International Journal of Innovative Research in Engineering and Management (IJIREM)
ISSN (Online): 2350-0557, Volume-10, Issue-4, August, 2023
https://doi.org/10.55524/ijirem.2023.10.4.8
Article ID IJIRD-1269, Pages 68-76
www.ijirem.org

Urban Roads Health Monitoring with HDM-4 Software for the Development of a Road Maintenance Management System

Ritakshi[1], and Ashish Kumar[2]

[1]M.Tech. Scholar, Department of Civil Engineering, RIMT University, Mandi Gobindgarh, Punjab, India
[2]Assistant Professor, Department of Civil Engineering, RIMT University, Mandi Gobindgarh, Punjab, India

Correspondence should be addressed to Ritakshi; ritakshiagastya@gmail.com

ABSTRACT- The aim of the study describes the adaptation of World Bank's Highway Development and Management commonly known as (HDM-4) for calibration of HDM-4 pavement deterioration models for selected pavement sections w.r.t local conditions over time with traffic. For this study road condition surveys along with different distresses measurement was done for 16 urban road sections in Patiala City and base data, structural & functional evaluation is performed on two stretches. It includes, Optimum Maintenance and Rehabilitation (M&R) Strategy along with Prioritization for all the selected road sections.

KEYWORDS- RMMS, HDM-4 Model, HDM-4 distress model calibration, validation of calibrated HDM-4 Model.

I. INTRODUCTION

A. General

Road transport is the most cost effective modes of transportation in India both for freight and passengers, keeping in view its level of penetration in populated areas. The Highway Development and Management System (HDM-4) developed by the World Bank is a powerful pavement management software tool capable of performing technical and economic appraisals of road projects, investigating 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 scope of the new HDM-4 tool has been broadened considerably beyond traditional project appraisals, to provide a powerful system for the analysis of road management and investment alternatives. In addition to updating the HDM-III technical relationships for vehicle operating costs, and pavement deterioration for flexible and unsealed pavements, new technical relationships have been introduced to model rigid concrete pavement deterioration, accident costs, traffic congestion, energy consumption and environmental effects. Road maintenance management system (RMMS) is a HDM-4 based pavement management tool which serves as an appraisal system for assessing the impacts of various maintenance and rehabilitation strategies on pavement service life and gives cost effective decisions.

The main objectives of this study:

- Extensive Literature review on past research developments related to scientific approach behind development of road management system in India.
- Collection of road network data for the selected national highways network including road inventory data, traffic volume data, and pavement distress survey data required for generating HDM-4 model from various publications.

II. LITERATURE REVIEW

Aggarwal et al. [1] used the HDM-4 model to design the Pavement Management System (PMS) for the Indian National Highway network. Five National Highways were chosen for the study, with a total length of 310 kilometers, inside the boundaries of Dehradun and Hardwar districts of Uttara hand and Saharanpur and Muzaffarpur districts of Uttar Pradesh. HDM-4 deterioration models were calibrated for Indian conditions using data acquired from road sections. The ideal M&R approach as well as the optimum Improvement strategy for the road section was discovered using Project Analysis in HDM-4, based on a superior NPV/Cost ratio. The remaining service life of each road section was calculated without the use of an M&R plan during the interim. The implementation of condition responsive maintenance methods as compared to scheduled type maintenance strategies resulted in a savings of more than 33 percent in highway agency costs during a 20-year review period. Under the auspices of Programme Analysis, a 10-year unconstrained work Programme for the entire network was drafted.

Kerali et al. [2] presented an overview of Highway Development and Management software (HDM-4). The World Bank developed HDM-4, which is the successor to the Highway Design and Maintenance Standards Model (HDM-III), to provide a standardized systems approach to road management with easily adaptable and user-friendly software tools. HDM-4 was created with the goal of presenting a powerful and methodical methodology for analysing road management and investment options. Additional features, such as models for rigid concrete pavement deterioration, vehicle operating costs, accident costs, traffic congestion impacts, cold climatic effects, a broader range of pavement types and structures, road safety, and environmental effects, were introduced in HDM-04. The HDM-4 includes three specific application tools for project level analysis, road work programming under budget constraints, and long-term network performance and cost planning. HDM-4 now has the ability to export and import data.

Mohit Mantrao [3] carried out a study on 9 urban road networks in the city of Patiala. This study presents the application of HDM-4 for the economic analysis of alternative maintenance and rehabilitation strategies for individual pavement sections. The main purpose of this case study is to assess the economic benefits arising out of investing in maintenance and rehabilitation of a pavement section at the appropriate time, as compared against carrying out minimum routine maintenance annually. Applicable rehabilitation activities, and the corresponding intervention levels are defined, and the timing of selected M&R activities are determined. He conducted functional evaluation on the selected road networks and generated maintenance strategies. In this study all alternative is compared to each other on economic analysis. The alternative 2 which comprises of providing 25 mm SDBC has been found as the optimum pavement maintenance management strategy.

Sanjay Deori et al. [4] carried out a study to calculate calibration of inbuilt distress models of Highway Development and Management (HDM-4) tool for Indian conditions and then Validation of calibration factors through similar pavement layer composition with different traffic scenario for different environmental and climatic zones of India by considering 23 sections on a NHDP Road project and Determination of realistic and logical calibration factors for different inbuilt distress models in HDM-4 where modified bituminous mixes are used in surface course and they concluded that the selected test sections in this study cover almost entire country from east to west and north to south including the variations in climatic and environmental conditions, traffic loading and the prevailing pavement layer compositions. It can be adopted for other high-speed corridors, viz. national highways of the country based on climatic conditions.

Chopra T. et al. [5] developed pavement distress model using HDM-4 program and calibrated it to the local conditions of Patiala city having 4 urban road sections. Majority of road sections are two lanes with pavement width ranging from 6m to 9m. Various road maintenance works have been proposed and assigned to road network to predict the effect of road works on progression of pavement distresses with time. Most favourable road maintenance strategy has been determined by comparing the economic benefits of various work alternatives in terms of cost benefits to road users and road agencies. On the basis of economic index of NPV and IRR it has been concluded condition responsive M&R strategy is far more economical than scheduled M&R strategy and hence is preferable in case of budget constraint.

III. SELECTION OF ROAD NETWORK

The prime most objective of this study is the identification of the road network for which the RMMS has to be developed. So for this study, we have selected 16 Urban Roads in Patiala City

The prime most objective of this study is the identification of the calibration factor, their validation and to develop RMMS for the selected road network. So for calibration & validation, we have selected 16 Urban Roads in Patiala City and base data, structural & functional evaluation is performed on two stretches as listed below in Table 1 which shows the link id and the name of the road section.

Table 1: Selected Road Network

Section ID	Link Name
PR_04	Secretariat Road
PR_13	Polo Ground Road

For determination of the calibration factors of distress and their validation six stretches was considered and for PR_04 and PR_13 RMMS study is carried out. Google map of both the road sections is shown in Figure 1 and Figure 2 with section id.

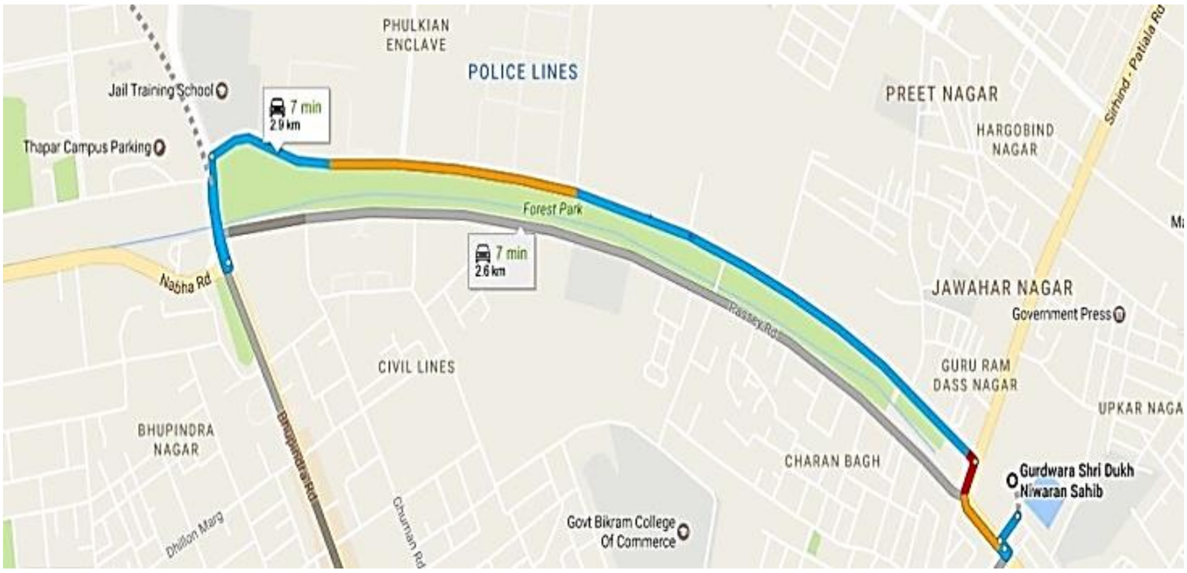


Figure 1: Secretariat Road (PR_04)

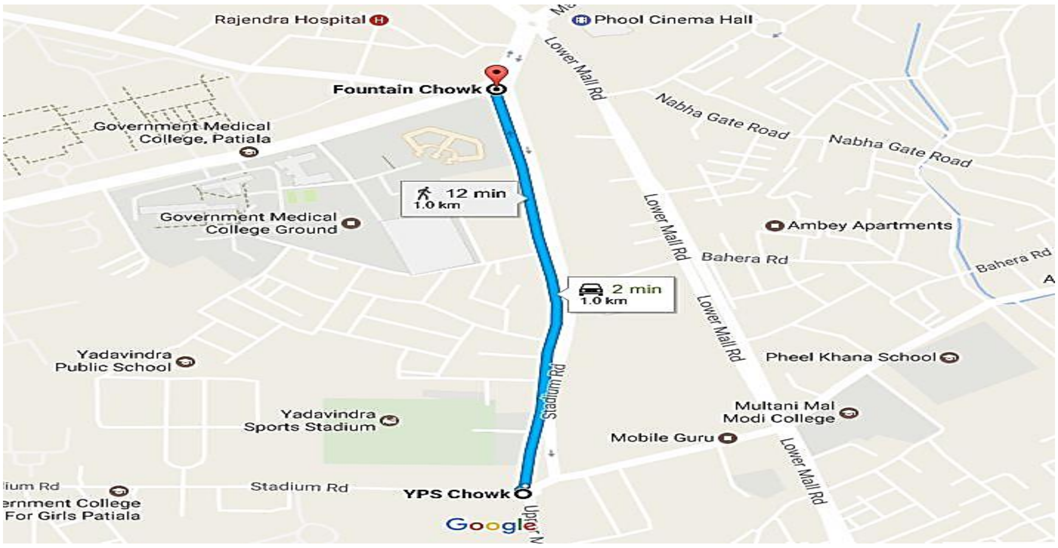


Figure 2: Polo Ground Road (PR_13)

A. *Statistical Data of Traffic*

- Secretariat Road
- Length in K.M. =2.25
- Right of Way (in meter) = 27.43
- Width of Carriageway (in meter) = 7.30
- Divided/ Undivided = Divided

B. *Polo Ground Road*

- Length in K.M. =2.25
- Right of Way (in meter) = 29.30
- Width of Carriageway (in meter) = 10
- Divided/ Undivided = Divided

C. *Vehicular Composition*

- Secretariat Road
- Cycle = 404 (25.4%)
- Rickshaw/ Rehri = 92 (5.8%)
- Scooter/M-Cycle = 548 (34.4%)
- Car/Jeep/Auto = 347 (21.8%)
- Bus/Truck/Tractor/Trolly = 196 (12.3%)
- Cart = 5 (0.3%) Total = 1592 (100%)

D. *Polo Ground Road*

- Cycle = 464 (19%)
- Rickshaw/ Rehri = 358 (14.5%)
- Scooter/M-Cycle = 722 (29%)
- Car/Jeep/Auto = 878 (35.6%)
- Bus/Truck/Tractor/Trolly = 34 (1.4%)
- Cart = 12 (0.5%) Total = 2468 (100%)

IV. CALIBRATION OF HDM-4

The calibration factors of inbuilt HDM-4 road deterioration models have been calculated for different pavement compositions by using Standard equations of HDM-4, this is 3rd level Calibration of the distress parameters and the equations used for calculation of Calibration factors are listed below:

- Calibration Equations

A. *Cracking Progression (For AC surfacing)*

dACA = Kcpa (CRP/CDS) [(1.84 * 0.45 * δtA+ SCA0.45)1/0.45 - SCA]

B. *Ravelling Progression (For PC surfacing)*

$$dARV = Kvp(1/RRF)(1/CDS^2)[(0.6 + 3.0 * YAX) * 0.352 * \delta tv + SRV^{0.35})^{1/0.35} - SRV]$$

C. *Potholing Progression (For PC surfacing)*

$$dNPTi = Kpp * ADISi[\frac{(1\ 1*CDB)(1\ 10*YAX)(1\ 0.005*MMP)}{(1\ 0.08*HS)}]$$

D. *Roughness Progression (For AC surfacing)*

$$\Delta IRI = Kgp(134\, e^{mt}(SNCK - 1)1^{-5}YE4 + 0.114(RDSb - RDSa) + 0.0066\Delta CRX + 0.42\Delta POT) + mIRIa$$

For determining the calibration factors for Cracking (Kcpa), Ravelling (Kvp) and Potholling (Kpp), data of 16 stretches of Patiala city were considered and their distresses values are taken from the Literature. Calculated calibration factors of cracking for all the 16 road sections are given in Table 2.

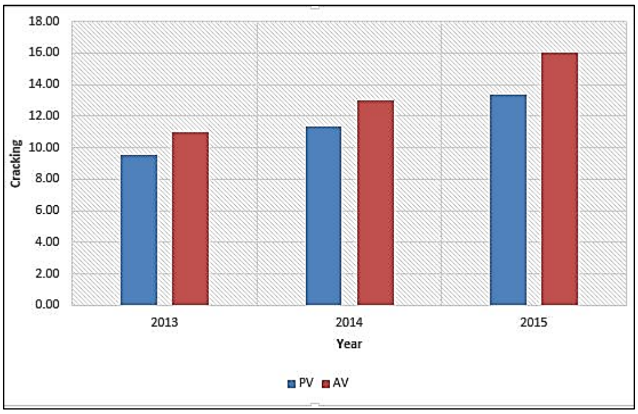
Table 2: Calculation of Kcpa

Section	dACA	K_{cpa}	CRP	CDS	Δt_A	SCA
PR01	3	0.603	0.82	1	1	6
PR02	2	0.351	0.82	1	1	8
PR03	2	0.402	0.82	1	1	6
PR04	2	0.484	0.82	1	1	4
PR05	2	0.351	0.82	1	1	8
PR06	2	0.484	0.82	1	1	4
PR07	1	0.166	0.82	1	1	9
PR08	3	0.656	0.82	1	1	5
PR09	3	0.434	0.82	1	1	12
PR10	1	0.176	0.82	1	1	8
PR11	1	0.201	0.82	1	1	6
PR12	1	0.187	0.82	1	1	7
PR13	3	0.453	0.82	1	1	11
PR14	2.8	0.612	0.82	1	1	5
PR15	2.15	0.432	0.82	1	1	6
PR16	2	0.437	0.82	1	1	5

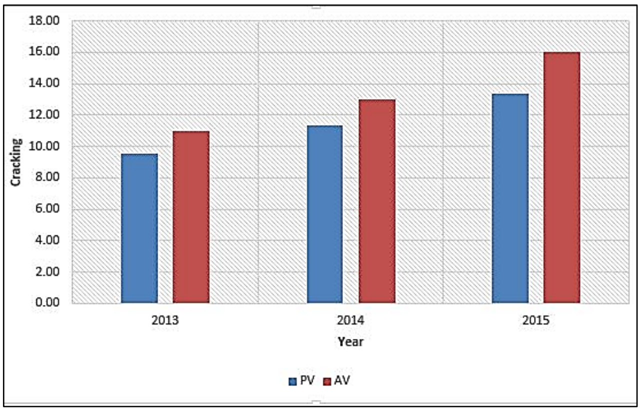
E. *Comparison for Cracking*

The following graphs shows a comparison of observed and predicted values of cracking at different period of time and at varying calibration of cracking only (0.2, 0.4, 0.6, 0.8, 1, 1.2).

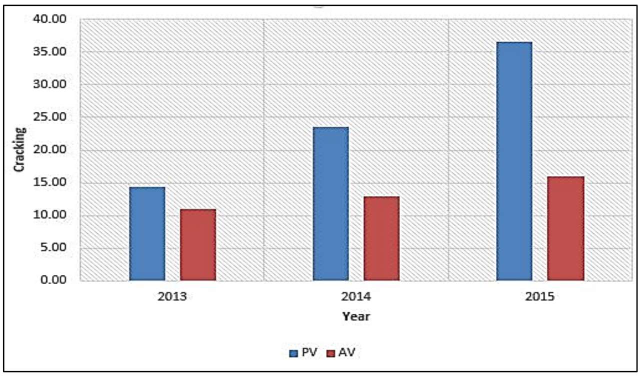
At Calibration 0.2



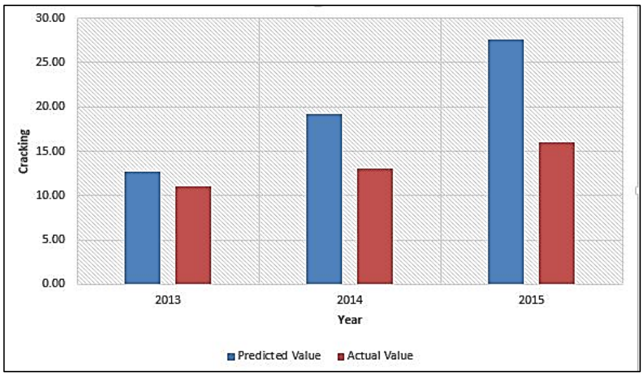
At Calibration 0.4



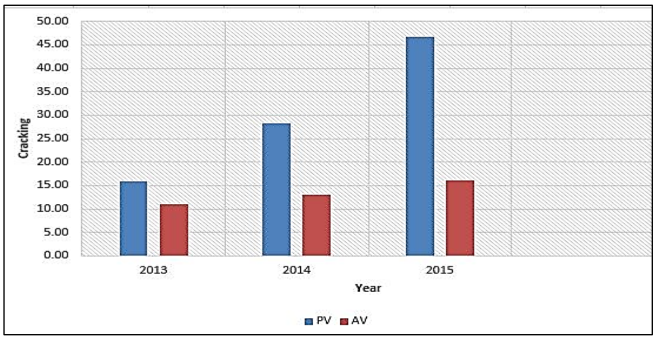
At Calibration 0.6



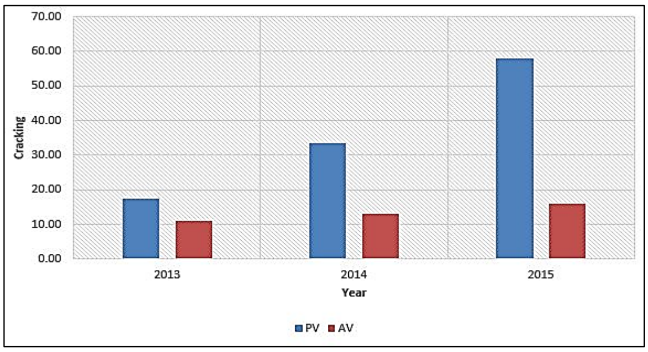
At Calibration 0.8



At Calibration 1.0



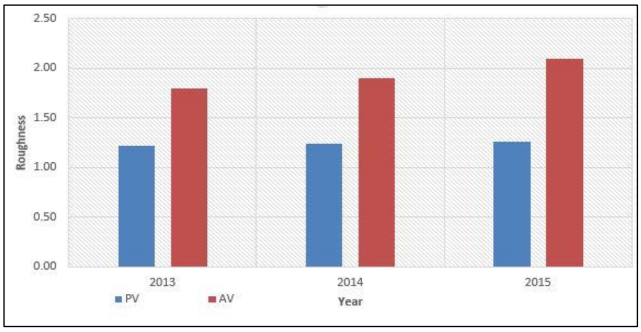
At Calibration 1.2



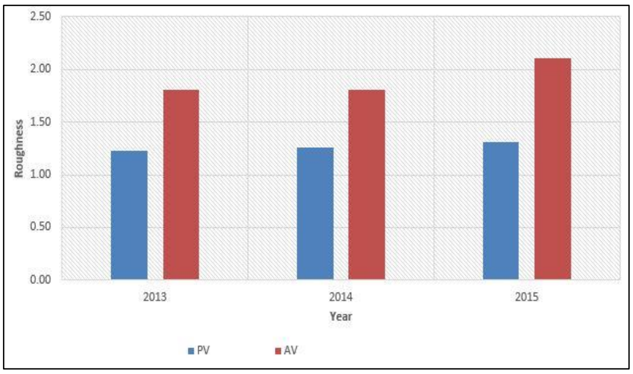
F. *Comparison for Roughness*

The following graph shows a comparison of observed and predicted values of roughness at different time period and at different calibration of roughness only (0.2, 0.4, 0.6, 0.8, 1, and 1.2). For roughness progression model calibration factor 0.8 gives quite accurate and comparable results for a particular road section and the percentage validation is 83.3%.

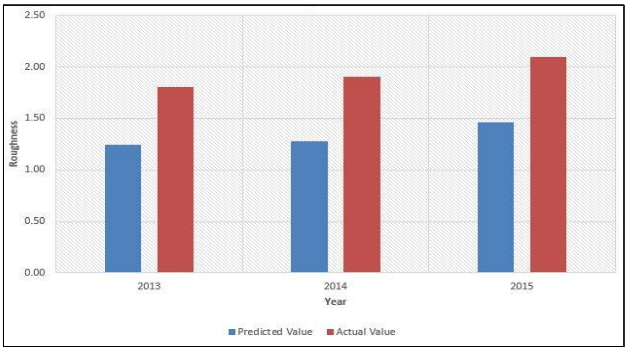
At Calibration 0.2



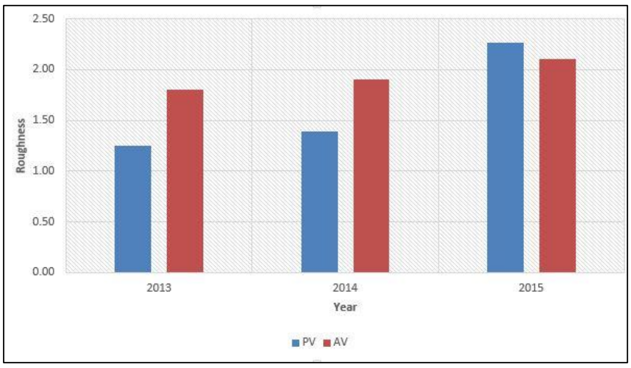
At Calibration 0.4



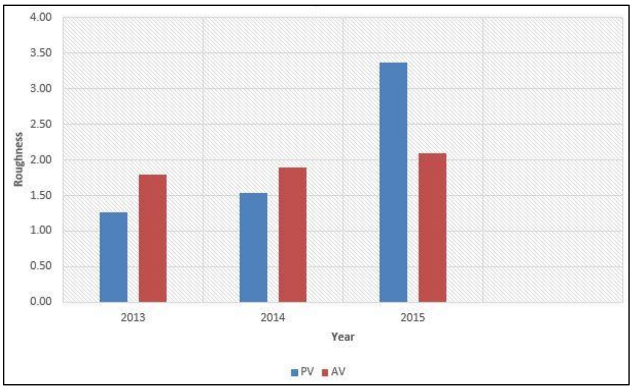
At Calibration 0.6



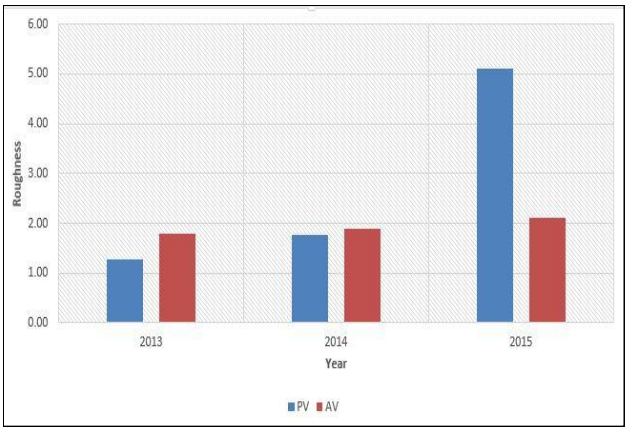
At Calibration 0.8



At Calibration 1.0



At Calibration 1.2



G. *Calculation of Calibration factor of Roughness (Kgp) and Cracking (Kcpa)*

(4) Following steps were adopted for calibration of HDM-4 road deterioration models:

- For calibration of surface distress initiation, the coefficient between the observed age years of pavement surface distress occurrence after construction to the age years of surface distress occurrence as predicted by the un-calibrated HDM-4 models have been determined for all the selected pavement sections.
- In the case of calibration of the distress progression, the HDM-4 software was run for all the selected sections with road network and vehicle fleet input data. Calibration factors were determined from the results of first run corresponding to minimum RMSE and maximum R^2 calculated using following Equations

$$RMSE = \sqrt{\sum_{i=1}^{n} (O_i - p_i)^2 / n}$$

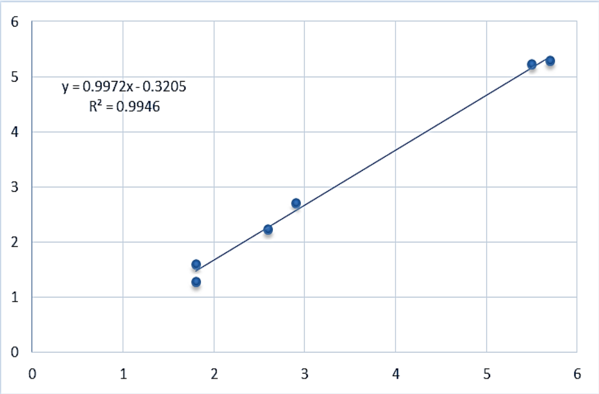
$$R^2 = 1 - \left[\sum \left((O_i - p_i)^2 / \left(O_i - O_{avg} \right)^2 \right) \right]$$

Where RMSE = root-mean-square error, R2 = goodness-of-fit measure (coefficient of determination), Oi = observed value of distress observation i, pi = predicted value of distress observation i, Oavg = average value of distress observations, n = no. of observations. Calculation of roughness calibration factors for various six road sections is shown in Table 3.

Table 3: Calculation of Calibration factor for Roughness

Calibration Factor	PR_01		PR_02		PR_04		PR_05		PR_08		PR_13	
	O_i	p_i	O_i	p_i	O_i	p_i	O_i	p_i	O_i	p_i	O_i	p_i
0.2	1.8	1.52	2.9	2.63	1.8	1.22	2.6	2.13	5.5	5.16	5.7	5.16
0.4	1.8	1.53	2.9	2.64	1.8	1.23	2.6	2.14	5.5	5.17	5.7	5.18
0.6	1.8	1.55	2.9	2.66	1.8	1.24	2.6	2.16	5.5	5.18	5.7	5.2
0.8	1.8	1.56	2.9	2.67	1.8	1.25	2.6	2.18	5.5	5.19	5.7	5.22
1	1.8	1.58	2.9	2.69	1.8	1.26	2.6	2.2	5.5	5.21	5.7	5.25
1.2	1.8	1.6	2.9	2.71	1.8	1.28	2.6	2.23	5.5	5.22	5.7	5.28

Six stretches were analyzed for year 2013 and we found that at calibration 1.2 calculated RMSE value is 0.351 which is minimum of all the calibration factors and corresponding R2 is maximum i.e. 0.994608 therefore we adopt coefficient of calibration for roughness (Kgpa) as 1.2.

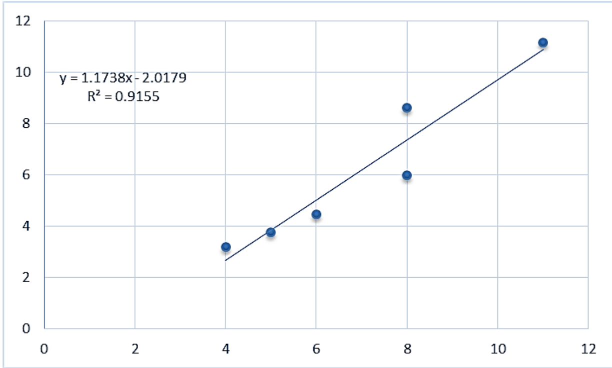


Calculation of cracking calibration factors for various six road sections is shown in Table 4.

Table 4: Calculation of Calibration factor for Cracking

Calibration Factor	PR_01		PR_02		PR_04		PR_05		PR_08		PR_13	
	O_i	p_i	O_i	p_i	O_i	p_i	O_i	p_i	O_i	p_i	O_i	p_i
0.2	6	3.64	8	4.99	4	2.56	8	7.3	5	2.64	11	9.57
0.4	6	4.47	8	5.99	4	3.2	8	8.6	5	3.78	11	11.15
0.6	6	5.3	8	6.99	4	3.84	8	9.91	5	3.92	11	12.72
0.8	6	6.12	8	7.98	4	4.48	8	11.21	5	4.56	11	14.3
1	6	6.95	8	8.98	4	5.12	8	12.51	5	5.2	11	15.87
1.2	6	7.78	8	9.98	4	5.76	8	13.81	5	5.83	11	17.45

For this study we found that at calibration 0.4 calculated RMSE value is 1.217 which is minimum of all the calibration factors and corresponding R2 is maximum i.e. 0.915486, which is closer to the calibration factor calculated for cracking (0.402) by using standard HDM-4 distress equation of Cracking, therefore we adopt coefficient of calibration for roughness (Kcpa) as 0.402.



V. APPLICATION OF HDM-4 FOR OPTIMUM MAINTENANCE STRATEGIES

A. *Data incorporation to HDM-4*

The input data for this study is included in the 'Patiala Urban Road Network', 'Patiala Urban Vehicle Fleet', and 'Maintenance and Rehabilitation works Standards' databases as defined in various sections. The input details are shown in Figure 3. The pavement section PR_01, PR_02, PR_04, PR_05, PR_08 and PR_13 are identified urban Road Network has been selected for this study as shown in Figure 4 but we are concerned with two stretches PR_04 and PR_13 only.

As in India there is mixed traffic and vehicular composition is shown in Figure 5.

The total traffic on the identified pavement section is taken in terms of AADT. Initial composition of various representative vehicles in the vehicle fleet, and the annual growth rate of each type of vehicles for the selected pavement section, is shown in Figure 6.

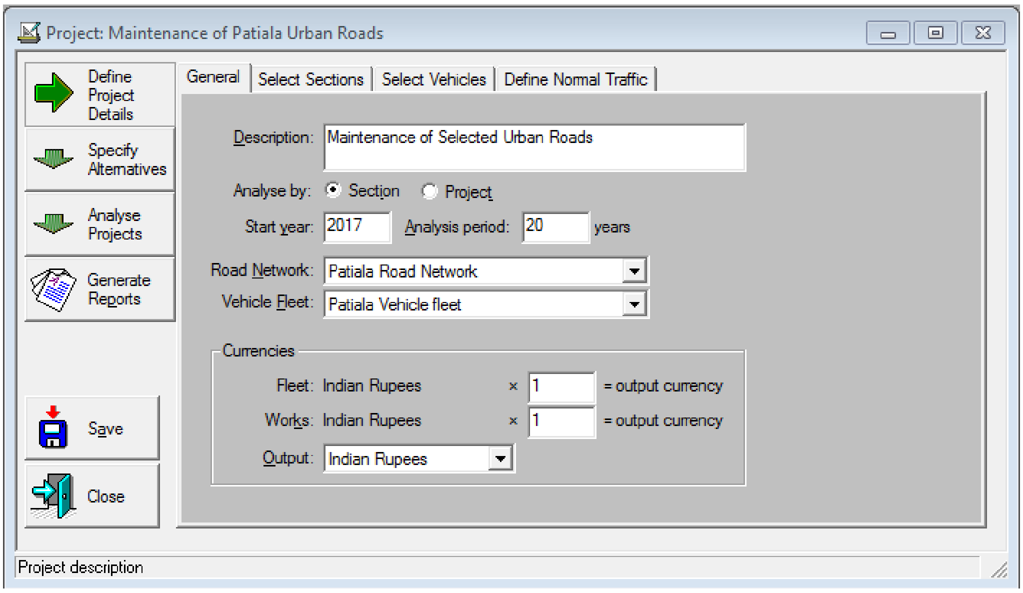


Figure 3: Input details for project analysis

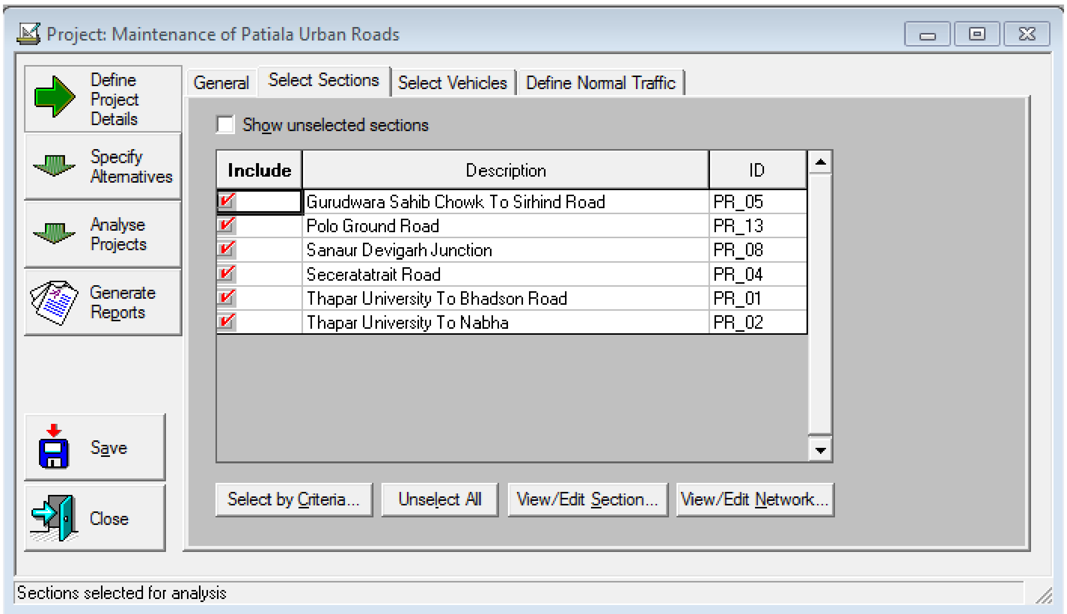


Figure 4: Selected Road Sections

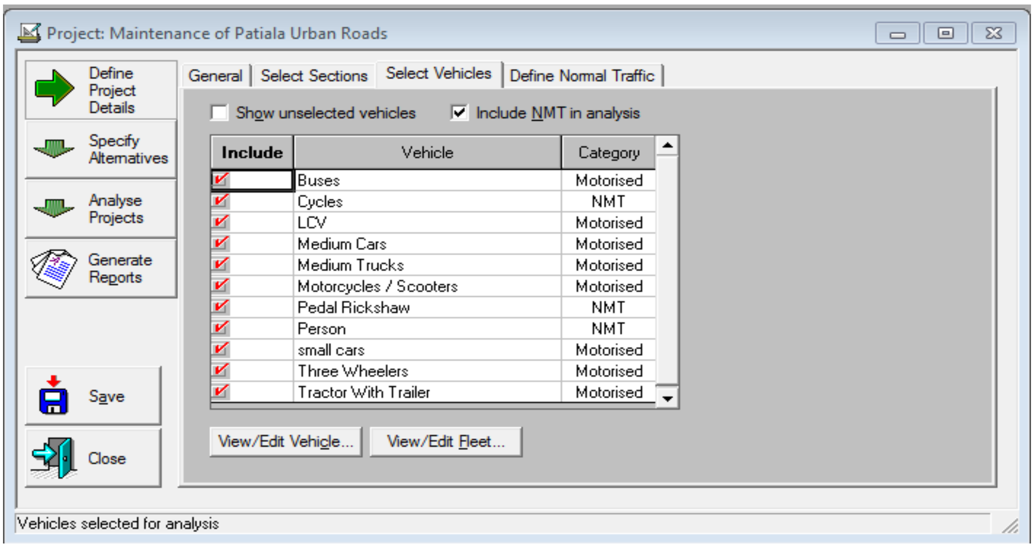


Figure 5: Composition of Vehicles

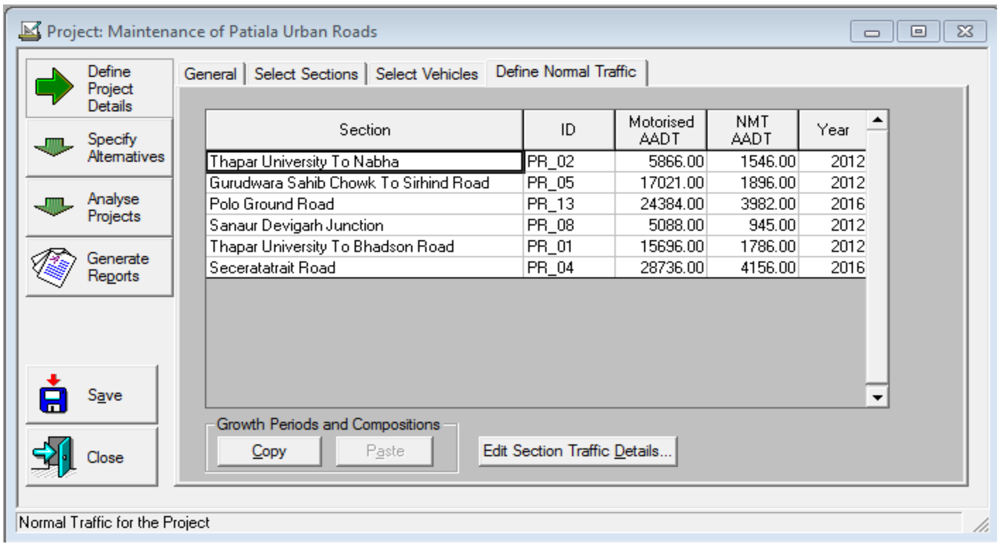


Figure 6: Road Section with traffic

B. Project Analysis

The HDM-4 Project Analysis is carried out for the selected pavement section at two different values of calibration i.e. default and with the calculated calibration factors. During set up of the project analysis, all the alternatives were compared with respect to routine and base alternatives. The pavement deterioration readings for all M&R strategies were generated for the analysis period of 20 years from 2017-2036.

- The pavement deterioration of the section PR_13 (Polo Ground Road) and for PR_04 (Secretariat Road Road) with calculated set of progression calibration Kcpa= 0.402, Kgp= 1.2, Kpp = 0.323, Kvp = 0.540 are analyzed under alternative M&R strategies over the analysis period of 20 years. The behavior of all the distresses was plotted as per their respective deterioration models incorporated in HDM-4 as shown in Figure 7 & Figure 8.
- The progression of Average Roughness of Polo Ground Road with due respect of time up to 20 years is shown in Figure 7 and the graph also shows the dip in the Roughness value after each and every M&R strategy

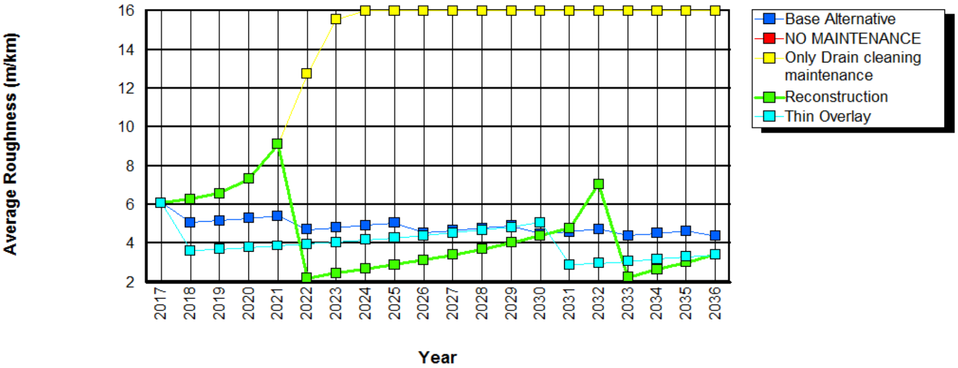


Figure 7: Polo Ground Road

For the Polo ground road when only side drain cleaning (scheduled activity) is done there is continuous increase in deterioration of the pavement and the roughness value approaches to 16, When Base Alternative activity (Reseal at 20 % when total damaged area is 19% + Resurfacing of Ravalled area when Ravelling and total damaged area is ≥ 10% + Patching Pothole when Pothole ≥ 2 No. per Km) is applied there is a considerable dip in the roughness value in 2018, 2022, 2026, 2030, 2033, 2036; A layer of 30 mm BC is required when roughness approaches to IRI ≥ 5 and this strategy is the most economical one and there is a considerable dip the roughness value as in year 2018, 2031 and Reconstruction of the Road is required when IRI is ≥ 8 and should be implemented in year 2022 and 2033.

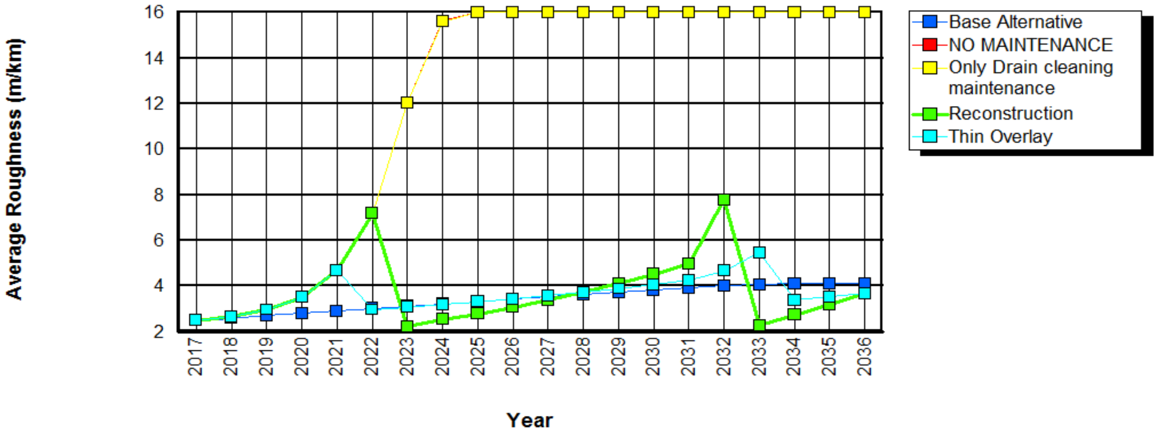


Figure 8: Secretariat Road

For the Secretariat Road when only side drain cleaning (scheduled activity) is done there is continuous increase in deterioration of the pavement and the roughness value approaches to 16, When Base Alternative activity (Reseal at 20 % when total damaged area is 19% + Resurfacing of Ravalled area when Ravelling and total damaged area is ≥ 10% + Patching Pothole when Pothole ≥ 2 No. per Km) is increasing linearly; A layer of 30 mm BC is required when roughness approaches to IRI ≥ 5 and this strategy is the most economical one and there is a considerable dip the roughness value as in year 2021, 2034 and Reconstruction of the Road is required when IRI is ≥ 8 and should be implemented in year 2023 and 2033.

VI. CONCLUSION

The study involved calibration of distress models of internationally recognized World Bank's HDM-4 system tool for selected pavement sections of Patiala City network having modified bituminous mix as surface course for

Indian climatic conditions. Calibration factors have been obtained for various pavement distress deterioration models for bituminous concrete (BC) wearing surface with varying pavement compositions, traffic and climatic conditions for the selected pavement sections. A generalized and logical calibration factors are obtained for the selected urban road network for Indian local conditions which can also fit into the other Urban Road network which are also falling under similar conditions under which the homogeneity of pavement test sections was identified for the study.

The HDM-4 pavement deterioration models for flexible pavements have been calibrated based on the available time series data collected from the pavement test sections and could also be used for predicting the road conditions for modified bituminous road surfacing for future maintenance planning and strategies. The percentage variability of observed and predicted values of distresses have been obtained for the validation and is found that there is more than 80% validity for cracking and roughness for all the six homogeneous test sections of Patiala City.

Comparative study of calculated calibrated distress factors from HDM-4 equations and the default factors has been successfully carried out for the two road sections. It has been observed that due to change in the calibration factors, the maintenance alternative shows a drastic change in the pavement deterioration models for future years. But due to higher sensitivity of the calibrated factors depending on the area of research, calibrated distress factors are manually determined from the available four-year data for formulating the maintenance strategies.

ACKNOWLEDGEMENT

It is an honour to express my grace to my attendant Assistant professor Ashish Kumar for the continuous support of my thesis and related research, for his patience, motivation, and immense knowledge. I am blessed to have such an inspirational mentor who motivated me all the time and his love for the research is totally appreciable. The way he has helped me and the material he provided all the time is perhaps the reason behind my research work. I am highly grateful to Dr. Sandeep Single, Head of the Department of Civil Engineering for their kind support and permission to use the facilities available in the University. The appreciation also goes to my parents who are right there to back me and are constantly support me in building my career.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

[1] Aggarwal.S, Jain S.S., Parida, M. Pavement Management Systems for a national highway network in India. 2004.

[2] Kerali, R, H. The Role of HDM-4 in Road Management. 2016.

[3] Mohit, Mantrao. Structural and Functional Evaluation of Urban Road Network of Patiala City for Developing Cost Effective Maintenance Stategies. s.l.: M.E Thesis, Thapar University Patiala, 2013.

[4] Deori S., Choudhary R., Tiwari D., Gangopadhyay S. Calibration of HDM-4 models for Indian conditions of flexible pavement having modeified bitumen in wearing course. s.l.: International Journal of Pavement Engineering, 2016.

[5] Development of Pavement Maintenance Management System of Urbn Road Network using HDM-4 Model. Chopra T., Parida M., Kwatra N., Mandhani J. s.l.: Internaional Journal of Engineering & Applied Sciences, Vol.9, 2017.