Pavement Performance Prediction and Maintenance Modelling for Flexible Pavements of Madhya Pradesh

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***Abstract*-India owns second largest road network in the world, being so prominent asset indicates the prerequisite for preserving it. The paper is a step towards an effort to do the same. It provides a way to analyse the outstanding factors which are more headed for affecting the pavement performance. Knowing such factors may help one to work in a way to improve the pavement performance with an eye on that influencing factor. Along with it, the work has taken an initiative by carrying prediction and maintenance modelling as an enhanced way of pavement management and preservation.**

***Keywords* - Pavement performance, Deterioration, Performance influencing factors, Relative Models, Absolute Models.**

I. INTRODUCTION

Proficient road transportation plays an imperative role in the economy of any Nation. India being a developing country, it is an issue to preserve and enhance its transportation system infrastructure within an allocated budget. So, with prime importance, if there exists a way to gear the road network for its better performance will pilot a pathway for its preservation and enhancement too.

The work ahead is an endeavour to conserve the pavement infrastructure with methodology of judging the factors related to the pavements with maximum influence on its performance. In reference with the work for improved pavement performance, indicates first to define what actually pavement performance and deterioration is. The ability of road to satisfy demands of traffic and environment over its design life is its performance. The reduction in the performance level of the pavement with the change in the value of performance indicating attributes over time is termed as deterioration.[2] It all revolves around the one term that is Pavement Management System (PMS). PMS derives different management practices which deal with improvement of pavement performance and quality. As a part of PMS, Performance modelling is one of a key facet which leads to take constructive decisions to improve pavement performance.

The paper comprises a fraction of pavement management system which includes performance modelling and maintenance modelling which mainly involves the pavement performance influencing and performance indicating attributes. According to Gupta et al.(2014) [1], the various performance influencing attributes are headed under three subheads; Traffic loading associated factors, construction, Structural composition and material properties associated factors, and Environmental associated factors. On the other hand, different attributes of pavement which indicates the performance are cracking, deflection, rutting, punchouts, roughness, spalling, Pavement Condition Rating (PCR), Riding Comfort Index (RCI) etc. Performance Modelling have different types which involves Deterministic and Probabilistic models, Relative and Absolute models, Network and Project level models. [7] [8].

II. LITERATURE REVIEW

Gupta et al.(2014) [3] in their work had listed the factors affecting pavement performance which are the basis for all developing models. They are categorised as traffic loading associated factors; construction, structural composition and material properties associated factors; environmental associated factors etc.

Shreedevi (2014) [5] in her research work had attempted to identify the parameters that affect the performance of roads and to develop performance models suitable to Kerala conditions. Author had also provided a vital review of the various factors that contribute to the pavement performance.
According to Prozzi and Madanat (2004) by reducing the prediction error of pavement deterioration, agencies can obtain significant budget savings through timely intervention and accurate planning.

Sadek et al. (1996) [6] had done a focused work for developing models for Virginia. The process of work includes initially categorization of roadway section on the basis of geographic location and pavement type, followed by assortment of significant predictors of deterioration. Regression Models were further developed; examined and evaluated for reliability, accuracy by various sensitivity analysis tests. They had provided a stated comparison of observed and predicted values that proved models to be reasonably correct.

Gulen et al. (2001) [4] in their writing stated the importance of collected data for development of performance prediction model. Through this literature, author emphasised on proper selection of explanatory variables along with sufficiency of data for creating pavement performance model. After developing improved models, there was observed increase of positive correlation in terms of models developed with previously collected data. This study clearly signifies that there should be adequacy for independent variables and required data.

Rose et al.(2007) [9] had made an attempt for developing deterioration models for rural roads as conditions prevailing for rural roads are entirely different. The parameters which contribute to the distress formation were identified. Distresses were expressed as percentage of area affected. Deterioration models were developed for Construction Quality, Ravelling Initiation, Ravelling Progression, Pothole Progression, Roughness Progression and Edge Failure. Further the validation of models was carried out by using Chi- Squared test. The study had identified that for rural roads, the influencing parameters are drainage rating and construction quality. Prevailing distresses highlighted through the work on the rural roads are ponding, ravelling, pothole and edge failure, and non linear models proved to be more reliable.

Song et al. (2010) [10] in their paper have used regression to investigate the relationship between pavement friction and influencing variables including traffic volumes, traffic patterns, rehabilitation activities, weather conditions and test speeds. Authors have developed stepwise regression model and further validated it through coefficient of determination (R^2).Through this study, there will be significant help to engineers to interpret effect of influencing variables on friction data and so take measures to improve pavement friction.

III. DATABASE

Eight roads sections categorized as low traffic volume roads were taken for executing performance modelling which are from the different districts of Madhya Pradesh. The roads so selected for proceeding work are categorised as low traffic volume roads as these roads have Commercial Vehicles per day (CVPD) less than 450. The different allied attributes with the roads were noted with their values which are stated in Table 3.1 and Table 3.2. These attributes includes both performance influencing along with performance indicating variables i.e. Deflection, Roughness comes under performance indicating variables whereas Thickness, California bearing Ratio (CBR), Passenger Car Unit (PCU), Commercial Vehicles per day (CVPD), Age till Date are the performance influencing variables.

IV. DATA ANALYSIS

The analysis drives with developing models in form of predicting performance and maintenance of flexible pavement. The analysis is initiated with generating hundred simulated data for the stated data of eight roads sections using Monte Carlo Simulation which will help to develop more precise and accurate models, as it is known that sufficiency in data will provide better results. The combined and simulated data for all eight roads is provided in Table 4.1.

Further process drives with two phases of work: a) Performance Prediction Modelling; b) Maintenance Modelling.

A) PAVEMENT PERFORMANCE PREDICTION MODELLING

Performance Prediction modelling comprises relative and absolute modelling. Relative model is one of the classified performance models which contain only one independent variable, like age or traffic etc. which provides dependency of performance indicating variable on it whereas an absolute model includes more than one independent variables for development of models. These models are developed by regression analysis on simulated data using Minitab Software.

Table 3.1 Performance Influencing Variables

Sr.no.	Name of Road Sections	District	Length (km)	Total Crust Thickness (mm)	CVPD	PCU	Age till date (Years)	CBR (%)
1	Piploda to Bumtalai	Shajapur	2.92	395	56	1227	0.83	8
2	Manasa Khuro Fanta	Mandsaur	4.20	430	30	762	1.083	4
3	Guliyana to Ratikhedi	Mandsaur	10.00	395	21	111	0.67	7
4	Malyakhedi to jamalpura Kochavi	Mandsaur	6.60	430	30	762	1.083	5
5	Chandkhedi to Sagoriya	Mandsaur	2.80	350	126	1008	0.2	7
6	Garoth Boliya to Rawati	Mandsaur	3.80	430	128	1020	0.2	7
7	Sani Temple to Chandmukh	Ujjain	5.00	450	26	416	1.083	5
8	Mundadi To Nahargarh	Mandsaur	11.20	430	80	700	2.083	5

Table 3.2 Performance Indicating Variables

Sr.no.	Name of Road Sections	District	Deflection (mm)	Roughness (m/km) (IRI)
1	Piploda to Bumtalai Road	Shajapur	2.909	7.286
2	Manasa Khuro Fanta Road	Mandsaur	2.657	6.900
3	Guliyana to Ratikhedi Road	Mandsaur	2.596	7.822
4	Malyakhedi to jamalpura Kochavi Road	Mandsaur	2.696	7.188
5	Chandkhedi to Sagoriya Road	Mandsaur	3.277	6.110
6	Garoth Boliya to Rawati Road	Mandsaur	3.532	6.415
7	Sani Temple to Chandmukh Road	Ujjain	2.725	7.416
8	Mundadi To Nahargarh Road	Mandsaur	3.093	6.967

Table 4.1 Simulated Data

Sr.no.	CVPD	CBR (%)	Age till date (Years)	PCU	Thickness (mm)	Deflection (mm)	Roughness (m/km) (IRI)
1	60	7.5	1.50	900	440.0	3.0	7.1
2	30	6.0	0.90	900	440.0	2.8	6.9
3	30	6.0	0.70	550	412.5	2.6	6.6
4	100	7.5	1.50	1150	440.0	3.0	7.3
5	100	7.5	1.50	1150	440.0	3.0	7.3
6	100	7.5	1.50	1150	440.0	3.0	7.3
7	130	8.5	2.05	1250	452.5	3.6	7.9
8	100	7.5	1.50	1150	440.0	3.0	7.3
9	30	6.0	0.70	550	412.5	2.6	6.6
10	30	6.0	0.70	550	412.5	2.6	6.6
11	60	7.5	1.50	900	440.0	3.0	7.1
12	30	4.5	0.40	250	372.5	2.6	6.2
13	60	7.5	1.50	900	440.0	3.0	7.1
14	130	8.5	2.05	1250	452.5	3.6	7.9
15	30	6.0	0.90	900	440.0	2.8	6.9
16	60	7.5	1.50	900	440.0	3.0	7.1
17	100	7.5	1.50	1150	440.0	3.0	7.3
18	130	7.5	1.50	1150	440.0	3.3	7.6
19	60	7.5	1.50	900	440.0	3.0	7.1
20	100	7.5	1.50	1150	440.0	3.0	7.3
21	30	6.0	0.70	550	412.5	2.6	6.6
22	30	6.0	0.70	550	412.5	2.6	6.6
23	30	6.0	0.70	900	412.5	2.6	6.9
24	60	7.5	1.50	900	440.0	3.0	7.1
25	130	7.5	1.50	1150	440.0	3.3	7.6
26	30	6.0	0.70	550	412.5	2.6	6.6
27	30	6.0	0.70	550	412.5	2.6	6.6
28	100	7.5	1.50	1150	440.0	3.0	7.3
29	30	4.5	0.40	250	372.5	2.6	6.2
30	60	7.5	1.50	900	440.0	3.0	7.1
31	30	6.0	0.70	550	412.5	2.6	6.6
32	30	4.5	0.40	250	372.5	2.6	6.2
33	60	7.5	1.50	900	440.0	3.0	7.1
34	30	4.5	0.40	250	372.5	2.6	6.2
35	30	6.0	0.90	900	440.0	2.8	6.9
36	30	6.0	0.70	550	412.5	2.6	6.6
37	30	6.0	0.70	550	412.5	2.6	6.6
38	130	8.5	2.05	1250	452.5	3.6	7.9
39	30	6.0	0.90	900	440.0	2.8	6.9
40	30	6.0	0.90	900	440.0	2.8	6.9
41	30	6.0	0.90	900	440.0	2.8	6.9
42	130	7.5	1.50	1150	440.0	3.3	7.9
43	30	6.0	0.90	900	440.0	2.8	6.9
44	130	8.5	2.05	1250	452.5	3.6	7.9
45	130	7.5	1.50	1150	440.0	3.3	7.9
46	100	7.5	1.50	1150	440.0	3.0	7.3
47	100	7.5	1.50	1150	440.0	3.0	7.3
48	30	6.0	0.70	900	412.5	2.6	6.9
49	30	4.5	0.40	250	372.5	2.6	6.2
50	130	8.5	2.05	1250	452.5	3.6	7.9
51	130	8.5	2.05	1250	452.5	3.6	7.9

Sr.no.	CVPD	CBR (%)	Age till date (Years)	PCU	Thickness (mm)	Deflection (mm)	Roughness (m/km) (IRI)
52	130	7.5	1.50	1150	440.0	3.3	7.9
53	30	6.0	0.70	550	412.5	2.6	6.6
54	60	7.5	1.50	900	440.0	3.0	7.1
55	100	7.5	1.50	1150	440.0	3.0	7.3
56	30	6.0	0.70	550	412.5	2.6	6.6
57	30	6.0	0.70	900	412.5	2.6	6.9
58	100	7.5	1.50	1150	440.0	3.3	7.6
59	130	8.5	2.05	1250	452.5	3.6	7.9
60	100	7.5	1.50	1150	440.0	3.0	7.3
61	130	7.5	1.50	1150	440.0	3.3	7.6
62	30	6.0	0.70	550	412.5	2.6	6.6
63	30	6.0	0.90	900	440.0	2.8	6.9
64	100	7.5	1.50	1150	440.0	3.0	7.3
65	130	7.5	1.50	1150	440.0	3.3	7.9
66	30	6.0	0.90	900	440.0	2.8	6.9
67	130	7.5	1.50	1150	440.0	3.3	7.6
68	60	7.5	1.50	900	440.0	3.0	7.1
69	130	8.5	2.05	1250	452.5	3.6	7.9
70	100	7.5	1.50	1150	440.0	3.0	7.3
71	30	6.0	0.90	900	440.0	2.8	6.9
72	30	6.0	0.70	900	412.5	2.6	6.9
73	30	6.0	0.70	900	412.5	2.6	6.9
74	30	6.0	0.70	900	412.5	2.6	6.9
75	130	7.5	1.50	1150	440.0	3.3	7.6
76	130	7.5	1.50	1150	440.0	3.3	7.9
77	30	6.0	0.70	900	412.5	2.6	6.9
78	60	7.5	1.50	900	440.0	3.0	7.1
79	30	6.0	0.70	900	412.5	2.6	6.9
80	60	7.5	1.50	900	440.0	3.0	7.1
81	130	8.5	2.05	1250	452.5	3.6	7.9
82	60	7.5	1.50	900	440.0	3.0	7.1
83	30	6.0	0.70	550	412.5	2.6	6.6
84	30	6.0	0.90	900	440.0	2.8	6.9
85	30	6.0	0.90	900	440.0	2.8	6.9
86	30	6.0	0.70	900	412.5	2.6	6.9
87	60	7.5	1.50	900	440.0	3.0	7.1
88	60	7.5	1.50	900	440.0	3.0	7.1
89	30	6.0	0.90	900	440.0	2.8	6.9
90	30	6.0	0.70	550	412.5	2.6	6.6
91	30	4.5	0.40	250	372.5	2.6	6.2
92	60	7.5	1.50	900	440.0	3.0	7.1
93	120	7.5	1.50	1150	440.0	3.3	7.6
94	30	6.0	0.70	550	412.5	2.6	6.6
95	30	6.0	0.70	900	412.5	2.6	6.9
96	30	6.0	0.70	900	412.5	2.6	6.9
97	30	6.0	0.70	550	412.5	2.6	6.6
98	30	6.0	0.70	550	412.5	2.6	6.6
99	30	6.0	0.70	550	412.5	2.6	6.6
100	30	4.5	0.40	250	372.5	2.6	6.2

Pavement Performance Prediction Models in the form of Relative Models

Relative models using regression analysis so developed are in linear form. Table 4.2 shows the developed relative models. The reliability of models is being validated on the basis of statistical criteria which states that the model with higher value Coefficient of multiple determination (R^2) and lesser value of Residual sum of squares (S) proves the best appropriate relative model and which principally shows a proper dependency of performance indicating variable on the performance influencing variable.

Pavement Performance Prediction Models with two more influential attributes together

Modelling with more than one influential parameter will sort more precisely the one's with higher influence and it also shows models with more than one parameter becomes more effective and efficient which triggers the further analysis of multiple regressions which will result into a better pavement performance prediction model. The section covers performance prediction modelling with the influential parameters bearing higher dependency as gained from relative models. Further, Table 4.3 shows the developed models with two variables and their reliability validates through static measures.

Table 4.2 Relative Models

Sr.no.	Performance Indicating Variables	Performance Influencing Variables	Relative Models	R^2 (%)	S
1	Deflection	CVPD	2.4473 + 0.007267 CVPD	84.98	0.12
2	Deflection	CBR (%)	1.1273 + 0.2656 CBR (%)	77.09	0.15
3	Deflection	Age till date	2.2020 + 0.6184 Age till date (Years)	87.88	0.11
4	Deflection	PCU	2.1230 + 0.000899 PCU	63.29	0.19
5	Deflection	Thickness	-2.055 + 0.01161 Thickness (mm)	55.78	0.21
6	Roughness	CVPD	6.3722 + 0.010772 CVPD	83.41	0.19
7	Roughness	CBR (%)	4.316 + 0.4085 CBR (%)	81.55	0.20
8	Roughness	Age till date	6.0355 + 0.8934 Age till date	81.89	0.20
9	Roughness	PCU	5.6850 + 0.001567 PCU	86.25	0.17
10	Roughness	Thickness	-1.077 + 0.01902 Thickness (mm)	67.12	0.27

Pavement Performance Prediction Models in the form of Absolute Models

As stated earlier, absolute models are basically one of the classifications of performance prediction modelling which includes more than one independent attributes, which together forms a model equation on which single dependent attribute depends. Absolute models so developed are with five of independent variables and one dependent attribute using multiple regressions.

Table 4.4 shows the absolute models and the reliability measures which signifies that the models so developed are beneficial for prediction or not.

Table 4.3 Models with Two Parameters

Sr.no.	Performance Indicating Variables	Performance Influencing Variables	Models with two parameters	R^2 (%)	S
1	Deflection	CVPD, Age	2.2698 + 0.003443 CVPD + 0.3674 Age	92.46	0.09
2	Deflection	CVPD, CBR (%)	1.873 + 0.004911 CVPD + 0.1079 CBR (%)	88.94	0.10
3	Deflection	Age, CBR (%)	3.232 + 1.1321 Age - 0.2410 CBR (%)	90.95	0.09
4	Roughness	PCU, CVPD	5.8834 + 0.005642 CVPD + 0.000929 PCU	95.02	0.10
5	Roughness	PCU, CBR (%)	4.975 + 0.000983 PCU + 0.1819 CBR (%)	90.61	0.15
6	Roughness	PCU, Age	5.7347 + 0.000966 PCU + 0.4158 Age	91.47	0.14

Table 4.4 Absolute Models

Sr.no.	Performance Indicating Variables	Performance Influencing Variables	Absolute Models	R^2 (%)	S
1	Deflection	CVPD, CBR (%), Age, PCU, Thickness	2.088 + 0.003970 CVPD - 0.2260 CBR (%) + 0.7571 Age - 0.000116 PCU + 0.00309 Thickness	95.17	0.07
2	Roughness	CVPD, CBR (%), Age, PCU, Thickness	4.516 + 0.005832 CVPD + 0.0742 CBR (%) - 0.117 Age + 0.000653 PC + 0.00288 Thickness	95.63	0.10

B) PAVEMENT MAINTENANCE MODELLING

Maintenance Priority Index (MPI) establishes a systematic and rational procedure of identifying pavement maintenance needs and priorities and selection of cost effective maintenance alternatives. This analysis comprises MPI to set priorities of road sections selected for their maintenance.

For calculation of MPI, the initial step is computation of Deflection Index (DI) and Riding Condition Index or Roughness Index (RI). For this purpose basic need is the values of permissible deflection and permissible roughness. According to Indian Practice Code [11], considering maximum value for Million Standard Axle (MSA) to be 10, then corresponding permissible deflection is 1.7 mm. Permissible roughness taken as 15 m/km [12]. Further, for MPI, Road Condition Index (RCI) needs to be calculated and traffic factor need to be known. Traffic Factor has been calculated with respect to standard axles and stated in Table 4.5.

$$\textbf{DI} = \frac{\textbf{Present (predicted) deflection * 5}}{\textbf{Maximum Permissible Deflection}}$$

$$\textbf{RI} = \frac{\textbf{Present (predicted) Roughness * 5}}{\textbf{Maximum Permissible Roughness}}$$

RCI = DI + RI ; MPI = RCI * Traffic Factor

Table 4.5 Traffic Factors

Sr.no.	Name of Road Sections	Cumulative number of standard axle	Traffic factor based on Cumulative number of standard axle [1]
1	Piploda to Bumtalai Road	1	3
2	Manasa Khuro Fanta Road	1	3
3	Guliyana to Ratikhedi Road	0.61	3
4	Malyakhedi to jamalpura Kochavi Road	1	3
5	Chandkhedi to Sagoriya Road	2.01	5
6	Garoth Boliya to Rawati Road	2.04	5
7	Sani Temple to Chandmukh Road	0.75	3
8	Mundadi To Nahargarh Road	0.65	3

The calculated outcomes of MPI and through which the stated Priority Order gained has been stated in tabular form in Table 4.6**.** These results provide clear and precise idea of road maintenance.

V. RESULTS AND CONCLUSIONS

More reliable relative models in terms of deflection is with CVPD and Age till date compared to other parameters as observed validation in terms of R^2 and S are more than 80% and near to zero respectively which is the stated requirement.

More reliable relative models for roughness is with CVPD and PCU as R^2 and S are more than 80% and near to zero respectively for CVPD and PCU.

Further, clear results are gained with models using two influencing parameters which stated that roughness possess most logical dependency on PCU and CVPD together and defection possess most logical dependency on CVPD and Age collectively. So the models only with PCU for roughness and CVPD and Age together for deflection can also provide good prediction results, if equipped with limited data of only PCU, CVPD and Age.

An absolute Models outcome are efficiently and effectively reliable to provide prediction results for pavement performance as R^2 is around 95% and S is almost zero proving these models will provide correct prediction results for pavement performance. Prediction Modelling can be used as a tool to predict deterioration of pavement and will help to enhance performance.

Maintenance Modelling provides a significant pathway to have a proper maintenance protocol which will prevent loss of 4 M's. As gained from the analysis for Maintenance Priority Index, the road with highest MPI i.e. Garoth Boliya to Rawati Road with MPI = 62.644 is top among rest of the road for providing maintenance. Thus, having a lot of maintenance work, MPI help to strategize work by setting priorities for which to be maintain first and so on. This helps to even work under allocated budget as maintaining with a strategy makes the road maintenance comparatively lesser. Thus, MPI as an Index has come up with a positive step in Pavement Management System.

Table 4.6 MPI and Priority Order

Sr.no.	Name of Road Sections	Deflection Index	Roughness Index	Road Condition Index	Traffic Factor	Maintenance Priority Index	Priority Order
1	Piploda to Bumtalai Road	8.551	2.428	10.985	3	32.957	6
2	Manasa Khuro Fanta Road	7.815	2.300	10.116	3	30.347	8
3	Guliyana to Ratikhedi Road	7.636	2.607	10.244	3	30.731	7
4	Malyakhedi to jamalpura Kochavi Road	7.930	2.396	10.326	3	30.980	5
5	Chandkhedi to Sagoriya Road	9.6387	2.0369	11.675	5	58.378	2
6	Garoth Boliya to Rawati Road	10.390	2.138	12.528	5	62.644	1
7	Sani Temple to Chandmukh Road	8.015	2.472	10.487	3	31.462	4
8	Mundadi To Nahargarh Road	9.0975	2.322	11.420	3	34.260	3

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