Calibration of HDM Model for the North South Expressway in Malaysia

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ABSTRACT

The Highway Development and Management (HDM) model has been adopted by many countries in the tropic as a planning and programming tool for pavement expenditure and maintenance standards for their road networks in order to achieve a specified standard objectives. The model simulates physical and economic conditions over the period of analysis and the results are presented in the Long Term Rolling Programme (LTRP) report. The essential part of the LTRP is the forecasted budget allocation. Adequate budget allocation would require the HDM model to generate good prediction of the actual pavement deterioration behaviour. The need for a calibration of the HDM model to local condition is therefore essential component of the pavement management process. The paper will discuss a case study where a preliminary calibration of HDM-4 roughness age-environmental factor has been carried out along the North South Expressway in Malaysia. The climatic condition of the expressway site is described as humid, hot and high monthly precipitation throughout the year. The methodology of the calibration and the adaptation process of the model will be presented and the findings of the calibration of two selected long term pavement performance (LTPP) sites will also be presented.

INTRODUCTION

In the development of a Pavement Management System (PMS) for PLUS, Pengurusan Lebuhraya Berhad (PLB), the Network Asset Manager for the North South Expressway, has adopted the Strategic Planning Model (SPM) for the management system. The PMS is developed to provide a cost effective maintenance programme for PLUS expressway. The main components of the SPM are the Highway Development Maintenance (HDM-4) and the HMS-2 computer programs. The SPM is depicted in a schematic diagram as shown in Figure 1.

HDM-III and more recently the HDM-4 models have been adopted in many countries in the tropic as a planning and programming tool for pavement expenditure and maintenance standards for their road networks in order to achieve a specified standard objectives. The HDM-4 has been used by the Malaysian Highway Authority, the Malaysian Public Works Department or JKR and PLUS, the expressway toll concessionaire in Malaysia. The highway management software program is used to develop a Long Term Rolling Programme (LTRP) which is intended to identify appropriate maintenance treatment options that can be applied on an expressway network. The economic results generated by the HDM-4 can be used for the prediction of the medium to long term expenditure profiles of a road network. The impact of each of the maintenance treatment option on the long-term pavement condition can also be observed from the HDM-4 output results.

The HDM predictive relationships has been applied in many developed and developing countries having markedly different technology, climatic and economic environments. The field experiments covered wide ranges of conditions, there remain some local factors that could not be introduced into the model because they would have made the model's input too complex or their effects could not be determined within the ranges observed (Bennett and Paterson, 2000). For these reasons, calibration of the HDM model to local conditions is necessary and recommended. Moreover, if calibration is not carried out the actual pavement deterioration trend and the HDM predicted deterioration may show large differences. Thus, inadequate local calibration can under or overestimate the budget allocation of highway expenditure.

In this research study, calibration of HDM-4 roughness age-environmental factor has been carried out along the North South Expressway in the Peninsular of Malaysia. The methodology of the calibration process and the results of the calibration obtained from two selected LTPP sites will be presented.

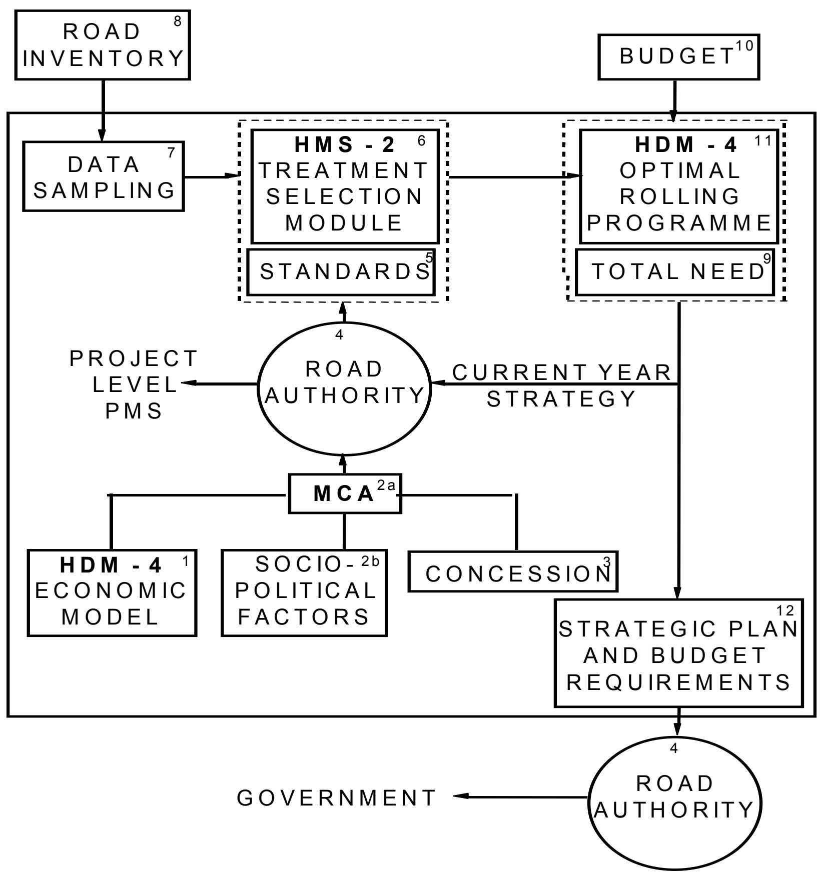

Figure 1 : The Strategic Planning Model (SPM) Flow Chart (Snaith, 2002)

CALIBRATION PROCESS

The length of the two lanes carriageway expressway which was constructed with flexible pavement is 680km and the climatic condition along the expressway is humid, hot and the monthly precipitation is considered high throughout the year. Other information required for the calibration are pavement construction, the level of oxidation and the quality of the bitumen used for the asphalt mix. The construction and material classification are designated as high quality construction, atmosphere moderately oxidizing and high quality bitumen.

The HDM-4 model simulates future changes to the road system from current conditions and the application of the model involves two important steps:

Data input - A correct interpretation of the data input requirements, and achieving a quality of input data that is appropriate to the desired reliability of the results.

Calibration of outputs - Adjusting the model parameters to enhance how well the forecast and outputs represent the changes and influences over time and under various interventions.

Essentially, there are three levels of calibration for the HDM calibration. The three calibration levels which involve low, moderate and major levels of efforts and resources are as follows:

- *Level 1 - Basic Application*

  This level involves a desk study and many default values will be adopted and the most sensitive parameters will be calibrated using the guidelines given in the HDM-4 Manual.

- *Level 2 – Main Calibration*

  This level of calibration will be accomplished for the parameters with quality historical data (e.g. roughness, cracking and rutting). Field survey will need to be carried out to measure additional pavement parameters in order for the key predictive relationships be calibrated to local conditions.

- *Level 3 - Adaptation*

  Undertakes major field surveys and controlled experiments at LTPP sites to enhance the existing predictive relationships.

In the calibration, the predictions of pavement distresses by HDM-4 shall be presented in spreadsheets and these predictions will then be compared with the actual observed field data and the necessary adjustment will be made to the calibration factors to make HDM-4 predictions reasonable. The flow-chart below shows a systematic steps in the calibration work.

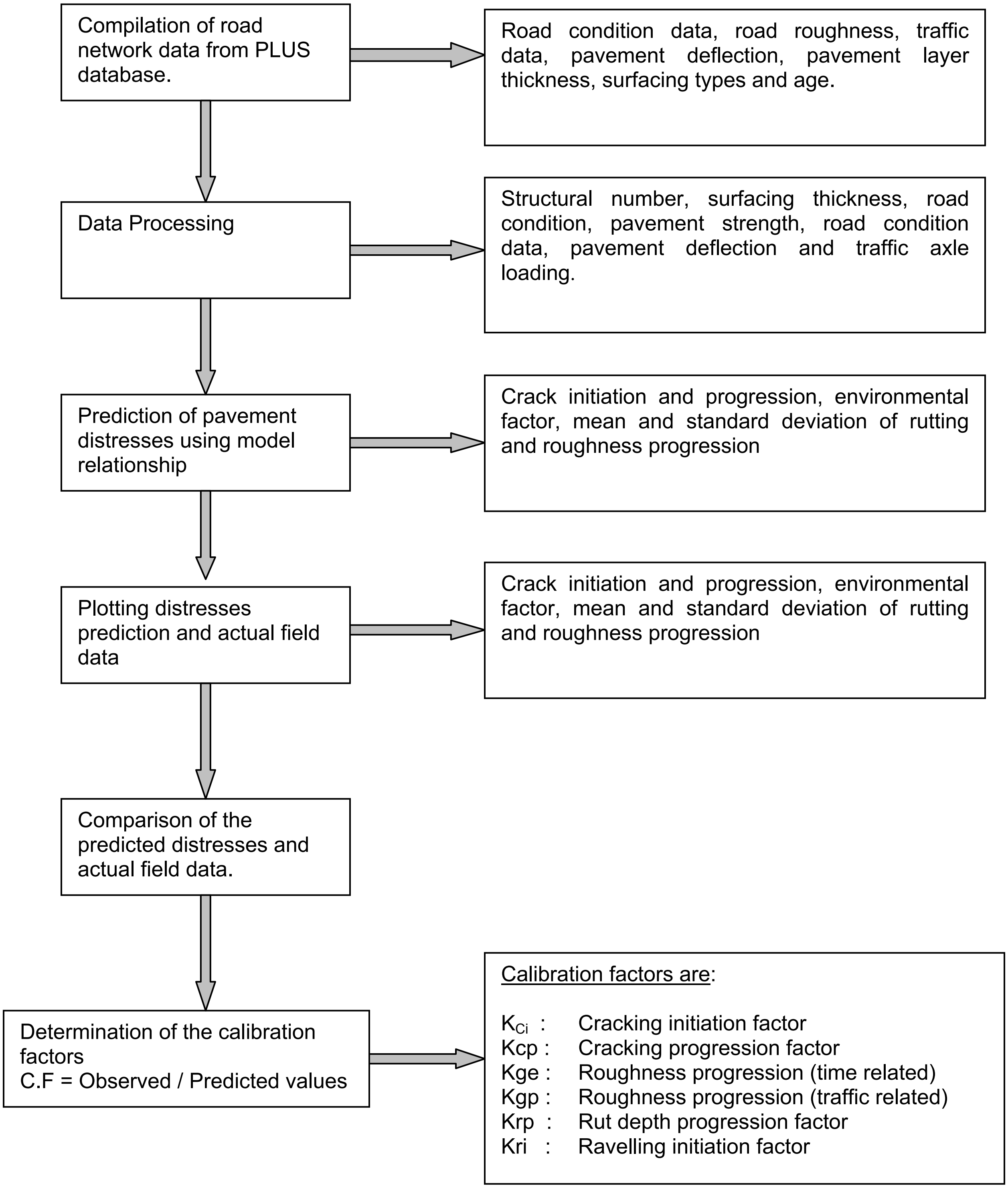

Figure 2: Flow Chart showing the Calibration Process

Level 1 - Calibration

The length of the expressway network in question consists of 680km two lane carriageways of flexible pavement construction and the calibration has been carried out on the bituminous pavement sections. The roughness-age-environmental factor determines the amount of roughness progression occurring annually on a non-structural time-dependent basis and it is related to the pavement environment. The roughness component due to environment is given as:

$$\Delta Rte = Kge * Rt$$

Where:

- ΔRte : is the change in the roughness component due to environment in the 1-year analysis time increment
- Kge : is the roughness age-environment calibration factor
- Rt : is the roughness at the beginning of the year t

For level 1 calibration, **Kge** was established based on the general environmental conditions, the road construction and drainage standards within the expressway network. This was done as follows:

$$Kge = meff / 0.023$$

and

$$meff = m * km$$

where meff: = effective environment coefficient
m = environment coefficient
km = modifying factor of environmental coefficient

Classification of road environment was determined from Table 7.2 of HDM-4 documentation, Volume 5 (Bennet & Paterson, 2000). Once the road environment has been established, the recommended values of environmental coefficient, **m** can then be determined from the HDM-4 Guideline. To demonstrate how the coefficient **m** is obtained, the following conditions were selected for the climate zone which is appropriate to the expressway environment.

Table 1: Classification of expressway environment

Data item	Temperature classification: Tropical
Temperature range (ºC)	20 – 35
	Moisture Classification: Humid
Monthly Precipitations (mm)	1500 – 3000
Typical Moisture Index	20 – 100

Table 2: Recommended environmental coefficient m value

	Temperature Classification: Tropical
Moisture Classification: Humid	0.025

The modifying factor of environmental coefficient for road construction and drainage effects, **km**, was taken from Table 7.4 in the same HDM-4 Guideline as 0.60. This corresponds to material quality of normal engineering standards, drainage and formation adequate for local moisture conditions, and moderately maintained.

Therefore,

$$meff = m * km = 0.025 * 0.60 = 0.015$$

The recommended roughness-age-environmental factor, **Kge** for Level 1 calibration is shown in Table 3.

Table 3: Recommended meff and Kge factors

Climatic Zones	meff factor	Kge
Tropical – Humid	0.015	0.652

Level 1 calibration has been presented in this section, Level 2 and Level 3 Calibration will be discussed in the following sections.

Selection of Calibration Sites

To carry out Level 2 and Level 3 Calibration, a total of 27 Long Term Pavement Performance (LTPP) calibration sites representing the 680km expressway of flexible pavement construction were identified. The length of the calibration site is 250m. The approach used to select the LTPP sites is to group sections of road of similar construction, traffic loading and age of construction together within a matrix by making the assumption that all road sections lying within a particular matrix element will behave in a similar manner. Three recognised primary parameters were used in the selection of the calibration sites including: Construction types (Thick, Medium and Thin); Traffic loadings (Heavy, Medium and Low) and Pavement age (Old, Medium and Young). The different ranges used for each parameter are as follows:

- *Construction Type:*
  - Thick pavement: Asphalt Thickness > 200mm
  - Medium pavement: 150 mm > Asphalt thickness ≥ 200mm
  - Thin Pavement: Asphalt Thickness ≤ 150mm
- *Traffic Loadings*
  - Heavy loading: traffic > 4 msa/year in one direction
  - Medium loading: 2 > Traffic ≥ 4 msa/year
  - Low loading: Traffic ≤ 2 msa/year

- *Pavement age:*
  - Old pavement: constructed prior to 1990
  - Medium pavement: constructed during or since 1990 and before 1993
  - Young pavement: constructed in 1993 or more recently

All calibration sites were selected in areas where no major maintenance (reconstruction or periodic) has been carried out since construction. The objective of this is to determine pavement deterioration patterns without the influence of pavement works.

Level 2 - Calibration

Level 2 calibration was carried out for those parameters with high and low impact on deterioration and for which time series data were available. These parameters include roughness-age-environment, rutting, cracking initiation, cracking progression, potholing and ravelling. To limit the length of the paper, this presentation will focus only on the calibration of the roughness-age-environment parameter. Similar calibration process will be used for adjusting the other distress parameters but the calibration work will not be presented.

2 LTPP sites have been selected for a presentation of Level 2 Calibration work. The LTPP sites identities and the respective pavement characteristics are listed in Table 4.
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Table 4: Selected LTPP Calibration sites

LTPP Site No	Length (m)	Thickness	Traffic Loading	Age
2	250	Thin	Light	Old
11	250	Thin	Heavy	Young

The parameter **Kge** is estimated directly from the HDM-4 predictive model for roughness progression as follows:

1. First, estimate the initial roughness for each LTPP calibration site after plotting the best-fit progression curve based upon the measured roughness values.

2. Using the initial roughness values, determine the predicted roughness progression using HDM-4 Kge default value of 1 and plot the curves for each LTTP site on the same graphs as the measured roughness.

3. Modify the Kge factor through an iterative process for each LTPP site until the predicted roughness progression curves come as close as possible to the measured roughness progression curves.

4. Adopt the above derived Kge factors as the Level 2 calibration factors for roughness-age-environment component of the roughness progression model.

The graphs used to determine the Kge calibration factor for LTPP site No.2 and No.11 by the best-fitting technique are depicted in Figure 3 and Figure 4 respectively. The results of the roughness-age-environment calibration for the two LTPP sites are summarized in Table 5.

Table 5: The Kge factors for the LTPP sites

LTPP Site No	Measured Roughness (2002)- IRI	Predicted Roughness (2002) - IRI	Kge	Predicted/ Measured (%)
2	3.62	3.66	0.652	1.09
11	3.36	3.40	0.400	1.18

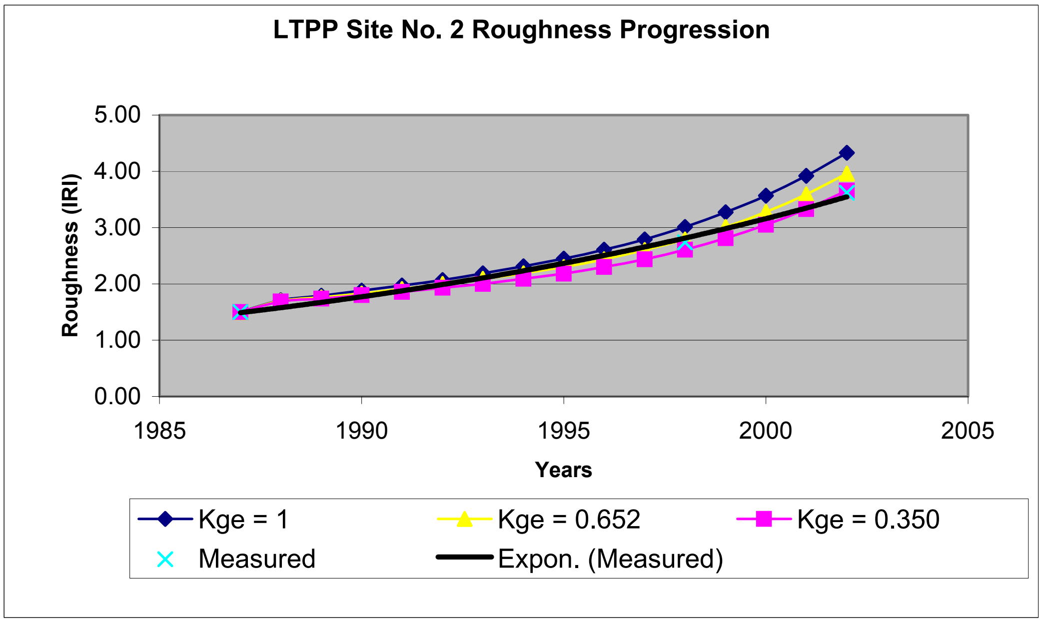

Figure 3 : Calibration factor for LTPP site No. 2

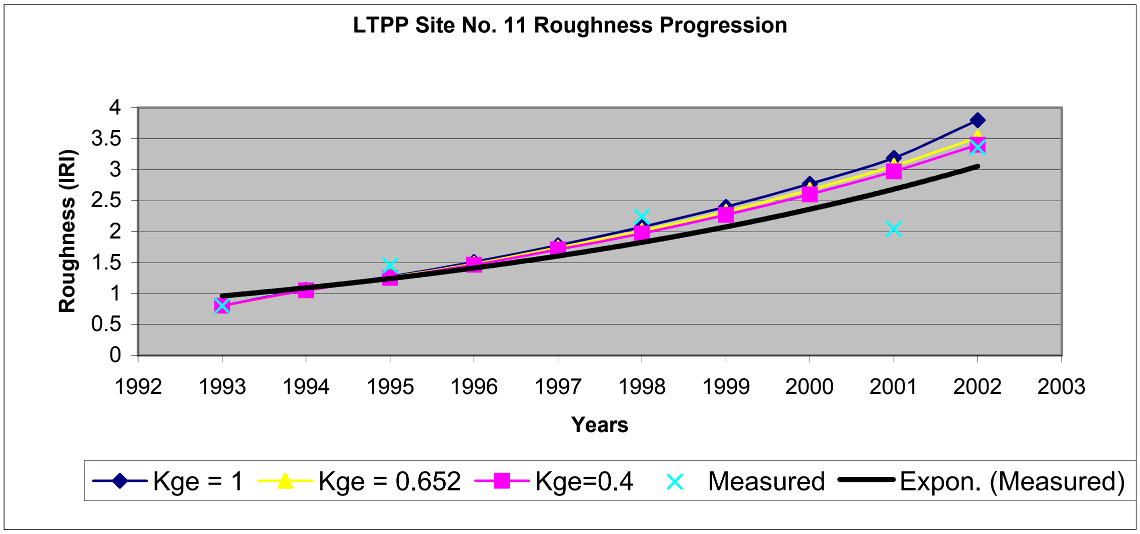

Figure 4 : Calibration factor for LTPP site No. 11

Level 3 - Adaptation

Having completed the main calibration in Level 2, further enhancement of the predictive relationships will be carried out in Level 3 calibration. For this purpose, there is a need to compile a time series pavement data for the next 5 to 10 years. The pavement data will be collected at the LTPP sites and the data will be used to verify the calibration factors obtained in Level 2.

CONCLUSION AND RECOMMENDATION

The process for the preliminary calibration of the roughness-age-environment factor, Kge, has been presented in this paper. Level 1 Kge calibration factor was obtained from HDM-4 Guideline and the value was determined to be 0.652 for the entire expressway. The Level 1 Calibration involved desk study and many default values were adopted using the guidelines given in the HDM-4 Manual.

For Level 2 calibration, the Kge factors for the selected LTPP sites No.2 and No.11 were calibrated to be 0.652 and 0.400 respectively. This level of calibration has been accomplished using the available historical pavement data (e.g. roughness, cracking and rutting) for the LTPP sites. It can be observed that Level 2 calibration yields a higher calibration factor for LTPP sites No.2.and this indicates that the rate of increase in roughness due to environmental effects is greater than site No.11.

Contrary to Level 1 Calibration which yield one global Kge factor for the entire expressway network, Level 2 Calibration would yield Kge factors for the individual LTPP sites which exhibit different pavement characteristics. With the Kge values for each of the pavement grouping, it is expected that the pavement performance of the entire expressway network can be better predicted and the economic output from the HDM-4 can be enhanced.

A key benefit of a calibrated HDM model is that it would generate good prediction of the actual pavement deterioration in local condition. With the enhancement in the predictive model, an appropriate maintenance budget can be forecasted more accurately and this ensure that adequate budget allocation has been provided. A well calibrated model would reduce the possibility of future funding shortages.

It is also envisaged that the calibration of the HDM model will assist in the production of the Long Term Rolling Programme (LTRP) with greater level of confidence for the expressway section.

Monitoring and measurements of the distress parameters on the LTPP sites for the next 5 to 10 years is recommended for achieving a full adaptation of the HDM-4 model for the expressway section. The adaptation exercise to be carried out in Level 3 Calibration will enhance the existing HDM predictive relationships and these new measurements shall used to refine this preliminary calibration of the roughness-age-environmental factor.

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