Development of Pavement Roughness Model and Maintenance Priority Index for Kerala State Highway I

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***Abstract*—The present study developed a Maintenance Priority Index (MPI) for the six sections of the State Highway (SH-1) using certain factors affecting pavement maintenance. The factors considered in this study were pavement condition, riding quality, traffic characteristics, land use characteristics and characteristic deflection of the pavement. A relationship between pavement roughness and distress parameters like area of ravelling, cracked area etc. also developed. The pavement distress data was collected on SH stretching from Vetturoad to Adoor. Roughness survey was conducted using Bump integrator and Benkelman beam was used for the measurement of deflections in the pavement. Pavement Condition Indexes (PCI) for each section was determined. The relation between pavement distress and pavement roughness was modelled using Multiple Linear Regression (MLR) analysis. The models were significant as the forecasting errors were within the limits.**

Keywords—Maintenance Priority Index, Pavement condition Index, Distress parameters, Pavement roughness.

I. INTRODUCTION

Pavement evaluation is an integral part of the Pavement Management System (PMS). Evaluating structural condition and functional condition of existing, in-service pavements constitutes annually a major part of the maintenance and rehabilitation activities undertaken by State Highway Agencies. The structural and functional condition of the pavements changes with passage of time due to the combined effects of its structural adequacy, composition and loading characteristics of traffic, environment conditions and the maintenance inputs provided. The process of accumulation of damage is called deterioration and the failure of pavement is said to have reached at the limiting stage of serviceability level. The physical sign of internal damage, for example cracking, rutting, potholes etc. are known as distress, which are the indicators of the pavement condition.

Pavement visual condition surveys are used for the measurement of pavement distresses. Pavement condition index and pavement roughness are used as indices for representing pavement functional condition. Structural condition of the pavement generally evaluated in terms of characteristic deflection of the pavements. Roughness has been universally accepted as a measure of functional condition of a pavement. The riding quality of the road pavement, major indicator of its service performance, was determined using the international roughness index (IRI).

Maintenance Priority Index (MPI) is a rating used to prioritize the maintenance schedule of pavement based on the certain factors affecting maintenance. The present study develops a Maintenance Priority Index by using PCI, IRI, traffic, land use characteristic and characteristic deflection of pavement.

The present research study was limited to six road sections distributed on one State High way road in Thiruvananthapuram district of the state of Kerala.

II. OBJECTIVES OF STUDY

Objectives of the study included,

- Identification of the different types of distresses on flexible pavement.
- Determination of the pavement condition index of the pavement.
- Development of a relationship between pavement distresses, age and pavement roughness.
- Development of a Maintenance Priority Index for the pavement.

III. LITERATURE REVIEW

In order to achieve a clear knowledge in the field of pavement performance and modelling techniques, a literature review was performed. Large numbers of studies have been conducted globally for developing pavement performance models.

Reddy and Veeraragavan (1997) developed deterioration models for in-service flexible pavements in India. They modelled future condition as the function of present condition, pavement strength, incremental traffic and age characteristics, and climate.

Mactutis et al.(2000) developed linear regression models between IRI and percentage cracking and average rut depth on a pavement. They considered 317 observations for model development.

Reddy and Veereragavan (2001) developed a priority ranking model for managing flexible pavements at network level. In this paper a priority ranking module that provides a systematic procedure to prioritize road pavement sections for improvement and selection of suitable maintenance strategies depending upon the budget is developed.

Sathyakumar and Vijayakumar(2004) reported a methodology for priority ranking of highway pavements for maintenance based on composite criteria. Questionnaire survey was used capture expert opinion and user opinion followed by functional evaluation to determine the crack area, percentage of potholes and present serviceability index.

Sreedevi (2006) developed an improvement priority index based on road inventory data, functional condition of the road, tourism potential and importance of the connecting primary road. This paper deals with the studies conducted on 80 road links connecting to tourist destinations having a total length of 441 km for improvement.

Sung-Hee Kim and Nakseok Kim (2006) developed a performance prediction model in flexible pavements using regression analysis method. Their conclusion were the multiple linear regression model is effective to forecast pavement performance when ratings with various Average Annual Daily Traffic (AADT)

Adebayo Owalabi and O. S. Abiola (2010) developed a priority assessment index for pavement management system (PMS) in Nigeria using artificial neural network (ANN) and linear regression. The variables such as traffic volume, pavement condition score and roughness index etc were combined into a convenient scale to get a single priority assessment index.

Muralikrishna and Veeraragavan (2011) In this study pavement deterioration models were developed to predict the performance and decide appropriate maintenance decisions at the right time. Roughness and deflection progression equations were developed using Statistical Packages for Social Sciences (SPSS). . Road user cost models and Life cycle cost analysis were used to compute the optimal timing and optimal option of maintenance strategies.

Different types of techniques were used for the development of the pavement performance prediction models.. Many of these models are developed for a particular region or country under specific traffic and climatic conditions. Different methods for modelling and prioritization methods were reviewed.

IV. RESEARCH METHODOLOGY

Methodology includes review of earlier projects, selection of study area, data collection, data analysis, and development of pavement Roughness model and development of Maintenance Priority Index. Study area stretches were selected based on the category of the road, terrain and traffic conditions, geographical location etc. Six road stretches distributed on one roads were selected for the study.

Data collection was done by primary and secondary survey. Primary data collection was done by field survey. Secondary data was collected from National Transportation Planning and Research Centre (NATPAC).The data collected were analysed to determine the performance parameters. The percentage of distresses, deflection and roughness value in m/km were determined by data analysis.

The model development involved identification of influencing parameters. Multiple linear regression models for six stretches were developed. The first step of Maintenance Priority Index development was the identification of factors affecting pavement maintenance. The composite index method used for the calculation of Maintenance Priority Index.

V. COLLECTION OF DATA

A. Study Area

A safe-corridor road safety project, 75-km stretch of State Highway1 (SH 1) from Vettu Road, near Kazhakuttam in Thiruvananthapuram, to Adoor in Pathanamthitta district in the second phase of the Kerala State Transport Project (KSTP) has been selected for the study. The study road was divided to six equal sections having 12.5 km length. Homogenous sections were selected as the study stretches on the study roads based on the factors like traffic, pavement layer details, type of surfacing, general surface condition, subgrade soil conditions and terrain type. Details of the homogenousroad sections are shown in the Table 1. Study stretches are shown in the Figure 1.

TABLE I. DISTRESSES ON DIFFERENT STRETCHES

Sl no.	Road section	Section ID	Section name
1	SH 1 Kazhakoottam-Adoor road(75Km)	HS 1	Pothencode-Alanthara
2		HS 2	Alanthara-Thattathumala
3		HS 3	Thattathumala-Ayur
4		HS 4	Ayur-Thrikannamangal
5		HS 5	Thrikannamangal –Thekkethery
6		HS 6	Thekkethery-Adoor

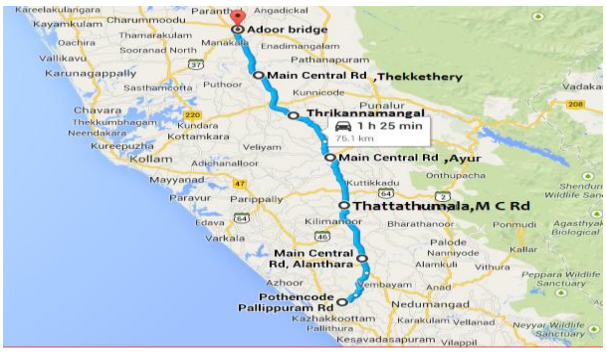

Fig. 1. Study road stretch

B. Pavement details

Pavement details collected in this study include pavement layer details, time of construction etc, which was collected from the NATPAC. The pavement surface is bituminous concrete 25mm thick providing on 50mm thick bituminous macadam. The study road is two lane and construction completed in the year of 2004.

C. Structural condition data

The structural condition data collected for the study include road inventory data and deflection measurement using Benkelman Beam. Road inventory details of pavement type, terrain, carriage way width, land use etc were collected from the NATPAC.Benkelman beam is a device used to measure the rebound deflection of pavement.Deflections were measured at 20 points in each kilometre, staggered at 50 meter interval in both directions with truck having rear axle load of 8.17tonnes and tyre pressure of 5.6 kg/cm^2. The measurements are taken as per the procedure given in IRC:81 (1997).

D. Functional condition data

Functional condition data were collected by visual condition survey. The different types of distress observed on these roads included ravelling, cracking, potholes and bleeding. The distresses were measured in terms of their severity. Pavement surface condition rating manual and distress identification manual are used for the identification of different distress and their severity.

Roughness of pavement is an indication of its riding quality. The fifth wheel bump integrator was used for the roughness measurement. It comprises of a standard pneumatic wheel mounted within a rectangular frame with single leaf spring on either side. Integrating unit, mounted on one side of the frame integrates the unevenness in centimeter for the measurement. For every 1mm/2.5cm of cumulative bumps, the bump recording counter registers one unit.Roughness of the six pavement stretches were in the range of 2.8- 4.1 m/km. Riding quality of the study road was average.

VI. DATA ANALYSIS AND RESULTS

Data collected from primary and secondary surveys were analysed. From the detailed functional data collected, distresses were expressed as percentage of the carriageway affected. Pavement condition index calculated using the results of visual condition survey. A relationship between pavement roughness and pavement distresses were developed using SPSS. Maintenance Priority Index (MPI) were developed using composite index method.

A. Visual Condition Survey

Visual condition survey was conducted separately on each stretch of the road. The different types of distress identified on the stretch are ravelling, potholes, longitudinal crack, alligator crack, block crack and bleeding. Percentage distresses on different stretches are shown in Table 2.

Results of the visual condition survey are following.

- The ravelling percentage was high, but large quantity ravelling was low severity.
- Bowl-shaped small sizes holes, low severity potholes were present on the pavement surface.
- Low severity longitudinal cracks were present on the pavement.
- Alligator cracks and block cracks with low and moderate severity were noted.
- Edge break, bleeding, etc were noticed.
- Rutting was not present in the pavement.
- Major distress like potholes and cracks were in very low percentage.

TABLE II. DISTRESSES ON DIFFERENT STRETCHES

Section	Distress	Percentage of distress
HS 1	Ravelling	34.45
	Crack	1.12
	Pothole	0.006
	Bleeding	0.066
HS 2	Ravelling	32.74
	Crack	1.28
	Pothole	0.006
	Bleeding	0.026
HS 3	Ravelling	31.30
	Crack	1.2
	Pothole	0.007
	Bleeding	0.069
HS 4	Ravelling	31.3
	Crack	1.12
	Pothole	0.008
	Patching	0.008
HS 5	Ravelling	30.8
	Crack	1.25
	Pothole	0.007
	Bleeding	0.056
HS 6	Ravelling	30
	Crack	1.12
	Pothole	0.005

B. Pavement Condition Index (PCI)

Pavement Condition Index (PCI) is a numerical index, ranging from 0 for a failed pavement to 100 for a pavement in perfect condition. Calculation of the PCI is based on the result of visual condition survey in which distress type, severity, quantity are identified. PCI values calculated for the stretches are shown in Table 3.

TABLE III. CALCULATED PCI VALUE

Name of road	PCI	Pavement Condition
HS 1	76	Good
HS 2	78	Good
HS 3	78	Good
HS 4	78	Good
HS 5	83	Good
HS 6	80	Good

Six homogenous pavement stretches are in functionally good condition. Pothencode-Alanthara Section (HS 1) was less PCI compared to other sections due to higher distresses.

C. Benkelman Beam Deflection Method

The deflections on each section were calculated using Benkelman beam deflection method and values are shown in the Table 4. The deflections in different sections are within the standard limits. The deflection measured on the study stretches of SH 1 varied from 0.29 to 0.54mm, so the study stretches of the road are reasonably strong.

TABLE IV. DEFLECTIONS ON EACH SECTION

Road sections	Deflection
HS 1	0.34
HS 2	0.29
HS 3	0.37
HS 4	0.53
HS 5	0.54
HS 6	0.59

D. Relationship between Roughness And Distress Data

An attempt has been made to develop mathematical relationship between distress parameters and pavement roughness. For developing the relationship, continuous seven year distress and roughness data obtained from NATPAC, were used. Pavement evaluation surveys were conducted by NATPAC every year on the study stretches before and after monsoon. For the model development, data pertaining to pavement age, ravelling, crack data were used. A scatter plot showing the relationship between Roughness and other variables is shown in Fig. 2 to Fig. 4

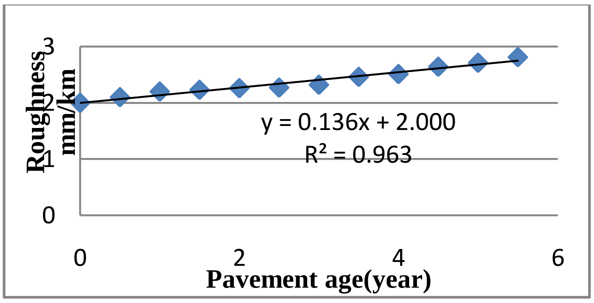

Fig. 2. Scatter plot of Pavement roughness and Pavement age

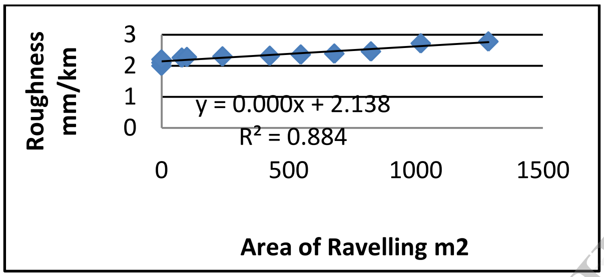

Fig. 3. Scatter plot of Pavement roughness and Ravelling

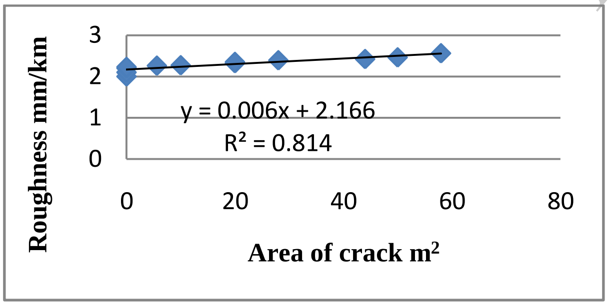

Fig. 4. Scatter plot of Pavement roughness and Crack

From the scatter diagrams, it is understood that Ravelling, cracks and pavement age has a linear relationship with Pavement roughness, i.e as the ravelling, crack and pavement age increases, roughness also increases.

Multiple linear regression analysis was carried out for the data of the each study stretch separately to determine the functional relationship between roughness and distress parameters. Regression models were developed by Statistical Packages for Social Sciences (SPSS). The following form of relation is assumed;

$$IRI = a_0 + a_1*R + a_2*C + a_3*A \quad (1)$$

where, a_0 = model constant; and a_1, a_2, and a_3 = coefficients of area of raveling (R), crack(C) and age of the pavement (A), respectively. R and C are expressed in m^2.

Among the data set, 90% of the data were used for model development in SPSS.The models developed for the different stretches are shown in Table 5. The coefficients of the variables were found to be significant in the 95% confidence interval.

TABLE V. MODELS DEVELOPED

Road sections	Model	R^2
HS 1	IRI=2.048+(0.001*R)-(0.015*C)+(0.08*A)	0.966
HS 2	IRI=2.035+(0.001*R)-(0.011*C)+(0.107*A)	0.981
HS 3	IRI=2.047+(0.001*R)-(0.007*C)+(0.074*A)	0.991
HS 4	IRI=2.072+(0.001*R)-(0.008*C)+(0.06*A)	0.981
HS 5	IRI=2.054+(0.001*R)-(0.015*C)+(0.05*A)	0.988
HS 6	IRI=2.058+(0.001*A3)-(0.014*C)+(0.053*A)	0.985

In all models crack showed less influence compared to other variables. This is because cracked area was comparatively less than area of ravelling. In all sections ravelling was present. Age of pavement has great influence in pavement roughness. The pavement deteriorations and distresses increase with time. Fig. 5shows predicted and observed roughness on each stretches.

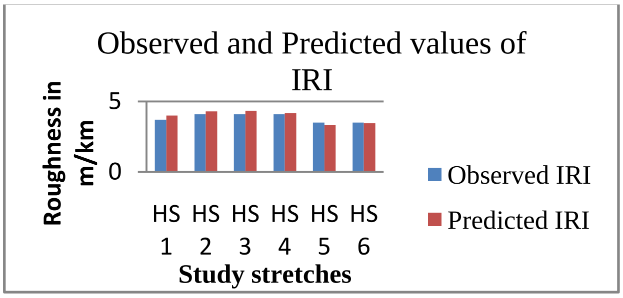

Fig. 5. Comparison of predicted and observed roughness on different stretches

Models developed were validated in terms of forecasting errors and goodness of fit. 10% data were used for model validation.Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Mean average percentage error (MAPE) were computed. The MAE and RMSE indicate how close the predicted values of IRI are to the observed values. MAE, RMSE and MAPE were calculated and shown in Table 6.

TABLE VI. CALCULATED MAE AND RMSE OF MODELS

Road section	MAE	RMSE	MAPE (%)
HS 1	0.34	0.346	10.45
HS 2	0.46	0.5	13.4
HS 3	0.53	0.563	14
HS 4	0.39	0.45	11
HS 5	0.09	0.104	2.7
HS 6	0.13	0.168	4.13

The values of MAE and RMSE were very low for all sections. So the developed models are more significant. MAPE expressed in percentage. If MAPE value is less the model is very significant. The MAPE value was higher for third section (HS 3). This is due to variation between observed and predicted IRI was high (7%) at section 3.

Models developed were checked for goodness of fit by plotting observed and Predicted IRI. R^2 values of all models developed were more than 0.5 and found to the significant.

E. Maintenance Priority Ranking

Maintenance priority ranking means prioritise the pavements based on the importance and urgency of repair to that section. The composite maintenance priority index was selected for pavement maintenance priority ranking procedure.

In maintenance priority-ranking procedure, a maintenance priority index (MPI) is calculated for every section that reflects the importance and urgency of repair to that section. MPI is calculated by multiplying each priority factor value by its weight and summing the products as follows:

$$MPI = \sum_{i=1}^{n} Vi * Wi \qquad (2)$$

Where, MPI = Maintenance Priority Index for any section,

W = Priority factor weight of importance to priority ranking

V = Priority factor value, (out of 100)

i = Index for the selected priority factors.

Priority factors considered for this study are traffic characteristics, functional condition factors, structural condition factors and land use characteristics. The values of priority factors are normalized to 100. Functional condition factors considered are pavement roughness (IRI) and pavement condition (PCI). Structural condition factor considered is characteristic pavement deflection. The priority factor value is either a measurable one such as pavement condition, operating traffic, measured riding quality as pavement roughness, or it is a qualitative one such as land use.

Priority factors and their weightage considered in this study are shown in the Table 7 below.The weightages were calculated by rank order centroid method.

TABLE VII. FACTORS AND THEIR IMPORTANCE

Factors	Weightage
Traffic	0.52
Structural condition	0.27
Functional condition	0.15
Land use	0.06

Maintenance Priority Index and the priority order for selected road sections were calculated and given in Table 8.

TABLE VIII. PRIORITY INDEX FOR PAVEMENT SECTIONS

Section	Traffic Index	Land use index	Structural condition index	Functional condition index	MPI	Priority Order
HS1	2.45	0.78	2.04	2.49	7.69	5
HS2	2.45	0.78	1.74	1.12	7.56	6
HS3	13.96	0.44	6.11	1.21	23.16	1
HS4	9.28	0.44	8.75	0.98	21.01	2
HS5	8.64	0.23	8.91	1.02	18.88	4
HS6	9.53	0.23	9.74	1.15	20.61	3

It was found that Maintenance Priority Index (MPI) is higher in the Thattathumala-Ayur section (HS3). This is because traffic on that section is high compared to other stretches. MPI value is lower at Alanthara-Thattathimala section (HS 2). The maintenance priority order was provided based on the maintenance priority index. The section with high maintenance priority index has first priority for maintenance. Maintenance Priority order for the road sections is show in Fig. 6.

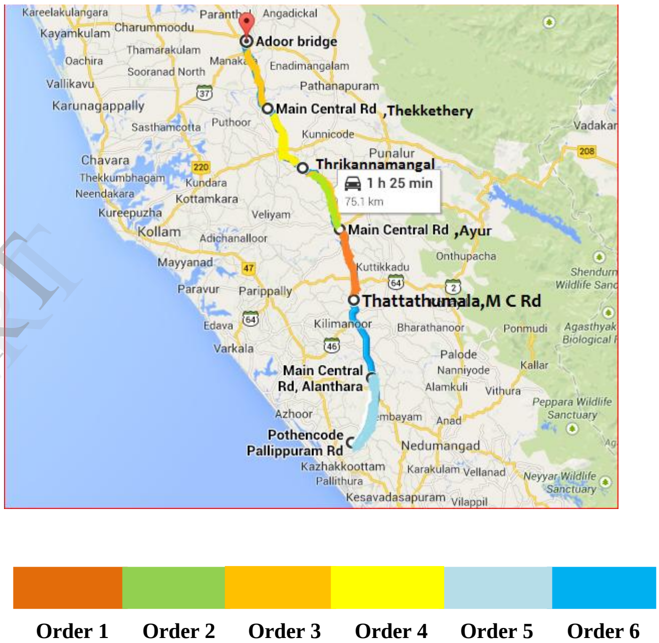

Fig. 6. Maintenance priority order of the sections on the study road

Based on MPI, concerned authority can decide the priority of road sections for maintenance work. It is suggested that if a road has either pavement condition index or roughness value or deflection value more than its permissible limit then irrespective of its MPI, preference should be given to that road for maintenance work.

VII. SUMMARY AND CONCLUSIONS

In this study six sections on the study road were considered. Detailed pavement evaluation surveys were conducted. The main distresses identified on the roads were ravelling, potholes and cracking. Pavement Condition Index for selected road stretches was calculated. Multiple linear regression models were developed for pavement roughness in each section in the study stretch. Independent variables selected for the models were found to be statistically significant. The developed models were validated and the performance was evaluate

Maintenance priority index was developed by composite index method. The factors affecting maintenance considered in the study were traffic volume, pavement roughness, pavement deflection, land use, pavement condition etc. The pavement sections were prioritized based on the maintenance priority index.

Maintenance priority index was higher at Thattathumala-Ayur section (HS3). So the maintenance work should be first conducted at this section. The MPI was lower at Alanthara – thattathumala section(HS 2). MPI can be used as a good maintenance scheduling tool in Pavement Management System (PMS).

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REFERENCES

[1] Gupta,A., Kumar,P., and Rastogi, R.(2011). “Pavement Deterioration and Maintenance Model for Low Volume Roads”, *International Journal of Pavement Research and Technology*, Vol.4 (4).

[2] Essam, A., Sharaf and Fathy, M., Mandeel (1998). “An analysis of the impact of different priority setting Techniques on network pavement condition” ,4th International Conference on Managing Pavements.

[3] Gasper, L.,Veeraragavan, A., and Bako (2009). “Comparison of road performance modelling of India and Hungary”, *Acta Technica Jaurinensis* , Vol. 2(1).

[4] Gharaibeh, N., Zou, Y., and Saliminejad, S. (2010). “Assessing the Agreement among Pavement Condition Indexes” , J. Transp. Eng., Vol.136(8), 765–772.

[5] Gupta, Kumar, P., and Rastogi, R. (2012). “Critical review of flexible pavement performance models developed for Indian perspective” , Indian Highways, *J. Indian Roads Congress*, Vol.40(3), 41-60.

[6] IRC: 81. (1997). “Guidelines for Strengthening of Flexible Road Pavements Using Benkelman Beam Deflection Technique”, Indian Roads Congress.

[7] IRC: SP: 16. (2004). “Guidelines for Surface Evenness of Highway Pavements (First Revision)”, Indian Roads Congress

[8] Jain, K.1, Jain, S.S., Chauhan, M.P.S.(2012). “Schedule and Condition Responsive Maintenance Strategies for Optimum Utilization of Maintenance Budget” , *International Journal of Engineering Research and Development*, Vol.1(8), 47-53

[9] Muralikrishna, P., and Veeraragavan. (2011). “Decision support system for performance based maintenance management of highway pavements.” *J. Transp. Research Board*, Vol.2205,155-167.

[10] Reddy, B.B, Veeraragavan, A. (2001). “Priority ranking model for managing flexible pavements at network level.” *J. Indian Roads Congress*, Vol.62(2), 379-394.

[11] Reddy, B.B., and Veeraragavan, A. (1997). “Deterioration models for in service flexible pavements in India”, *Proc. XIIIth Int. Road Federation world meeting* Toronto, Ontario, Canada.

[12] Sandeep Choudhary, Agarwal, P. K. (2013) “An Innovative Strategy for Maintenance of Highway Pavement” ,*International Journal of Engineering Research and Applications* , Vol. 3(3), 54-60

[13] Sathish Chandra, Chalumuri RaviSekhar, Anish Kumar Bharati and B.Kangadurai (2013). “Relationship between Pavement Roughness and Distress Parameters for Indian Highways” ,*Journal of Transportation Engineering, ASCE* ,Vol.139(5).

[14] Sathyakumar,M.,and Vijayakumar, V.N.(2004). “Development of methodology for priority ranking of highway pavements for maintenance based on composite criteria” Highway Research Bulletin, 31-49 .

[15]Sreedevi,B,G,(2006),"Prioritization of roads for improvement- A case study of road links connecting to tourist destinations in Kerala", Journal OfIndianRoadsCongress,253-260