is a part of the calibration process.

The sensitivity of different road deterioration and maintenance input parameters are classified according to their impact elasticity in “Highway Development and Maintenance Management Model” (HDM-4 version-2). The more the impact elasticity, the more the sensitivity of the input parameters. And so the calibration factor of that parameter will differ more.

The aim of this paper is to quantify impact elasticity of some of the most important parameters of road deterioration and work effects model. In this paper, sensitivity analysed of the deterioration parameters which have been already classified in HDM-4 Volume 5 Sensitivity Class I, is provided. The way we are following here is the Traditional Ceteris Paribus (TCP) method in which by changing single input parameter and holding other parameters to be unchanged, the impact elasticity will be calculated. Impact elasticity is the ratio of the percentage change of specific result by the percentage change to individual input parameters of the pavement deterioration models. This study is executed by the project analysis of the HDM-4 application using TCP method and then the results are used to find the impact elasticity which is used for sensitivity ranking.

The parameters which are chosen from the sensitivity class-I for the deterioration sensitivity analysis are as follows: Adjusted Structural Number (SNP), Pavement Roughness and All Structural Cracking. Each parameter has been studied separately from real road sections of Dhaka zone. For the lack of sufficient data and time, only the data of Dhaka zone has been chosen which covers approximately 11% of National Highway.

The result of this paper shows that, for Dhaka zone, Adjusted Structural Number (SNP) has impact on Roughness. Roughness has impact on two common parameters: All Structural cracking and Mean Rut Depth. All Structural Cracking has impact on two common parameters: Wide Structural Cracking and Ravelled Area. All data has been taken from the RHD RMMS database tool.

Keywords: *Sensitivity analysis, HDM-4, Road deterioration, Impact elasticity, Traditional ceteris paribus method.*

1. INTRODUCTION

Bangladesh is a developing country of current world. Especially at the beginning of the 21st century, its economy is developing rapidly. With the improvement of its economic condition, the usage of transportation is increasing rapidly, so as the roads. As a result, most of the roads are now in very poor condition. Insufficient maintenance and rehabilitation of Bangladesh's road network has resulted in chronic congestion, with traffic growth outstripping capacity on strategic corridors. So it has now become very essential to take necessary steps for pavement maintenance and rehabilitation. This can only be done after the proper analysis of present condition and finding the major causes of the road deterioration. Evaluation of pavement is a requirement in the pavement management system (Haas, 1975).

Most of the highway and road projects are constructed with high budgets but it is a matter of regret that these roads deteriorate earlier than the expected time for the lack of attention to the maintenance at the right time. Prioritization of projects and their maintenance at the right time not only can improve the condition of the pavement, but also will economize the investment and optimize allocated budgets. For this purpose, Highway Design and Maintenance Management System (HDM-4) models are developed to manage analysis and make strategy for the road and highway projects. The software is designed to provide prediction of the performance and treatment programing of the roads, estimation of funds, budget allocation, project appraisal, also to study policy impacts and more applications for special cases (Bannour, 2015).

Effectiveness of these models is dependent on its ability and level of accuracy. Model predicts the performance of the pavement in which pavement performance is affected by the factors such as structural design, material properties, traffic situation, methods of the construction, operation cost of the vehicles, environment condition in which the project is located and maintenance policies (Giummarra, 2007).

HDM-4 is a prediction software which helps to predict the future road condition. But calibration of this software for local condition is a must. And the first step of calibration process is to do the sensitivity measurements of the input parameters. Sensitivity analysis of the individual input parameters of pavement deterioration models have a critical role in the prediction process, because proper concentration and emphasis can be given to the most sensitive and important parameters and less to less sensitive; by this way, loosing of time will be prevented (Zakaria, 2013).

To calculate the sensitivity of HDM-4 Deterioration models, the highest sensitive parameters which have been introduced by HDM-4 Manual (Volume 5 Section 4) are chosen (Bennett & Paterson, 2004). The following input pavement deterioration parameters were selected: Adjusted Structural Number (SNP), Roughness and All Structural Cracking. And The following parameters are the affected results of pavement deterioration models: Adjusted Structural Number (SNP), Pavement Roughness, All Structural Cracking, Wide Structural Cracking, Transvers Thermal Cracking, Raveled Area, No. of Pothole, Edge Break, Mean Rut Depth, Rut depth Standard Deviation, Texture Depth and Skid Resistance (Mushule, 2001).

2. METHODOLOGY

In HDM-4, the predictions sometimes or always differ from the field data or actual data. So it is very important to adjust the calibration factors for model prediction. HDM-4 is the new version of HDM-III and it has more calibration factors than HDM-III (Kerali & Odoki, 2000). So proper calibration factors should be determined for each local conditions and road networks for a better quality prediction. But first sensitivity analysis should be done for each parameters.

It is important for users to be aware of the general level of sensitivity of the model of each parameter so that appropriate emphasis is given to important parameters and less emphasis to second or third order effects. The influences of individual parameters differ according to the particular parameter. And these variations occur under different circumstances.

Sensitivity analysis were conducted with the HDM-4 RUE (Road User Effects) and RDWE (Road Deterioration and Work Effects) sub-models so as to determine the levels of sensitivity and to rank them (Bennett & Paterson, 2004). It was determined by the **IMPACT ELASTICITY**, which is simply the ratio of percentage change in a specific result to the percentage change of the input parameter, holding all the other parameters constant at a mean value.

Different approaches can be used in sensitivity analysis. Among them, the traditional **CETERIS PARIBUS** method is used here. Here a single factor is changed while holding the other factors constant. On the basis of the analysis, four classes of model sensitivity have been establishes as a function of the impact elasticity. The higher the sensitivity, the more sensitive the model predictions (Jain, 2005). The Sensitivity classes of HDM are explained in the Table 1.

Table 1: HDM Sensitivity Classes (Bennett, 2004)

Impact	Sensitivity Class	Impact Elasticity
High	S-I	> 0.50
Moderate	S-II	0.20 - 0.50
Low	S-III	0.05 - .20
Negligible	S-IV	< 0.05

2.1 Data Collection

Because HDM-4 predicts future road performance from current and historical conditions, the reliability of its results depends upon how well input data represent actual conditions and how well HDM-4 predictions model actual behaviour.

Here the sources of data were Road Transportation and Highways Division and RMMS Database. And all the roads of Bangladesh are divided into three groups: National Highways, Regional Highways and Zilla Roads (Maintenance and Rehabilitation Needs Report of 2018-2019 for RHD Paved Roads 2018). Different Types of Road Coverage in Bangladesh are presented in Figure 1 below.

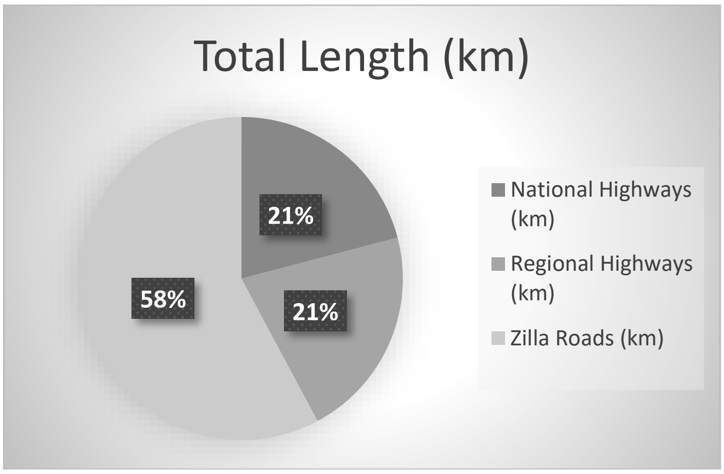

Figure 1: Different Types of Road Coverage in Bangladesh (Maintenance and Rehabilitation Needs Report of 2018 - 2019 for RHD Paved Roads 2018)

Again all the roads are divided into 10 zones by RHD department. The zones are: Barishal, Chittagong, Comilla, Dhaka, Gopalganj, Khulna, Mymensingh, Rajshahi, Rangpur and Sylhet (Road Maintenance & Management System [RMMS], 2018-2019). Different road zone lengths are presented in Table 2. The selected zone for this paper is Dhaka zone. Because appropriate amount of data for the analysis was found for this zone.

Table 2: Different Road Zone Lengths of Bangladesh (RMMS, 2018)

Road Zone	National Highways (km)	Regional Highways (km)	Zilla Roads (km)	Total (km)
Barishal	117.9	266.1	823.8	1207.8
Chitagong	422.9	442.4	1054.4	1919.7
Comilla	334.8	317.7	1419.4	2071.9
Dhaka	403.2	431.6	461.7	1296.5
Gopalganj	261	156.8	646.3	1064.1
Khulna	469.5	566.5	1426.6	2462.6
Mymensingh	302.5	385.9	1232.3	1919.7
Rajshahi	509	459.8	1149.9	2118.7
Rangpur	584.4	360.6	1739.6	2684.6
Sylhet	355.6	434.4	440.7	1230.7
Total	3760.8	3821.8	10393.7	17976.3

2.2 SENSITIVITY ANALYSIS

The purpose of sensitivity analysis is to find out the most important individual input parameters to pavement deterioration models. This will help the users to be aware of the most sensitive parameters, and then the emphasis can be put on collection of them.

Sensitivity of the individual parameters of pavement deterioration models in HDM-4 is determined by the impact elasticity. Impact elasticity is the ratio of the percentage change to a specific result by the percentage change to individual input parameters of the pavement deterioration models (Bennett & Paterson, 2004)

To find the sensitivity of the parameters, two methods are used in this sensitivity analysis: Traditional Ceteris Paribus (TCP) and Factorial Latin Hypercube (FLH) (Ognjenovic, 2015). In this paper, the 1st method is used for the analysis. Traditional Ceteris Paribus (TCP) is used in this paper and the purpose is to find the sensitivity of the following parameters to the pavement deterioration:

a) Sensitivity of *SNP* to pavement Deterioration;
b) Sensitivity of Roughness to Pavement Deterioration;
c) Sensitivity of All Structural Cracking to Pavement Deterioration;

To find out the exact sensitivity of individual inputs the case with no maintenance is the paper desired one, and any decision can only be taken according to those results. So here no maintenance case analysis is done in HDM-4 software.

2.2.1 Sensitivity Analysis of Dhaka Zone

In this paper, Sensitivity was done for Dhaka zone with respect to three input parameters separately. Sensitivity analysis was done using Traditional Ceteris Paribus method.

2.2.1.1 Sensitivity to Adjusted Structural Number (SNP)

Sensitivities of pavement deterioration parameters to the SNP are determined by using the Traditional Ceteris Paribus (TCP), in which two input values of SNP are iterated and then its impact elasticity to the deterioration parameters are calculated, and then ranked as the levels mentioned later in Table 3.

Table 3: Sensitivity to SNP for Dhaka Zone

Sensitivity to SNP after 10 years						
	1st Iteration		**2nd Iteration**			
Deterioration	Original Value	End Value	Original Value	End Value	% Change	Impact Elasticity
SNP	4.1	3.12	5.2	4.34	26.83	
Roughness	5.44	8.76	5.44	9.33	6.51	0.243
All Structural Cracking(sq. m)	4.6	6.21	4.6	6.21	0	0
Wide structural cracking (sq. m)	2.9	4.45	2.9	4.45	0	0
Transverse Thermal Cracking	0	0	0	0	0	0
Raveled AREA (sq. m)	3.48	6.44	3.48	6.44	0	0
No. of potholes	0.26	0.68	0.26	0.68	0	0
Edge break area (sq. m)	2.96	3.1	2.96	3.1	0	0
Mean Rut depth	2	2.09	2	2.1	0.48	0.074
Rut depth Standard Deviation	0.5	0.61	0.5	0.62	1.64	0.061
Texture depth	3	2.3	3	2.3	0	0
Skid Resistance	1	1	1	1	0	0

Level 1	Impact Elasticity greater than 0.5
Level 2	Impact Elasticity greater than 0.2 and less than 0.5
Level 3	Impact Elasticity greater than 0.05 and less than 0.2
Level 4	Impact Elasticity less than 0.05

So from the above table, the most sensitive parameters found are Roughness, Mean Rut Depth and Rut Depth Standard Deviation. The impact elasticity of the roughness is 0.243 with respect to SNP. It is in between 0.2 and 0.5. So it has a sensitivity of level 2. The impact elasticity of the other two parameters are in the range of 0.05 to 0.2. So these parameters have level 3 sensitivity.

2.2.1.2 Sensitivity to Roughness

Sensitivity of the Pavement Roughness to the pavement deterioration parameters are determined by using the Traditional Ceteris Paribus (TCP). In which two input values are iterated for Roughness and then their impact elasticity to the deterioration parameters are calculated. After that they are ranked as the levels mentioned later in Table 4.

Table 4: Sensitivity to Roughness for Dhaka Zone

Sensitivity to Roughness after 10 years						
	1st Iteration		**2nd Iteration**			
Deterioration	Original Value	End Value	Original Value	End Value	% Change	Impact Elasticity
Roughness	4.2	7.76	6.48	9.98	54.29	
SNP	4.8	3.45	4.8	3.45	0	0
All Structural Cracking(sq m)	4.6	5.92	4.6	7.94	34.12	0.629
Wide structural cracking (sq m)	2.9	4.45	2.9	4.45	0	0
Transverse Thermal Cracking	0	0	0	0	0	0
Raveled AREA (sq m)	3.48	6.44	3.48	6.44	0	0
No. of potholes	0.26	0.68	0.26	0.68	0	0
Edge break area (sq m)	2.96	3.1	2.96	3.1	0	0
Mean Rut depth	2	2.1	2	0.9	57.14	1.053
Rut depth Standard Deviation	0.5	0.63	0.5	0.65	3.17	0.0585
Texture depth	3	2.3	3	2.3	0	0
Skid Resistance	1	1.2	1	1.3	8.33	0.154

Level 1	Impact Elasticity greater than 0.5
Level 2	Impact Elasticity greater than 0.2 and less than 0.5
Level 3	Impact Elasticity greater than 0.05 and less than 0.2
Level 4	Impact Elasticity less than 0.05

So from the above table, the most sensitive parameters found are All Structural Cracking, Mean Rut Depth, Rut Depth Standard Deviation and Skid Resistance. The impact elasticity of the All Structural Cracking and Mean Rut Depth are greater than 0.5. So these parameters have level 1 sensitivity. The impact elasticity of Rut Depth Standard Deviation and Skid Resistance are in between 0.05 to 0.2. So they have a sensitivity of level 3.

2.2.1.3 Sensitivity to All Structural Cracking

Sensitivity of the Pavement Roughness to the pavement deterioration parameters are determined by using the Traditional Ceteris Paribus (TCP). In which two input values are iterated for All Structural Cracking and then their impact elasticity to the deterioration parameters are calculated. After that they are ranked as the levels mentioned later in Table 5.

Table 5: Sensitivity to All Structural Cracking for Dhaka Zone

Sensitivity to All Structural Cracking after 10 years						
	1st Iteration		**2nd Iteration**			
Deterioration	Original Value	End Value	Original Value	End Value	% Change	Impact Elasticity
All Structural Cracking	6	7.3	3.2	4.8	46.67	
SNP	4.8	3.66	4.8	3.79	3.55	0.076
Roughness	5.44	9.2	5.44	9.43	2.5	0.054
Wide structural cracking (sq m)	2.9	4.12	2.9	5.44	32.04	0.687
Transverse Thermal Cracking	0	0	0	0	0	0
Raveled AREA (sq m)	3.48	5.64	3.48	6.26	10.99	0.236
No. of potholes	0.26	0.68	0.26	0.68	0	0
Edge break area (sq m)	2.96	3.1	2.96	3.1	0	0
Mean Rut depth	2	2.1	2	2.1	0	0
Rut depth Standard Deviation	0.5	0.63	0.5	0.63	0	0
Texture depth	3	2.3	3	2.3	0	0
Skid Resistance	1	1	1	1	0	0

Level 1	Impact Elasticity greater than 0.5
Level 2	Impact Elasticity greater than 0.2 and less than 0.5
Level 3	Impact Elasticity greater than 0.05 and less than 0.2
Level 4	Impact Elasticity less than 0.05

So from the above table, the most sensitive parameters found are SNP, Roughness, Wide Structural Cracking and Raveled Area. The impact elasticity of Wide Structural Cracking is 0.687 with respect to All Structural Cracking. It is greater than 0.5. So it has a sensitivity of level 1. The impact elasticity of the Raveled Area is 0.236 which is in the range of 0.2 to 0.5. So it has a sensitivity of level 2. The impact elasticity of the SNP and Roughness are in the range of 0.05 to 0.2. So these parameters have level 3 sensitivity.

2.2.1.4.Changes of Road Conditions of Dhaka Zone over Time

A prediction of the road conditions has been made for Dhaka zone using HDM-4. The average roughness over time for Dhaka zone is shown in Figure 2 and the progression of damaged surface area over time is shown in Figure 3 below.

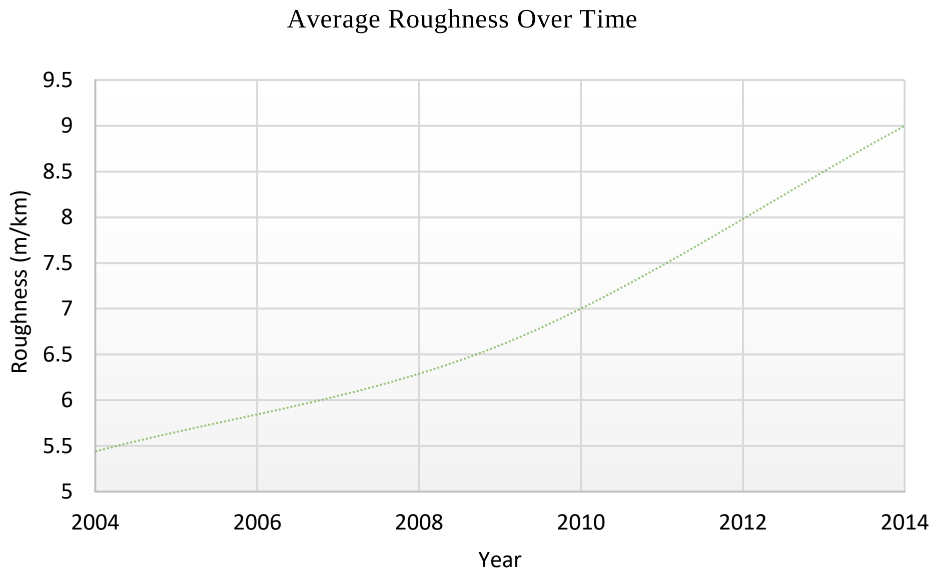

Figure 2: Average Roughness over Time

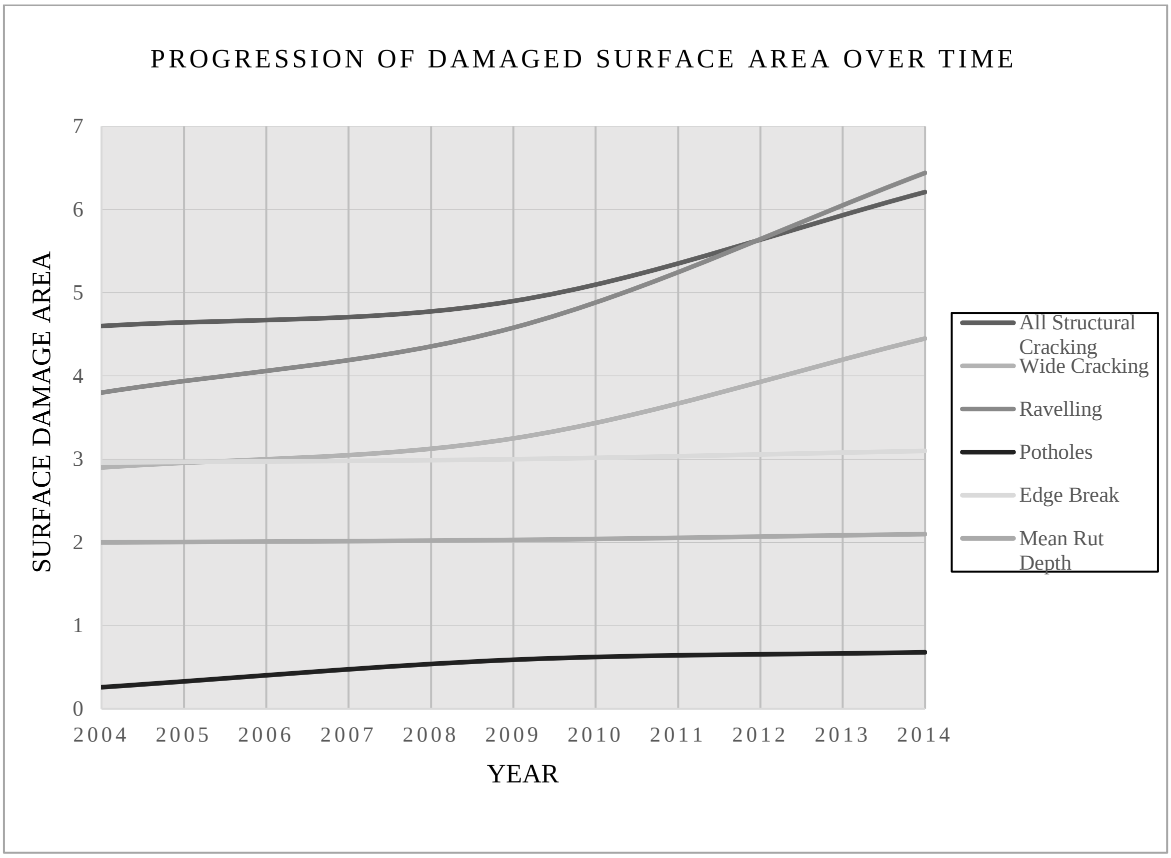

Figure 3: Progression of Damaged Surface Area over Time

3. ILLUSTRATIONS

3.1 Equations

$$\% \, Change = \frac{End\,Value_{1st\,iteation} - End\,Value_{2nd\,Iteration}}{End\,Value_{1st\,iteation}} * 100 \qquad \text{(Kandary, 2016)} \qquad (1)$$

$$Impact\ Elasticity = \frac{Percentage\ Change\ In\ specific\ result}{Percentage\ change\ in\ critical\ parameter} \qquad \text{(Bennett \& Paterson, 2004)} \qquad (2)$$

4. CONCLUSIONS

The whole paper, in a glance, is stated in the following:

1. Pavement deterioration models for sensitivity analysis are selected here from the hdm-4 manual (volume 5). The models selected here are introduced as the highest level of the sensitivity in the volume.
2. The results of the impact elasticity of deterioration model shows that adjusted structural number (snp) has impact on the following parameters for Dhaka zone: roughness (level 2 sensitivity), mean rut depth (level 3 sensitivity) and rut depth standard deviation (level 3 sensitivity).
3. The results of the impact elasticity of deterioration model shows that roughness has impact on the following parameters for Dhaka zone: all structural cracking (level 1 sensitivity), mean rut depth (level 1 sensitivity), rut depth standard deviation (level 3 sensitivity) and skid resistance (level 3 sensitivity).
4. The results of the impact elasticity of deterioration model shows that all structural cracking has impact on the following parameters for Dhaka zone: wide structural cracking (level 1 sensitivity), raveled area (level 2 sensitivity), roughness (level 3 sensitivity) and snp (level 3 sensitivity).
5. In this paper, we got the sensitive parameters of different sections. And these parameters need to be calibrated to get a better prediction for the future works. So, these sensitivity parameters would be helpful in finding the different calibration factors of the sub-model parameters.
6. All the other parameters do not need to be calibrated or ‘do nothing’ should be applied because the prediction of these parameters will not be affected by the critical parameters.

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