Pavement maintenance and prioritization using AHP: A case study of Rajkot city

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Abstract *:* The road network is deteriorating by climatic factors as well as traffic operations on it. By neglecting to maintain these roads, deterioration rapidly increases over time leading to inaccessibility and immobility in urban areas. Also increases vehicle operating cost. A systematic approach needs to be developed for deciding effective maintenance and rehabilitation strategies which should incorporate all the processes involved in the formulation of pavement maintenance plans and programs. The application of Analytic Hierarchy Process (AHP) method for the prioritization of pavement maintenance sections is widespread now-a-days. Although the evaluation of pavement maintenance section through AHP method is simple, where the relative importance (on Saaty's scale) assigned to each parameter in the hierarchy varies between the experts (transportation professionals) consulted, which leads to discrepancies in the final rankings of the sections', due to the subjectivity in the process. Further, experts base their decisions solely on their experience while consideration is not given to the actual quantitative physical condition of the roads. To overcome these difficulties an objective based AHP method is proposed in this study, where pair wise comparison values are assigned based on the collected field data from a road network in Rajkot city, consisting of 2 road sections. The final ranking list of candidate sections takes into consideration the priority weight of alternatives, which reflect the road conditions. The parameter or alternative was ranked first which has highest weightage value and it was more prior than other so, considered first for the maintenance work.

***Keywords* - Analytic Hierarchy Process (AHP); Maintenance Prioritization; Priority ranking.**

I. INTRODUCTION

The development of any country is depends upon a transportation system. Road transportation system makes crucial contribution to economic & social development and growth for the nation. Also brings important social benefits for a nation. In India a huge portion of the roads are urban roads. Urban road in India are imperative piece of urban improvement and it secures common development by providing access to economic and social infrastructure and facilities. But these roads are deteriorating by climatic factors as well as traffic operations on it. By neglecting to maintain these roads, deterioration rapidly increases over time leading to inaccessibility and immobility in urban areas. Lack of maintenance affects people badly as the time for access to markets and other social infrastructure is increased. Also affects on vehicle operating cost and road user safety. Many agencies construct urban roads without a sustainable maintenance arrangement in place. For developing and maintaining a good road network requires scrupulous planning, enormous funds, construction techniques, strict quality control and other related aspects. Due to budget constraints, it is not possible to carry out maintenance and rehabilitation work of the all roads at a time. A systematic approach needs to be developed for deciding effective maintenance and rehabilitation strategies which should incorporate all the processes involved in the formulation of pavement maintenance plans and programs and for that the concept of pavement maintenance prioritization is necessary to be carried out. To prioritize pavement maintenance activities, a number of decision making methods have been introduced and implemented under Pavement Management System (PMS) study. These methods vary from simple ranking to complex optimization. The main objective of the PMS is to avoid the bias derived from judgment and help in the decision-making by using objective information based on pavement distress and other objective measures. Most of the highway agencies have adopted a practice of expressing the pavement maintenance priority in the form of priority index, which is computed by means of empirical expression. Although using a mathematical equation is convenient, often they do not have a clear physical meaning and cannot accurately combine different factors into a single equation. This inevitably leads to overlooking of various contributing effects of actual characteristics of distress. Furthermore, not all the factors and parameters involved can be expressed quantitatively and measured in compatible units. In view of these shortcomings and constraints, Analytic Hierarchy Process (AHP) is the most suitable choice for the prioritization of pavement sections for maintenance at network level. Although the evaluation of the pavement maintenance section through AHP method is simple, but the relative importance (on Saaty's scale) assigned to each parameter in the hierarchy varies between the experts (transportation professionals) consulted, which leads to discrepancies in the final rankings of the sections. Hence the process can be termed subjective. Further, experts base their decisions solely on their experience while due consideration is not given to the actual quantitative physical condition of the roads. To overcome these difficulties an objective based AHP method is proposed in this study, where pair wise comparison values are assigned based on the collected field data from a road network in Rajkot city, consisting of 2 flexible road sections.

II. STUDY AREA

General of study area:

Rajkot city is selected as study area for the project work. Rajkot is the fourth-largest city in the state of Gujarat, India, after Ahmadabad, Surat and Vadodara. Rajkot is the centre of the Saurashtra region of Gujarat. Rajkot is the 35th-largest urban agglomeration in India, with a population of more than 1.3 million. Total road network length of Rajkot city is 2291km (RMC area: 1799km, RUDA area: 492km).

Study road section:

For the study of pavement maintenance prioritization, three Road sections of length 1 km is selected from study area (Rajkot city). The road section-1 starts from Shyamal intersection (0 km) and ends at Vagal chowk (1 km). The road section-2 starts from Vagal chowk (0 km) and ends at Udgam School (1 km). These road stretches carries all the type of vehicles and also has many merging and diverging roads, so they also contribute in additional number of vehicles. So, these roads are important roadway in Rajkot city.

Figure-1 Road map of selected stretch-1 (Shyamal intersection to Vagal chowk)

Figure-2 Road map of selected stretch-2 (Vagal chowk to Udgam school)

III. METHODOLOGY

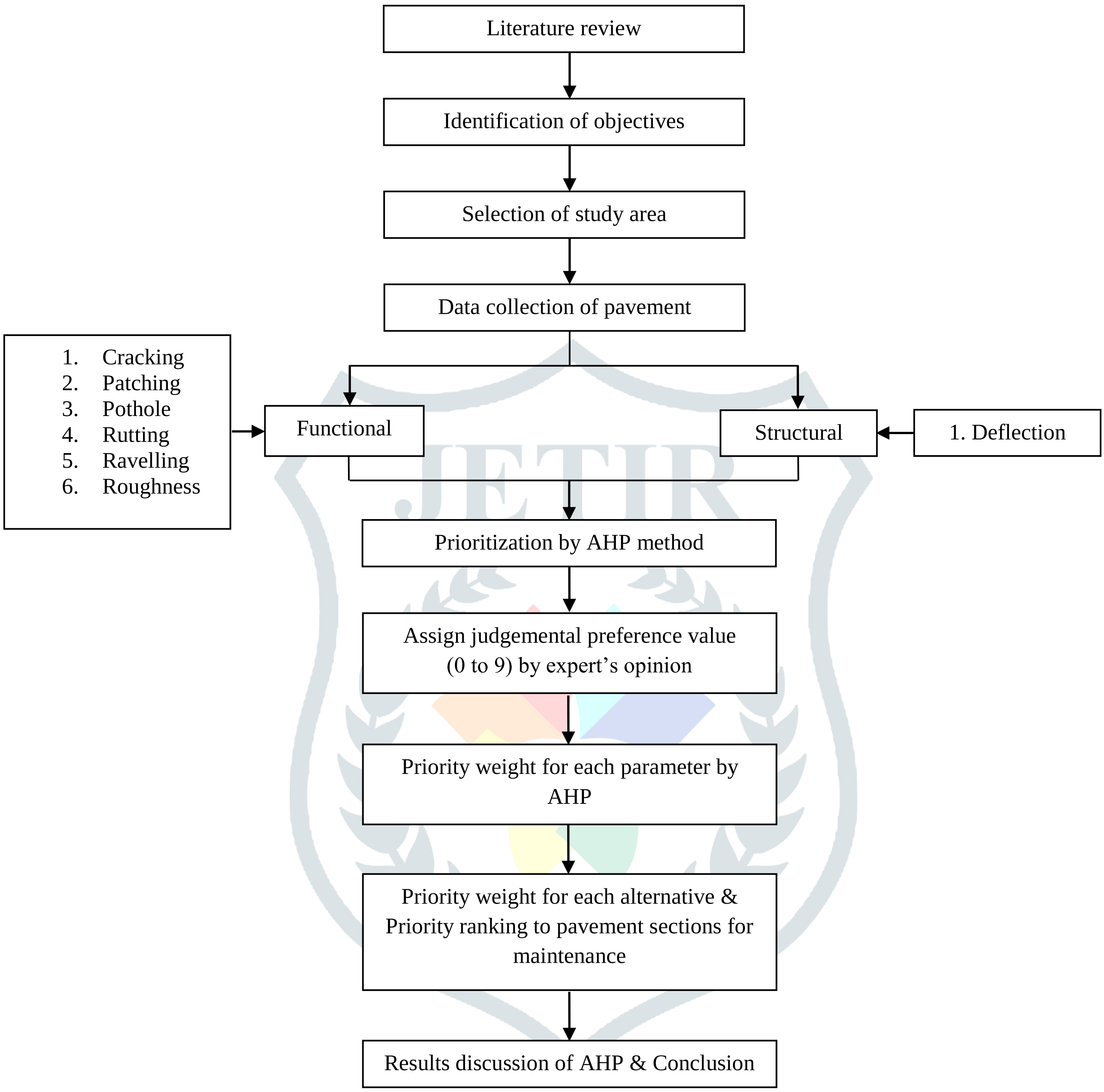

Figure-3 Framework of study methodology

IV. DATA COLLECTION

1) Road inventory data
2) Traffic Volume data
3) Distress data by visual inspection
4) Roughness data for functional evaluation (Using Bump integrator)
5) Deflection data for structural evaluation (Using Benkelmen Beam Deflection)

Road inventory data:

General road information was collected as road inventory data. It includes name of road section, type of road section, type of road pavement, total width of road section, length of road section, carriageway width, shoulder width, median width etc.

Table-1 Road inventory data of study road sections

Name of road section	Shyamal intersection to Vagal chowk	Vagal chowk to Udgam school
Type of road section	Four lane divided	Four lane divided
Pavement Type	Flexible	Flexible
Total width of road	24.384 m	24.384 m
Length of road section	1000 m	1000 m
Carriageway width	7.774 m	7 m
Shoulder width	1.524 m	1.524 m
Median width	0.923 m	0.923 m

Traffic volume data:

The video-graphy survey of 12 hours (8:00 am to 8:00 pm) was conducted on selected road section-1 and road section-2. The classified volume count was carried out from the video graphy survey to extract traffic volume according to category wise vehicle count. Traffic volume count from the video-graphy was carried out fewer than 9 categories such as, Two-wheeler, Auto, Car, Truck, Bus, Light commercial vehicle, Multi-axle vehicle, Non-motorized and pedestrian. The traffic volume was converted into PCUs by using PCU value for particular category of vehicle as per Indian Highway Capacity Manual (Indo HCM – 2017).

Table-2 Classified traffic volume at study road section-1

Vehicle types	Shyamal intersection to Vagal chowk			Vagal chowk to Shyamal intersection		
	Number of vehicle	PCU of vehicle	TV in PCUs	Number of vehicle	PCU of vehicle	TV in PCUs
Two-wheeler	2615	0.36	949	2122	0.37	792
Auto	259	0.58	156	132	0.49	69
Car	1889	1	1889	1222	1	1222
Truck	377	3.18	1206	386	3.42	1327
Bus	76	1.62	128	38	1.62	67
LCV	617	2.41	1491	696	2.62	1832
MAV	184	4.56	844	208	5.04	1053
NM	80	0.34	35	49	0.34	23
Pedestrian	190	-	-	190	-	-
TOTAL	**6097**	**-**	**6698**	**4853**	**-**	**6385**

Table-3 Classified traffic volume at study road section-2

Vehicle types	**Vagal chowk to Udgam school**			**Udgam school to Vagal chowk**		
	Number of vehicle	PCU of vehicle	TV in PCUs	Number of vehicle	PCU of vehicle	TV in PCUs
Two-wheeler	2619	0.34	890	3943	0.39	1539
Auto	141	0.39	54	185	0.39	72
Car	2114	1	2114	2205	1	2205
Truck	458	3.30	1514	520	3.18	1653
Bus	97	1.93	188	144	1.93	216
LCV	739	2.46	1819	714	2.36	1685
MAV	294	5.52	1623	297	5.04	1497
NM	94	0.34	31	148	0.34	51
Pedestrian	121	-	-	194	-	-
TOTAL	**6556**	**-**	**8233**	**8157**	**-**	**8978**

Distress data:

The major distresses of flexible pavement which was present on the both study road sections (flexible pavement) measured in both directions upward side and downward side. The study roads were divided into 10 sections of length 100m and then after distresses were measured on both directions of both road sections. The distress data includes, Alligator cracking, Longitudinal cracking, Transverse cracking, Rutting, Ravelling, Patching, Potholes, Roughness and Deflection etc. And also the severity levels of present distresses are measured according to guidelines of pavement distress identification manual. From the measured area of distresses, percentage area defected by particular distresses were calculated.

Table-4 Percentage area defected by particular type of distress (%) for both study road sections

Distress Type	Percentage area defected by particular type of distress (%)			
	Road section-1		Road section-2	
	Shyamal intersection to Vagal chowk	Vagal chowk to shyamal intersection	Vagal chowk to Udgam school	Udgam school to Vagal chowk
AC (%)	2.941	2.249	5.207	3.254
RUT (%)	0.336	0.221	3.801	2.194
RAV (%)	0.689	0.388	7.995	4.312
POT (%)	0.017	0.009	0.027	0.392
PAT (%)	2.053	0.656	0	0
LC % (m)	0.391	0.272	0.973	1.440
TC % (m)	0.371	0.270	0.419	0.501

Roughness data (Functional evaluation):

Roughness or unevenness is an important pavement characteristic because it affects riding quality of pavement. Roughness or unevenness data was carried out by Fifth Wheel Bump Integrator on selected stretches of road section. Bump Integrator shows no. of bumps present in the road on the selected section of roads. Unevenness Index was calculated based in the roughness data. The ratio of bumps count and the length travelled determines Unevenness Index which is measured in mm/km for given road sections.

Table-5 Roughness/unevenness index (mm/km) for both study road sections

Roughness	Road section- 1		Road section- 2	
	Shyamal intersection to Vagal chowk	Vagal chowk to Shyamal intersection	Vagal chowk to Udgam school	Udgam school to Vagal chowk
UI (mm/km)	**2710**	**2045**	**3155**	**3260**

Deflection data (Structural evaluation):

Performance of flexible pavements is closely related to the elastic deflection of pavement under the wheel loads. The deformation or elastic deflection under a given load depends upon sub grade soil type, its moisture content and compaction, the thickness and quality of pavement courses, drainage conditions, pavement surface temperature etc. Pavement deflection is measured by the Benkelman Beam deflection equipment.

Table-6 Characteristics pavement deflection (mm) for both study road sections

Pavement deflection	Road section- 1		Road section- 2	
	Shyamal intersection to Vagal chowk	Vagal chowk to Shyamal intersection	Vagal chowk to Udgam school	Udgam school to Vagal chowk
Characteristic Deflection	**2.96 mm**	**2.19 mm**	**3.07 mm**	**2.79m**

V. AHP MODEL DEVELOPMENT

AHP was developed by Saaty in the 1970s for dealing with complex problems of technological, economical and sociological. AHP aims to quantify relative priorities for a given set of alternatives on a ratio scale. AHP is a mathematical technique, and is used for multi-criteria decision making to help the decision maker to select the best alternative. In this method, the complex structure of the problem is reduced by handling this complexity at different levels. Each level consists of a group of parameters possessing similar characteristics. In this method, an overall goal is at the top or first level followed by a set of criteria at midlevel, followed by a set of alternatives to reach the overall goal. Usually, the criteria are further divided into sub criteria, sub-

sub criteria and so on, depending on the complexity of the problem. A nine-point scale is suggested for AHP to compute the relative importance of all elements, compared pair wise.

The relative importance of each numeric value in Saaty's scale is: 1 if criteria i and j are of equal importance, 3 if criterion i is little more important than criterion j, 5 if criterion i is strongly more important than criterion j, 7 if criterion i is very strongly more important than criterion j, 9 if criterion i is absolutely more important than criterion j, and 2, 4, 6, 8 for intermediate importance.

The judgmental value for pairs of attributes Ci and Cj are presented by an n-by-n matrix as shown below,
A = (aij) (i, j = 1, 2, 3….n)
Where aij is defined by the following entry rules:
Rule-1 If aij =α, then aji = 1/α, α ≠ 0
Rule-2 If Ci is judged to be of equal relative importance as Cj, then aij = aji = 1. Obviously aii = 1 for all i.

$$A = \begin{bmatrix} aii & aij & \cdots & ain \\ \frac{1}{aij} & ajj & \cdots & ajn \\ . & . & \cdots & . \\ \frac{1}{ani} & \frac{1}{anj} & \cdots & \frac{1}{ann} \end{bmatrix}$$

A positive reciprocal matrix which consists of a different set of pair wise comparison is represented above. Where i, j ≤ n, n indicates the number of alternatives being compared within one set of pair wise comparisons, aij denotes the importance of alternative i over alternative j.
In this study four flexible pavement road sections were selected for the project work. Nine parameters alligator cracking, longitudinal cracking, transverse cracking, rutting, ravelling, patching, pothole, roughness and deflection were selected as main criteria for prioritization and also five sub criteria were selected. Pavement maintenance prioritization by AHP will be carried out using following steps,

1. Decompose the decision-making problem into a hierarchy
2. Make pair wise comparisons and establish priorities among the elements in the hierarchy.
3. Weights for achieving goal by expert opinion survey.
4. Developing a pair wise comparison matrix for each criterion.
5. Normalizing the resulting matrix (Dividing each entry of ranking matrix by its column total).
6. Averaging the values in each row to get the corresponding rating.
7. Calculating and checking the consistency ratio. (CR ≤ 0.1)
8. Calculate the weighted average rating for each decision alternative. Choose the one with the highest score.

To check for consistency in judgments of a decision maker, the consistency ratio (CR) which is defined as the proportion of the consistency index (CI) and the random index (RI) is used to examine the entire matrix 'A' using below equation:
CR = CI/RI
Where CI is as given by: Define RI and CI
CI = (λmax – n) ÷ (n-1)
Where n is the size of the matrix. The values of the random index for quantities of attribute to the different size of the matrix were adopted. Also, a matrix is considered consistent only if CR ≤ 0.1.

Table-7 Random index for AHP (N = 2, 3, 4, 5, 6, 7, 8, 9, 10)

N	2	3	4	5	6	7	8	9	10
Random index	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

Table-8 Sub criteria range of selected parameters for AHP

Criteria	Defected area (%) by particular type of distress	Longitudinal & Transverse cracking % (m)	Roughness (mm)	Deflection (mm)
Poor	0 % to 0.50 %	0 to 0.50	0 to 1000	0 to 1.50
Fair	0.51 % to 1.0 %	0.51 to 1.0	1001 to 2000	1.51 to 3.0
Good	1.01 % to 2.0 %	1.01 to 2.0	2001 to 3000	3.01 to 4.5

Very good	2.01 % to 4.0 %	2.01 to 4.0	3001 to 4000	4.51 to 6
Excellent	> 4.0 %	> 4.0	> 4000	> 6

Table-9 Weightage and consistency measure of sub criteria through AHP

SCALE	Excellent	V.Good	Good	Fair	Poor	Weights
Excellent	1	3	5	7	9	**0.502**
V.Good	1/3	1	3	5	7	**0.26**
Good	1/5	1/3	1	3	5	**0.134**
Fair	1/7	1/5	1/3	1	3	**0.067**
Poor	1/9	1/7	1/5	1/3	1	**0.034**

Priority weightage of selected parameter by AHP:

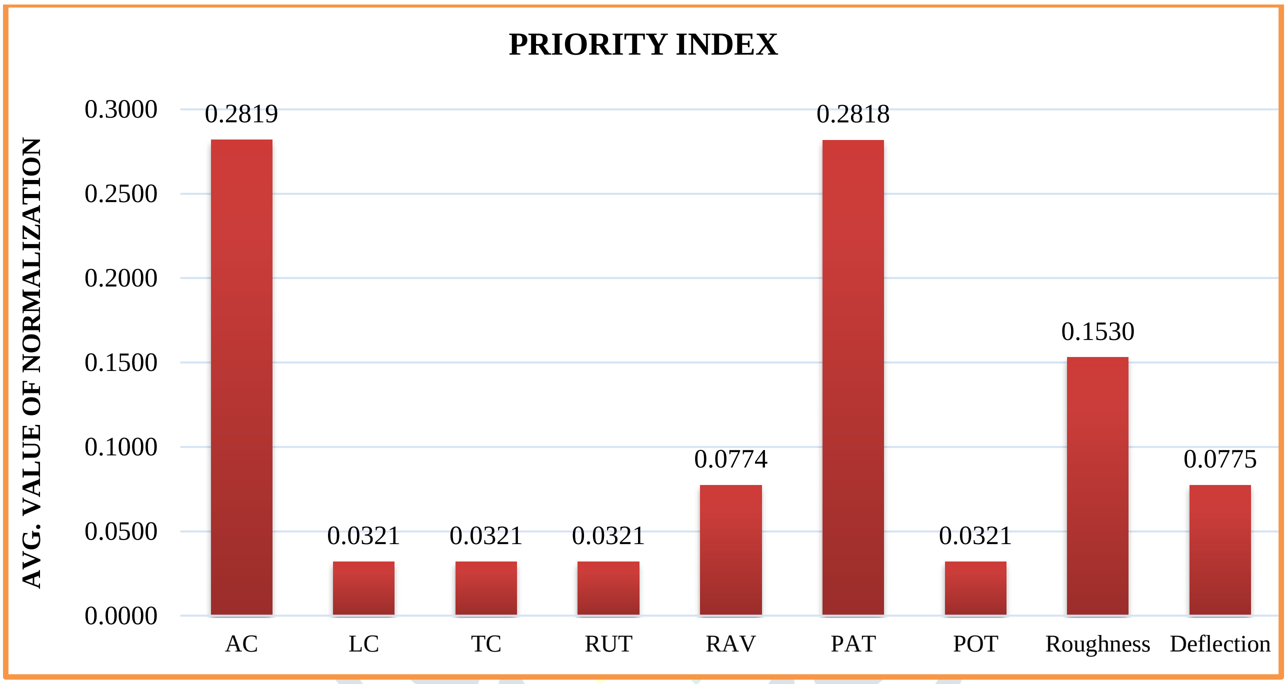

Figure-4 AHP model for road section-1 (Shyamal intersection to Vagal chowk)

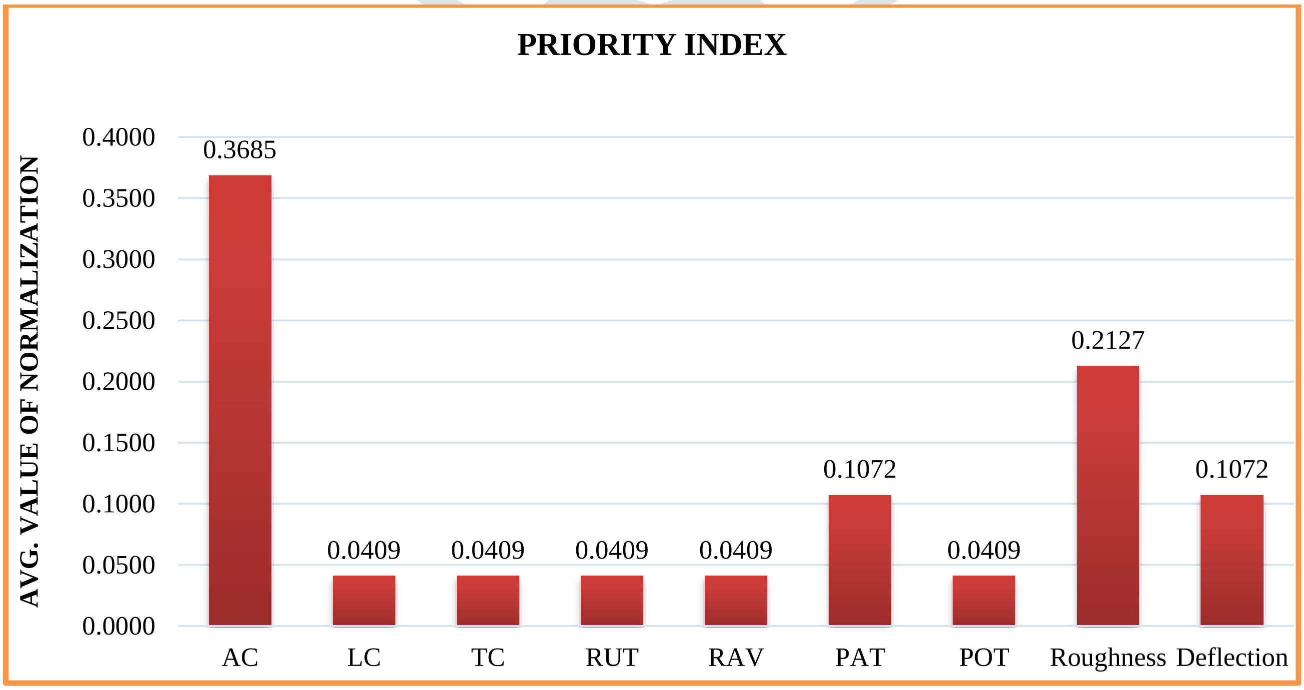

Figure-5 AHP model for road section-1 (Vagal chowk to Shyamal intersection)

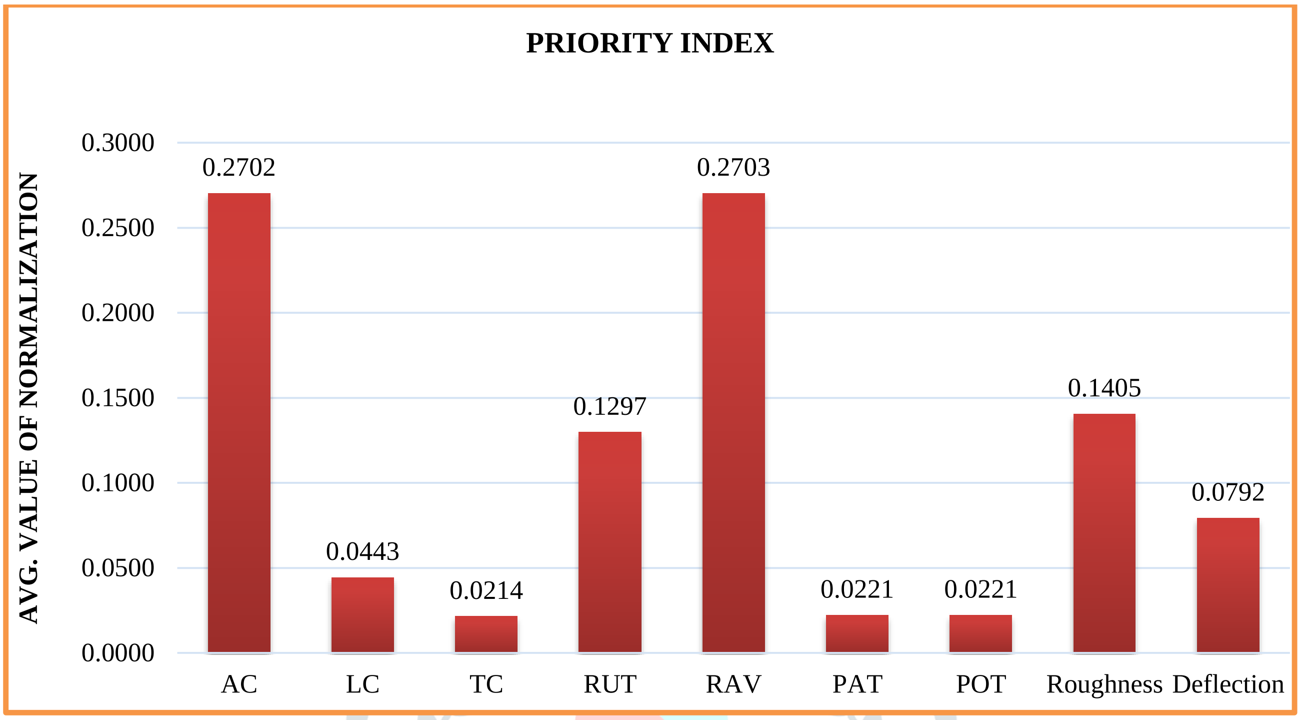

Figure-6 AHP model for road section-2 (Vagal chowk to Udgam school)

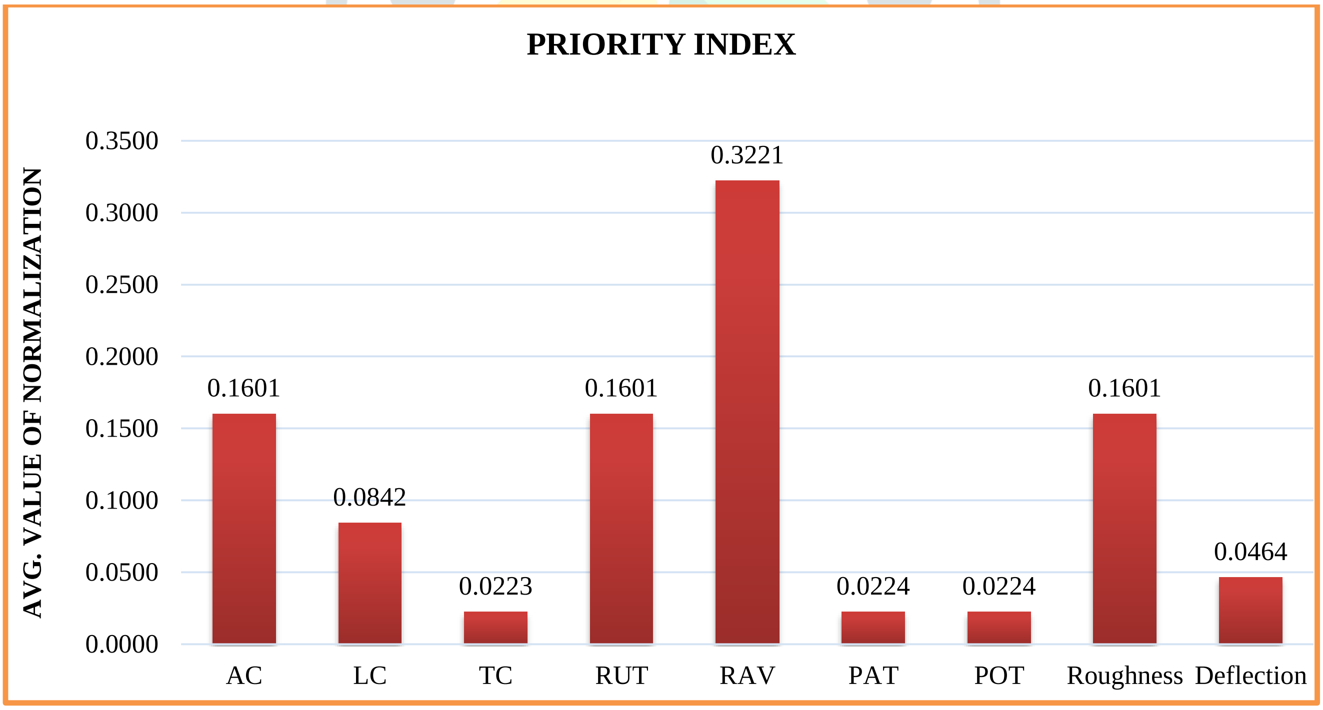

Figure-7 AHP model for road section-2 (Udgam school to Vagal chowk)

Results discussion of AHP:

Table-10 AHP weightage and ranking to selected parameters

Criteria (Parameter)	Road section-1				Road section-2			
	Shyamal intersection to Vagal chowk		Vagal chowk to shyamal intersection		Vagal chowk to Udgam school		Udgam school to Vagal chowk	
	AHP weightage	AHP rank	AHP weightage	AHP rank	AHP weightage	AHP rank	AHP weightage	AHP rank
Alligator crack	0.2819	1	0.3685	1	0.2702	2	0.1601	2
Longi. crack	0.0321	6	0.0409	4	0.0443	6	0.0842	3
Trans. crack	0.0321	6	0.0409	4	0.0214	8	0.0223	6
Rutting	0.0321	6	0.0409	4	0.1297	4	0.1601	2
Ravelling	0.0774	5	0.0409	4	0.2703	1	0.3221	1
Patching	0.2818	2	0.1072	3	0.0221	7	0.0224	5
Pothole	0.0321	6	0.0409	4	0.0221	7	0.0224	5
Roughness	0.1530	3	0.2127	2	0.1405	3	0.1601	2
Deflection	0.0775	4	0.1072	3	0.0792	5	0.0464	4

VI. CONCLUSION

From the results of AHP it was conclude that,
For road section-1 (Shyamal intersection to Vagal chowk) alligator cracking has highest weightage value = 0.2819 & ranked 1st, patching has weightage value = 0.2818 & ranked 2nd, roughness has weightage value = 0.1530 & ranked 3rd and followed by other parameter. For road section-1 (Vagal chowk to Shyamal intersection) alligator cracking has highest weightage value = 0.3685 & ranked 1st, roughness has weightage value = 0.2127 & ranked 2nd, patching and deflection has weightage value = 0.1072 & ranked 3rd followed by other parameter.

For road section-2 (Vagal chowk to Udgam school) ravelling has highest weightage value = 0.2703 & ranked 1st, alligator cracking has weightage value = 0.2702 & ranked 2nd, roughness has weightage value = 0.1405 & ranked 3rd followed by other parameter. For road section-2 (Udgam school to Vagal chowk) ravelling has highest weightage value = 0.3221 & ranked 1st, alligator cracking, rutting and roughness has same weightage value = 0.1601 & ranked 2nd, longitudinal cracking has weightage value = 0.0842 & ranked 3rd followed by other parameter.

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