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Development of Pavement Deterioration Models and Strategy for Maintenance Management

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ABSTRACT-Large scale industrialization and commercial activities since independence have resulted into an unprecedented traffic growth. The share of the road transport, in the last four decades, has increased from 26% to 80% for passenger traffic and from 11% to 60% for goods traffic. Due to paucity of the resources, stage construction practices have thus for been followed for the development of trunk roads. The network now is greatly short of its structural capacity for the present day unanticipated high traffic volumes. The increase in vehicle population during the same period has been about 70 times. The pace of growth of road infrastructure has not been commensurate with the growth of traffic. The road length has increased from 4 lack km in 1951 to only about 21 lack km in 1995. The trunk road network, consisting of NHs and SHs, through only about 8% of total road length, is responsible for catering to about 2/3 of goods traffic carried by the road sector in the country.

PMS includes activities with design, construction and maintenance of pavements. The PMS systems have become important tools for the road engineer to organize the activities of the road sector to meet the ever increasing demands of growing traffic in a developing country like India. The highway profession is at the crossroads and there are challenges, threats and pressures from all directions. Concerted efforts are now underway to developed road management and planning tools to improve upon the existing road network under the financial constraints. These tools are essential for the assessing the financial needs of the highway sector, evaluating the alternative maintenance strategies and prioritizing the work programs.

In this study, an attempt is made to development of pavement deterioration models to estimate the performance of the road network and to predict future deterioration levels of pavements with minimum data. For analysis selected stretches on the five major road networks in Warangal city are used to measure the various parameters related to pavement evaluation and data so obtained is used for development of the maintenance strategies for various distress Which are observed on the pavement?

I.INTRODUCTION

During the last four decades, the country has experienced all round development, which has resulted into exploration in the vehicle population. The pace of road development has not been the required order to meet the increased demand. As a result, the existing trunk route system has become structurally inadequate to sustain the high magnitude of stresses by the unanticipated increase in traffic volumes and axle loads and ultimately failure of the road pavements.

The funds available for preserving and up keeping of the existing road network, which is highly distressed, are by large, diminishing every year. The network has reached a condition at which heavy investments are needed to bring into a satisfactory level. The availability of such huge capital is rather doubtful. The need for efficient and effective management of the vast road network has thrown upon a challenge to the highway professionals of the country, as a whole. The only option left is to manage the roads with in the available limited resources, in an optimal manner, by making use of the scientific pavement management tools.

The concept of pavement management system involving life-cycle cost analysis, for managing the road pavements, is fast finding acceptance amongst the highway engineers. Pavement deterioration models, for prediction of pavement condition at a failure date, form an important input in the pavement management system for

1. Assessing the state of health of pavements
2. Deciding upon the optimal maintenance and rehabilitation treatments for a given
   Operation situation and Planning and programming of short term and long term maintenance budgets, these tools are needed and are used for economic analysis of various alternate Maintenance & Rehabilitation (M&R) strategies.

To perform such difficult tasks, tools are needed suiting to the existing our own conditions. The practice thus far has been to make use of the HDM-3 models, developed by the World Bank, after calibration for local conditions. But since these models are developed based on studies conducted in other conditions, where the road and traffic conditions and different, a need was therefore; felt to develop deterioration models for Indian conditions

II. OBJECTIVES OF THE STUDY

Based on the importance of pavement maintenance, the following are the broad objectives of the study

- To plan, direct and control maintenance activities so that an acceptable level of service, consistent with the class pavement is achieved
- To evaluated the methods and materials used in maintenance so that economical and efficient practice are developed
- Selection of the suitable modeling approaches based on the data requirements and formulation of the methodology for model development
- Maintenance management procedure for application for purpose for flexible pavements
- Development of deterioration models based on the selected approach

III. LITERATURE REVIEW

Aggarwal et al. (2005) has given an overall picture of the problems of road networks in developing countries, which are rapid traffic growth, inadequate funding for maintenance and upkeep, lack of skilled man power, attitude towards maintenance etc. Thube et al. (2005) critically reviewed the maintenance management strategy for low volume roads in India and stressed the need for development of pavement distress data base, deterioration models, optimal investment and maintenance strategy and highlighted the need for a suitable National level policy regarding paving of unpaved low volume roads in India.Juang and Amirkhanian, (1992) documented the findings of a study carried out on the use of Pavement Management System (PMS) in the United States. A model using fuzzy logic for a PMS based on priority ranking was developed. An index called Unified Pavement Distress Index (UPDI) was also developed and this was used to measure the distress condition of the pavement. Guidelines for rating six types of distresses, weights among the different types of distresses, fuzzy set representations, fuzzy mathematics and the definition of UPDI and its use in pavement database were given by this approach.Collop and Cebon, (1995) reported a whole-life performance model (WLPPM). This model is capable of making deterministic pavement damage predictions resulting from realistic traffic and environmental loading. Realistic predictions of pavement degradation with traffic has been obtained by taking into account most of the primary factors of vehicle/pavement interaction. Simulation by WLPPM shows that short- wave length surface – roughness components can be smoothed out, and traffic loading increases the amplitude of long wave length components.Morosick et al., 2000 has reported calibration of HDM-4 relationships for cracking, rutting and roughness against observed rates of deterioration of inter-urban roads in WestJava. The detailed models were found to be successful at using the extent of defects on under designed or poorly constructed roads. The calibration factor in the detailed model was close to unity, with a value of 1.3 for roads with heavy traffic and 1.0 for roads with light to medium traffic. The value of K for the aggregate model had to be increased approximately five fold to compensate for lack of distress terms *ie,* 5.3 for roads with heavy traffic and 5.5 for the roads with lighter traffic. The paper highlights that if the issues related to institutional data, engineering and systems are resolved and major reinvention is applied, it can be turned into opportunities which will substantially strengthen the pavement.Nasir et.al., (2010) compared six pavement condition indices from five DOT’s in the United States, using the distress and ride quality data obtained from the Pavement Management Information System of the Texas Department of Transportation. The computed scores were compared visually using scatter plots and statistically using paired t –test. The results showed significant differences among seemingly similar pavement condition indexes.Ferreira et al. (2011) compared the reported pavement performance models (PPM’S) to recommend the ones for use in the Portuguese Pavement Management Systems (PMS). The models analyzed were the HDM, AASHTO, the Nevada PMS, the Collop- Cebon whole-life pavement performance, the Swedish PMS and the Spanish PMS. The study recommended AASHTO model for an initial phase of implementation of the

Portuguese PMS. The same model was used in an LCCA model in the USA (Chen and Flintsch,2007).Roy et al., (2003) conducted a study to calibrate HDM-4 Road deterioration and Work Effect models to Indian conditions, by comparing the HDM–4 models with the Pavement Performance Study (PPS) models, developed for Indian conditions. The calibration factors were developed for two types of pavement surfacing, viz, Bituminous Concrete (BC) and Premix Carpet (PC) for varying Cumulative Standard Axle loads (CSA) and Modified Structural Numbers (MSN). Regression equations were developed, relating the calibration factors and the CSA and MSN values.Reddy et al. (2004) highlighted in his paper that the IRC guidelines for strengthening of road pavements using Benkelman Beam technique are based on limited experience in India gathered during the sixties and seventies and has little relevance to the present day traffic and axle load. Though overlay design methods using falling Weight Deflectometer and Deflectograph are accurate and scientific, they are costly and require skilled manpower.Freeman et al. (2004) proposed a method for predicting stresses in pavements under vehicular loadings. Each pavement layer was characterized by a co-efficient of lateral stress, which is similar to the commonly used co-efficient of lateral earth pressure (k). Several instrumented test sections were established and studied to determine coefficients of lateral stresses for common paving materials. A closed form solution based on the central limit theorem of probability is presented which can be used for predicting stresses within pavement structures. It is also applicable to multilayered structures.A three-stage model was used to describe the primary, secondary and tertiary stages to establish the relationship between the number of load repetitions and permanent deformation. The algorithm can also be used for identifying the transition point between stages like flow number, and determine the model parameters from typical laboratory data (Fujie et al., 2004).Uzhan (2004) reported a mechanical empirical framework for determining the permanent deformation in flexible pavements. The procedure uses rational material properties. It can be used as an analysis tool, for design also. This method is a compromise between simple and advanced approaches, between linear elasticity and finite element approaches. The proposed procedure uses the actual temperature distribution in the asphalt layer for every hour in the whole design period. It was found that increasing the thickness of the AC layer (with a stable material) for stiffening the pavement structure will lead to reduction in permanent deformation of the pavement.

IV.**METHODOLOGY AND DATA COLLECTION AND ANALYSIS**

Selection of Road Section

The stretches on which studies are already conducted for pavement evaluation during previous studies were only selected for the present work so as to apply evaluation technique and give suitable maintenance measures.

State Highways and District Road approaching Warangal city are selected to locate at a distance away from the city. The following road sections along with the type of the highway are listed below.

- Warangal – Karimnagar Road – SH
- Warangal – Khammam Road – SH
- Warangal – Narasampet Road – ODR
- Warangal – Hyderabad Road – SH
- Warangal – Eturunagaram Road – ODR

Measurement of Rut Depth

A rut is a longitudinal surface depression in the wheel path. It may have associated transverse displacement. Specific pavement studies (SPS)-3 ONLY. Record maximum rut depth to the nearest millimetre, at 15.25-m intervals for each wheel path, as measured with a 1.2-m straight edge. The details of the rut depth measurements and its analysis on the road stretches identified by the kilometre age on five roads approaching Warangal City are presented in the following TABLE I to X

Analysis of Rut Depth

TABLE I

Warangal – Karimnagar Road (118/00-121/00)

Chainage		Rut Depth(mm)		Total	Average	X^2	Mean	SD
From	**To**	**LWP**	**RWP**		**X**			
118	118.2	13	10	23	11.5	132.25	12.531	1.987
118.2	118.4	12	16	28	14	196		
118.4	118.6	12	14	26	13	169		
118.6	118.8	10	3	13	6.5	42.25		
118.8	119	12	11	23	11.5	132.25		
119	119.2	12	10	22	11	121		
119.2	119.4	12	13	25	12.5	156.25		
119.4	119.6	12	13	25	12.5	156.25		
119.6	119.8	16	15	31	15.5	240.25		
119.8	120	14	12	26	13	169		
120	120.2	14	12	26	13	169		
120.2	120.4	12	14	26	13	169		
120.4	120.6	14	16	30	15	225		
120.6	120.8	14	12	26	13	169		
120.8	121	14	12	26	13	169		
121		14	11	25	12.5	156.25		

Characteristic Rut Depth = X+2(SD) = 16.50mm

Table II Karimnagar – Warangal Road (121/00-118/00)

TABLE II

Karimnagar – Warangal Road (121/00-118/00)

Chainage		Rut Depth(mm)		Total	Average	X^2	Mean	SD
From	**To**	**LWP**	**RWP**		**X**			
118	118.2	13	13	26	13	169	13.094	1.268
118.2	118.4	12	12	24	12	144		
118.4	118.6	16	13	29	14.5	210.25		
118.6	118.8	9	18	27	13.5	182.25		
118.8	119	12	16	28	14	196		
119	119.2	14	13	27	13.5	182.25		
119.2	119.4	12	11	23	11.5	132.25		
119.4	119.6	13	14	27	13.5	182.25		
119.6	119.8	13	11	24	12	144		
119.8	120	16	14	30	15	225		
120	120.2	18	10	28	14	196		
120.2	120.4	12	13	25	12.5	156.25		
120.4	120.6	11	10	21	10.5	110.25		
120.6	120.8	14	11	25	12.5	156.25		
120.8	121	14	11	25	12.5	156.25		
121		14	16	30	15	225		

Characteristic Rut Depth = X+2(SD) = 15.63mm

Critical Road: Warangal – Karimnagar Road = Max Rut Depth = 16.50 mm

TABLE III

Warangal – Narsampet Road (12/00-15/00)

Chainage		Rut Depth(mm)		Total	Average	X^2	Mean	SD
From	To	LWP	RWP		X			
12	12.2	14	8	22	11	121	8.813	1.448
12.2	12.4	12	10	22	11	121		
12.4	12.6	14	6	20	10	100		
12.6	12.8	12	4	16	8	64		
12.8	13	10	6	16	8	64		
13	13.2	8	8	16	8	64		
13.2	13.4	15	6	21	10.5	110.25		
13.4	13.6	12	5	17	8.5	72.25		
13.6	13.8	10	6	16	8	64		
13.8	14	12	4	16	8	64		
14	14.2	11	3	14	7	49		
14.2	14.4	10	5	15	7.5	56.25		
14.4	14.6	14	8	22	11	121		
14.6	14.8	10	4	14	7	49		
14.8	15	14	5	19	9.5	90.25		
15		12	4	16	8	64		

Characteristic Rut Depth = X+2(SD) = 11.71mm

TABLE IV

Narasampet – Warangal Road (15/00-12/00)

Chainage		Rut Depth(mm)		Total	Average	X^2	Mean	SD
From	To	LWP	RWP		X			
12	12.2	12	4	16	8	64	9.594	2.417
12.2	12.4	10	3	13	6.5	42.25		
12.4	12.6	18	5	23	11.5	132.25		
12.6	12.8	24	6	30	15	225		
12.8	13	16	5	21	10.5	110.25		
13	13.2	17	3	20	10	100		
13.2	13.4	11	4	15	7.5	56.25		
13.4	13.6	13	3	16	8	64		
13.6	13.8	16	6	22	11	121		
13.8	14	15	8	23	11.5	132.25		
14	14.2	19	8	27	13.5	182.25		
14.2	14.4	14	4	18	9	81		
14.4	14.6	11	7	18	9	81		
14.6	14.8	12	3	15	7.5	56.25		
14.8	15	10	5	15	7.5	56.25		
15		12	3	15	7.5	56.25		

Characteristic Rut Depth = X+2(SD) = 14.43 mm

Critical Road: Narsampet – Warangal Road = Max Rut Depth = 14.43 mm

TABLE V

Warangal – Khammam Road (141/00-144/00)

Chainage		Rut Depth (mm)		Total	Average	X^2	Mean	SD
From	To	LWP	RWP		X			
141	141.2	15.5	16	31.5	15.75	248.0625	**14.231**	**1.614**
141.2	141.4	14	15	29	14.5	210.25		
141.4	141.6	14.5	16	30.5	15.25	232.5625		
141.6	141.8	17	12	29	14.5	210.25		
141.8	142	13	13	26	13	169		
142	142.2	16	12	28	14	196		
142.2	142.4	12.7	12	24.7	12.35	152.5225		
142.4	142.6	14	14	28	14	196		
142.6	142.8	14.5	14.5	29	14.5	210.25		
142.8	143	14	16.5	30.5	15.25	232.5625		
143	143.2	13.5	13.7	27.2	13.6	184.96		
143.2	143.4	14	13.5	27.2	13.75	189.0625		
143.4	143.6	15	21.5	36.5	18.25	333.0625		
143.6	143.8	13	13	26	13	169		
143.8	144	11	11	22	11	121		
144		15	15	30	15	225		

Characteristic Rut Depth = X+2(SD) = 17.46 mm

TABLE VI

Khammam – Warangal Road (141/00-144/00)

Chainage		RutDepth (mm)		Total	Average	X^2	Mean	SD
From	To	LWP	RWP		X			
141	141.2	13.3	14.5	28	14	196	13.847	2.160
141.2	141.4	13.5	15	28.5	14.25	203.0625		
141.4	141.6	13	13	26	13	169		
141.6	141.8	10	10	20	10	100		
141.8	142	10	12.5	22.5	11.25	126.5625		
142	142.2	12.5	11.7	24.2	12.1	146.41		
142.2	142.4	10	14.5	24.5	12.25	150.0625		
142.4	142.6	13	14.5	27.5	13.75	189.0625		
142.6	142.8	12	13.5	25.5	12.75	162.5625		
142.8	143	15	16	31	15.5	240.25		
143	143.2	11.5	13.7	25.2	12.6	158.76		
143.2	143.4	16	13.5	29.5	14.75	217.5625		
143.4	143.6	17	16.5	33.5	16.75	280.5625		
143.6	143.8	13.7	13.7	27.4	13.7	187.69		
143.8	144	17	17	34	17	289		
144		14	22	36	18	324		

Characteristic Rut Depth = X+2(SD) = 18.17 mm

Critical Road: Khammam – Warangal Road = Max Rut Depth = 18.17 mm

TABLE VII

Warangal – Hyderabad Road (126/00-129/00)

Chainage		Rut Depth (mm)		Total	Average	X^2	Mean	SD
From	To	LWP	RWP		X			
126	126.2	12	12	24	12	144	13.688	2.489
126.2	126.4	13	15	28	14	196		
126.4	126.6	14	14	28	14	196		
126.6	126.8	14	14	28	14	196		
126.8	127	12	13	25	12.5	156.25		
127	127.2	16	15	31	15.5	240.25		
127.2	127.4	16	16	32	16	256		
127.4	127.6	6	14	30	15	225		
127.6	127.8	12	17	29	14.5	210.25		
127.8	128	17	17	34	17	289		
128	128.2	16	16	32	16	256		
128.2	128.4	13	18	31	15.5	240.25		
128.4	128.6	14	13	27	13.5	182.25		
128.6	128.8	5	9	14	7	49		
128.8	129	14	15	29	14.5	210.25		
129		12	14	26	13	169		

Characteristic Rut Depth = X+2(SD) = 18.60 mm

Table VIII

Hyderabad -- Warangal Road (126/00-129/00)

Chainage		Rut Depth (mm)		Total	Average	X^2	Mean	SD
From	To	LWP	RWP		X			
126	126.2	28	24	52	26	676	15.156	3.124
126.2	126.4	15	15	30	15	225		
126.4	126.6	15	13	28	14	196		
126.6	126.8	15	17	32	16	256		
126.8	127	13	14	27	13.5	182.25		
127	127.2	14	14	28	14	196		
127.2	127.4	14	13	27	13.5	182.25		
127.4	127.6	15	14	29	14.5	210.25		
127.6	127.8	16	19	35	17.5	306.25		
127.8	128	13	13	26	13	169		
128	128.2	11	20	31	15.5	240.25		
128.2	128.4	12	14	26	13	169		
128.4	128.6	14	15	29	14.5	210.25		
128.6	128.8	14	16	30	15	225		
128.8	129	13	14	27	13.5	182.25		
129		12	16	28	14	196		

Characteristic Rut Depth = X+2(SD) = 21.40 mm

Critical Road: Hyderabad – Warangal Road = Max Rut Depth = 21.40 mm

TABLE IX

Warangal – Eturunagaram Road (147/00-150/00)

Chainage		Rut Depth (mm)		Total	Average	X^2	Mean	SD
From	To	LWP	RWP		X			
147	147.2	12	10	22	11	121	7.844	3.171
147.2	147.4	6	5	11	5.5	30.25		
147.4	147.6	11	11	22	11	121		
147.6	147.8	11	9	20	10	100		
147.8	148	1	13	14	7	49		
148	148.2	7	1	8	4	16		
148.2	148.4	8	5	13	6.5	42.25		
148.4	148.6	9	5	14	7	49		
148.6	148.8	16	10	26	13	169		
148.8	149	2	6	8	4	16		
149	149.2	12	5	17	8.5	72.25		
149.2	149.4	14	10	24	12	144		
149.4	149.6	9	4	13	6.5	42.25		
149.6	149.8	12	2	14	7	49		
149.8	150	13	8	21	10.5	110.25		
150		2	2	4	2	4		

Characteristic Rut Depth = X+2(SD) = 14.18 mm

TABLE X

Eturunagaram -- Warangal Road (147/00-150/00)

Chainage		Rut Depth (mm)		Total	Average	X^2	Mean	SD
From	To	LWP	RWP		X			
147	147.2	10	3	13	6.5	42.25	10.813	2.549
147.2	147.4	15	2	17	8.5	72.25		
147.4	147.6	15	1	16	8	64		
147.6	147.8	14	7	21	10.5	110.25		
147.8	148	9	11	20	10	100		
148	148.2	15	11	26	13	169		
148.2	148.4	16	12	28	14	196		
148.4	148.6	17	11	28	14	196		
148.6	148.8	8	8	16	8	64		
148.8	149	11	4	15	7.5	56.25		
149	149.2	15	10	25	12.5	156.25		
149.2	149.4	12	8	20	10	100		
149.4	149.6	12	10	22	11	121		
149.6	149.8	14	11	25	12.5	156.25		
149.8	150	16	11	27	13.5	182.25		
150		15	12	27	13.5	182.25		

Characteristic Rut Depth = X+2(SD) = 1115.91 mm

Critical Road: Eturunagaram –Warangal Road = Max Rut Depth = 15.91 mm

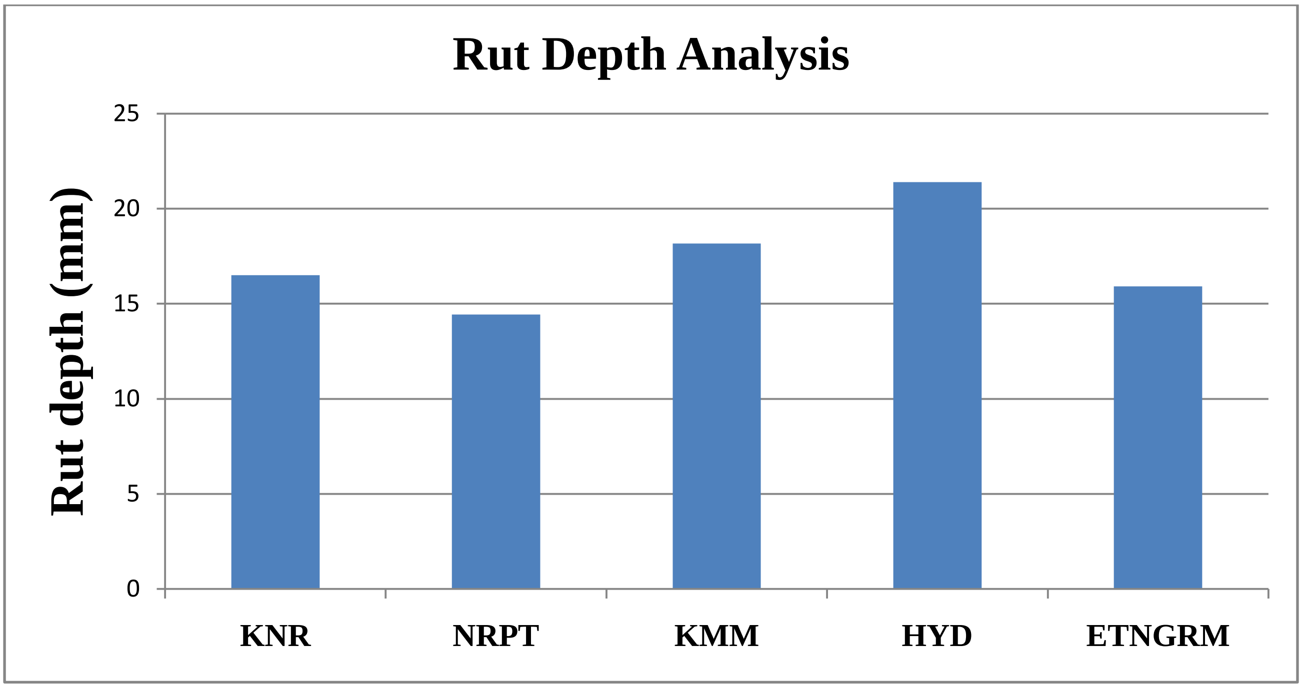

Fig.1 Rut Depth Analysis Chart

V.CONCLUSIONS

The share of the road transport, in the last four decades, has increased from 26% to 80% for passenger traffic and from 11% to 60% for goods traffic. The increase in vehicle population during the same period has been about 70 times. The trunk road network, consisting of NHs and SHs, though only about 8% of total road length, is responsible for catering to about 2/3 of goods traffic carried by the road sector in the country. Due to this there is an impact on functional and structural requirements of pavement. Therefore, highway pavements need to be monitored and maintenance strategies so as to maintain to the roads up to minimum levels of performance. Therefore the pavement need to be monitored and maintained by providing the thickness and maintenance strategies as to maintain roads up to minimum level of performance. In the light of above mentioned issues, there is an urgent need to develop scientific procedures for arranging pavements in an order that need maintenance or rehabilitation. Also pavements deterioration models are developed to predict the future values of various variables with the field values.

An attempt is made in this to develop a frame work for pavement maintenance as part of the overall management process for Indian conditions. The main focus is on the development of deterioration models which estimated the serviceability of the pavement and by this model predict the future deterioration of the pavement. By knowing the deterioration of pavement, different maintenance strategies can be used based on the distress type and preventative treatment can be used effectively.

REFERENCES

[1] Aggarwal S, Jain S.S and Parida M (2005), *Use of Pavement Management systems in Developing Countries*, Indian Highways.

[2] Aggarwal S, Jain S. S and Parida M (2002), *A critical Appraisal of pavement Management system*, Journal of the Indian Roads Congress, Volume 63-2

[3] Andreas L, Jonathan R and Siman C (2002), *Asphalt pavement deterioration models for wild climatic conditions, (web search).*

[4] Bassam S, Mitri H and Hormoz P (2005), *Three Dimensional dynamic analysis of Flexible conventional pavement foundation*, Journal of Transportation Engineering.© ASCE,

[5] Chakarbarti S, Ratwat M S and Mondal B (1995), *Highway Design and Maintenance Standards Model (HDM) Calibration and adaption of Indian conditions*, Journal of Indian Roads Congress, Volume 56-1, 75-101.

[6] Collopl A C and Cebon D (1995), *Parametric study of factors affecting flexible pavement performance*, 'Journal of Transportation Engineering', 121, 485 – 494.

[7] Dr. R. Gary Hicks, P.E. Stephen B. Seeds, P.E. David G. Peshkin, P.E. *Selecting a Preventive Maintenance Treatment for Flexible Pavement* Foundation for Pavement Preservation 2025 M Street, NW Suite 800 Washington, DC

[8] Ferreira A, Santos L P, Wu H and Flintsch G (2011), *'Selection of pavement Performance models for use in the Portuguese PMS'*, International Journal of Pavement Engineering, Vol-12, No.1, 87-97.

[9] Freeman R B and Harr M E (2004), *Stress Reduction for Flexible Pavement Systems'*, Journal of Transportation Engineering © ASCE, 496- 502.

[10] Fujie Z, Tom S and Lijun S (2004), *Verification and modelling of three stage Permanent deformation behaviour* of asphalt mixes, Journal of Transportation Engineering © ASCE,

[11]Gedafa D S (2006), *Comparison of flexible pavement performance using KENLAYER and HDM–4'*, Fall Student Conference, Ames, Iowa (Web Search).

[12] Gedafa D S (2007), *Performance prediction and maintenance of flexible pavement*, Proc. Mid-continent transportation research symposium, Ames, Iowa.

[13] Jain S S, Parida M and Rawat M S (1998), '*A Rational Approach for Pavement Management System for Urban Roads*', Journal of Indian Roads Congress, 70-99

[14]Jain S S, Parida M and Aggarwal S (2004), *Application of HDM-4 for network level pavement management system for Indian National Highway network*.' CE & CR,46-55.

[15] Jain S S, Aggarwal S & Parida M (2005), *HDM-4 Pavement Deterioration Models for Indian National Highway Network*', Journal of Transportation Engineering © ASCE 623-631.

[16] J.A., Prozzi, M.ASCE, and S.M. Madanat, M.ASCE *Development of pavement performance models by combining experimental and Field Data*, journal of infrastructure systems (c) ASCE / march 2004.

[17] Joseph M A, Sreedevi B G and Elangovan T (2004), *Reliability based pavement design charts for low volume roads in Kerala'*, Indian Highways, 25 – 33.

[18] John E Patrick and Dr. Rosslyn Bailey., *Use of Pavement Deterioration Models in Pavement Design*, Opus International consultants, New Zealand.