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CALIBRATION OF RUTTING AND ROUGHNESS DISTRESS MODELS OF HDM-4 FOR DEVELOPING PAVEMENT MAINTENANCE MANAGEMENT

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The Highway Development and Management model (HDM-4) is a tool developed by the World Bank to aid highway administrators and engineers in the process of decision making for preparing of road investment programme and determining the road network maintenance strategies. HDM-4 essentially models the interaction between the traffic volume, environment and pavement composition to predict the different kinds of distress that develop in pavements over time. Since distress is caused due to different conditions and progresses at different rates, therefore it is necessary to calibrate the HDM-4 model as per the local conditions. The aim of the study is to calibrate the HDM-4 pavement deterioration model in terms of rutting and roughness for the urban road network of Patiala (Punjab, India). In our study, we select 15 road sections and group them based on varying traffic and pavement age. The pavement condition data, which was measured starting from 2012 to the end of 2014, is fed as the input to the HDM-4 distress models. The calibration process is performed using statistical analysis between the observed and predicted value of the distress by keeping minimum Root Mean Square Error (RMSE) and maximum R-square (R^2). The determined calibration factors are validated and further used for developing pavement deterioration models which prove to be helpful in building a Pavement Maintenance and Management system for Patiala.

Keywords: Urban roads, India, Highway administration, Patiala, PMMS.

1 INTRODUCTION

The Road network in India is the second largest comprising of National Highways, State Highways, Major District Roads, other District and Urban Roads (Mandhani 2017). The traffic on the urban road in India in terms of volume and axle load is increasing at an alarming rate with an annual growth of the order of about 10% (MoRT&H 2004). This increase in vehicle population and road usage has put an immense strain on the present urban road leading to a wide-spread deterioration of the pavements. The situation has motivated the development of Pavement Maintenance Management Systems (PMMS) for the roads in our country, most of which belong to the national highway network. It is important to note here that the utilization and maintenance strategies of the urban road networks are totally different from that of the highway networks. The number of trips in the urban road network is small while diversions and intensity of the traffic are very large and non-uniform (Chopra *et al.* 2018), which is very unlike the highway road network. Therefore, the pavement management systems developed for the highway roads cannot be directly used for urban roads. To motivate the use of maintenance strategies for urban road networks as well, in our present study we develop a PMMS using Highway Development and Maintenance (HDM-4) pavement deterioration model for pavement sections in the urban areas of the city of Patiala, Punjab (India). The main objective of a model developed on HDM-4 is to detect pavement deterioration patterns to predict the deterioration of pavement with time under traffic loads (Bannour *et al.* 2017). HDM-4 is made to be used for a broad range of environmental conditions but before that HDM-4 needs to be calibrated as per the local condition to produce better results. If used without calibration, an HDM-4 model will predict the pavement performance, which does not accurately meet with the observed pavement specifications. Therefore, calibration is necessary to predict more indicative output in the environment other than the regions, in which it was developed (Bennet and Paterson 2000). The calibration of HDM-4 model as per local condition has been successfully executed in developed countries. However, in developing countries like India attempts are still being made for successful implementation of calibration of HDM-4 as per varying climate and traffic conditions. Therefore, our present study focuses on the calibration of HDM-4 pavement deterioration model in terms of rutting and roughness for 15 road sections in city Patiala, India for development of PMMS.

Table 1. Details of 15 selected pavement section of the urban road network.

Section ID	Name of Road	Length in km	Width of Carriageway(metre)	Drainage condition	Classification
UR01	ThaparUniv. - Bhadson Road	0.80	6.80	Fair	Other Road
UR02	ThaparUniv. - Bhupindra Road	1.05	7.30	Fair	Sub-Arterial
UR03	Thapar Uni. - Gurdwara Sahib	2.50	7.50	Good	Other Road
UR04	Passey Road - Civil Line	1.00	7.20	Very Poor	Other Road
UR05	Gurudwara Sahib Chowk - Sirhind Road	2.25	7.00	Good	Sub-Arterial
UR06	Leela Bhawan Chowk – Cantonment	0.70	11.50	Good	Sub-Arterial
UR07	Gurdwara Sahib Chowk - Bus Stand Road	0.90	7.50	Poor	Sub-Arterial
UR08	Thikriwala Chowk - Sangrur Road	1.00	7.50	Good	Sub-Arterial
UR09	Thikriwala Chowk - Badungar Road	0.80	11.80	Fair	Other Road
UR10	Bus Stand Chowk - Gurbax Colony	2.10	6.0	Poor	Other Road
UR11	Fountain Chowk - Leela Bhawan	0.70	12.5	Good	Sub-Arterial
UR12	Fountain Chowk - Lower Mall	2.25	7.5	Fair	Other Road
UR13	ThaparUniv. -Gurudwara Sahib	2.25	7.30	Fair	Sub-Arterial
UR14	Leela Bhawan Chowk- 22 No bridge	2.10	7.50	Good	Sub-Arterial
UR15	Leela Bhavan- Guruduwara Sahib	1.46	10.0	Fair	Sub-Arterial

2 URBAN ROAD NETWORK

The urban road network in Patiala comprises of 52 road sections. In our study, 15 road sections were selected for developing the pavement distress model. Each of the 15 selected road sections has been assigned Section IDs such as UR01, UR02 etc. (shown in Table 1). Each pavement section also includes the road length, carriageway width, drainage conditions and classification of the road system. The selected pavement sections have been further classified into groups of 4 based upon the varying pavement age and commercial traffic, as shown in Table 2.

Table 2. Homogenous section group for selected pavement sections.

Homogenous Group	Section Name	Pavement Age	Commercial Traffic
GROUP 1	UR08, UR10, UR15	0-6 Years	Less than 7%
GROUP 2	UR02, UR04, UR06, UR12	6-12 Years	More than 7%
GROUP 3	UR01, UR03, UR05, UR11	0-6 Years	Less than 7%
GROUP 4	UR07, UR09, UR13, UR14	6-12 Years	More than 7%

3 METHODOLOGY

Extensive field work was conducted for 3 successive years beginning from 2012 to the end of the year 2014 for collecting the requisite data about the road sections. The initial work included identification of roads, a collection of pavement data, which included the inventory data such as the geometry of the road, structure evaluation (to determine the load carrying ability of the structure), functional evaluation (to check pavement condition and roughness etc.), climate, temperature and the thickness of the pavement. The traffic volume data was collected from Municipal Corporation Patiala. The next phase involved calibrating the model for the specific local conditions. The inventory data of the pavement was used as input to the HDM-4 pavement deterioration model. The calibration of the model, which has been explained in detail in Section 3.1, was achieved by using regression.

3.1 Calibration of HDM-4

For calibrating the HDM-4 distress model, the software program was executed for all the selected road sections with input data as the traffic volume data and the pavement characteristics. For the first run in HDM-4, calibration factor was determined by obtaining minimum RMSE and max R^2 calculated by two equations:

$$\mathrm{RMSE} = \sum_{i=1}^{n} \sqrt{(\mathrm{Ob} - \mathrm{Pd})^2 / \mathrm{N}} \tag{1}$$

$$\mathrm{R}^2 = 1 - \left[\sum\left((\mathrm{Ob} - \mathrm{Pd})^2 / (\mathrm{Ob} - \mathrm{Oavg})^2\right)\right] \tag{2}$$

Where RMSE = root mean square error, R^2 =coefficient of determination, Ob=measured (observed) value of distress, Pd=predicted value of distress by HDM-4 model, Oavg= average observed value of distress, N= no of observations

After obtaining the calibration factor for the first stage, the model was run for the second stage for further improvement by incrementing the calibration factor by 0.01. The data collected for the year 2012 was used as input to the HDM-4 model. The distress estimations made by the model for year 2013 were compared with the actual values of distress measured in the field for the year 2013. A correlation was observed between the two values (measured and estimated) of distress based on the goodness of fit, which was determined by obtaining minimum RMSE and maximum R^2. The calibration factors obtained were different for different groups due to varying traffic volume data and pavement characteristics. The method of calibration for roughness distress model for Group 4 is shown as an example in Table 3. The final calibrated values for each mode of the distress model for different groups are shown in Table 4.

Table 3. Calibration of roughness distress model for group 4.

	UR 07		*UR09*		*UR13*		*UR14*			
Calibration Factor	Obsv	Pred	Obsv	Pred	Obsv	Pred	Obsv	Pred	RMSE	R-Squared
1.00	4.80	4.57	2.20	2.16	5.70	4.74	2.30	2.32	0.4940	0.9743
1.50	4.80	4.67	2.20	2.32	5.70	4.87	2.30	2.49	0.4348	0.9771
1.90	4.80	4.74	2.20	2.46	5.70	4.97	2.30	2.63	0.4221	0.9800
1.95	4.80	4.75	2.20	2.47	5.70	4.99	2.30	2.64	0.4168	0.9808
1.96	4.80	4.75	2.20	2.47	5.70	4.99	2.30	2.64	0.4168	0.9808
1.97	4.80	4.75	2.20	2.48	5.70	5.00	2.30	2.65	0.4163	0.9811
1.98	4.80	4.76	2.20	2.48	5.70	5.00	2.30	2.65	0.4168	0.9808
1.99	4.80	4.76	2.20	2.49	5.70	5.00	2.30	2.66	0.4199	0.9809
2.00	4.80	4.76	2.20	2.49	5.70	5.00	2.30	2.66	0.4199	0.9809
2.01	4.80	4.76	2.20	2.49	5.70	5.01	2.30	2.66	0.4157	0.9817
2.02	4.80	4.76	2.20	2.50	5.70	5.01	2.30	2.67	0.4197	0.9817
2.03	4.80	4.76	2.20	2.51	5.70	5.01	2.30	2.67	0.4215	0.9810

Table 4. Final calibrated value for all groups.

Distress Model	Group 1	Group 2	Group 3	Group 4
Rutting Progression	2.64	2.64	2.74	2.83
Roughness Progression	2.63	2.75	2.42	2.01

4 RESULTS AND DISCUSSIONS

The HDM-4 model requires validation before it can be it for local conditions. Therefore, the results obtained after calibration by HDM-4 distress were further validated for the year 2014 for different group sections to check the dependability and adequacy of the HDM-4 distress model. Validation was done for all groups consisting of homogenous section using regression analysis and percentage variability. The validation of Group 4 consisting of 4 sections is shown as an example in the following sub-sections.

4.1 Rutting Distress Model for Group 4

The measured value of rutting progression is compared with the value of rutting determined by the calibrated HDM-4 model, for the year 2014, for all selected pavement sections of Group 4 (shown in Table 3). The two values are plotted against each other to determine the correlation between them, as shown in Figure 1. The variability in the percentage between the two values (observed and predicted) of distress lies between 4 to 24 %, which is quite reasonable, and the coefficient of relation determined between the two values is 0.7435, which is also quite reasonable and indicates the efficacy and reliability of the calibrated HDM-4 rutting distress model.

4.2 Roughness Distress Model for Group 4

The measured value of roughness progression is compared with the value of roughness as determined by calibrated HDM-4 model for the year 2014 for all selected pavement sections of Group 4, as shown in Table 5. The two values are plotted against each other to determine the correlation between them, which is shown in Figure 2. The variability in the percentage between the two values of distress lies between 0 to 28 %, which is quite reasonable, and coefficient of relation determined between the two values is 0.9857, which is also quite reasonable and tells the efficacy and reliability of the calibrated HDM-4 roughness distress model.

Table 5. Rutting and roughness model validation for group 4.

Section	Observed	Predicted	Variability	R^2
UR07	06	6.24	4	0.743
UR09	11	10.25	6.81	
UR13	09	9.64	7.11	
UR15	08	6.12	23.50	

Section	Observed	Predicted	Variability	R^2
UR07	5.3	5.26	4	0.985
UR09	2.3	2.94	6.81	
UR13	6.1	5.45	7.11	
UR15	2.6	3.05	23.50	

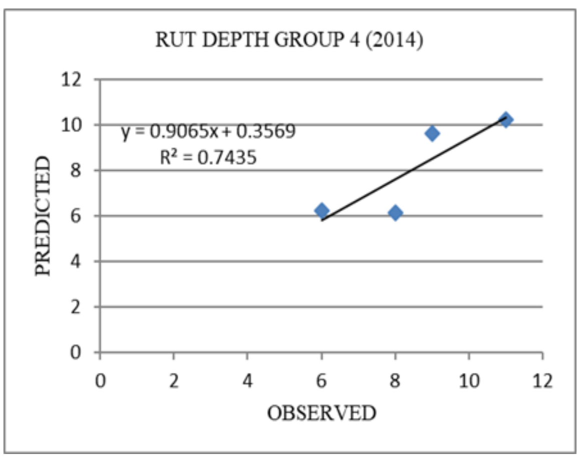

Figure 1. The graph for rutting model validation.

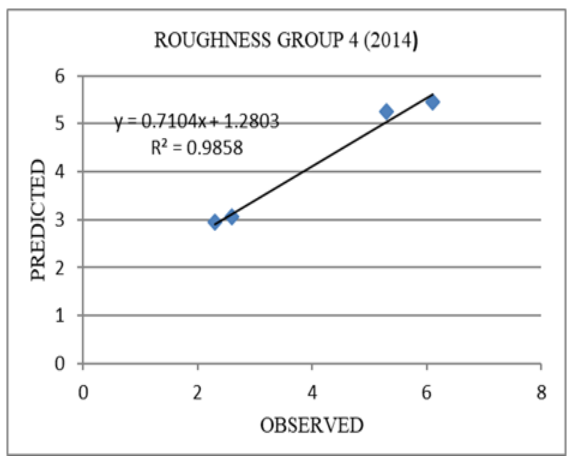

Figure 2. The graph for roughness model validation.

4.3 Chi-Square Test

The Chi-Square test was done for checking the goodness of fit correlation between the measured (observed) distress and the value determined by HDM-4 model. The $X^2_{calculated}$ (from chi-square formula) for distress model for all the different groups were compared with the $X^2_{critical}$ with a level of significance equal to 5% and (N-1) of degrees of freedom. The Chi-Square test was done for all different groups consisting of homogeneous sections and group 4 having homogeneous section is shown as an example in Table 6. The value of Chi(X) is determined using Eq. (3).

$$X^2 = \sum (Od - Pd)^2 / Pd \quad (3)$$

where Od=observed value of distress Pd=Predicted value of distress by HDM-4 model.

As the value of $X^2_{calculated}$ is less than $X^2_{critical}$ therefore null hypothesis is accepted and a significant relation is established between the two values of the distress model having no statistical difference.

Table 6. Chi-Square Result for Validation of Group 4.

Distress Model	Linear Regression	$X^2_{calculated}$	$X^2_{critical}$	DOF	R^2
Rutting Progression	y = 0.906*x*+0.356	1.537	7.815	3	0.743
Roughness Progression	y = 0.710*x*+1.280	0.283	7.815	3	0.985

5 CONCLUSIONS

- The aim of the study was to calibrate the two-distress model, i.e., rutting and roughness distress model for developing pavement deterioration model for urban road network in India.
- The HDM-4 distress model obtained a good correlation between observed and predicted value of distress after calibration, which tells that a calibrated HDM-4 model can serve as a decent predictive model for pavement distress of urban road networks as well.
- The percentage of variability for rutting distress model lies from 8 to 24% and for roughness distress model from 1 to 7 % is quite reasonable considering different climatic conditions, pavement age, and traffic.
- The calibration factor for rutting distress model ranges from 2.63 to 2.84 and 2.01 to 2.75 for roughness distress model, which are quite reasonable for flexible pavement in urban city road network of Patiala, Punjab, India.
- The calibration factors obtained can be applied to the urban road network of the city having similar traffic and the environmental conditions like city Patiala, Punjab, India.

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