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TECHNICAL NOTE

LEVEL 1 CALIBRATION OF HDM-4 ANALYSIS WITH A CASE STUDY

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Abstract: Adequate budget allocation would require the HDM-4 model to generate good prediction of the actual pavement deterioration behavior. The need for a calibration of the HDM model to local condition is therefore an essential component of the pavement management process. Reliable calibration factors are useful for budgeting purpose and it avoids under estimate or over estimates the budget. This paper presents a case study where a level 1 calibration has been carried out for a State Highway in Uttar Pradesh, India. The climatic condition of the site is under humid, hot and high monthly precipitation throughout the year. Two methods have been proposed to find out the calibration factors. The calibration factors namely roughness age environment, crack initiation and crack propagation are found to be 0.650, 0.970 and 1.030 respectively for the case study using method 1 calibration method and 0.650, 0.864 and 1.157 respectively using method 2 calibration. Economic analysis has been carried out taking default calibration factors and level 1 calibration factors and NPV (net present value) and IRR (internal rate of return) were found Rs. (million) 368.1 (26.5 %) and 422.4 (27.9 %) respectively. Level 1 Calibration involved desk study and many default values have been adopted but the major factors like roughness age environment, crack initiation and crack propagation are important to simulate local condition. A well calibrated model for this local condition would reduce the possibility of future funding shortages. Level 1 calibration may be carried out easily based on few secondary data within few weeks and useful for economic analysis, prioritization and budgeting for maintenance of the road network.

Keywords: *Calibration, HDM calibration, level-1 calibration*

1.0 Introduction

The Pavement Management System (PMS) for State Road Project has been adopted to provide a cost effective maintenance programme. The main component of PMS is the Highway Development Maintenance (HDM-4) computer programs. 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 specified standard objectives. 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 have been applied in many developed and developing countries having markedly different technology, climatic and economic environments. HDM 4 analysis requires various input data collected from field and can be used after calibrating HDM model suitable for local condition. 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 calibrations can lead to an under or overestimate budget for highway expenditure (Bennett and Paterson, 2000).

In this research study, Level 1 calibration of HDM-4 has been carried out for a State Highway project in Uttar Pradesh. Level 2 calibration is not always possible due to lack of the required long time series data. Therefore, aim of this present paper is to find out level 1 calibration factors for a region / project based on very limited available data.

2.0 Calibration Process

The Model Calibration is required for accuracy of prediction of certain behavior, e.g., pavement performance. The accuracy of the predicted pavement performance and vehicle resource consumption depends on the extent of calibration applied to the default values of HDM-4 Model that suits the local conditions. In other words, the default equations in the HDM-4 Model, if used without calibration, would predict pavement performance that might not accurately match with actual performance of the road sections. It is important that pavement performance model needs to be duly calibrated to reflect the observed rates of pavement deterioration on the roads where the model is applied.

The length of the two lanes carriageway state highway which is to be constructed with flexible pavement is 10 km and the climatic condition along the highway is humid, hot and the monthly precipitation has been considered high throughout the year. 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 the following two important steps:

(i) 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. This includes configuration of HDM-4 and this will focus on inputs such as vehicle fleet, speed-flow types, traffic flow pattern, climate zones, accident rates, and the relationships between detailed and aggregate data.

(ii) Calibration outputs: adjusting the model parameters to enhance how well the forecast and outputs represent the changes and influences over time and under various interventions. Calibration of the HDM-4 model focuses on the components that determine the physical quantities, costs and benefits predicted for the road deterioration (RD), works effects (WE), road user effects (RUE) and Socio-Economic Effects (SEE) analysis.

The three calibration levels which involve low, moderate and major levels of efforts and resources are as follows:

Level 1: Application: based on a desk study of available data and engineering experience of pavement performance.
Level 2: Verification: based on measured pavement condition data collected from a large number of road sections.
Level 3: Adaptation: Experimental data collection required to monitor the long-term performance of pavements within the study area.

2.1 Sensitive Parameters in HDM 4 Analysis

On the basis of the three key factors of locational sensitivity, parameter impact on the model output, and the availability of calibration resources, candidate parameters for calibration are recommended for the case region. The roughness progression factor was found to have the highest impact on the net present value (NPV) of life-cycle costs. The roughness-age, cracking progression, and pothole progression factors were found to be the next influential on the NPV (Mariah and Haas 1996).From results of NPV, the study recommended a priority list in allocating recalibration efforts.

There are different approaches which can be used for undertaking sensitivity analysis. The approach use is called ceteris peribus method –changing one single factor and keeping all other factors constant. The alternative approach, using factoral experiments, which combined all other levels of one factor with all levels of all other factors were not used due to large number of combinations to considerer. Thus, the analysis does not consider factor interaction. On the basis of analyses, four classes of model sensitivity have been established as a function of impact elasticity. The higher the elasticity, more the sensitive model predictions. Sensitivity class have been presented in Table 1.

Table 1: HDM Sensitivity Class

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

3.0 Literature Review

The purpose of the study is to improve decision-making on expenditures in the road sector in Nigeria by enabling effective and sustainable utilization of the latest HDM-4 knowledge. The study basis for an effective implementation of decision-support methods and computerized tools for use by the 'Federal Ministry of Works (FMW), Road Sector Development Team (RSDT), Federal Road Maintenance Agency (FERMA) and other related agencies to achieve sustainable operation of Nigerian road management system.

The adaptation of the model for Nigeria was based data from field studies carried out as well as data from statutory agencies. Data collected and analyzed for aspects of the assignment were on climate, vehicle operating cost, traffic characteristics and on the various road pavement types dominant on the network. Due to the nature of data available cross-sectional method was used for the calibration of the HDM-4 model to simulate the local condition of Nigeria. The default values have all been updated to be consistent with the relevant pavement deterioration factors have all been updated based what pertains in Nigeria. The information from the road agencies on construction practices and local specification used in the selection of the road pavement layer materials for bituminous (surface dressed and asphaltic concrete) and unsealed roads in order to reflect local quality control regime with respect to completed road works Road Sector Development Team (2014).

The Highway Development and Management-4 (HDM-4) tool has been widely used for the pavement management activities across the world. This tool has inbuilt pavement performance prediction models, vehicular performance models and economic analysis tools. Exhaust emissions are one of the important outputs of vehicular performance models that are helpful in assessing viability of investment options and environment impact assessment activities. There are seven exhaust emission models (for different components like hydro carbon, carbon monoxide, particulate emissions etc.) available within HDM-4. These models are required to be calibrated so that the predictions made by calibrated HDM-4 models represent the specific local ground conditions. The work presented here is an attempt to calibrate the HDM-4 emission models to Indian conditions. Initially sensitivity analysis of emission models was conducted to find sensitive input variables in emission model that affect model output significantly. It was found that operating weight, pavement gradient and vehicle life are very sensitive inputs into HDM-4 emission models. Based on the sensitivity analysis and data obtained from a previous study were used in calibration of emission models for Indian conditions. Further these calibrated emission models were used to predict emissions for urban conditions prevailing in India. Comparison of predicted and measured values indicate that all emission models for two lane road and Carbon Monoxide emission model for four lane road over-predicts for two wheelers, car, light commercial vehicles and busses, while under-predicting for trucks (Prasad et al. 2013).

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 will help in better assessment of the maintenance and rehabilitation requirements of pavements and improve 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 (Thube and Thube 2013).

The HDM-4 model used for pavement management activities must be adjusted to the specific conditions of a country or region where they are to be used by adjusting certain calibration factors. The results obtained from calibrating the cracking, ravelling, potholing, rut depth, and roughness models contemplated in HDM-4 version 1.1 for surface treatments are presented and compared with the results obtained from equivalent models of HDM-III. In this task, the "windows" methodology was used, which consists of reconstructing the distress performance curve of a specific road category starting with observation of the condition of different roads with similar characteristics (such as traffic, pavement structural capacity, and climatic conditions) but of different ages. On the basis of the results obtained, recommendations for calibrating the performance models are proposed, and calibration factors more adequate for characteristics specific to Chilean surface treatments are established. On comparing the results of the calibrated models of HDM-III and HDM-4, it is concluded that both cases furnish similar values, and use of HDM-4 models is recommended because of their operating advantages and because they afford a greater flexibility, which allows them to more aptly adapt to a broader number of cases and situations (Herman et al. 2012).

Fuel consumption costs are an essential part of the costs that highway agencies must consider when evaluating pavement-investment strategies. These costs depend on the vehicle class and are influenced by vehicle technology, pavement-surface type, pavement condition, roadway geometrics, environment, speed, and other factors. This paper presents the results of a calibration exercise of the HDM 4 fuel consumption model to US conditions using field data collected as part of the NCHRP project 1-45. Statistical analysis showed that there is no difference between the observed and the estimated fuel consumption at 95 per cent confidence level. The calibrated HDM 4 model was able to predict fuel consumption with an error ranging from 2.5 per cent for articulated trucks to 8 percent for medium cars Zaabar and Chatti (2010).

Pavement deterioration data for sealed granular and asphalt roads in the LTPP database are currently insufficient, in terms of the variation in the values of the variables, to develop reliable calibrations for HDM-4 road deterioration (RD) models in Australasia. However, wide ranging historical deterioration data from the state and New Zealand road authority (SRA) networks are available, although the quality of this SRA data is not as good as the LTPP data. Consequently, SRA data from some states were used to calibrate HDM-4 RD models which should improve the reliability of deterioration predictions for the State and New Zealand road networks in which the RD model calibrations were made. These calibrated HDM-4 RD models can be either refined or simplified when new data from the existing and the additional LTPP sites become available. This report documents the calibration of HDM-4 RD models for sealed granular and asphalt pavements based on SRA historical deterioration data. SRAs supplied historical roughness and rutting deterioration data and some supplied cracking deterioration data and maintenance history Austroads Technical Report (2008).

HDM-4 RD models were calibrated to suit conditions in Victoria, Tasmania, South Australia, Queensland and New Zealand. Rutting and roughness RD models were calibrated for all these SRAs, except Queensland. Cracking RD models were calibrated for South Australia due to the reasonable quality of its cracking data. Cracking data from Victoria, Tasmania and New Zealand were either of inadequate quality or too insignificant, in terms of extent of cracking, to be considered in the analysis, hence cracking models were not calibrated for the data from these authorities. The development of generic RD models for roughness, rutting, cracking and deflection is expected to commence during 2007-08 to enable wider application of these models Austroads Technical Report (2008).

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 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 (Garry et al. 2006). The costs and benefits of the alternative investment strategies are estimated using relationships classified under two broad categories: Road User Effects (RUE) and Road Deterioration and Works Effects (RDWE).

Relationships under the RUE include models to estimate vehicle operating costs (VOC), travel time and exhaust emissions, whereas relationships under the RDWE include models to predict the deterioration of pavement and the impacts of maintenance activities on the pavement condition. The RUE components are estimated as a function of factors such as vehicle characteristics, pavement condition, etc., whereas the RDWE are predicted as a function of factors such as environmental conditions, traffic characteristics, etc. As these factors vary from country to country, local calibration of both the RUE and RDWE relationships is a prerequisite for a sound road investment decision-making. The transferability of the HDM-4 tool across countries to suit local conditions is ensured through a set of calibration factors that are adjusted in such a manner that the differences between the estimated RUE and RDWE components and the observed ones are minimized. This paper presents the results of a preliminary calibration exercise, one of the first in Japan, of the RUE relationships of five typical vehicles i.e., small passenger cars, medium passenger cars, medium trucks, heavy trucks and heavy buses. The basic input data required for the calibration were obtained from reports published by the Japanese trucks and buses operating companies, car dealers, etc., and earlier studies on VOC and exhaust emissions undertaken by different Japanese government agencies. Calibration factors were estimated for the parts consumption and labour hours for the VOC relationships and for the nitrous oxide, carbon monoxide, hydrocarbon, particulates, carbon dioxide and sulphur dioxide exhaust for emissions relationships. It was found that the use of HDM-4 default parameters overestimates both the parts consumption and labour hours in comparison to the actual consumption in Japan for all the five vehicle types considered. However, the estimates of the exhaust emissions were found to be less for some vehicles and high for others.

To determine the adjustment factors for various models in HDM-4 for asphalt pavements, an analysis in a diverse range of geographical areas in Chile has been conducted. These models included cracks, ravelling, potholes, rutting and roughness. The technique used to develop the calibration was the “windows” method, which allowed for the construction of the evolution curve for a pavement’s behavior using deterioration data. This data was taken from observations at different ages and on different roads with similar characteristics. Finally, the conclusions of the study are presented along with some recommendations for the use of the HDM-4 models calibrated during the study. The conclusions take into account the various different situations in which the models might be applied (Valdes et al. 2006).

4.0 Proposed Methodology for Level 1 Calibration

Calibration for level 1 has been carried out using the methodology presented in Section 7, HDM – 4, Volume Five, A guide to Calibration and Adaptation (Bennett and Paterson, 2000). Roughness age environment factor determines the amount of roughness progression occurring annually on a non-structural time dependent basis. Six deterioration factors have the impact on net elasticity. Their ranking has been mentioned in Table 7.1 of HDM 4, Volume Five. From this table, it is observed that roughness age environment, cracking initiation and crack propagation are the three most critical deterioration factors. These three factors shall be calibrated using the methodology as mentioned in Sections 7.2.1, 7.2.2 and 7.2.3 of HDM 4, Volume Five. These three calibration factors as mentioned earlier have been considered in analysis. Detail methodology has been presented in the following sections 3.1, 3.2 and 3.3. Therefore, calibration factor has been determined using following two methods Method 1: Consider 5 year is actual crack initiation and Method 2: Consider range 4-5 years crack initiation period.

4.1 Roughness Age Environment Adjustment Factor

The length of the project road consists of 10 km 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 occurring annually .The roughness component due to environment is given as:

$$\Delta Rte = Kge \times R_t \qquad (1)$$

Where:

ΔRte : the change in the roughness component due to environment in the 1-year analysis time increment

Kge : the roughness age-environment calibration factor; and

R_t : 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:

$$Kge = meff / 0.023 \quad (2)$$

$$meff = m \times km \quad (3)$$

where:
meff : effective environment coefficient;
m : environment coefficient; and
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 moisture and temperature classifications have been selected for the climate zone which is appropriate to the local environment.

4.2 Cracking Initiation

Initiation of cracking and the progression of the cracking are two separate prediction models. Cracking initiation is predicted in terms of the surfacing age when first visible crack appears on the road surface. Cracking is deemed to have started at the age of the surface. HDM-4 effectively initiates cracking when 0.5% of the carriageway surface area is cracked. During the progression phase, cracking gradually spreads to cover, eventually, the entire pavement area if no treatment is applied.

4.3 Propagation

The rate cracking propagation in the analysis year is a function of cracking area, surface type and other factors such as construction, bitumen quality and climate. The adjustment factor multiplies the amount of increased area of cracking, so factor value greater than 1 accelerates the progression of cracking. For level 1 calibration, it is recommended that the factor should be taken as the inverse value of cracking initiation factor i.e.

$$Kcp = 1/Kcia \quad (4)$$

Where,
Kcpa : Crack propagation.

Default values have been considered for other calibration factors (Bennett and Paterson, 2000).

5.0 Case Study

A real case study has been considered. The project road comprises construction of 10 km new Bypass with two lane configuration expressway standard. The proposed bypass is shorter than existing road of 13 km length. Subgrade CBR has been taken as 10 %. Following Pavement compositions for new section has been recommended and presented in Table 2.

5.1 Determination: Roughness Age Environment Adjustment Factor

Recommended environmental coefficient, m value obtained from Table 7.3, HDM 4, Volume 5(Bennett and Paterson, 2000). The modifying factor of environmental coefficient for road construction and drainage effects, km, has been taken from Table 7.4 of the same HDM-4 Guideline (HDM 4, Volume 5) as 0.60. This corresponds to material quality of normal engineering standards, drainage and formation adequate for local moisture conditions, and moderately maintained. Therefore,

$$meff = m \times km = 0.025 \times 0.60 = 0.015$$

The recommended roughness-age-environmental factor, Kge is 0.65(0.015/0.023=0.65) for Level 1 calibration. The roughness-age –environmental factor, Kge for different climate zones have also been calculated and presented in Table 5.

Table 2: Pavement Compositions

Pavement Layer	Thickness(mm)
Asphalt Concrete	40
Dense Bituminous Macadam	85
Wet Mix Macadam	250
Granular Sub Base	200

Design traffic loading has been calculated and presented in Table 3.

Table 3: Design Traffic Loading

Year	Mini Bus	Stand Bus	LCV	2 Axle Truck	3 Axle Truck	MAV	MSA		
VDF	1.1	1.1	1.1	3.1	5.4	8.9	Year Wise	Cumulative	MSA/Lane
LDF	0.5	0.5	0.5	0.5	0.5	0.5			
2012	20	20	381	381	533	229			
Growth Rate	5	5	7.5	5	8.5	6.5			
2013	21	21	410	400	578	244	Construction Period		
2014	22	22	440	420	627	260			
2015	23	23	473	441	681	277	1.47		
2016	24	24	509	463	739	295	1.57		
2017	26	26	547	486	801	314	1.68	2	0.8
Growth Rate	5	5	7.5	5	8.5	6.5			
2018	27	27	588	511	870	334	1.81	3.49	0.9
2019	28	28	632	536	943	356	1.94	5.43	1.0
2020	30	30	680	563	1024	379	2.08	7.51	1.0
2021	31	31	730	591	1111	404	2.23	9.74	1.1
2022	33	33	785	621	1205	430	2.39	12.13	1.2
Growth Rate	5	5	6	5	7	5.5			
2023	34	34	832	652	1289	454	2.54	14.68	1.3
2024	36	36	882	684	1380	478	2.70	17.38	1.4
2025	38	38	935	718	1476	505	2.87	20.24	1.4
2026	40	40	991	754	1580	533	3.05	23.29	1.5
2027	42	42	1051	792	1690	562	3.24	26.53	1.6
2028	44	44	1114	832	1809	593	3.44	29.96	1.7
2029	46	46	1181	873	1935	625	3.65	33.61	1.8
2030	48	48	1252	917	2071	660	3.88	37.49	1.9
2031	51	51	1327	963	2216	696	4.12	41.62	2.1
2032	53	53	1406	1011	2371	734	4.38	46.00	2.2
2033	56	56	1491	1061	2537	775	4.65	50.65	2.3

Environmental parameters along the project road are presented in Table 4.

Table 4: Value of Environmental parameters

Environmental Parameters	Value
Temperature range	22-34^{0}C
Moisture Classification	Humid
Yearly Precipitations	1700 mm
Typical Moisture Index:	35 - 95
Moisture Classification	Humid

Table 5: Roughness Age-Environment Calibration Factor

Moisture Classification	Kge											
	Temperature Classification											
	Tropical			Tropical			Tropical			Tropical		
	Construction and Drainage			Construction and Drainage			Construction and Drainage			Construction and Drainage		
	High	Normal	Variable	High	Normal	Variable	High	Normal	Variable	High	Normal	Variable
Arid	1.30	2.17	2.83	0.26	0.43	0.57	0.54	1.09	1.41	0.87	1.74	2.26
Semi-Arid	0.26	0.43	0.57	0.42	0.70	0.90	0.76	1.52	1.98	1.30	*2.61*	*3.39*
Sub humid	0.52	0.87	1.13	0.65	1.09	1.41	1.30	2.61	3.39	2.17	4.35	5.65
Humid	0.65	1.09	1.41	0.78	1.30	1.70	2.17	4.35	5.65	4.35	8.70	11.30
Per humid	0.78	1.30	1.70									

5.2 Cracking Initiation and Propagation

All crack and wide cracking are input data but, only all cracking data were available. For level 1 calibration, crack initiation, past data was collected from local government, near the project side but they have not recorded properly. They informed that crack has been found in the rage of 4 to 5 years after construction of road. Detail methodology has already been presented in Section 3.0.

Final calibration factors adopted for economic analysis are presented in Table 6 for method 1. Flow Chart for method 2 is presented in Figure 1. Detail calculation has been presented in Annexure 1.

Table 6 Adopted Values of Major Calibration Factor

Major Calibration Factor	Adopted Value
Roughness Age Environment	0.650
Crack Initiation	0.970
Crack Propagation	1.030
Rut Depth Progression	1.000
Roughness Progression General	1.000
Potholing Progression	1.000
Ravelling Progression	1.000

Economic analysis has been carried out taking default calibration factors and level 1 calibration factors and NPV(net present value) , IRR(internal rate of return have calculated and found to be Rs (million)368.1, 422.4 and 26.5%, 27.9% respectively for method 1. Predicted cracking initiation time found using calibration factors is closed to actual time.

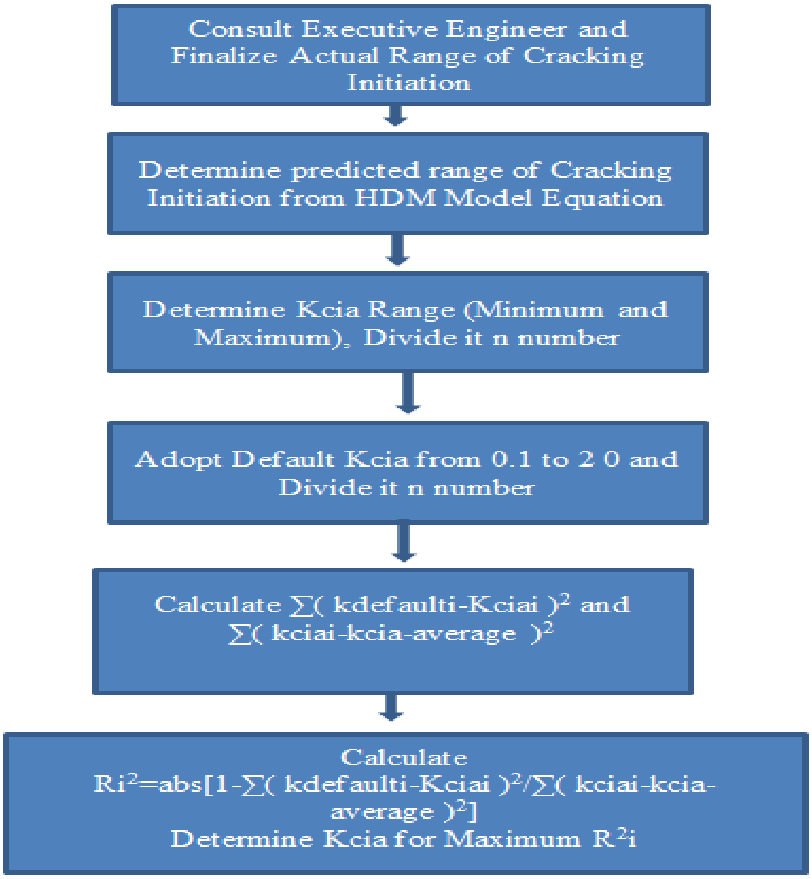

Figure 1 Methodology for Level 1 Calibration

Quality control is the most important parameter for HDM 4 analysis. Therefore, quality control should be considered and actual execution of work shall be stickily followed as per quality norms establish during execution of the work. Kcia has been calculated varying CDS from 0.25 to 1.00. Different values of Kcia have been presented in Table 7.

Table 7 Values of CDS and Kcia

C DS	Kcia
0.25	3.15
0.50	2.17
0.75	1.43
1.00	0.97

Reliability analysis of Kcia has been calculated and presented in Annexure 1.Detail calculation for method 2 is also presented in Annexure 1.

6.0 Conclusions

The process for the level 1-calibration factors have been found out using HDM 4 level 1 calibration method using model and verified using HDM 4 software. Optimized NPV and IRR values have been found using calibrated factors. Therefore, economic analysis may be carried out using actual calibration factors in place of default values. The Level 1 Calibration involved desk study and many default values have been adopted using the guidelines given in the HDM-4 Manual. The major sensitive parameters are reported in Table 4 of this paper. Actual pavement deterioration for this local project area may be determined using these calibration factors which are established for this local condition.

With the improvement in the predictive model, an appropriate maintenance budget can be forecasted more accurately and this ensures that adequate budget allocation has been provided. A well calibrated model for this local condition would reduce the possibility of future funding shortages. Level 1 calibration may be carried out easily based on few secondary data within few weeks and useful for economic analysis, prioritization and budgeting for maintenance of the road network. Two methods have been proposed for level 1 calibration. Proposed methodology mentioned in Method 2 may be useful for calibration level 2 for cases when different data are available for calibration. The proposed methodologies may be used for the determination of calibration factor to use economic analysis for feasibility study and budget purposes.

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ANNEXURE 1

Calibration equation for all cracks with granular base course is given by:

$$ICA = K_{cia}\{CDS^2 a_0 exp\ [a_1 SNP + a_2\ (YE4/SNP^2]\ + CRT\}$$

ICA = Time to initiation of all structural cracks in years;
CDS = Construction defects indicator for bituminous surfacing;
YE4 = Annual number of equivalent axle load in MSA/Lane;
SNP = Average annual structural number of the pavement in year; and
CRT = Crack retardation time due to maintenance in year.

a0, a1 and a2 values are 4.21, 0.14 and -17.1(Obtained from Table B3-4 of HDM 4, Volume Five) as reported here in.

Table A1: Determination of a0, a1 and a2 values

Pavement Type	Surface Material	HSOLD	Equ	a0	a1	a2	a3	a4
AMGB	All	0	3	4.21	0.14	-17.1		
	ALL except CM	>0	4	4.21	0.14	-17.1	30	0.025
	CM	>0	5	13.2	0	-20.1	20	1.4
AMAB	All	0	3	4.21	0.14	-17.1		
		>0	4	4.21	0.14	-17.1	30	0.025
AMAP	All	>0	4	4.21	0.14	-17.1	30	0.025
AMSB	All	0	1	1.12	0.035	0.371	-0.418	-2.87
		>0	2	1.12	0.035	0.371	-0.418	-2.87
STGB	All	0	3	13.2	0	-20.7		
	ALL except CM	>0	4	13.2	0	-20.7	20	0.22
	CM	>0	5	13.2	0	-20.7	20	1.4
STAB	All	0	3	13.2	0	-20.7		
	ALL except CM	>0	4	4.21	0.14	-17.1	20	0.12
	CM	>0	4*	4.21	0.14	-17.1	30	0.025
STAP	All	>0	4	4.21	0.14	-17.1	20	0.12
STSB	All	0	1	1.12	0.035	0.371	-0.418	-2.87
		>0	2	1.12	0.035	0.371	-0.418	-2.87

CRT can be determined using the following formula as mentioned here in.

$$CRT_{aw} = Min\left[CRT_{bw} + \frac{CRM}{YXK}, \frac{CRTMAX}{YXK}, 8 \right]$$

Where,

YXK	=	Max (YAX, 0.1)
CRT_{aw}	=	Cracking retardation time after works, in year
CRT_{bw}	=	Cracking retardation time before works, in year
CRM	=	Change in CRT due to preventive treatment
$CRTMAX$	=	Maximum limit of CRT
$YAX = YE4$	=	Annual number of equivalent axle load in MSA/Lane.

Table A2: Determination of CRM and CRTMAX values

Pavement Type	Surfacing Material	HSOLD	Rejuvenation		Fog Seal	
			CRM	CRTMAX	CRM	CRTMAX
AMGB	All	0	1.5	3	0.8	1.6
	All except CM	>0	1.5	3	0.8	0.4
	CM	>0	0.75	1.5	0.4	1.6
AMAP			1.5	3	0.8	1.6
AMSB			1.5	3	0.8	1.6
AMSB			1.5	3	0.8	1.6
STGB	All	0	3	6	1.6	3.2
		>0	1.5	3	0.8	1.6
STAB			1.5	3	0.8	1.6
STAP			1.5	3	0.8	1.6
STSB			1.5	3	0.8	1.6

SPN has been calculated based on Volume 6 of HDM 4(Section B 2). Structural number of AC and DBM has been calculated for E Value 1700 MPa using the following formula (Equ. B2.26, HDM Volume 6) and calculated at 0.34.

‘$a1=0.412\times log_{10}(1700/1000)+0.246=0.34.$

E values of base and sub base are considered 200 MPa and 100 MPa respectively.

Therefore,

‘$a2=0.249\times log_{10}(200-0.439=0.134.$

$a1=0.229\times log_{10}(100)-0.348=0.106.$

Structural number for subgrade has been determined using following equation:

$SNSG=3.5[Log_{10}(10)]-0.85\{log_{10}(10)\}^2-1.43=1.22$

AC=40 mm, DBM=85 mm, Base=250 mm and GSB=200 mm.

$SNP_{dry}=[(40+85)\times0.34+250\times0.134+200\times0.106]/25+1.22=5.1.$

There will some loss of strength due to formation crack of 0.5% of the carriageway and reduced structural number will be 4.91 which is calculated based on reduced structural number of AC and DBM equal to 0 .3.

Design Traffic per lane has been calculated and presented in Table A1. HDM predicted year for crack initiation has been calculated using following values:

Table A3: HDM predicted year for crack initiation

CDS	1
Kcia default	1
a0	4.21
a1	0.14
a2	-17.1
YE4	1.11
SNP	4.91
CRT	1.35
Actual Year	5
Predicted Year	5.15
Kcia	0.97
Yax	1.11
CRTbw	0
CRM	1.5
CRTMAX	3
CRT	1.35

The same problem has been solved using Kcia=0.97 and predicted year using HDM Model equation has been found as 5-years which coincides with the actual value. Crack propagation value is 1.03(1/0.97). The variation of Kcia with respect to CDS has been calculated and presented in Fig. A1. From this figure, it is noticed that due to poor construction quality, initiation of crack increases firstly. Quality control is the most important parameter for HDM 4 analysis. Therefore, quality control should be considered and actual execution of work shall be strictly followed as per quality norms establish during execution of the work.

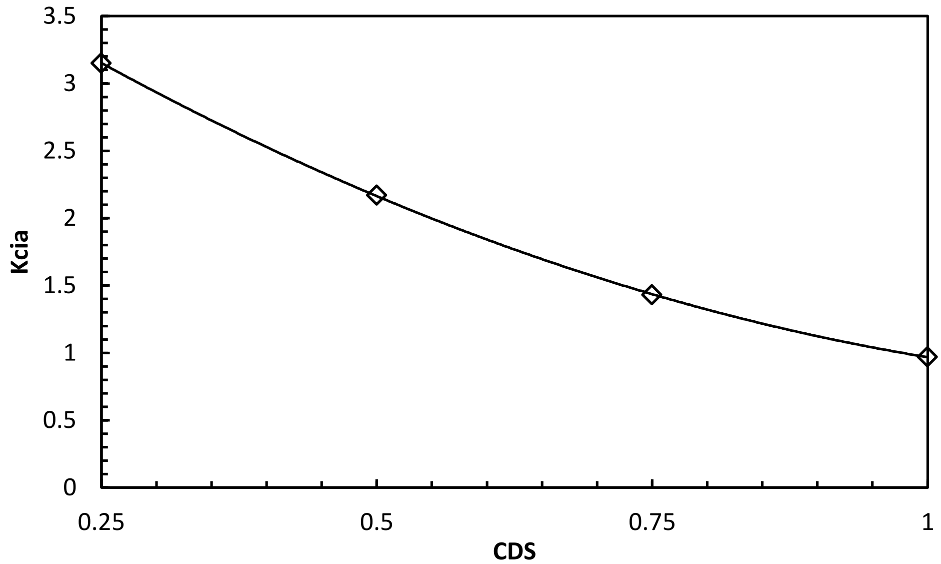

Figure A1: Variation of Kcia vs. C D S

Mean and standard deviation of Kcia are 1.93 and 0.95 respectively with coefficient of variation 0.49. Generated normal value of Kcia is set at value of 1.7.

Calibration Factor for Method 2

Crack initiation varies from 4 to 5 years. Based on this assumption two values of kcia were determined which varies from 0.79 to 0.93. These two values have been interpolated as presented here in. Default k values are taken 0.1 and 20. These two values are also divided in 100 interpolations and presented here in. Final K value has been determined based on the methodology as presented in flow chart 2. Detail calibration calculation is shown in Table A4 and calibration factor, kcia is 0.859 for first step and final value is 0.864 after further tuning. Therefore, Kcia=0.864, Kcpa=1.157. Excel Sheet developed to find out calibration factor and presented here in.

Table A4: Excel Data Sheet for Determination of Calibration Factor for Proposed Method 2.

Sl No	K1	K2	$(k1-k2)^2$	$\sum(k1-k2)^2$	$(k1i-1av)^2$	$\sum (k1i-k1av)^2$	$Abs(R^2)$
1	0.930	20.000	363.665	363.665	0.005	0.005	74216.327
2	0.929	19.801	356.167	719.832	0.005	0.010	152960.857
3	0.927	19.602	348.748	1068.581	0.005	0.014	236628.406
4	0.926	19.403	341.407	1409.987	0.004	0.018	325658.283
5	0.924	19.204	334.144	1744.131	0.004	0.023	420539.111
6	0.923	19.005	326.959	2071.090	0.004	0.027	521815.568
7	0.922	18.806	319.852	2390.942	0.004	0.030	630096.223
8	0.920	18.607	312.823	2703.765	0.004	0.034	746062.679
9	0.919	18.408	305.872	3009.637	0.003	0.037	870480.261
10	0.917	18.209	298.999	3308.636	0.003	0.041	1004210.585
11	0.916	18.010	292.205	3600.841	0.003	0.044	1148226.359
12	0.915	17.811	285.488	3886.329	0.003	0.047	1303628.906
13	0.913	17.612	278.850	4165.179	0.003	0.050	1471668.983
14	0.912	17.413	272.290	4437.469	0.003	0.052	1653771.623
15	0.910	17.214	265.807	4703.276	0.003	0.055	1851565.920
16	0.909	17.015	259.403	4962.679	0.002	0.057	2066920.892
17	0.908	16.816	253.077	5215.757	0.002	0.060	2301988.908
18	0.906	16.617	246.829	5462.586	0.002	0.062	2559258.520
19	0.905	16.418	240.659	5703.245	0.002	0.064	2841619.129
20	0.903	16.219	234.568	5937.813	0.002	0.066	3152440.583
21	0.902	16.020	228.554	6166.367	0.002	0.067	3495671.784
22	0.901	15.821	222.618	6388.985	0.002	0.069	3875963.672
23	0.899	15.622	216.761	6605.746	0.002	0.071	4298823.687
24	0.898	15.423	210.981	6816.727	0.001	0.072	4770811.269
25	0.896	15.224	205.280	7022.008	0.001	0.073	5299787.314
26	0.895	15.025	199.657	7221.664	0.001	0.075	5895235.264
27	0.894	14.826	194.112	7415.776	0.001	0.076	6568678.310
28	0.892	14.627	188.645	7604.421	0.001	0.077	7334226.967

Sl No	K1	K2	$(k1\text{-}k2)^2$	$\sum(k1\text{-}k2)^2$	$(k1i\text{-}1av)^2$	$\sum(k1i\text{-}k1av)^2$	Abs(R^2)
29	0.891	14.428	183.256	7787.677	0.001	0.078	8209305.701
30	0.889	14.229	177.945	7965.622	0.001	0.079	9215628.641
31	0.888	14.030	172.712	8138.334	0.001	0.079	10380526.807
32	0.887	13.831	167.557	8305.891	0.001	0.080	11738779.163
33	0.885	13.632	162.481	8468.372	0.001	0.081	13335178.205
34	0.884	13.433	157.482	8625.855	0.001	0.081	15228186.669
35	0.882	13.234	152.562	8778.417	0.001	0.082	17495249.011
36	0.881	13.035	147.720	8926.136	0.000	0.082	20240671.022
37	0.880	12.836	142.956	9069.092	0.000	0.083	23607589.229
38	0.878	12.637	138.269	9207.361	0.000	0.083	27796645.661
39	0.877	12.438	133.661	9341.023	0.000	0.083	33096025.734
40	0.875	12.239	129.131	9470.154	0.000	0.083	39931496.683
41	0.874	12.040	124.680	9594.834	0.000	0.084	48953231.380
42	0.873	11.841	120.306	9715.139	0.000	0.084	61193872.425
43	0.871	11.642	116.010	9831.149	0.000	0.084	78373320.728
44	0.870	11.443	111.793	9942.942	0.000	0.084	103529174.717
45	0.868	11.244	107.653	10050.595	0.000	0.084	142440405.905
46	0.867	11.045	103.592	10154.187	0.000	0.084	207228300.943
47	0.866	10.846	99.608	10253.795	0.000	0.084	326970508.546
48	0.864	10.647	95.703	10349.498	0.000	0.084	586706254.964
49	0.863	10.448	91.876	10441.374	0.000	0.084	1331807960.000
50	0.861	10.249	88.127	10529.501	0.000	0.084	5372194615.327
51	0.860	10.050	84.456	10613.958	0.000	0.084	
52	0.859	9.851	80.863	10694.821	0.000	0.084	5456541226.428
53	0.857	9.652	77.349	10772.169	0.000	0.084	1374001186.857
54	0.856	9.453	73.912	10846.081	0.000	0.084	614857207.653
55	0.854	9.254	70.553	10916.634	0.000	0.084	348106964.587
56	0.853	9.055	67.273	10983.907	0.000	0.084	224161371.343
57	0.852	8.856	64.070	11047.978	0.000	0.084	156575646.168
58	0.850	8.657	60.946	11108.924	0.000	0.084	115669759.416

Sl No	K1	K2	$(k1-k2)^2$	$\sum(k1-k2)^2$	$(k1i-1av)^2$	$\sum (k1i-k1av)^2$	$Abs(R^2)$
59	0.849	8.458	57.900	11166.824	0.000	0.085	89021233.973
60	0.847	8.259	54.932	11221.756	0.000	0.085	70683770.287
61	0.846	8.060	52.042	11273.797	0.000	0.085	57519373.110
62	0.845	7.861	49.230	11323.027	0.000	0.085	47744252.645
63	0.843	7.662	46.496	11369.523	0.000	0.085	40283173.702
64	0.842	7.463	43.840	11413.364	0.000	0.086	34456476.229
65	0.840	7.264	41.263	11454.626	0.000	0.086	29817330.722
66	0.839	7.065	38.763	11493.389	0.000	0.087	26062106.098
67	0.838	6.866	36.342	11529.731	0.001	0.087	22978576.083
68	0.836	6.667	33.998	11563.729	0.001	0.088	20414745.603
69	0.835	6.468	31.733	11595.462	0.001	0.088	18259418.891
70	0.833	6.269	29.546	11625.008	0.001	0.089	16429712.035
71	0.832	6.070	27.437	11652.444	0.001	0.090	14862810.734
72	0.831	5.871	25.406	11677.850	0.001	0.091	13510399.795
73	0.829	5.672	23.453	11701.303	0.001	0.092	12334818.050
74	0.828	5.473	21.578	11722.881	0.001	0.093	11306353.526
75	0.826	5.274	19.781	11742.662	0.001	0.094	10401307.968
76	0.825	5.075	18.063	11760.724	0.001	0.095	9600590.242
77	0.824	4.876	16.422	11777.146	0.001	0.096	8888679.577
78	0.822	4.677	14.859	11792.006	0.001	0.098	8252851.454
79	0.821	4.478	13.375	11805.381	0.002	0.099	7682592.719
80	0.819	4.279	11.969	11817.350	0.002	0.101	7169154.794
81	0.818	4.080	10.641	11827.990	0.002	0.103	6705208.914
82	0.817	3.881	9.391	11837.381	0.002	0.105	6284577.583
83	0.815	3.682	8.219	11845.599	0.002	0.107	5902023.563
84	0.814	3.483	7.125	11852.724	0.002	0.109	5553082.716
85	0.812	3.284	6.109	11858.833	0.002	0.111	5233930.579
86	0.811	3.085	5.171	11864.004	0.002	0.113	4941275.089
87	0.810	2.886	4.311	11868.315	0.003	0.116	4672269.773
88	0.808	2.687	3.530	11871.845	0.003	0.119	4424443.036

Sl No	K1	K2	$(k1-k2)^2$	$\sum(k1-k2)^2$	$(k1i-1av)^2$	$\sum(k1i-k1av)^2$	$Abs(R^2)$
89	0.807	2.488	2.826	11874.672	0.003	0.121	4195640.235
90	0.805	2.289	2.201	11876.873	0.003	0.124	3983975.948
91	0.804	2.090	1.654	11878.527	0.003	0.128	3787794.445
92	0.803	1.891	1.185	11879.711	0.003	0.131	3605636.779
93	0.801	1.692	0.794	11880.505	0.003	0.134	3436213.267
94	0.800	1.493	0.481	11880.985	0.004	0.138	3278380.359
95	0.798	1.294	0.246	11881.231	0.004	0.142	3131121.133
96	0.797	1.095	0.089	11881.320	0.004	0.146	2993528.756
97	0.796	0.896	0.010	11881.330	0.004	0.150	2864792.431
98	0.794	0.697	0.009	11881.339	0.004	0.154	2744185.383
99	0.793	0.498	0.087	11881.426	0.005	0.159	2631054.582
100	0.791	0.299	0.242	11881.668	0.005	0.163	2524811.896
101	0.790	0.100	0.476	11882.145	0.005	0.168	2424926.469