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Full Length Research Paper

The use of analytical hierarchy process in priority rating of pavement maintenance

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Decision makers often perform pavements repairs without considering the maintenance priority and without utilizing a systematic procedure. These kinds of arbitrary decisions do not usually guarantee the effectiveness of budget allocation. Rating approach in Analytical Hierarchy Process (AHP) is one of the most effective techniques in decision making process which was used to facilitate the prioritization of alternatives on the basis of important parameters like pavement condition index, traffic volume and road type. In this study, relative weights of criteria, sub-criteria and inconsistency rate in each pairwise comparison matrix were calculated with the help of MATLAB software, coded M-Files as well as Expert Choice software. Finally, with Ideal-Mode synthesizing in Expert Choice software, final weights for all criteria and sub-criteria were obtained. As a case study, a number of streets in district number 6 of Tehran municipality (Iran) were selected and the final rating model was run to determine the maintenance priority index for 131 sections. It was concluded that based on the existing conditions, the rating approach in AHP method prioritized the impaired sections for maintenance easily and effectively.

Key words: Analytical hierarchy process, pavement maintenance, pavement condition index, traffic volume, roadway width.

INTRODUCTON

Due to the limited allocated budget in pavement maintenance operations, it is necessary to develop a comprehensive prioritization schedule to choose sections with higher priority first, in order to fulfil the needs in pavements network (Moazami et al., 2011). In this paper, rating approach in AHP was utilized and prioritization was modeled on the basis of important criteria like pavement condition index (PCI), traffic volume (TV), road type and their sub-criteria. Pairwise comparisons between criteria and sub-criteria were obtained by capturing the PMS (Pavement Management System) experts' perceptions towards the importance of factors affecting the maintenance priority. Relative weights of criteria, sub-criteria and the rate of inconsistency in each pairwise comparison matrix were calculated with the help of MATLAB software, coded M- Files as well as Expert choice software. Finally with Ideal-Mode synthesizing in Expert Choice software, final weights for all criteria and sub-criteria were obtained. The main scope of this study was developing a systematic way to calculate the maintenance priority index of any section based on the existing conditions (PCI, TV and Road Type).

In the case study, a number of streets in district number 6 of Tehran municipality were selected. Taleghani street, Sepahbod Gharani street, Ghaem Magham Farahani street (both directions), Mirzaye Shirazi street (both directions), Karim Khane Zand street (both directions), Ostad Motahhari street, and Hafez street, were divided to 131 sections for better investigation. Since large amounts of money are wasted for inadequate rehabilitation works in Tehran (Iran), it would be wise to develop a priority rating model for maintenance of flexible pavements. The developed model in this study can effectively determine the maintenance priority index of sections based on their existing conditions. Therefore, it guarantees the effectiveness of budget allocation.

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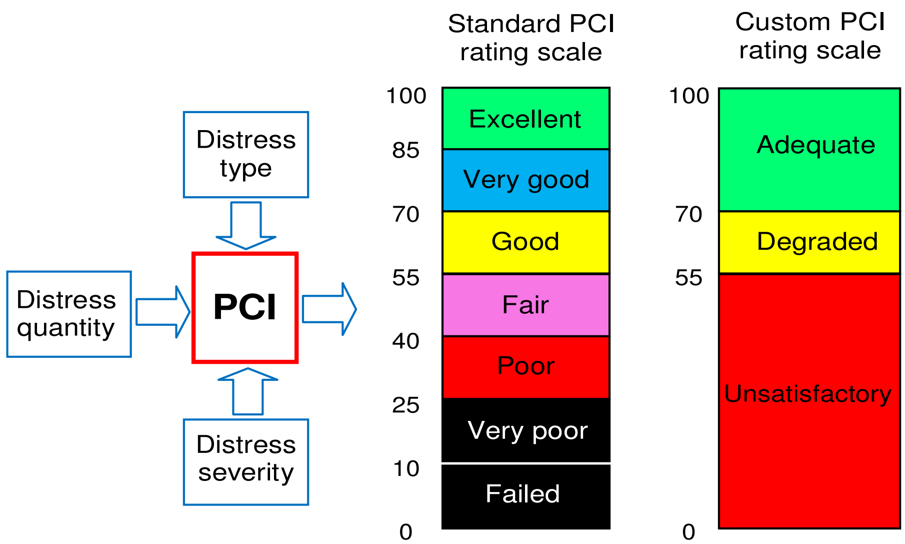

Figure 1. Numerical representation of PCI and pavement quality condition (micro paver 5.3 manual).

Table 1. Sub-criteria for PCI.

Sub-criteria for PCI	Values
EXCELLENT	86-100
VERY GOOD	71-85
GOOD	56-70
FAIR	41-55
POOR	26-40
VERY POOR	11-25
FAILED	0-10

METHODOLOGY OF THE STUDY

Rating approach in analytical hierarchy process is one of the most effective and popular methods in decision making process, especially when the number of alternatives is high. In this study, PMS experts' perceptions were considered to find out significant criteria affecting the maintenance priority. This deep search resulted in developing a rating model based on PCI, TV, Road Type criteria and their sub-criteria (Figure 2). In this rating approach, pairwise comparisons between criteria and sub-criteria were done by considering ideas of 200 PMS experts. These experts were requested to identify the preference of each criterion over the rest and the superiority of each sub-criterion within a specific group. Relative weights of criteria, sub-criteria and inconsistency rate in each pairwise comparison matrix were calculated using MATLAB codes and Expert Choice software (Figures 3 to 6). Finally, with Ideal-Mode synthesizing in Expert Choice software, final weights for all criteria and sub-criteria were obtained (Table 7). These final weights were used to calculate the maintenance priority index for 131 sections in the case study. Methodology of the study will be discussed more in detail further on.

Modeling parameters

Pavement Condition Index, Traffic Volume, Road Type criteria and their sub-criteria which were used in this study are explained here:

Pavement condition index

Pavement condition index is the most precise index in many pavement evaluation studies. PCI incorporates data from 19 different kinds of pavement distresses as well as their severity and quantity. Furthermore, it gives an insight to the causes of distresses and the relation between pavement deterioration and climatic and/or loading conditions. Therefore, it provides an index of the pavement's structural integrity, as well as surface operational condition. PCI index is extensively used in pavement condition surveys for airfield pavement, roads and parking lots and has gained popularity among the pavement experts (McPherson and Muchnick, 2005; Kaur and Pulugurta, 2007; Gallego et al., 2008; Mishalani and Gong, 2009; Kirbas and Gursoy, 2010; Moazami and Muniandy, 2010a). Federal Aviation Administration (F.A.A.), U.S. air force, American Public Works Association (APWA) and many other agencies worldwide accept this method for pavement condition assessment. More details on PCI method are available in ASTM D6433 – 09 (1999). "Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys". PCI is the only pavement rating index that has gained an ASTM standard designation.

In PCI calculation, pavement deterioration rate is a function of distress type, distress severity, and density of distress. For each type, each level and extent of damage according to some nomographs a deduct value is obtained. Deduct values indicate the degree of effect that each combination of distress type, severity level, and distress density has on pavement condition. Eventually, a proportion of the sum of these deduct values is subtracted from 100 and the PCI is determined. The value of PCI varies between 100 for a new pavement with no distress to 0 for a failed pavement. Hence, pavements with lower PCI should be given higher priority for maintenance. Pavement quality condition for different values of PCI is illustrated in Figure 1. In AHP modeling, the PCI criterion was divided to 7 sub-criteria. These sub-criteria are presented in Table 1. Using this evaluation index also enables decision makers to account for pavement life cycle costs, by introducing the critical point. Critical PCI is the PCI after which the pavement begins to deteriorate rapidly. Therefore, it would be a wise and prudent

Table 2. Urban roads classification.

Road type	Suitable width	Minimum width	Minimum and maximum number of lanes in one direction
Major arterial (freeway, expressway)	3.75	3.50	2-4
Highway with maximum speed up to 90 (km/hr)	3.50	3.25	2-4
Minor arterial (commercial part)	3.50	3.25	1-3
Minor Arterial (non-commercial part or one way)	3.25	2.75	1-3
Access	3.25	2.75	Only 1

Table 3. Capacity values for a meter wide of any type of urban roads.

Road type	Capacity for a meter wide (pcu/hr)
Access	133
Two way collector	220
Minor arterial, two way(commercial part of city)	253
Minor arterial, two way(non-commercial part of city)	240
Minor arterial, one way	240
Major arterial (low width or small median Blvd.)*	280
Major arterial (high width Blvd.)	333
Intra-urban expressway	413

*With riding less than 7. 5 m or median less than 1 m.

Table 4. Sub-criteria for traffic volume.

Hourly traffic volume (TV)	Passenger car per hour per direction
Low volume (low vol.)	<433 (pcu/hr)
Medium volume (med vol.)	433 to 2660 (pcu/hr)
High volume (high vol.)	2660 to 6200 (pcu/hr)
Others	≥6200 (pcu/hr)

decision to keep all the sections above this point. A sample of deterioration model and rate of changes in PCI during years was also published for the same case study (Moazami et al., 2010b).

Road type

Road type is another important criterion which was considered in pavement rehabilitation prioritization. Three functional classes for roads, include expressway, arterial and access, were used in this study as the sub-criteria for road type in AHP modeling. The major difference among these three groups is the priority given to mobility or inversely the access. In this classification, expressways have the highest mobility and the lowest level of access which result in high speeds of vehicles. Therefore, safety problems in the presence of distresses such as bleeding, polished aggregate, weathering and raveling are more prone to occur in expressways. Consequently, road functional class is of high significance when determining pavement maintenance priority.

Traffic volume

Traffic volume over each section also affects the pavement maintenance priority. The greater the traffic volume through a section is, the higher the priority will be. Indeed, for a highly crowded road, on-time maintenance and rehabilitation would cause considerable reduction in the operational costs of a great number of vehicles. Consequently, when two roads have equal PCI values and equal classification, the one with greater traffic volume should be given higher priority. The Transportation Research Center of Sharif University (Iran) (2004) conducted the “urban comprehensive studies” of Tehran. According to these studies, urban roads classification and capacity values for a meter wide of all types of roads are as Tables 2 and 3, respectively. According to Tables 2 and 3 and using the suitable width, upper limits of hourly traffic volume for the three mentioned types of roads are as follows:

Access streets: $3.25 \times 133 = 433(pcu/hr)$

Minor arterials: $3 \times 3.5 \times 253 = 2660(pcu/hr)$

Expressways: $4 \times 3.75 \times 413 \approx 6200(pcu/hr)$

These values were used to determine the boundaries of sub-criteria for traffic volume criterion as illustrated in Table 4. To consider the requirement for very high-volume streets, another sub-criterion called “others” was also introduced.

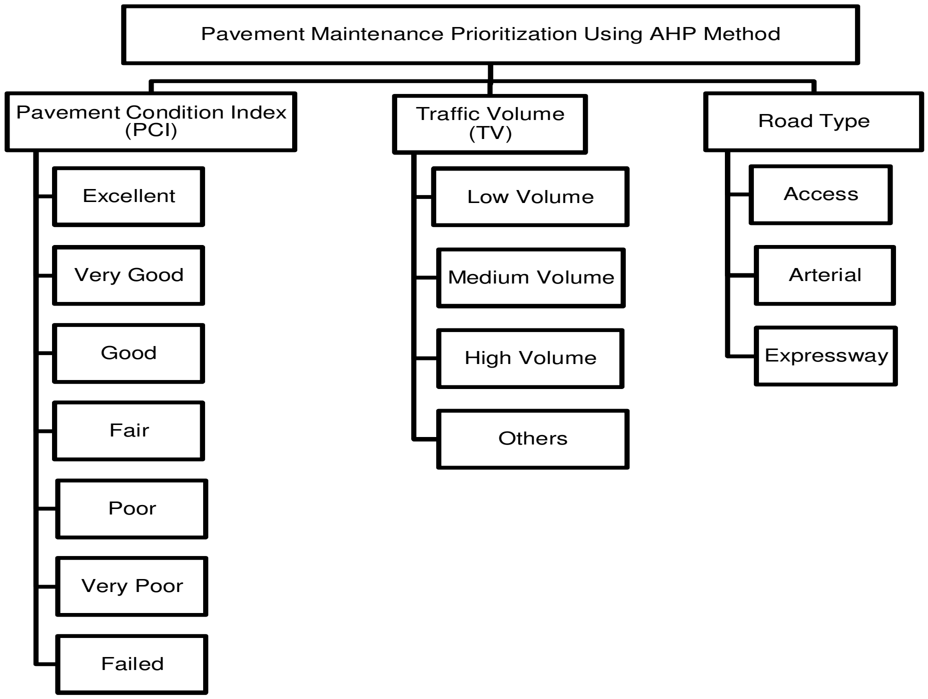

Figure 2. Hierarchy of pavement rehabilitation and maintenance prioritization.

Table 5. Numerical superiority in pairwise comparison.

Verbal judgements	Numerical value
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Preference between the above range	2,4,6,8

CONCEPT OF ANALYTICAL HIERARCHY PROCESS

Analytical hierarchy process, introduced by (Saaty, 1980), is one of the most effective techniques in decision making process. This technique is based on pairwise comparison and enables managers to investigate several different criteria in the selection of the best alternative. In other words, AHP compares criteria on a ratio scale and incorporates qualitative and quantitative criteria to facilitate the selection of the best alternative (Saaty, 1994). As a result of its comprehensive but simple characteristic (easy calculation and straight forward judgement), analytical hierarchy process has been exploited by many experts in different fields.

Su et al. (2006) applied AHP method to rank 25 major rail projects to determine implementation priorities and budget allocations. Farhan and Fwa (2009) concluded that, the absolute AHP method can be successfully applied for pavement maintenance prioritization. In this research, also rating approach in AHP method (absolute AHP) was used which is suitable for prioritization of a large number of alternatives. Generally, AHP involves the following phases: (a) structuring a hierarchy, (b) calculating the relative weights on the basis of one-on-one comparisons and checking the consistency of judgements, (c) synthesise the relative weights to obtain the final weights. The AHP method was described in detail by Saaty and Vargas (2000).

Structuring the hierarchy (rating approach) and creating pairwise comparison matrices

Level 1 of the hierarchy comprises the target and at level 2, all the criteria can be depicted which included PCI, TV and Road Type. For each criterion a number of sub-criteria were defined at level 3. Figure 2 depicts the hierarchy of pavement rehabilitation and maintenance prioritization. All comparisons between criteria and sub-criteria performed in AHP are pairwise comparisons. When component (i) is being compared with component (j), the superiority of (i) over (j) is quantized as Table 5 (Saaty, 1980). In this research pairwise comparisons between criteria and sub-criteria were done by considering ideas of 200 PMS experts. These experts were requested to fill up the questionnaires. In cases that there was a major difference between experts' ideas about the preference of one member over the others in pairwise comparison matrices , each of the decision makers was supposed to apply his/her own idea and then

Table 6. Inconsistency index for random matrixes.

n	I.I.R	n	I.I.R
1	0	6	1.24
2	0	7	1.32
3	0.58	8	1.41
4	0.90	9	1.45
5	1.12	10	1.49

personal judgements ,with the help of geometric mean, were converted to group judgement. Aczel and Saaty (1983) illustrated that geometric mean is the best method for synthesizing judgements in group analytical hierarchy process. The geometric mean for given values

$X_1, X_2, \ldots, X_n$, is:

$$X = \sqrt[n]{X_1 . X_2 \ldots . X_n} \quad (1)$$

Calculating the relative weights and judgements consistency

The outcome of each set of pairwise comparisons is expressed as a positive reciprocal matrix. For example, the ultimate comparison matrix for criteria in this study was as follows:

$$A = \begin{array}{c} \\ \text{PCI} \\ \text{TV} \\ \text{Road Type} \end{array} \begin{array}{c} \begin{array}{ccc} \text{PCI} & \text{TV} & \text{Road Type} \end{array} \\ \begin{bmatrix} 1 & 5 & 5 \\ \frac{1}{5} & 1 & 2 \\ \frac{1}{5} & \frac{1}{2} & 1 \end{bmatrix} \end{array} \quad (2)$$

For instance, ultimate group judgement indicated that the importance of PCI criteria over TV was 5 (strongly preferred). Eigenvector method is often used to derive the relative weights of criteria and sub-criteria. For pairwise comparison matrix A, Eigen values (λ) are obtained after solving the equation "determinant $(A - \lambda . I) = 0$". Furthermore, by solving the matrix equation $(A - \lambda_{max} I)W = 0$, the relative weight vector (Eigenvector) is calculated. As an example, the relative weight vector for matrix 2 is obtained as follows:

$$\det(A - \lambda I) = \begin{vmatrix} 1-\lambda & 5 & 5 \\ \frac{1}{5} & 1-\lambda & 2 \\ \frac{1}{5} & \frac{1}{2} & 1-\lambda \end{vmatrix} = 0$$

$$\Rightarrow (1-\lambda)^3 - 3(1-\lambda) + \frac{5}{2} = 0 \Rightarrow \begin{Bmatrix} \lambda_1 = 3.05362 \\ \lambda_2 = i \\ \lambda_3 = -i \end{Bmatrix}$$

$$(A - \lambda_{max} I)w = \begin{vmatrix} -2.05362 & 5 & 5 \\ \frac{1}{5} & -2.05362 & 2 \\ \frac{1}{5} & \frac{1}{2} & -2.05362 \end{vmatrix} \times \begin{vmatrix} W_1 \\ W_2 \\ W_3 \end{vmatrix} = 0$$

$$\Rightarrow \begin{Bmatrix} -2.05362W_1 + 5W_2 + 5W_3 = 0 \\ \frac{1}{5}W_1 - 2.05362W_2 + 2W_3 = 0 \\ \frac{1}{5}W_1 + \frac{1}{2}W_2 - 2.05362W_3 = 0 \\ W_1 + W_2 + W_3 = 1 \end{Bmatrix}$$

$$\Rightarrow \begin{Bmatrix} W_1 = 0.70885587 \\ W_2 = 0.17862039 \\ W_3 = 0.11252374 \end{Bmatrix}$$

In addition, the value of inconsistency for each pairwise comparison matrix is obtained from Equations 3 and 4:

$$I.R. = \frac{I.I.}{I.I.R.} \quad (3)$$

$$I.I. = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

$I.R.$: Rate of inconsistency (value of inconsistency)
$I.I.$: Inconsistency index
$I.R.R.$: Inconsistency index for random matrix
n : Number of criteria or sub-criteria being compared in one pairwise comparison matrix

Inconsistency index for random matrix is obtained from Table 6. Therefore, the value of inconsistency for pairwise comparison matrix 2 is:

$$I.I. = \frac{3.05362 - 3}{2} \approx 0.02681$$

$$I.R. = \frac{0.02681}{0.58} \approx 0.046$$

Saaty (1980) recommended that inconsistency in human judgements should not be more than 0.1. In this paper,

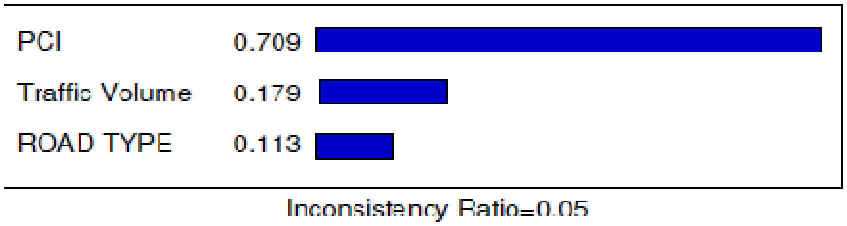

Figure 3. Relative weights and rate of Inconsistency in criteria pairwise comparison matrix.

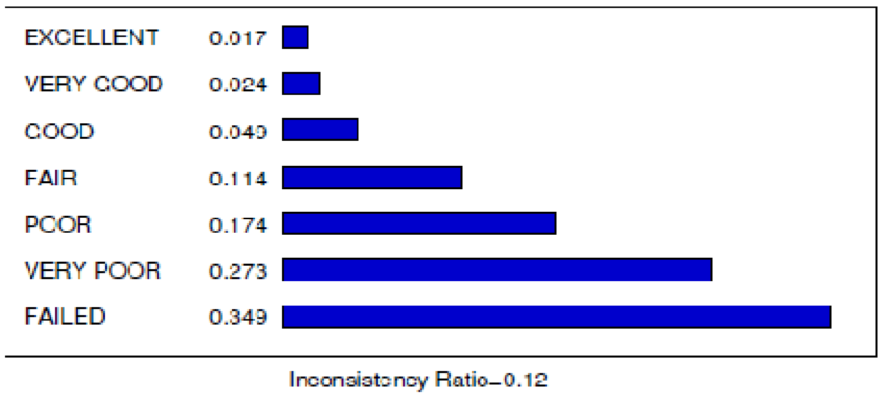

Figure 4. Relative weights and rate of inconsistency in PCI's sub-criteria pairwise comparison matrix.

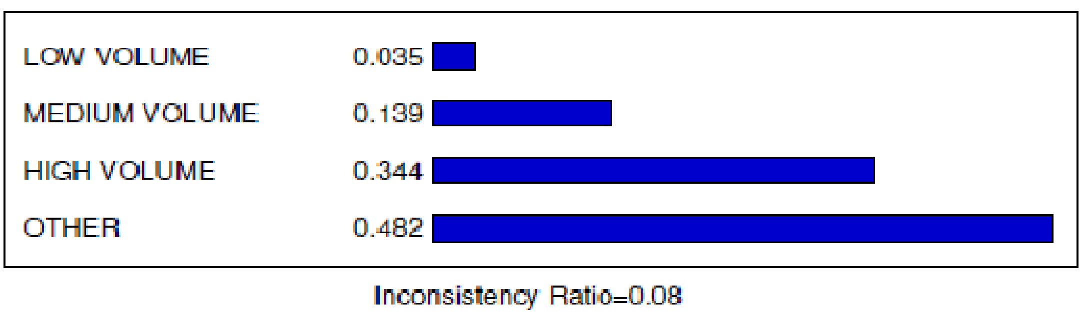

Figure 5. Relative weights and rate of inconsistency in TV's sub-criteria pairwise comparison matrix.

due to the large number of sub-criteria and therefore creation of large matrices, calculating the relative weights by MATLAB M-Files seemed difficult. To reduce the computation time without loss of accuracy, Expert Choice software was used. Relative weights and the value of inconsistency for each comparison matrix are illustrated in Figures 3 to 6. Figure 4 shows the relative weights for PCI's sub-criteria. The inconsistency rate for this pairwise matrix is above 0.1. This is because, most of the PMS experts do believe that keeping the sections conditions above the critical PCI point (typically above the Fair condition) is very important and this bias judgment increases the matrix inconsistency.

Rating approach in AHP and synthesizing the relative weights to obtain final weights

Rating approach is utilized when the number of alternatives is high. In this case, instead of pairwise comparison between alternatives (relative measuring), rating approach (absolute measuring) is used. It should be mentioned that in AHP method and Expert Choice software for each single matrix, pairwise comparisons are applicable for a maximum of nine elements. In addition, in a single matrix, when the number of elements for comparison is high, consistency control will be difficult and meaningless. In such cases, pairwise comparison is

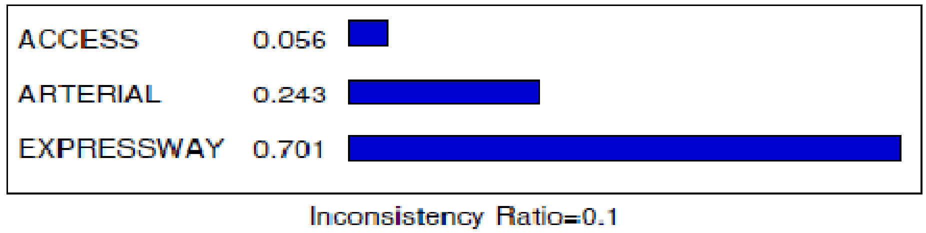

Figure 6. Relative weights and rate of inconsistency in road type's sub-criteria pairwise comparison matrix.

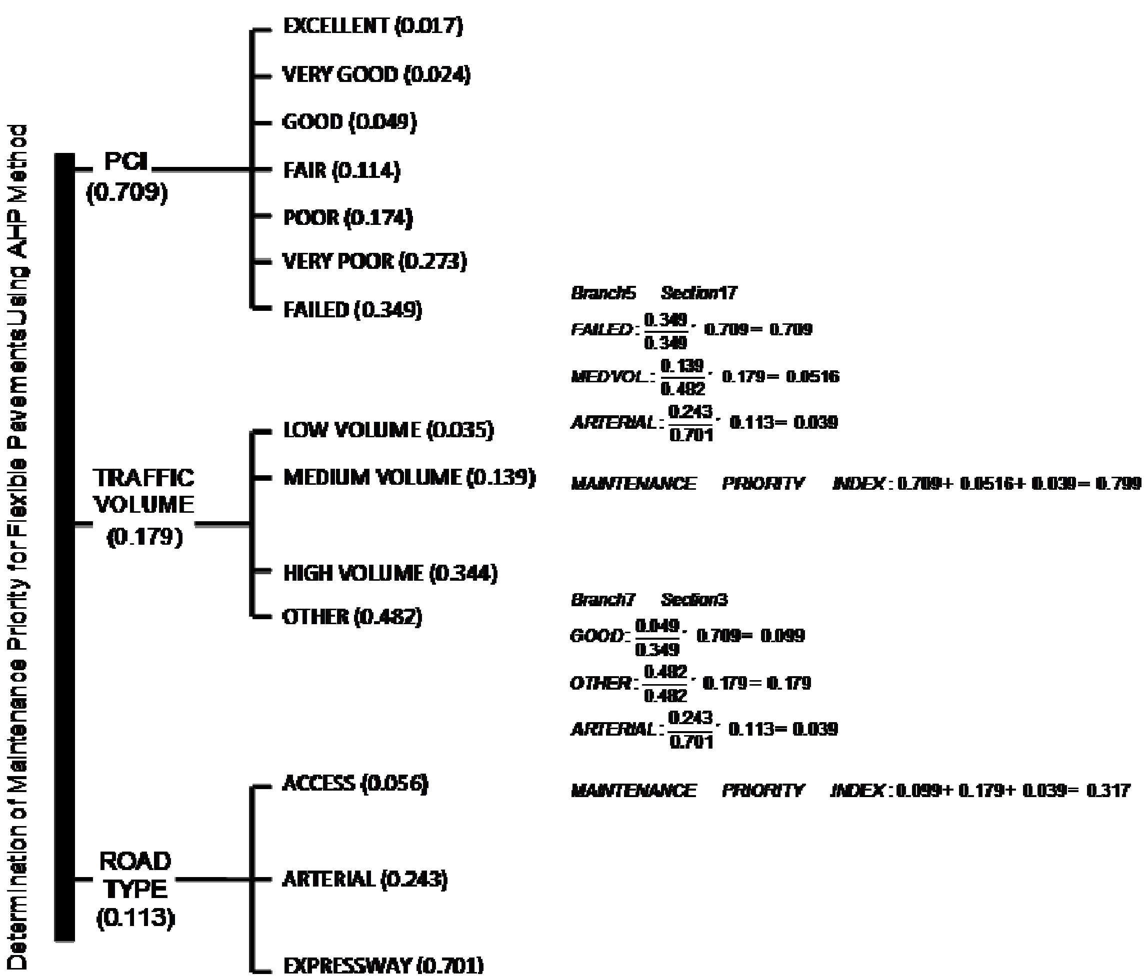

Figure 7. Relative weights of criteria and sub-criteria and maintenance priority for branch 5 section 17 and branch 7 section 3 of the case study.

not effective and it is recommended to use absolute measuring (rating approach). Consequently, at level 3 instead of alternatives, different sub-criteria are defined. In rating approach, criteria and sub-criteria are compared on pairwise basis, while alternatives are absolutely measured. After pairwise comparison and calculation of relative weights, final weight of each sub-criterion is calculated by synthesizing. Generally, ideal-mode (performance mode) and distributive-mode (dominance mode) are used for synthesizing.

In Ideal-Mode synthesizing (proposed mode in this study) in order to calculate the final weight for each sub-criterion, the weight of that sub-criterion is divided by the largest sub-criteria weight among the same group and then multiplied by the weight of corresponding criterion. Sum of the final weights, is used as the maintenance priority index for each section. Figure 7 indicates the relative weights for all criteria and sub-criteria. This figure

Table 7. Synthesizing relative weights and calculating final weights.

Synthesis of leaf nodes with respect to goal (ideal mode)				
Overall inconsistency index=0.1				
Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
PCI=0.709	FAILED=0.709 VERY POOR=0.554 POOR=0.353 FAIR=0.230 GOOD=0.099 VERY GOOD=0.049 EXCELLENT=0.035			
Traffic volume=0.179	OTHER=0.179 HIGH VOLUME=0.127 MEDIUM VOLUME=0.052 LOW VOLUME=0.013			
Road type=0.113	EXPRESSWAY=0.113 ARTERIAL=0.039 ACCESS=0.009			

also shows the maintenance priority indexes for branch 5 section 17 (Mirzaye Shirazi north to south direction at Sarv intersection) and branch 7 section 3 (Karim Khane Zand east to west direction at Kheradmand intersection) of the case study. According to the available data on the first section, the PCI was 3, directional hourly traffic volume over this section was 2135 (pcu/hr) and Road type was arterial. So, this section is put in FAILED, MED VOL. and ARTERIAL sub-criteria, respectively. Finally, normalized maintenance priority is 0.799. For the other example of the case study, the PCI was 57, directional hourly traffic volume over this section was 15953 (pcu/hr) and Road type was arterial. Therefore, this section is put in GOOD, OTHER and ARTERIAL sub-criteria, respectively. Finally, normalized maintenance priority for branch 7 section 3 is 0.317. Table 7 indicates the final weights for all criteria and sub-criteria used in rating approach. Therefore, using the numbers in "Level 2" column, the decision maker will be able to identify the maintenance priority index according to each section specifications. This table can be used as a reference for determination of maintenance priority index in flexible pavements. Higher maintenance priority index indicates urgent necessity for maintenance activities.

Case study and data collection

District No. 6 of Tehran municipality is the most important and effective area in terms of accommodating a large number of daily trips. It is situated in Central Business District (CBD) as well. In this area, Taleghani, Sepahbod Gharani, Ghaem Magham Farahani (both directions), Mirzaye Shirazi (both directions), Karim Khane Zand (both directions), Ostad Motahhari and Hafez streets were studied as the case study. For better investigation, they were divided to 131 sections. Pavement structure, traffic volume, construction history, and pavement condition were considered when dividing these branches into sections (Ismail et al., 2009). It should be noted that in this case study, distress inspection was performed by evaluator inspector group for 131 sections. In all sections, specifications of the street's cross section, distress type, quantity and severity were inspected. Pavement distresses details were then entered to MicroPAVER system for automatic PCI calculation. Automatic PCI calculation is one of the micro PAVER capabilities (Feighan et al., 1989). Figure 8 indicates the condition of sections during survey.

While distress inspection, hourly traffic volume was gathered precisely. Most of the intersections in district No.6 had been equipped with SCATS (Sydney Coordinated Adoptive Traffic System) system. Traffic data in this study were collected by the detectors, buried in the asphalt layer, in SCATS system and by means of recorded videos from CCTV. In some sections, traffic statistics were also collected in the field using manual mechanical counting board. 2 h peak flow in the morning, 2 h peak flow in the afternoon and 4 h flow in the intermediate hours of the day were considered for field surveys. These three methods of data collection including traffic data from SCATS detectors, CCTV and local statistics, guaranteed the precision of the collected traffic data.

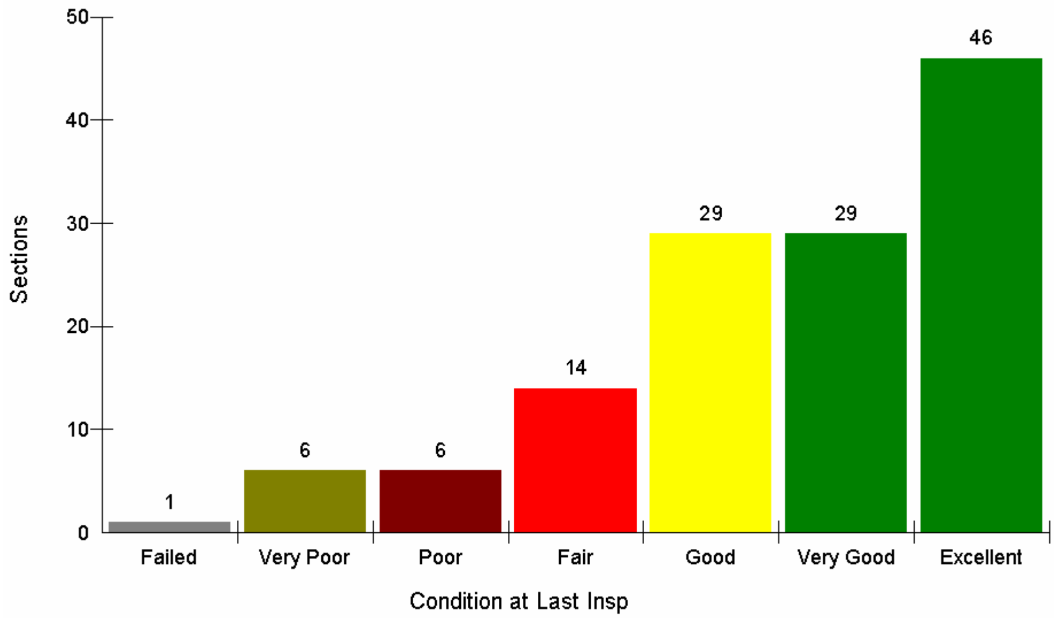

Figure 8. The condition of sections (surveyed summer 2006).

DISCUSSION

Since prioritization is a decision making process, statistical models are not very responsive. So, designers must use decision making processes. Analytical hierarchy process is one of the simplest and most useful methods in multi-criteria decision making. Considering ideas of those who are directly involved in pavement maintenance programs is an effective way, to find out the important parameters for determination of maintenance priority of each section. Due to the PMS experts' perceptions a rating model based on PCI, TV, Road Type criteria and their sub-criteria was developed. Different sub-criteria were defined for each parameter; these classifications were mainly based on Tehran's urban comprehensive studies. AHP method is based on pairwise comparisons which facilitate calculations and judgements. In this study, in order to obtain more realistic and reliable comparison matrices, all personal judgements (questionnaires filled up by PMS specialists) were converted to group judgements. Expert Choice software was then used to calculate the relative weights in each pairwise comparison matrix.

This software provides lesser computation time without any loss of accuracy. The proposed model in this study can be easily and precisely used to specify the maintenance priority index for each section according to its specifications. The final rating model was used for prioritization of 131 sections in the case study. However, because of the space limitations, the maintenance priority index for only two sections was presented here. Using the numbers in "Level 2" column (Table 7); the decision maker will be able to identify the maintenance priority index according to each section's specifications. This table can be used as a reference for determination of maintenance priority index in flexible pavements. Higher maintenance priority index indicates urgent necessity for maintenance activities. As it can be seen in Figure 7 branch 5, section 17 should be maintained prior to with branch 7, section 3.

Conclusion

1. Due to the fact that, allocated budget for maintenance and rehabilitation operations is limited; therefore all the sections that need rehabilitation do not receive enough budget and would not undergo the annual maintenance program. Consequently, prioritization is of high significance.
2. In this study, an inventory database for main streets in Tehran was developed. Based on the condition survey performed, it was found that approximately 57% of sections surveyed were in "very good" and "excellent" conditions. More importantly, 22% of the network could be rated as "good." Also, it was found that 11% of the sections surveyed were in "fair" condition. Ideally, these sections should receive maintenance as soon as possible to avoid costly maintenance actions in the future. Overall, the network had a PCI of 76, which was considered a "very good" rating.
3. Using maintenance priority index, introduced in this study, managers would be able to prioritize the maintenance of impaired sections based on their conditions. This systematic selection will guarantee the effectiveness of budget allocation.

REFERENCES

Aczel J, Saaty T (1983). Procedures for Synthesizing Ratio judgements. J. Math. Psychol., 27: 93-102.

ASTM D 6433 (1999) Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys, 1999.

Farhan J, Fwa TF (2009). Pavement Maintenance Prioritization Using Analytic Hierarchy Process. Trans. Res. Record., 2093: 12-24.

Feighan KJ, Shahin MY, Sinha KC, White TD (1989). A Prioritization Scheme for the Micro PAVER Pavement Management System. Trans. Res. Record, p. 1215, Transportation Research Board.

Gallego E, Moya M, Piniés M, Ayuga F (2008). Valuation of low volume roads in Spain. Part 2: Methodology validation. Biosyst. Eng., 101(1): 135-142.

Ismail N, Ismail A, Atiq RA (2009). An Overview of Expert Systems in Pavement Management. Eur. J. Sci. Res., 30(1): 99-111.

Kaur D, Pulugurta H (2007). Fuzzy Decision Tree Based Approach to Predict the Type of Pavement Repair. Proceedings of WSEAS International Conference on Applied Informatics and Communications, ISSN: 1790-5117, ISBN: 978-969-8457-96-6, Vouliagmeni Beach, Athens, Aug 24-26, pp. 1-6.

Kirbas U, Gursoy M (2010). Developing the basics of pavement management system in Besiktas district and evaluation of the selected sections. Sci. Res. Essays, 5(8): 806-812.

McPherson EG, Muchnick J (2005). Effects of Street Tree Shade on Asphalt Concrete Pavement Performance. J. Arboricul., 31(6): 303-310.

Mishalani RG, Gong L (2009). Optimal infrastructure condition sampling over space and time for maintenance decision-making under uncertainty. Trans. Res. Part B., 43: 311-324.

Moazami D, Muniandy R (2010a). Fuzzy Inference and Multi-criteria Decision Making Applications in Pavement Rehabilitation Prioritization. Australian J. Basic Appl. Sci., 4(10): 4740-4748.

Moazami D, Muniandy R, Hamid H, Md. Yusoff Z (2010b). Developing a Comprehensive Pavement Management System in TEHRAN (IRAN) Using MicroPAVER. Electronic J. Geotech. Eng., 15: 1782-1792.

Moazami D, Behbahani H, Muniandy R (2011). Pavement Rehabilitation and Maintenance Prioritization of Urban Roads Using Fuzzy Logic. Expert Syst. Appl., 38(10): 12869-12879.

Saaty T L (1980). The Analytic Hierarchy Process. McGraw-Hill, New York.

Saaty T L (1994). Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process. RWS Publications, Pittsburgh, Pa.

Saaty TL, Vargas LG (2000). Models, Methods, Concepts and Application of the Analytic Hierarchy Process, Kluwer Academic Publishers.

Su CHW, Cheng MY, Lin FB (2006). Simulation-enhanced approach for ranking major transport projects, J. Civil Eng. Manage., 12(4): 285-291.

Transportation research center of Sharif University of technology (2004). Reports of function time trip-volume, great Technical studies of Tehran transportation.