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Research Paper

SOFTWARE DEVELOPMENT FOR CALIBRATION OF HIGHWAY DEVELOPMENT AND MANAGEMENT TOOL (HDM-4) FOR LOCAL CONDITIONS

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The Highway Development and a Management System (HDM-4) developed by World Bank is a powerful pavement management software tool capable of performing technical and economic appraisals of road projects, investing road investment programs and analyzing road network preservation strategies. Its effectiveness is dependent on the proper calibration of its predictive models to local conditions. The use of appropriate calibration factors in HDM-4 pavement deterioration models will facilitate more reliable and rational prediction of pavement deterioration for the road network under considerations. This in turn will help in better assessment of the maintenance and rehabilitation requirements of pavements and improved pavement management system. In the present study, computer programs in 'Visual C' language have been developed for calibration of pavement deterioration progression models stipulated in HDM-4 tool such as cracking, ravelling, edge break and pothole for surface treatments with unbound base types of pavement composition used for Low Volume Roads (LVR) in India.

Keywords: Pavement, Deterioration models, Low volume roads, Calibration

INTRODUCTION

The World Bank's HDM-4 program is the recommended choice of the World Bank and other international banks on the highway construction and maintenance management projects funded by theses institutions. These programs perform a comprehensive life-cycle analysis of agency costs, user costs, and benefits using condition deterioration models for roughness, cracking, ravelling, rutting and edge breaking. The HDM-4 version has extensive features for creating the network level database and M, R&R work programs. The HDM performance prediction models are empirical regression models and needs for calibration (especially, the distress progression models), if used in different geographical areas.

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BACKGROUND LITERATURE

Central Road Research Institute (CRRI), in India has conducted a long-term research; named Pavement Performance Study (PPS) and developed pavement deterioration models for National/State highways but LVR were not included in the study (CRR, 1994). Chakrabarti *et al.* (1995) and Roy Neetu *et al*. (2003) attempted to calibrate HDM III and HDM-4 pavement deterioration models for State highway networks in Gujarat and Kerala States of India. Rhode *et al.* (1998) calibrated and used HDM-4 based PMS in the Gauteng Province of South Africa and showed the influence of calibrated performance models in pavement management systems decision. Elmi *et al.* (2000) presented a procedure for calibrating four pavement deterioration models of HDM-III for Italian two lane rural roads. But this is only a first level calibration as it has been developed only with analytical algorithms without making use of any experimental data. Carrof *et al.* (2001) presented a series of examples and procedures that can be implemented to achieve calibration of HDM task to some countries of Eastern Europe. Solminihac *et al.* (2003) attempted to calibrate the pavement performance models for surface treatment to Chilean local conditions using the "window" monitoring techniques. Martin (2004 and 2005) developed an empirical structural deterioration model based on 42 observations at some 21 monitored arterial road sections over a number of years, for sealed unbound granular pavements in Australia.

HDM-4 MODEL FORMS AND INDEPENDENT VARIABLES

Pavement deterioration manifests itself in various kinds of distresses, each of which is modeled separately in HDM-4. Model forms that use combinations of distresses in the form of a single index of 'condition' or damage functions are too restrictive. The ideal maintenance treatment for a particular section of road will depend on principal cause of the distress and this may be concealed where combined index methods are used. The HDM-4 road deterioration models attempt to model the complex interaction between vehicles, the environment, the pavement structure and surface. The models used to predict the deterioration of bituminous pavements in HDM-4 have several common characteristics such as (Morosiuk *et al.,* 2002):

i. Individual types of deterioration are modeled rather than a composite index,

ii. The deterioration models are of the structured empirical form, and

iii Deterioration models for a particular type of distress are interactive with other types of distress

The types of deterioration of a bituminous pavement can be categorized into cracking, surface disintegration, permanent deformation, longitudinal profile and friction. The development of these modes of deterioration may be dependent on a number of factors, which can be broadly classified as pavement strength, material properties, traffic loading and environment. The distress types, which are modeled in HDM-4 and the independent variables which are used in the deterioration models, are given in Table 1.

Table 1: Types of Distress and Independent Variables Used in HDM-4 Pavement Deterioration Models

Distress Mode	Distress Type	Independent Variables			
		Pavement Strength	Material Properties	Traffic Loading	Environ-ment
Cracking	Structural	*	*	*	*
	Transverse thermal		*		*
Disintegration	Ravelling		*	*	*
	Potholing	*	*	*	*
	Rutting – surface wear			*	*
	Edge break		*	*	*
Deformation	Rutting – structural	*	*	*	*
	Rutting – plastic flow		*	*	*
Profile	Roughness	*	*	*	*
Friction	Texture depth		*	*	
	Skid resistance		*	*	

Source: Morosiuk *et al.* (2002)

Flexible Pavement Deterioration Models in HDM-4

Road deterioration model equations as stipulated in HDM-4 software for surface treatments with unbound base pavement types as used for LVR in India are given in Table 2 and the brief descriptions of the various parameters used in these models are given in manuals of HDM-4.

NEED FOR CALIBRATION OF HDM-4 PAVEMENT DETERIORATION MODELS

The objective of an HDM analysis is to model pavement deterioration. This entails predicting the deterioration of pavement under time and traffic, the road user effects, and the effects of maintenance on pavement condition and rate of deterioration. As with any model, HDM is a representation of reality. How well the model prediction reflects reality is dependent upon a combination of validity of underlying HDM relationships, accuracy and adequacy of the input data and calibration factors used in the analysis (Bennett and Paterson, 2000).

It is important that prior of using HDM-4 for the first time in any country, the system should be configured and calibrated for local use. Since HDM-4 has designed to be used in a wide range of environments, calibration of HDM-4 provides the facility to customize system operation to reflect the norms that are customary in the environment under study. The use of appropriate calibration factors in HDM-4 pavement deterioration models will facilitate more reliable and rational prediction of pavement deterioration for the road network under considerations. The default equations

Table 2: HDM-4 Pavement Deterioration Models for Surface Treatments with Unbound Base Pavements

S. No.	Model Description	HDM-4 Road Deterioration Models
1.	Cracking Initiation	$ICA = K_{cia}\left[CDS^2 * 13.2 * e^{\{0.0*SNP-20.7(YE4/SNP^2)\}} + CRT\right]$
2.	Cracking Progression	$dACA = K_{cpa}\left(\frac{CRP}{CDS}\right)\left[\left(1.76*0.32*\delta t_A + SCA^{0.32}\right)^{\frac{1}{0.32}} - SCA\right]$
3.	Ravelling Initiation	$IRV = K_{vi} CDS^2 * 10.5 * RRF * e^{(-0.156*YAX)}$
4.	Ravelling Progression	$dARV = K_{vp}\left(\frac{1}{RRF}\right)\left(\frac{1}{CDS^2}\right)\left[\left((0.6+3.0*YAX)*0.352*\delta t_v + SRV^{0.35}\right)^{\frac{1}{0.35}} - SRV\right]$
5.	Potholing Initiation	$IPT_i = K_{pi} * 2.0\left[\frac{(1+a_1*HS)}{(1+a_2*CDB)(1+a_3*YAX)(1+a_4*MMP)}\right]$
6.	Potholing Progression	$dNPT_i = K_{pp} * a_0 * ADIS_i\left[\frac{(1+a_1*CDB)(1+a_2*YAX)(1+a_3*MMP)}{(1+a_4*HS)}\right]$
7.	Roughness Progression	$\Delta RI = K_{gp}\left[\left[134 * e^{(m*K_{gm}AGE3)} * (1+SNPK_b)^{-5} * YE4\right] + (0.0066*\Delta ACRA) + (0.088*\Delta RDS)\right.$ $\left. + \left[0.00019(2-FM)\left\{\left[(NPT_a * TLF) + \left(\Delta NPT * \frac{TLF}{2}\right)\right]^{1.5} - (NPT_a)^{1.5}\right\}\right] + (m * K_{gm} * RI_a)\right]$
8.	Edge-break Progression	$dVEB = Keb * a_0 * PSH * (AADT)^2 * ESTEP(S)^{a1}\left[a_2 + \frac{MMP}{1000}\right] * 10^{-6}$

Source: Odoki et al. (2000)

in HDM-4 if used without calibration, would predict pavement performance that may not accurately match with that of observed on specific road sections. Thus, calibration is necessary to 'fine-tune' the regression coefficients to predict more representative outputs in the environments, other than the regions in which the models were developed (Bennett and Paterson, 2000). Since the underlying HDM relationships have proven to be robust and applicable in a number of countries, the reliability of most HDM analyses depends on the input data and the calibration factors. The only way of assessing the adequacy of the HDM deterioration models are by comparing the model predictions to the known data. For example, one may have data on the current roughness of a number of pavements of known ages. By using the HDM model to predict the condition of the pavement of the same age with the same attributes from when they were new, one could assess whether the HDM models were giving appropriate predictions. The calibration factors should be used to adjust the rates of deterioration for specific road sections or regions, for particular types of pavement. For example, a section of a road in a hilly region may deteriorate at a different rate to a section of road in a plain region, even though the two sections are nominally homogeneous in all other respects.

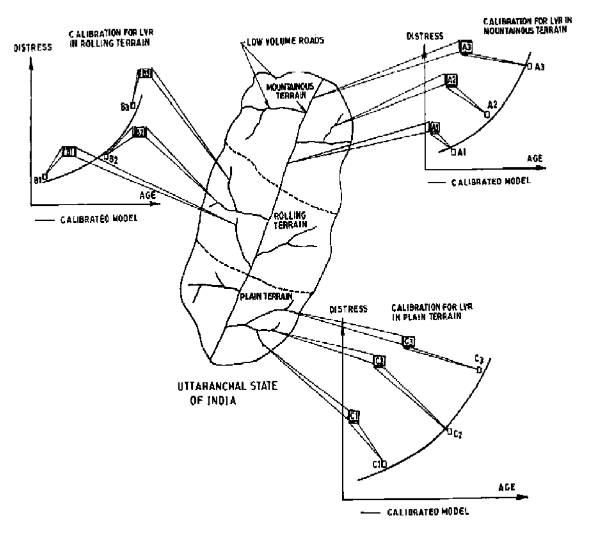
STATISTICAL CALIBRATION METHODOLOGY ADOPTED IN THE PRESENT STUDY

To facilitate calibration and local adaptation, HDM-4 road deterioration models contain 'calibration factors', which are linear multipliers for modifying the predictions to suit to the local conditions. In HDM-4, the default value of each of these calibration factors has been set to unity. However, these factors need to be adjusted to local conditions, so that the predictions made by the models reflect the observation made in the local conditions under investigation. Local adaptation of the HDM-4 pavement deterioration model through the calibration factors requires the availability of good quality quantitative time series data on the occurrence of distress for different pavement sections and traffic combinations under local conditions. To calibrate a pavement performance model, it is necessary to possess a group of distress data that serve to represent the real performance curve; preferably the data represents a relatively longer period of time. The process of calibration then consists of determining the adjustment factors (k_i) which will achieve the best agreement between the model's predictions and the field data. "Test Section" or "Film" method and "Window" technique has been used for development/ calibration of pavement deterioration models in various studies. In test sections calibration methodology, it is necessary to measure data continuously for an extended period of time for each selected section, for obtaining reliable predictive data.

'Window' technique has been used for calibration of pavement distress models in the present study because it offers the possibility of relying on a broader inference space and the possibility of integrating data gathered in previous studies with the new data for further refinement of pavement distress models. This methodology also permits section distress measurements to be made in a brief period of time and consequently allows for the evaluation of a greater number of sections and categories. The another reason for suggesting the "window' technique in this study is the absence of long-term historical pavement performance data for LVR in India, while there is an immediate need for the development of pavement deterioration models for this category of roads.

In terms of 'window' technique applications, the first step consists of defining homogeneous low volume road sections according to their most representative variables as: structure, traffic, geometry, and climate. Each of these sections is then considered as a window in a pavement's performance curve and, together with other windows (similar individual sections) represents a particular pavement's performance. If the sections in a chosen window have different ages, the performance curves for different distress types can be obtained. In the same model, these curves should present relatively similar trends over the years. The performance data obtained from field observations may then be compared with the data obtained through modeling. This methodology enables one to calibrate the different models by using adjustment factors k_i. For another group of sections or for windows with different characteristics, the data should present different trends, which in turn will modify the k_i values obtained when performing the calibration. The details of calibration methodology evaluated in the present study are shown in Figure 1.

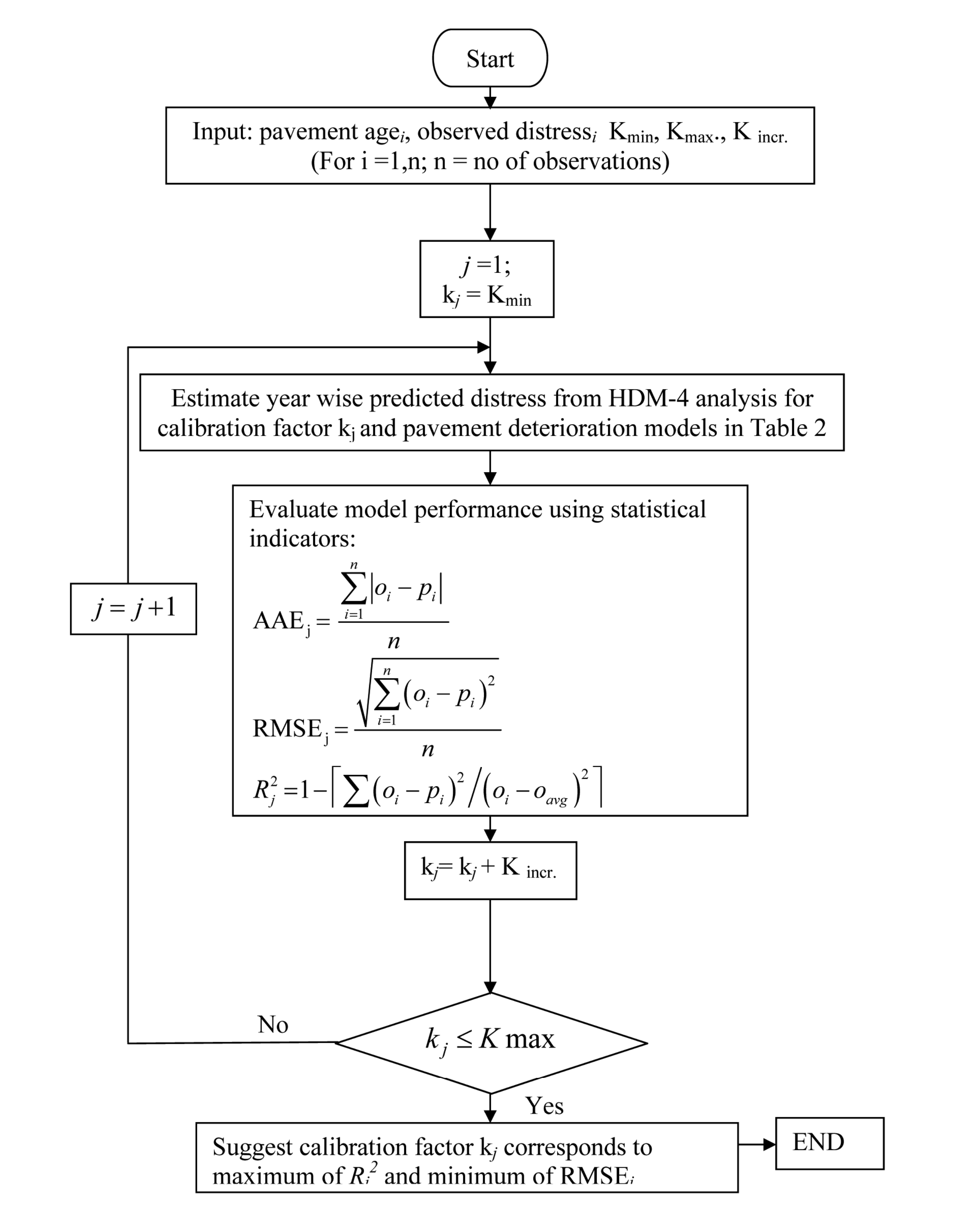
Figure 1: Calibration Methodology Adopted in the Study



The procedure proposed for the statistical calibration of pavement performance models is based mainly on determining the factors that allow for a more precise or better adjustment of the simulated distress curves to the real performance data. Two different procedures are followed for calibration, depending on whether the factor to be determined corresponds to the initiation or progression phase of distress. The procedure proposed for calibrating surface distress initiation factors are based on obtaining the coefficient between the observed year of occurrence of the distress to the year of occurrence as predicted by the uncalibrated models. In the case of the progression factors, the calibration is carried out by minimizing the squares of the differences of the estimated and observed data or Sum of Squared Differences (SSD). A typical raveling model performance curve indicating the observed data and the curve obtained from the model predictions is presented in Figure 2, so the ideal adjustment consists of minimizing differences to achieve the most accurate and real performance in time. Minimizing the SSD value assists in reducing the estimated average error, which in turn will make it possible to locate the calibration factor that ensure the best adjustment of the distress curve and therefore the calibration of the analysed performance model.

An analysis of verification of prediction quality of model is also performed in the study by comparing observed versus predicted distresses values for each of the model. The following statistical indicators are used for comparison of models:

Figure 2: Flow Chart Showing Calibration Methodology Adopted in Study



$$AAE = \frac{\sum_{i=1}^{n} |o_i - p_i|}{n} \quad ...(1)$$

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n} (o_i - p_i)^2}}{n} \quad ...(2)$$

$$R^2 = 1 - \left[\sum (o_i - p_i)^2 / (o_i - o_{avg})^2 \right] \quad ...(3)$$

where,

K	HDM-4 calibration factor for particular distress
AAE	Average Absolute Error
RMSE	Root Mean Square Error
R^2	Goodness of fit measure (coefficient of determination)
n	No. of observations
o_i	Actual value of distress observation *i*
p_i	Predicted value of distress observation *i*; and
o_{avg}	Average value of distress observations

DEVELOPMENT OF COMPUTER PROGRAM FOR CALIBRATION OF HDM-4 DETERIORATION MODELS

In the present study, four computer programs in 'Visual C' language are developed for the calibration of following HDM-4 pavement deterioration models for LVR:

- Cracking progression model;
- Ravelling progression model;
- Edge break progression model; and
- Pothole progression models.

The details of various input and output parameters considered for the development of each of the four programs are given in Table 3, which are based upon the HDM-4 pavement deterioration equations as described in Table 2. The flow chart giving details of general methodology followed for the development of calibration program for each deterioration model is shown in Figure 2. Typical program output results of details of ravelling calibration program giving details of calibration factors and corresponding values of AE, RMSE, and R^2 are given in Table 4. The calibration factor corresponding to minimum RMSE and maximum R^2 are suggested for each of the pavement deterioration models.

The computer program developed in the present study will be useful for determining the appropriate HDM-4 calibration factors for Low Volume roads, once the historical observed pavement distress and age data for group of pavements in any particular cell is known. The program shall be used in two stages for calibration of HDM-4 deterioration models. In the first stage calibration program shall be run for varying calibration factors from K_{min} = 0.1 to K_{max} = 20, at an increment of 0.1. Once, the calibration factor corresponding to minimum RMSE and maximum R^2 has been determined from the first stage, the program shall be further run for second stage by taking K_{min} and K_{max} values within the closer range of calibration factor as determined from first run, and at the smaller increment of 0.01, for further refinement of calibration factor K.

Table 3: Details of Input and Output Parameters for Calibration Program

Program Description	Details of Input Parameters	Details of Output Parameters
Cracking progression calibration program	project ID, project description, year of analysis, analysis period, CRP, CDS, K_{cpa} (min), K_{cpa} (max), increment in K_{cpa} value, Details of observed cracking of different rural road sections in the category, i.e., age and observed cracking (in % area) details	$K_{cpa\ i}$ and corresponding AAE_i, $RMSE_i$, and R^2 ,for all K_{cpa} between K_{cpa} (min) and K_{cpa} (max)
Raveling progression calibration program	project ID, project description, year of analysis, analysis period, RRF, CDS, average annual daily motorized traffic, traffic growth road, K_{vp} (min), K_{vp} (max), increment in K_{vp} value, Details of observed cracking of different rural road sections in the category i.e., age and observed cracking (in % area) details	$K_{vp\ i}$ and corresponding AAE_i, $RMSE_i$, and R^2 ,for all K_{vp} between K_{vp} (min) and K_{vp} (max)
Edge break progression calibration program	project ID, project description, year of analysis, analysis period, PSH,AADT, ESTEP, MMP, a_0, a_1, a_2, S, K_{eb}(min), K_{eb} (max), increment in K_{eb} value	$K_{eb\ i}$ and corresponding AAE_i, $RMSE_i$, and R^2 ,for all K_{eb} between K_{eb} (min) and K_{eb} (max)
Pothole progression calibration program	project ID, project description, year of analysis, analysis period, CRP, CDS, HS, a_0, a_1, a_2, a_3, a_4, RRF, CDB, MMP, K_{cpa}, K_{vp}, TLF, K_{pp}(min), K_{pp} (max), increment in K_{pp} value	$K_{pp\ i}$ and corresponding AAE_i, $RMSE_i$, and R^2 ,for all K_{pp} between K_{pp} (min) and K_{pp} (max)

Table 4: Typical Calibration Output from Ravelling Progression Calibration Program

Kvp	AAE	RMSE	R Square
0.100	9.880	3.440	0.470
0.110	8.610	2.960	0.610
0.120	7.270	2.450	0.730
0.130	5.970	1.950	0.830
0.140	4.880	1.510	0.900
0.150	4.190	1.260	0.930
0.160	5.200	1.410	0.910
0.170	6.960	1.920	0.830
0.180	9.150	2.630	0.690
0.190	11.720	3.460	0.460
0.200	14.580	4.290	0.170
0.210	16.760	4.790	-0.030
0.220	19.060	5.380	-0.300
0.230	20.780	5.760	-0.490
0.240	22.380	6.110	-0.680
0.250	24.060	6.510	-0.910
0.260	25.080	6.680	-1.000
0.270	26.090	6.840	-1.100
0.280	27.140	7.020	-1.220
0.290	28.220	7.220	-1.350
0.300	29.330	7.440	-1.490
0.310	30.480	7.680	-1.650
1.070	71.640	16.550	-11.320
1.080	71.770	16.570	-11.350
1.090	71.910	16.600	-11.380
1.100	72.060	16.620	-11.420

CONCLUSION

i. Pavement performance data for low volume roads as well as high volume roads being constructed under Pradhan Mantri Gram Sadak Yojana (PMGSY) and under National Highway Authority of India (NHAI) in India are presently being collected under various research schemes.

ii. The methodology suggested in the present study can be very well quickly used for calibration of HDM-4 suggested pavement deterioration models for these roads.

iii. Appropriately calibrated HDM-4 pavement deterioration models will be very useful for deciding optimal maintenance management strategies for vast network of these roads under the constrained budget scenario for maintenance.

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