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Pavement Maintenance Prioritization of Urban Roads Using Analytical Hierarchy Process

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Abstract: For a highway agency, it is not possible to take up the maintenance requirements for all road sections within a network at a time due to budget constraints. This makes a need for priority ranking model to select and schedule road sections for maintenance treatments according to their maintenance needs.

The objective of this study is to use Analytic Hierarchy Process (*AHP*) for developing a priority ranking model for maintenance of urban roads. The priority model has also been developed using Direct Assessment (*DA*) method and results were compared with AHP model. In Direct Assessment method, the experts were asked to rate the importance of each parameter affecting the road maintenance, on a scale of 0 to 100 percent whereas in AHP the experts were asked to make a pair-wise comparison between the parameters based on Saaty's scale i.e. 1 to 9. The pair wise comparison matrix was prepared and evaluated for inconsistencies using Expert Choice version 11 software. Statistical tests were performed to show that the collected data exhibited good consistency and repeatability. The developed priority ranking models has been applied to an urban road network of Noida city, near Delhi, consisting of 21 urban road sections.

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Key words*: Analytic hierarchy process; Direct assessment; Maintenance prioritization; Urban roads.*

Introduction

Urban roads have witnessed phenomenal increase in number of vehicles due to steep rise in industrial, commercial and residential activities. The economic loss due to poor condition of roads amounts to a huge sum. When required funds are not available to maintain the roads to the desired level of service, Pavement Management System (PMS) can provide a solution. A widely accepted practice is to express maintenance priority in the form of a priority index, computed by means of an empirical mathematical expression. Though convenient to use empirical mathematical indices often, do not have a clear physical meaning and cannot accurately and effectively convey the priority assessment or intention of highway agencies and engineers. In an attempt to overcome this, Analytic Hierarchy Process (AHP) could be one of the options and is used in this study for setting the maintenance priorities for urban road network. AHP is a powerful group decision-making tool and is especially useful in dealing with complex decision situations that involve objective as well as subjective preferences of the decision makers. AHP is a robust and valuable tool that can help remove conflict in a group decision making scenario by making the whole decision process more formulated and transparent. In particular, the AHP based approach can serve as a reasonable tool to prioritise data requirements for pavement management quantitatively.

Researchers have presented different methods for prioritization of pavement sections for maintenance, some of them are extracted here. AHP has been used in determining the rational weights of importance of pavement maintenance priority ranking factors [1]. These weights were obtained by capturing the local people's perception towards that vital part of the pavement management system (PMS). Priority ranking methodology based on priority index concept has been developed using the overall distress index model and traffic adjustment factors [2]. It involved a process of acquisition of expert opinion through a series of questionnaires and the derivation of weighted average condition measures. Farhan [3] explored the use of an AHP for the prioritization of pavement maintenance activities. The main aim was to identify an approach that can reflect the engineering judgment of highway agencies and engineers more closely. The study concluded that absolute AHP is suitable for the pavement maintenance prioritization process. Prioritization based upon models including effects of all important factors such as pavement condition index, road type, traffic volume as well as rehabilitation and maintenance cost has been developed [4]. Moazami [5] applied AHP for determining maintenance priority indices for 131 road sections by means of three modeling parameters viz. pavement condition index (PCI) value, traffic volume and the road type. Smith [6] conducted preliminary investigations to incorporate AHP into municipal infrastructure capital planning. The author recommended testing the AHP model over multiple and longer datasets and conducting sensitivity analysis to ensure validity of selected weighing values. Ameri [7] used AHP to find the most suitable type of concrete pavement from four different types of concrete pavement based of their performance qualities. Fuzzy mode AHP was used where the judgment matrix are fuzzy numbers that could be later modified by the designers. Farashah [8] calculated the City of Markham's overall

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road network condition based on the AHP method and the City of Markham existing method. The study concluded that the results from the AHP method are very close to the City of Markham method. The different approaches for priority ranking of road maintenance were presented viz. (a) Ranking based on Subjective rating, and (b) Ranking based on Economic Indicator using HDM-4 (Highway Development and Management) [9].

The main objective of this study is to develop the prioritization model or Priority Index (PI) for maintenance of urban pavement sections using AHP. Comparison of PI computed using AHP and DA for prioritizing maintenance is also done. The scope of the study is limited to the model development for urban roads only. An urban road network consisting of 21 road sections (total length 60 km) has been identified to apply this model and prioritize the sections for maintenance.

Study Methodology

First part of the study was to decide the parameters governing the priority ranking for maintenance of road sections. Based on the extensive literature it was decided that major factors that affect priority ranking are pavement condition, road class, riding quality, safety conditions, traffic volume, drainage conditions, importance to community and structural adequacy and the same were consider for this study. The study included the data collection in two parts. The first was the expert opinion survey to decide the weightage of various parameters governing the priority ranking for maintenance of road sections. The second part included the field data collection, the details of which are given in sub-section.

Expert Opinion Survey

The expert opinion survey was conducted by preparing the questionnaire to calculate the weightage of each parameter for deciding the priority of road sections for maintenance using AHP. The questionnaire consisted of two levels. Level 1 comparison included the major factors affecting the pavement maintenance and level 2 included the sub-classification of factors considered in level 1. The questionnaire consisted of the various parameters in Level 1 as shown in Table 1.

The questionnaire consisted of the following factors in Level 2:

(i) *Pavement Condition (PSR – range)*: PSR value was sub-divided into five categories such as, Very Good (4–5), Good (3–4), Fair (2-3), Poor (1-2) and Very Poor (0–1) [10].

(ii) *Road Class*: Four road classes viz. Arterial, Sub Arterial, Collector Street and Local Street were considered.

(iii) *Riding Quality*: Riding quality was considered in terms of roughness, which was sub- divided as Good (2000 mm/km), Average (3000 mm/km), Low (4000 mm/km). [10].

(iv) *Safety conditions*: Safety conditions were measured in terms of skid resistance and was sub-divided as Good (Above 65), generally satisfactory (55 – 65), Satisfactory (45 – 55), Potentially Slippery (Below 45).) [11].

(v) *Traffic volume*: It was sub-divided as High (> 4500 CVPD), Medium (450 – 4500 CVPD), Low (< 450 CVPD) (*CVPD* – Commercial vehicles per day). [10].

(vi) *Drainage Conditions*: It was categorized in terms of time taken for removal of free water and was sub-divided as Excellent (2 hours), Good (1 day), Fair (7 days), Bad (1 month), Very Bad (water will not drain). [12].

(vii) *Importance to Community*: Following factors were considered: Road Class, Distance from CBD, Operating Traffic, and Availability of alternate routes during maintenance and Distance from important buildings and public places.

(viii) *Structural Adequacy*: It was sub-divided as Good (No overlay is required), Fair (Overlay required in single layer BC) and Poor (Overlay required in terms of BC + DBM) (BC – bituminous concrete, DBM – dense bituminous concrete).

The questionnaire was prepared considering the above parameters and the experts were asked to make the pair wise comparisons between various parameters and rate on a scale of 1-9 as recommended by Saaty [13]. Experts were also asked to rate the importance to be given to the person’s response in terms of percentage, to assign weightage to the responses from people belonging to each group. The experts were grouped into.

Academicians, Managers, Engineers, Supervisors, Students and Non-Pavement Qualified. The sample size of the questionnaires required to be collected for the analysis should be at least 4 to 5 times the number of independent variables or parameters considered [14].

Table 1. Definition of Parameters in Level 1.

Parameters	Description
Pavement Serviceability Rating (PSR)	The Present Serviceability Rating Measures the Pavement's Structural Integrity and Surface Operational Condition, Value Ranging from 0 to 5.
Road Class	Major/minor Road; Arterial, Sub-arterial, Collector or Local Street; Commercial or Residential.
Riding Quality	Existence of Bumps, Longitudinal Corrugation and Unevenness in the Road Surface that Cause High Stress to Vehicles and Discomfort to the Road Users (Drivers and Passengers). [Road Roughness]
Safety Conditions	Smoothness of the Road Surface Causes Safety Hazards to Vehicle Stopping and Braking. Maintaining the Skid Resistance or Surface Friction to Reduce Accident Rates (Rear-end Type). [Based on Skid No. (BPT)]
Traffic Volume	Operating Traffic Volume Determines the Extent of Road Utilization by the Public.
Drainage Conditions	Drainage Condition is Accessed Based on the Time Taken for the Removal of Free Water
Importance to Community	Overall Importance to Community Determined by its Distance from Official Buildings or Important locations Such as Hospitals, School, Availability of Alternate Routes During Maintenance, Distance from CBD etc.
Structural Adequacy	Overlay Requirement Based on Benkelman Beam Deflection Technique

The first level consists of 8 parameters. Thus a total of 55 samples were collected for this study. Out of these, nine forms have been discarded for which the consistency ratio was greater than 0.1. So finally the judgment of 46 experts has been considered for further analysis.

Feild Data Collection

In order to apply the AHP and DA model for prioritizing the maintenance of road sections a case study of Noida (also known as Gautam Buddha Nagar), urban roads was selected. Noida is an urban city of Uttarpradesh State near Delhi, capital of India. The details of selected 21 urban road sections are given in Table 2. The data collected included the functional & structural evaluation, assessing the drainage conditions, traffic volume count & identifying the road class for all the selected urban roads. The details of field data collected are presented in Table 3.

Statistical Analysis of the Data Collected from Expert Opinion Survey

Statistical tests were performed for level 1 parameters to check the reliability of the data. For the use of parametric hypothesis testing it requires the assumption that the random samples are selected from normal population. K-S test was done to test the normality of the data.

Normality Check Using Kolmogorov-Smirnov (K-S) Test

The Table 4 shows the results of K-S test, where it is clear that all factors statistically represent normal distributions (after removing outlier values in some cases) at a significance level of 95%. Based on this result, the parametric hypothesis testing was done since the normality assumption is satisfied.

Repeatability Checks

The repeatability of the obtained data for the weight of priority factors was done by checking the variation within the data. The collected data of individuals were randomly divided into two subsets or groups with each group having 23 data points. Table 5 shows the results of the comparison between the variances of the two groups. From this table, the first conclusion row shows that all factors have similar variances (Null hypothesis not rejected). Based on this conclusion, the second comparison step was carried out where the exact t-test was done for testing the means for each factor. In all the tests, the null hypotheses H_o of all factors were not rejected as shown in second conclusion row. This showed that all factors in the two subsets had similar statistical means and therefore, measurements are repeatable.

Comparison between Surveyed Groups

As stated earlier, different groups of individuals were surveyed in this study. To quantify any differences existing between these groups, two groups were formed: (i) Engineers and (ii) Others, which consisted of all academicians, supervisors, students. The statistical comparison technique was employed for the variances and means of these two groups for all the main factors. Table 6 shows the result of the first step of variance comparison and the second step for means comparison of all eight factors. Based on this conclusion, the second comparison step was carried out where the

Table 2. Urban Road Sections Selected For Case Study.

S. N.	Name of Road	Section ID	Length (km)
1	Noida Link Road	A1	3.8
2	Jamnalal Bajaj Marg (MP Road No 1)	A2	3.5
3	Maharaja Agrasen Marg & Ashok Marg (MP Road No 2)	A3	6.0
4	Amrapali Marg & Golf Marg (MP Road No 3)	A4	7.5
5	Udhyog Marg	A5	3.2
6	Vindayachal Marg & Shivalik Marg	A6	2.2
7	Nithari Road	A7	2.4
8	Kamal Marg	A8	3.0
9	Khoda Village Road	A9	2.2
10	Sector - 62 Road Along NH-24	A10	2.0
11	Sector - 62 Road	A11	3.3
12	Kakral Road (60M) (Phase – II)	A12	1.8
13	Mahamaya Balika Inter college Road (60M)	A13	4.0
14	Panchsheel Bal Inter College Road (45M)	A14	2.3
15	45M Peripheral Road in Sector – 88	A15	2.5
16	24M Road in Sector – 88	A16	3.0
17	Amity University Road (Between Sector 125 & 126)	A17	0.7
18	Lotus Valley Inter School Road (Between Sector 126 &127)	A18	0.7
19	Road along NGN Expressway (45M) (Connecting Sector 126 & 127)	A19	2.0
20	Harsing Nagar Marg	A20	3.2
21	Road between Sector 7 & 8 (Near Vasundhara Enclave)	A21	0.7
	Total		60.0

Table 3. Field Data Collected for Selected Urban Sections.

Sections ID	Road Class	MT AADT	Roughness (UI mm/km)	Drain Condition	PSR	Benkelman Beam Deflection (mm)
A1	Arterial	64476	2156	Good	5	1.04
A2	Arterial	27598	3455	Good	5	1.18
A3	Arterial	35807	2563	Fair	5	1.1
A4	Arterial	33381	2156	Fair	5	0.72
A5	Arterial	24912	2156	Poor	5	0.52
A6	Sub-Arterial	20332	2237	Poor	4	1.15
A7	Sub-Arterial	16804	2868	Fair	5	0.94
A8	Sub-Arterial	19930	2645	Poor	5	2.203
A9	Sub-Arterial	18450	2481	Poor	4	1.15
A10	Local Street	10637	3185	Poor	4	1.52
A11	Collector	12686	2399	Poor	3	182
A12	Arterial	7961	3126	Poor	3	1.3
A13	Collector	2290	4018	Fair	5	2.86
A14	Arterial	6114	2237	Good	5	2.21
A15	Local Street	1324	2645	Good	5	2.04
A16	Collector	3660	3244	Good	5	3.34
A17	Collector	3279	3421	Good	5	1.54
A18	Local Street	6066	3194	Fair	5	1.65
A19	Collector	5373	3143	Poor	4	1.83
A20	Sub-Arterial	18645	2156	Good	5	1.3
A21	Sub-Arterial	7826	3252	Fair	5	1.42

Note: PSR - Present Serviceability Index, MT – Motorized Traffic, AADT – Annual Average Daily Traffic, UI – Unevenness Index.

Table 4. Results of Normality Checks for Level 1 Parameters.

Factor	Max D
PSR Rating	0.133
Road Class	0.115
Riding Quality	0.109
Safety Conditions	0.105
Traffic Volume	0.128
Drainage Conditions	0.097
Importance to community	0.126
Structural Adequacy	0.132

Note: N = Number of observations = 46, D = Deviation, Significance level = 95%, Probability = $p < 0.05$

exact t-test was done for testing the means for each factor. It was observed that in the case of factor 2 (road class), Engineers and Other groups showed statistically different means. All other comparisons of means of the two groups had same statistical means. This is evidence that the variation of data is statistically minimal, and it can be concluded that the collected data is repeatable. Another conclusion is that some factors in the collected data cannot be pooled together, and needs to be adjusted for the type of individuals and their experiences.

Comparison of Weights Calculated Using Direct Assessment and AHP

Table 5. Summary of the Comparison Test for Variation within AHP Data.

Statistics	Factor 1 PSR		Factor 2 Road Class		Factor 3 Riding Quality		Factor 4 Safety Conditions		Factor 5 Traffic Volume		Factor 6 Drainage Condition		Factor 7 Imp to Community		Factor 8 Structural Adequacy	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Mean	0.178	0.137	0.083	0.087	0.145	0.174	0.13	0.126	0.114	0.125	0.095	0	0.114	0	0.14	0
SD	0.098	0.081	0.045	0.042	0.056	0.077	0.084	0.05	0.044	0.065	0.045	0	0.085	0	0.062	0
Observations	23	23	23	23	23	23	23	23	23	23	23	#	23	#		
F	1.457		1.103		0.523		1.983		0.455		0.851		3.024		0.747	
$F_{critical}$ two-tail	2.047		2.047		2.047		2.047		2.047		2.047		2.047		2.047	
Conclusion 1	Not Reject H_o, Use t-test		Not Reject H_o, Use t-test		Reject H_o, use t*-test		Not Reject H_o, use t-test		Not Reject H_o, use t-test		Not Reject H_o, use t-test		Not Reject H_o, use t-test		Not Reject H_o, use t-test	
t or t* statistic	1.582		-0.305		-1.459		0.185		-0.712		-1.691		0.387		0.644	
$t_{critical}$ two-tail	2.015		2.015		2.015		2.015		2.015		2.015		2.015		2.015	
Conclusion 2	Not Reject H_o		Not Reject H_o		Not Reject H_o		Not Reject H_o		Not Reject H_o		Not Reject H_o		Not Reject H_o		Not Reject H_o	

Table 6. Summary of the Comparison Test for Variation among Groups.

Statistics	Factor 1 PSR		Factor 2 Road Class		Factor 3 Riding Quality		Factor 4 Safety Conditions		Factor 5 Traffic Volume		Factor 6 Drainage Condition		Factor 7 Importance to Community		Factor 8 Structural Adequacy	
	Engg.	Others	Engg.	Others	Engg.	Others	Engg.	Others	Engg.	Others	Engg.	Other	Engg.	Others	Engg.	Others
Mean	0.163	0.146	0.075	0.103	0.159	0.158	0.136	0.11	0.117	0.123	0.112	0	0.104	0	0.129	0.1
SD	0.099	0.074	0.039	0.045	0.071	0.063	0.074	0.052	0.054	0.056	0.049	0	0.074	0	0.061	0.1
Observations	31	15	31	15	31	15	31	15	31	15	31	#	31	#	31	15
F	0.34		4.535		0.001		1.453		0.088		1.323		0.468		0.284	
$F_{critical}$ two-tail	2.3082		2.0406		2.3082		2.3082		2.0406		2.3082		2.0406		2.0406	
Conclusion 1	Not Reject H_o, use t-test		Reject H_o, use t*-test		Not Reject H_o, use t-test		Not Reject H_o, use t- test		Not Reject H_o, use t-test		Not Reject H_o, use t-test		Not Reject H_o, use t-test		Not Reject H_o, use t-test	
t or t* Statistic	0.583		-2.168		0.03		1.205		-0.296		1.15		-0.684		-0.533	
$t_{critical}$ Two Tail	2.0154		1.96 Mann-Whitney		2.0154		2.0154		2.0154		2.0154		2.0154		2.0154	
Conclusion 2	Not Reject Ho		Reject H_o		Not Reject H_o		Not Reject H_o		Not Reject H_o		Not Reject Ho		Not Reject H_o		Not Reject H_o	

Note: Engg. – Engineers.

Table 7. Summary of the Comparison Test between Weigthage Calculated using AHP and Direct Assessment.

Statistic	Factor 1 PSR		Factor 2 Road Class		Factor 3 Riding Quality		Factor 4 Safety Conditions		Factor 5 Traffic Volume		Factor 6 Drainage Condition		Factor 7 Importance to Community		Factor 8 Structural Adequacy	
	AHP	Direct	AHP	Direct	AHP	Direct	AHP	Direct	AHP	Direct	AHP	Direct	AHP	Direct	AHP	Direct
Mean	0.157	0.16	0.084	0.106	0.159	0.183	0.128	0.121	0.119	0.121	0.106	0	0.11	0	0.133	0.1
SD	0.091	0.067	0.043	0.061	0.068	0.091	0.068	0.049	0.054	0.053	0.047	0	0.076	0	0.067	0.1
Observations	46	46	46	46	46	46	46	46	46	46	46	#	46	#	46	46
Z	-0.718		-2.82		-1.348		-0.564		-0.595		-0.753		-1.951		-2.212	
Wilcoxon Z Critical	1.96		1.96		1.96		1.96		1.96		1.96		1.96		1.96	
Conclusion	Samples are Statistically Similar		Samples are Statistically Different		samples are statistically similar		samples are statistically similar		samples are statistically similar		samples are statistically similar		samples are statistically similar		samples are statistically different	

Wilcoxon statistical test was performed on the data collected by questionnaire for direct weight assignment and AHP method. Wilcoxon test is a non-parametric test and it was used since the direct assessment data does not satisfy a normal distribution. The results presented in Table 7 shows that weight of all the level 1 factors except Road Class and Structural Adequacy, computed using both the methods are statistically similar. This concludes that the direct assessment method of factor weight calculation is a consistent method since its results match with the well-defined, widely accepted and verified AHP method. Similar results were concluded for the comparison of AHP and Direct Assessment methods [15].

Weight Estimation for Each Selected Parameters

Using AHP

As the number of parameters and sub-parameters at level 1 & 2 were more, the comparison matrix formed has large number of elements. Hence for solving and estimating the factor weights, Expert Choice 11 pro software has been used. The software calculated the Eigen Vector of the comparison matrix and weights have been calculated. Check for consistency has also been carried out for each expert opinion. The input of pairwise comparison for factors at level 1 as obtained from one of the questionnaire, in software is shown in Fig. 1. The factor weight and the CR as resulted from software is shown in Fig. 2.

The Table 8 shows the weightage of experience or importance to be given to the corresponding person's response in determining the priority ranking process. The weights obtained from the result are applied to each person's response to the weightage factors to calibrate the model for accuracy in determining the final weightage factors. The weights of importance of all level 1 factors, the sub level factors, as well as the sub-factors of importance to community, are adjusted for the individual experience by taking the weighted average. The final calculated weights are given in the flow chart Fig. 3.

Using Direct Assessment (DA)

The calculation for weights using Direct Assessment was done using

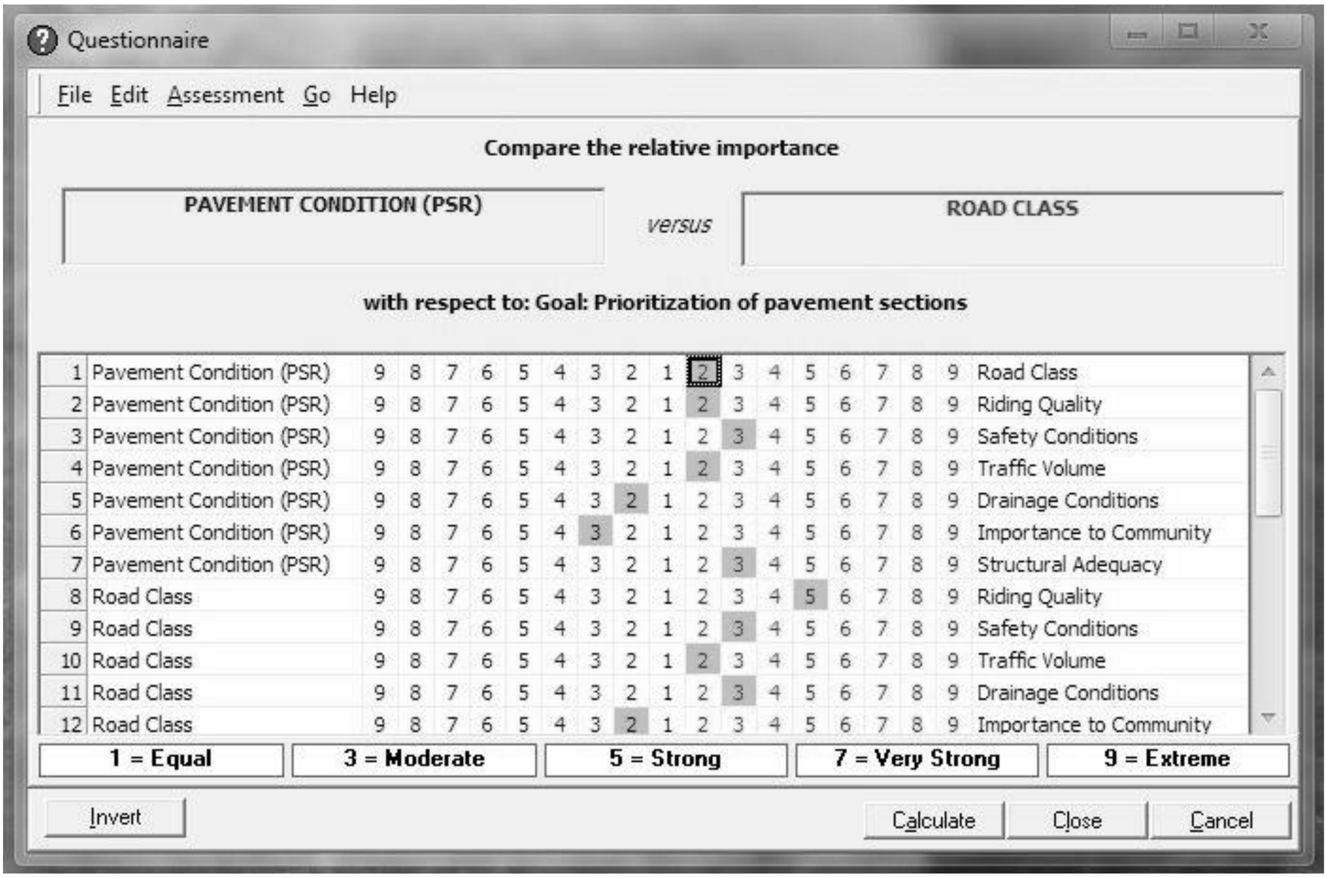

Fig. 1. Questionnaire Input Window of Expert Choice 11 Pro.

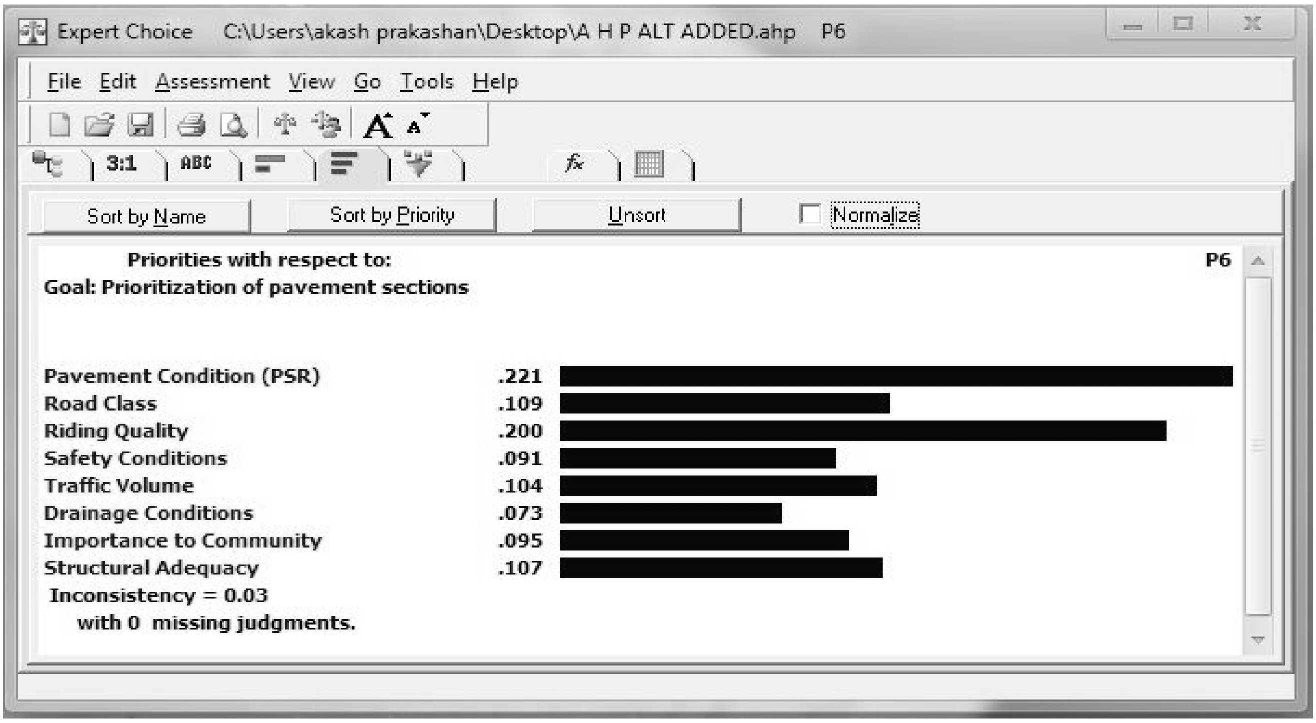

Fig. 2. Output of Priority Weights and Inconsistencies.

Table 8. Experience Weightage.

Person Group	Academician	Manager	Engineers	Supervisors	Students	Non-Pavement Qualified
Average Weight	16.86	14.75	34.15	17.02	11.53	5.68

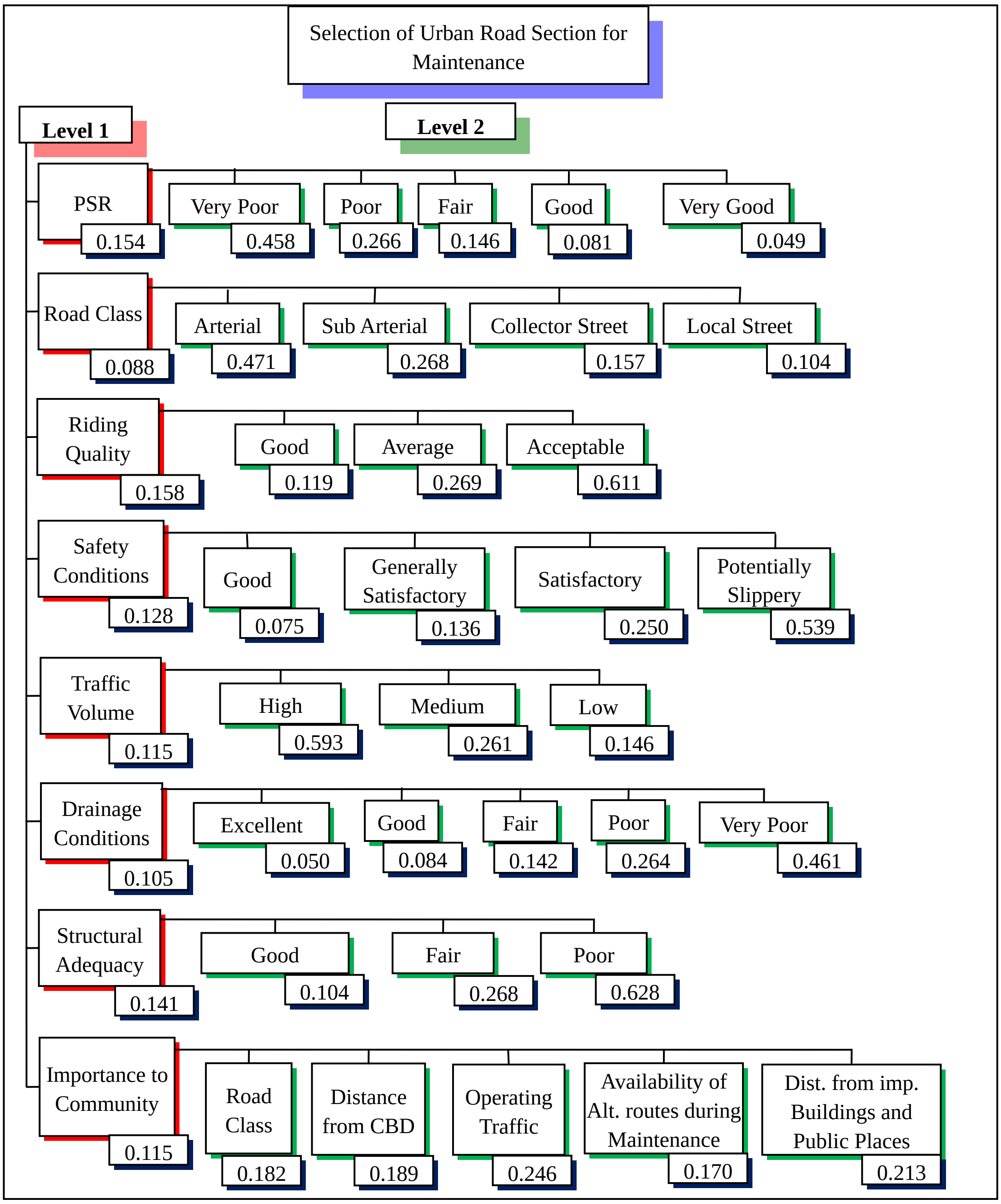

Fig. 3. Final Weightages Obtained Using AHP.

computational functions in Microsoft Excel. The experience weights obtained from the result in Table 8 are applied to each group of people's response to the weightage factors to calibrate the model for accuracy in determining the final weightage factors. Fig. 4 shows the final weightages obtained through direct assessment.

Calculation of Priority Index (PI) Value

The final PI value for each road section was calculated by adding the PI's for individual parameter considered using Eq. (1).

$$PI = PI_1 + PI_2 + PI_3 + PI_4 + PI_5 + PI_6 + PI_7 + PI_8 \quad (1)$$

Where, PI = Final Priority Index of road section, PI_1 = Priority Index of PSR, PI_2 = Priority Index of Road Class, PI_3 = Priority Index of Riding Quality, PI_4 = Priority Index of Safety Condition, PI_5 = Priority Index of Traffic Volume, PI_6 = Priority Index of Drainage Condition, PI_7 = Priority Index of Importance to Community, PI_8 = Priority Index of Structural Adequacy.

The Priority Index of individual PI's excluding PI_7 was computed using the Eq. (2) [1].

$$PI_i = \sum\left[\left(\frac{W_i}{W_{imax}}\right) \times F_i\right] \quad (2)$$

where, PI_i = Priority Index of each criteria at level 1 (range 0 to 1), W_i = weight of each subcriteria at level 2 of parameter i, W_{imax} = highest weight of all subcriteria's at level 2 of parameter i, and F_i = Weight of related criteria at level 1.

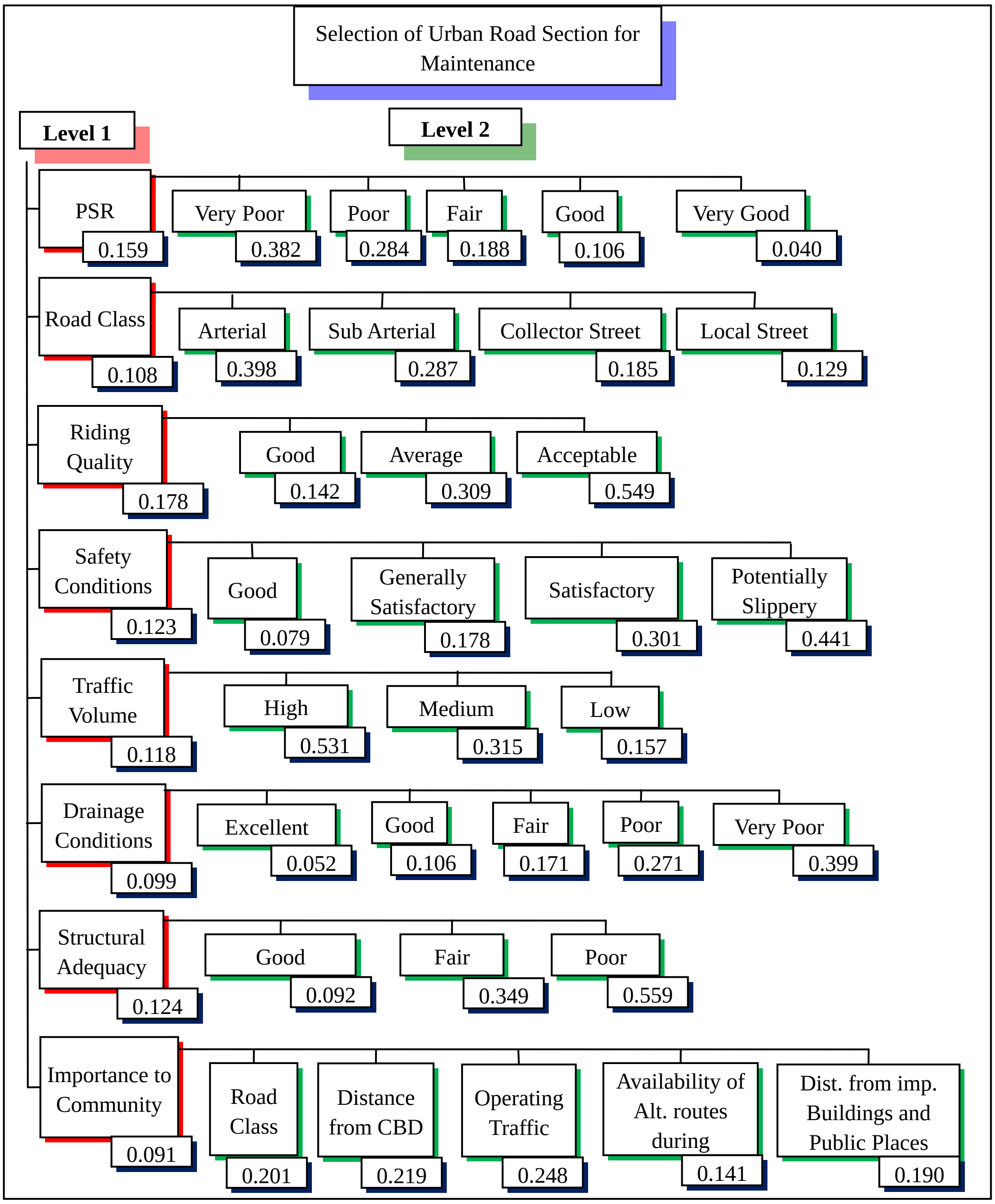

Fig. 4. Final Weightages Obtained Using Direct Assessment.

The values of F_i and $W_{max\ i}$ for all parameters as obtained using DA and AHP are presented in Figs. 3 and 4, respectively.

The above procedure was used to compute the PI value of all parameters except ‘Importance to Community’ (PI_7), since it involves a further level of sub-criteria. The PI value for Importance to Community (PI_7) parameter is calculated using the Eq. (3).

$$PI_7 = PI_{IC\,1} + PI_{IC\,2} + PI_{IC\,3} + PI_{IC\,4} + PI_{IC\,5} \tag{3}$$

where, PI_7 = Priority Index for Importance to Community, $PI_{IC\,1}$ = Priority Index of Road Class, $PI_{IC\,2}$ = Priority Index of Distance from CBD, $PI_{IC\,3}$ = Priority Index of Operating Traffic, $PI_{IC\,4}$ = Priority Index of Availability of Alternate Routes, $PI_{IC\,5}$ = Priority Index of Distance from Important Buildings and Public Places.

The Priority Index, PI_7 is computed using the Eq. (4).

$$PI_{ICi} = \sum\left[\left(\frac{W_{ICi}}{W_{ICimax}}\right) \times F_{ICi}\right] \tag{4}$$

The values of $F_{IC\ i}$ and $W_{IC\ max\ i}$ for all parameters as obtained using DA and AHP are presented in Figs. 3 and 4, respectively.

The sample calculation of PI value for one of the pavement section i.e. Udhyog Marg (Section ID – A5), of Noida city is presented. As per the existing condition of this section, the PSR value was 5, Road Class (RC) was Arterial, Roughness value (RQ) was 2156 mm/km, Safety condition (SC) was good, Traffic volume CVPD (TV) was 24912, Drainage condition (DC) was poor, Overlay requirement (SA) was in BC+DBM, the road section is situated far from CBD (Dist CBD), alternate routes were available during maintenance and was situated near to some important buildings and public places.

Table 9. Estimating Priority Index for Section UR 05 Using AHP Model.

Priority Parameter	Rating	Priority Index	
PSR	: V. Good	: (0.049 / 0.458) * 0.154	= 0.0165
Road Class	: Arterial	: (0.471 / 0.471) * 0.084	= 0.084
Riding Quality	: Average	: (0.269 / 0.611) * 0.158	= 0.0696
Safety Condition	: Good	: (0.075 / 0.539) * 0.128	= 0.0178
Traffic Volume	: High	: (0.593 / 0.593) * 0.115	= 0.115
Drainage Conditions	: Poor	: (0.263 / 0.461) * 0.105	= 0.0599
Structural Adequacy	: Poor	: (0.628 / 0.628) * 0.141	= 0.141
Imp. to Community			
Road Class	: Arterial	: (0.471 / 0.471) * 0.182	= 0.182
Distance from CBD	: Far	: (0 / 1) * 0.189	= 0
Operating Traffic	: High	: (0.593 / 0.593) * 0.246	= 0.246
Avail of alt. Routes	: Yes	: (1 / 1) * 0.170	= 0.170
Dist. from imp. Build.	: Near	: (1 / 1) * 0.213	= 0.213
0.0165 + 0.084 + 0.0696 + 0.0178 + 0.115 + 0.0599 + 0.141 + 0.112 * (0.182 + 0 + 0.244 + 0.170 + 0.213)			
PI = 0.5944			

Table 10. Estimating Priority Index for Section UR 05 Using DA Model.

Priority Parameter	Rating	Priority Index	
PSR	: V. Good	: (0.040 / 0.382) * 0.159	= 0.017
Road Class	: Arterial	: (0.398 / 0.398) * 0.108	= 0.108
Riding Quality	: Average	: (0.309 / 0.549) * 0.178	= 0.100
Safety Condition	: Good	: (0.079 / 0.441) * 0.123	= 0.022
Traffic Volume	: High	: (0.531 / 0.531) * 0.118	= 0.118
Drainage Conditions	: Poor	: (0.271 / 0.399) * 0.099	= 0.054
Structural Adequacy	: Poor	: (0.559 / 0.559) * 0.124	= 0.124
Imp to Community			
Road Class	: Arterial	: (0.398 / 0.398) * 0.201	= 0.201
Distance from CBD	: Far	: (0 / 1) * 0.219	= 0
Operating Traffic	: High	: (0.531 / 0.531) * 0.248	= 0.248
Avail of alt. Routes	: Yes	: (1 / 1) * 0.141	= 0.141
Dist. From imp. Build	: Near	: (1 / 1) * 0.190	= 0.190
PI = 0.017 + 0.108 + 0.100 + 0.022 + 0.118 + .054 + 0.124 + 0.091 * (0.201 + 0 + 0.248 + 0.141 + 0.190)			
PI = 0.6139			

This section can be put in category of VERY GOOD (PSR), ARTERIAL (RC), AVERAGE (RQ), GOOD (SC), HIGH (TV), POOR (DC), POOR (SA). And as per the importance of road to community, this section can be categorized as ARTERIAL (RC), FAR (Dist CBD), HIGH (OT), YES (Avail. of alt. routes) and NEAR (Dist. imp. Buildings).

The calculations for priority index (PI) using AHP and DA models are shown in Table 9 and Table 10 respectively.

Application of Prioritization Models for Maintenance of Urban Road Sections

Priority Index values for all 21 selected urban road sections in Noida, were calculated using the above stated procedure and the sections were ranked accordingly for maintenance. The calculated PI values and rankings by both DA and AHP method are given in Table 11. In case of urgency and lack of available funds the priority order given in the Table 11 can be adopted for maintenance of road sections. The results showed a good agreement between direct assessment method of collection individuals' opinions about the weight of importance of priority factors and Analytical Hierarchy Process (AHP) pair-wise comparison method. This agreement strengthens the direct assignment method since the AHP method is considered one of the pioneering psychometric-based methods of prioritization.

Discussion of Results

The main objective of this study was to develop prioritization model for maintenance of urban pavement sections using AHP. Extensive number of factors that needs to be considered for maintenance programs were studied and selected for estimation of their priority indices. The parameters divided into two levels as main parameters and sub parameters were evaluated using questionnaire based survey. Experts from various groups were surveyed and the collected data were grouped into academicians, engineers, managers, supervisors and students. The different statistical tests showed that the collected data form AHP were statistically similar, since the null hypothesis of equal means could not be rejected. This also indicated that the collected data exhibited good consistency and repeatability. The

Table 11. Priority Index and Priority Ranking for Urban Road Sections.

Sections ID	DA Priority Index	AHP Priority Index	DA Priority Rank	AHP Priority Rank
A1	0.5865	0.5847	14	12
A2	0.6841	0.6774	2	2
A3	0.6225	0.6189	5	4
A4	0.6224	0.6188	6	5
A5	0.6139	0.5944	10	7
A6	0.6196	0.5899	8	8
A7	0.5872	0.5726	13	14
A8	0.5923	0.5793	12	13
A9	0.6192	0.5897	9	9
A10	0.6476	0.6240	3	3
A11	0.6215	0.5863	7	10
A12	0.7496	0.7055	1	1
A13	0.5558	0.4939	18	17
A14	0.5693	0.5604	16	15
A15	0.4269	0.3728	21	21
A16	0.5224	0.4564	20	19
A17	0.5396	0.4807	19	18
A18	0.5953	0.5856	11	11
A19	0.5616	0.4518	17	20
A20	0.5710	0.5594	15	16
A21	0.6280	0.5988	4	6

surveyed individual groups showed some variation in their opinions regarding the weight of each factors and thus adjustment of weights in AHP based on their experiences was done.The statistical tests prove the robustness of AHP for maintenance priority programs. Expert Choice software has proven to be adequately fast and robust in calculation of weights with consistency checks even for the large structure and parameters in each levels of the applied model. A sample ranking for a study area consisting of 21 road sections was done using the index values estimated from AHP and Direct Assessment method and showed comparable results. The established priority index (PI) values from the study can be further used by highway agencies to evaluate their road sections for ranking in highway maintenance programs.

AHP technique could adequately and efficiently rank large number of pavement sections for maintenance, unlike the engineering judgments that can handle relatively less number of pavement sections at the same time. Its robustness helped also to remove conflict in a group decision making scenario by making the whole decision process more formulated and transparent as in the present case. In particular, the AHP based approach could serve as a reasonable tool to prioritize data requirements for pavement management quantitatively.

Conclusions

Following are the salient findings of this study:

i. Riding quality (0.158) had the highest weightage in priority ranking process followed by PSR rating (0.154), structural adequacy (0.141), safety condition (0.128), traffic volume (0.115), importance to community (0.112), drainage conditions (0.105) and road class (0.088), using AHP.
ii. Riding quality (0.178) had the highest weightage in priority ranking process followed by PSR rating (0.159), structural adequacy (0.124), safety condition (0.123), traffic volume (0.118), road class (0.108), drainage condition (0.099) and importance to community (0.091) using Direct Assessment.
iii. The 21 urban road sections in Noida were ranked according to their priority for maintenance by estimating the Priority Index using Direct Assessment and AHP models. The ranking of the road section using the two methods showed comparable results.
iv. A limitation in AHP method is that the same weight will be assigned to the lower and upper limits, since the range in scales are less and is fixed, which could lead to less precise result in some cases.
v. Since the priority ratings are influenced by seasonal factors, climatic, and environmental conditions, highway maintenance policy emphasis and pavement maintenance and repair technology, there is a need for each highway agency to develop its own set of routine maintenance priority ratings and to periodically update these ratings as part of the continuing process of highway pavement maintenance management.

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