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Performance Assessment of Flexible Pavements: Fuzzy Evidence Theory Approach

Shruti Wadalkar [a*], Ravindra K. Lad [b], Rakesh K. Jain [a]

[a] *Dr. D. Y. Patil Institute of Technology, Pimpri, Pune, 411018, Savitribai Phule Pune University, India.*

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Abstract

Pavement performance evaluation is one of the most important steps of the pavement management system. It consists of identifying pavement condition according to various distresses occurs in the pavement surface. Data collection in performance assessment of road is done in several ways. An attempt has been made to address the problem and a new formalism is proposed for performance assessment of flexible pavements. Vagueness in the perception of expert for performance assessment of pavement based on techno-scientific parameters in linguistic terms for the domain base usage coupled with impression in parametric data calls for the application of fuzzy modeling. For this study fuzzy evidence theory weightage method “Dempster’s Shafer’s (D-S)” is applied to determine the Pavement Condition Distress Index (PCDI) of flexible pavement. D-S theory provides a designed framework to overcome the risk of uncertainty and ignorance. For the assessment of pavements five major structural indicators like longitudinal cracks, transverse cracks etc. and eleven major functional indicators like potholes, rutting, patching etc. are considered. Expert opinion is taken from the experts who are involved in the field of transportation engineering. Questionnaire Survey methodology has been adopted for the collection of experts opinions. Five linguistic terms are used for the same, which are, ‘Very important’, ‘Important’, ‘Average’, ‘Less important’ and ‘Not Important’. Based on PCDI, Pavement Condition Index (PCI) is calculated. The rating of flexible pavements is also done based on PCI. For the application of the model, five road segments of MIDC Chakan, Pune area is considered. PCI of all the road segments is determined by using the stated index. Based on PCI value, road segment 1 rated 5 with less PCI value and road segment 4 rated 1 with high PCI value. The defined method is also compared with the rating system given in Indian Road Congress (IRC -82-2015).

Keywords: Pavement; Performance; Assessment; Distress Condition; Structural Indicators and Functional Indicators.

1. Introduction

Pavement management is the process of planning the maintenance and repair of a road network to provide better conditions for the road network. A Pavement Management System (PMS) is a planning tool used to aid pavement management decisions. Typical tasks performed by pavement management systems include: identifying good, fair and poor pavements; Assign importance ratings for road segments, based on traffic volumes, road functional class, and community demand; Schedule maintenance of good roads to keep them in better condition; Schedule repairs of poor and fair pavements as remaining available funding allows. Most of the cost-effective Maintenance and Rehabilitation (M&R) strategies developed using the pavement management system (PMS) is due to accurate pavement evaluation [1]. Distresses are recorded in terms of their extent and severity. Rating of stretches for prioritization is done based on their condition. While standard templates are available for rating different distresses, still there are possibilities of variation in human judgments [2]. Decision-making in pavement management involves uncertainties, subjective

* Corresponding author: wadalkarshruti@yahoo.in

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judgment, and risk [3]. It is well understood that many databases for pavement management are quite incomplete [4]. Conflicting evidence is quite common in pavement management as data collection for condition assessment can be performed in several ways [3].

The performance indicators in assessing pavement conditions are often subjective and hence fuzzy theory could be used to quantify subjectivity and model the ambiguity involved in the system [5]. The randomness of the parameters and quantification difficulties are the main issues with deterministic performance models [6]. Moazami et al. (2011) first introduced the concept of fuzzy set theory through his paper and it is generally agreed that an essential point in the evaluation of the modern concept of uncertainty was the publication of his seminal essay, even though some ideas presented in the paper were envisioned some 30 years earlier by the American philosopher. Pavement Rehabilitation Prioritization has been done using fuzzy inference and multi-criteria decision-making [7]. Afterward several researchers were used fuzzy logic for the pavement performance assessment. Fuzzy logic and expert system approaches were used in evaluating flexible pavement distress [8]. Pavement condition assessment was done using the fuzzy logic theory and analytic hierarchy process [9]. A reliable statewide pavement-performance study was done using a confidence evaluation system [10]. An approach to pavement treatment selection using a fuzzy logic inference system was presented [11]. Pavement performance prediction was done through fuzzy logic using the Marine Corps air station [12]. Piecewise Linear (PL) performance models for flexible pavements were developed using PMS data [13]. Fuzzy MulticriteriaDecision-Making approach was used for Pavement Project Evaluation using Life-Cycle Cost / Performance Analysis [14]. The most appropriate and straightforward technique of defining the pavement condition state in the absence of detailed data of distress indices was developed [15]. The Fuzzy Logical approach was used to estimate the values of the roughness index. In this study, they considered distresses as input parameters for determining the roughness index [16]. A new decision method of basic fuzzy soft set in the determination of maintenance scheduling of asphalt pavement was used where the survey data of pavement condition in the form of road surface roughness, deflection, pavement damage condition, and traffic volume is used [17].

The theory of Evidence was first formulated by Shafer in 1976 [18]. The D-S theory has been applied in the fields of statistical inference; diagnostics, risk analysis, and decision analysis [19]. The D-S theory provides a unifying framework for representing uncertainty as it can include the situations of risk and ignorance as exceptional cases. (A decision-making model using Dempster's – Shafer theory) [20]. To overcome the limitations of uncertainty and ambiguity in the decision, in this study the main objective is to apply fuzzy MCDM by using evidence theory weighting method for the rating of roads constructed as flexible pavement. The methodology adopted in this work is shown in Figure 1.

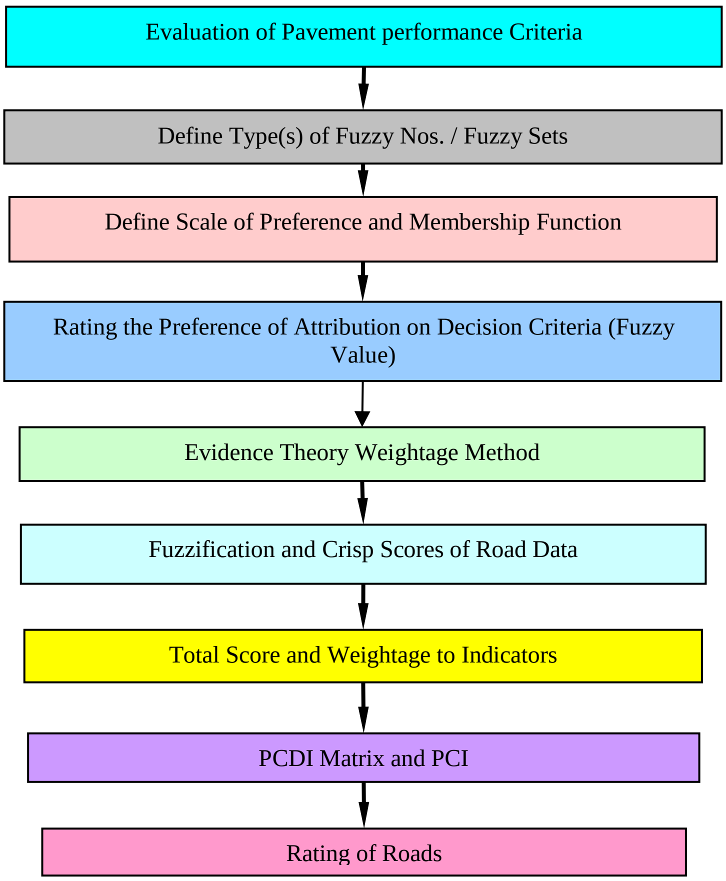

Figure 1. Methodology Chart

2. Evidence Theory Weightage Method

In the evidence theory weighting method, weight to each sub-indicator is considered based on the relation of sub-indicator with each other. Because the knowledge in this regard may be inadequate, it is proposed to use an evidence theory method that took care of human ignorance or inadequacy of experience and established the interactive relationship between the sub-criteria. Experts' perceptions are required to be taken from academicians and professionals, who are involved in the field of transportation engineering, for individual sub-indicator and a combination of sub-indicator of structural and functional indicators. The importance of weighting factors for this sub-indicator is calculated by using combined evidence. Combined evidence can be obtained from two independent sources (for example, from two experts in the field of inquiry) and expressed by two primary assignments m_1 and m_2 on some power set.

As a primary assignment, for individual sub-indicators and combination of sub-indicators, crisp score of fuzzy numbers of a linguistic term can be calculated by using Equation 1 and then primary assignments m_1 and m_2 for each structural and functional indicator can be obtained by dividing the crisp score of each indicator (C_{mk}) component by the total of all indictors $(\sum C_{mk})$. The two basic assignments m_1 and m_2 on some power setting must be appropriately combined to obtain a joint basic assignment $m_{1,2}$ by Equation 2.

$$A_{ij}^{k} = \left(\frac{1}{p} \right) \cdot \left(a_{i1}^{k} + a_{i2}^{k} + \ ... + a_{ip}^{k} \right) \text{for } i = 1, 2, ..., n \text{ and } j = 1, 2, ..., p \tag{1}$$

$$e = (x_1 + x_2 + x_3 + x_4) / 4$$

$$m_{1,2}(A) = \frac{\sum_{B \cap C = A} m_1(B) \cdot m_2(C)}{1 - K} \quad \text{for all } A \neq \phi \text{ and } m_{1,2}(\phi) = 0, \text{ where} \tag{2}$$

$$K = \sum_{B \cap C = \phi} m_1(B) \cdot m_2(C) \tag{3}$$

Equation 2 of combining evidence is referred to as Dempster's rule of combination. As per this rule, the degree of evidence $m_1(B)$ from the first source that focuses on set $B \in P(x)$ and the degree of evidence $m_2(C)$ from the second source that focuses on set $C \in P(x)$ can be combined by taking the product $m_1(B).m_2(C)$, which focuses on the intersection $B \cap C$. This is precisely the same way in which the joint probability distribution can be calculated from two independent marginal distributions; consequently, it is justified on the same grounds. However, since some intersections of indicators from the first $[m_1(B)]$ and second $[m_2(C)]$ sources may result in the same set A, it is a must to add the corresponding products to obtain $m_{1,2}(A)$. Moreover, some of the intersections may be empty. Since it is required that $m_{1,2}(\phi) = 0$, the value K is not included in the definition of the joint primary assignment $m_{1,2}$. This means that the sum of products $m_1(B).m_2(C)$ for all indicators B of m_1 and all indicators C of m_2 such that $B \cap C \neq \phi$ is equal to $(1 - K)$. To obtain a normalized basic assignment $m_{1,2}$ that is $\sum_{A \in P(x)} m(A) = 1$ it is required to divide each of these products by factor $(1 - K)$. The value of K is obtained using the equation 3. The $m_{1,2}$ obtained from the above equation for each sub-indicator of the road is the normalized weight [21].

3. Case Study

The values of pavement performance indicators are collected by experimentation on roads of Pune (PCMC) region. For the study, MIDC Chakan Industrial area has been considered. Chakan is a major automobile hub. It is now home to a Special Economic Zone (SEZ) promoted by the Maharashtra Industrial Development Corporation (MIDC). Over 750 large and small industries, including a number of automobile component manufacturers are based in the area. Hence by considering the importance of the area in the economic development of the country, the road condition in this area is assessed through the developed model. For the study, five different road segments of MIDC, Chakan Industrial area are considered. Five roads of MIDC Phase I and Phase IV are considered separately for rating purposes. All the streets are flexible pavements; asphalt roads. Details of roads are given in the following table 1.

Table 1. Details of Road Segments

Road	Location	Land width (M)	Metal width (M)	Total length (Km)
I	MIDC Phase I	20	5.5	2.15
II	MIDC Phase I	60	16	4.925
III	MIDC Phase II	45	7.5	5.3
IV	MIDC Phase II	20	5.5	2.50
V	MIDC Phase II	30	7.5	3.85

Structural distress viz. longitudinal cracking (LC), transverse cracking (TC), fatigue cracking (FC), block cracking (BC), deflection (Def), and functional distress viz. Rutting (RUT), corrugation (C), shoving (S), potholes (Po), patching (Pa), raveling (RAV), bleeding (B), pumping (Pu), drop-Off (Do), polished aggregates (Pag), depression (D) are measured on the selected road segments. The average values of defects are shown in the following Table No.2.

Table 2. Percentage Value of Distresses for all Roads

Sr. No.	Defects	ROAD 1	ROAD 2	ROAD 3	ROAD 4	ROAD 5
1	LC	9.26	5.95	7.12	0.229	0.28
2	TC	25.44	1.20	37.86	1.356	24.72
3	FC	0.72	0.20	0.05	0.057	0.07
4	BC	0.76	0.20	0.06	0.008	0.01
5	Def	1.17	5.50	0.97	1.05	1.02
6	RUT	1.50	0.99	0.05	0.023	0.55
7	C	0.14	1.00	0.08	0.050	0.04
8	S	0.16	0.28	0.02	0.024	0.01
9	Po	0.16	0.08	0.05	0.046	0.25
10	Pa	2.24	0.28	0.11	0.321	0.05
11	RAV	0.14	1.00	0.08	0.056	0.04
12	B	0.59	0.47	0.41	0.095	0.33
13	Pu	0.03	0.05	0.00	0.000	0.00
14	Do	0.14	0.03	0.02	0.019	0.03
15	Pag	0.23	0.63	0.38	0.734	1.56
16	D	0.12	0.07	0.05	0.008	0.00

Opinions of experts for all distress as pavement performance indicators have been taken for flexible pavements. The experts were the professionals and academicians in the field of transportation engineering. Total fourteen experts were selected from the pilot study. Experts' views were made for individual sub-indicators and a combination of sub-indicators of structural and functional indicators of flexible pavement. Experts' opinion was taken in the linguistic terms as VI meant that the sub-criterion is "Very important," I meant "Important," A meant "Average" and LI meant "Least Important" NI meant "Not Important". The trapezoidal fuzzy scale is used for giving fuzzy numbers to the linguistic term shown in Figure 2.

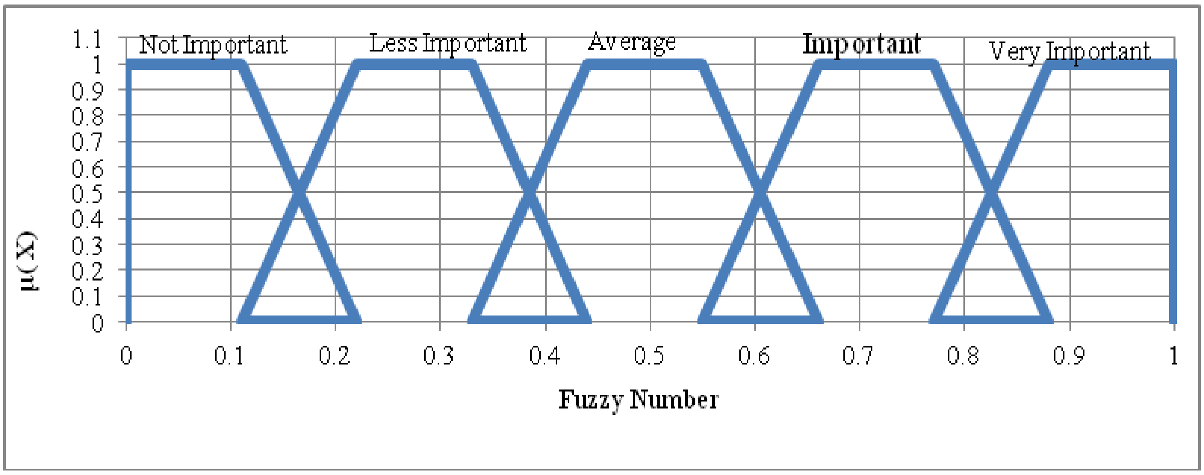

Figure 2. Fuzzy Numbers for Linguistic Terms

As a mass assignment for individual sub-indicator, the combination of sub-indicator and the relation of all sub-indicator with each other, crisp score of fuzzy numbers of a linguistic term is calculated and then the masses m_1 and m_2 for each indicator is obtained by dividing the score of the indicator (C_{mk}) by the total of all indicators $(\sum C_{mk})$. Mass assignment for structural indicators by considering academician one and two is shown in Table 3.

Table 3. Mass Assignment for Structural Indicators (Academicians 1, 2)

Pavement Performance Indicators	Expert 1			Expert 2		
	Linguistic Term	Crisp Score	m_1	Linguistic Term	Crisp Score	m_2
Structural Indicators						
LC	I	0.722	0.063	A	0.500	0.044
TC	VI	0.916	0.080	I	0.722	0.063
FC	I	0.722	0.063	VI	0.916	0.080
BC	I	0.722	0.063	I	0.722	0.063
Def	VI	0.916	0.080	VI	0.916	0.080
LC ∪ TC	I	0.722	0.063	I	0.722	0.063
LC ∪ FC	I	0.722	0.063	I	0.722	0.063
LC ∪ BC	I	0.722	0.063	I	0.722	0.063
LC ∪ Def	I	0.722	0.063	I	0.722	0.063
TC ∪ FC	A	0.500	0.044	A	0.500	0.044
TC ∪ BC	I	0.722	0.063	A	0.500	0.044
TC ∪ Def	I	0.722	0.063	VI	0.916	0.080
FC ∪ BC	A	0.500	0.044	I	0.722	0.063
FC ∪ Def	I	0.722	0.063	VI	0.916	0.080
BC ∪ Def	A	0.500	0.044	LI	0.278	0.024
LC ∪ TC ∪ FC ∪ BC ∪ Def	VI	0.916	0.080	VI	0.916	0.080
Total		$\sum C_{mk})$ = 11.462	1		$\sum C_{mk})$ = 11.408	1

Similarly, mass assignment for all indictors is calculated by considering the combination of all experts' opinions with each other. Applying equation as shown below, with usual notations of Dempster's rule to m_1 and m_2, combined evidence (joint primary assignment) $m_{1,2}$ is obtained by Equation 2 To determine the values of m1,2, firstly, the normalization factor (1-K) is calculated by Equation 3. Applying Equation 3, as shown below, with usual notations, K is obtained as follows.

$$K = \sum_{B \cap C = \varphi} m_1(B) \cdot m_2(C) \qquad K = 0.418$$

The normalization factor was then $(1 - K) = 0.582$.

Values of combined evidence $m_{1,2}$ is calculated by Equation 2. For example;

$$m_{1,2}(LC) = m_1(LC).m_2(LC)m_1(LC).m_2(LC \cup TC) + m_1(LC).m_2(LC \cup FC) + m_1(LC).m_2(LC \cup BC) + m_1(LC).m_2(LC \cup Def) + m_1(LC).m_2(LC \cup TC \cup FC \cup BC \cup Def) + m_1(LC \cup TC).m_2(LC) + m_1(LC \cup TC).m_2(LC \cup FC)m_1(LC \cup TC).m_2(LC \cup BC) + m_1(LC \cup TC).m_2(LC \cup Def) + m_1(LC \cup FC).m_2(LC) + m_1(LC \cup FC).m_2(LC \cup TC) + m_1(LC \cup FC).m_2(LC \cup BC) + m_1(LC \cup FC).m_2(LC \cup Def) + m_1(LC \cup BC).m_2(LC) + m_1(LC \cup BC).m_2(LC \cup TC) + m_1(LC \cup BC).\ m_2(LC \cup FC) + m_1(LC \cup BC).m_2(LC \cup Def) + m_1(LC \cup Def).m2(LC) + m1(LC \cup Def).m2(LC \cup TC) + m_1(L \cup Def).m_2(LC \cup FC) + m_1(LC \cup Def).m_2(LC \cup BC) + m_1(LC \cup TC \cup FC \cup BC \cup Def)m_2(LC)/(1-K) = 0.148$$

Similarly, values of combined evidence ($m_{1,2}$) for the remaining structural and functional indicators are calculated, and the same are as shown in the Table 4.

Table 4. Combination of Degrees of Evidence from Two Independent Sources (Academicians: Expert 1 and Expert 2)

Sr. No.	Pavement Performance Indicators	Expert1	Expert2	Combined Evidence
		m_1	m_2	$m_{1,2}$
1	**Structural Indicators**			
	LC	0.063	0.044	0.148
	TC	0.080	0.063	0.082
	FC	0.063	0.080	0.047
	BC	0.063	0.063	0.014
	Def	0.080	0.080	0.011

Functional indicators			
R	0.021	0.020	0.036
C	0.016	0.014	0.025
S	0.011	0.008	0.019
Po	0.021	0.026	0.019
Pa	0.021	0.020	0.011
Rav	0.011	0.014	0.012
B	0.011	0.014	0.003
P	0.021	0.014	0.004
DO	0.021	0.008	0.001
PA	0.021	0.002	0.001
De	0.021	0.026	0.001

The combined evidence, by considering a combination of mass assignments from other experts, for each sub-indicator of structural and functional indicators is calculated. Tables 5 and 6 shows combined evidence from all experts for each sub-indicator.

Table 5. Combined Evidence from all Experts (Academicians)

Combined Evidence	Structural Indicators					Functional Indicators										
	LC	**TC**	**FC**	**BC**	**Def**	**R**	**C**	**S**	**Po**	**Pa**	**Rav**	**B**	**P**	**Do**	**PA**	**D**
$m_{1,2}$	0.0151	0.084	0.053	0.015	0.011	0.036	0.025	0.019	0.019	0.011	0.012	0.003	0.004	0.001	0.001	0.001
$m_{1,3}$	0.119	0.083	0.046	0.014	0.013	0.033	0.024	0.01	0.02	0.015	0.011	0.041	0.005	0.005	0.002	0.002
$m_{1,4}$	0.148	0.099	0.048	0.012	0.012	0.035	0.022	0.009	0.02	0.016	0.011	0.004	0.005	0.005	0.002	0.002
$m_{1,5}$	0.137	0.088	0.046	0.019	0.012	0.042	0.027	0.017	0.022	0.011	0.010	0.004	0.003	0.003	0.002	0.002
$m_{1,6}$	0.137	0.088	0.046	0.019	0.017	0.041	0.023	0.160	0.024	0.012	0.010	0.004	0.003	0.003	0.002	0.002
$m_{1,7}$	0.168	0.098	0.048	0.018	0.012	0.033	0.022	0.015	0.018	0.015	0.013	0.048	0.04	0.03	0.002	0.002
$m_{2,3}$	0.108	0.076	0.059	0.013	0.013	0.035	0.024	0.014	0.020	0.011	0.095	0.035	0.055	0.022	0.001	0.003
$m_{2,4}$	0.135	0.089	0.062	0.011	0.012	0.037	0.023	0.013	0.019	0.012	0.091	0.003	0.005	0.002	0.001	0.026
$m_{2,5}$	0.124	0.080	0.060	0.017	0.012	0.044	0.027	0.023	0.027	0.008	0.009	0.003	0.003	0.001	0.001	0.002
$m_{2,6}$	0.124	0.080	0.060	0.017	0.012	0.044	0.023	0.021	0.023	0.009	0.009	0.004	0.004	0.002	0.001	0.002
$m_{2,7}$	0.154	0.089	0.063	0.015	0.012	0.035	0.023	0.021	0.018	0.011	0.011	0.004	0.004	0.001	0.001	0.002
$m_{3,4}$	0.109	0.087	0.064	0.008	0.015	0.037	0.024	0.008	0.022	0.016	0.093	0.005	0.070	0.008	0.001	0.004
$m_{3,5}$	0.102	0.076	0.061	0.015	0.014	0.0442	0.029	0.014	0.026	0.116	0.010	0.005	0.005	0.005	0.002	0.003
$m_{3,6}$	0.102	0.076	0.061	0.015	0.014	0.043	0.025	0.013	0.028	0.013	0.010	0.051	0.005	0.005	0.002	0.003
$m_{3,7}$	0.125	0.090	0.064	0.015	0.014	0.036	0.025	0.013	0.022	0.017	0.012	0.005	0.006	0.005	0.003	0.003
$m_{4,5}$	0.123	0.091	0.054	0.014	0.013	0.047	0.028	0.013	0.024	0.013	0.009	0.005	0.005	0.005	0.002	0.003
$m_{4,6}$	0.123	0.091	0.054	0.014	0.013	0.046	0.023	0.013	0.027	0.014	0.010	0.005	0.005	0.005	0.002	0.003
$m_{4,7}$	0.150	0.104	0.057	0.013	0.013	0.038	0.024	0.012	0.021	0.018	0.011	0.005	0.006	0.005	0.002	0.003
$m_{5,6}$	0.114	0.082	0.059	0.023	0.012	0.058	0.028	0.022	0.029	0.010	0.010	0.005	0.034	0.003	0.003	0.003
$m_{5,7}$	0.143	0.095	0.062	0.021	0.013	0.047	0.028	0.021	00024	0.013	0.013	0.005	0.004	0.003	0.003	0.003
$m_{6,7}$	0.143	0.065	0.062	0.021	0.013	0.048	0.025	0.021	0.027	0.015	0.014	0.006	0.004	0.004	0.0030	0.048

Table 6. Combined Evidence from all Experts (Professionals)

Combined Evidence	Structural Indicators					Functional Indicators										
	LC	**TC**	**FC**	**BC**	**Def**	**R**	**C**	**S**	**Po**	**Pa**	**Rav**	**B**	**P**	**Do**	**PA**	**D**
$m_{1,2}$	0.185	0.080	0.049	0.015	0.015	0.037	0.021	0.025	0.015	0.014	0.012	0.007	0.004	0.003	0.001	0.002
$m_{1,3}$	0.202	0.086	0.041	0.016	0.011	0.041	0.028	0.021	0.015	0.009	0.010	0.007	0.003	0.002	0.002	0.002
$m_{1,4}$	0.194	0.078	0.038	0.020	0.013	0.039	0.027	0.022	0.015	0.010	0.010	0.006	0.003	0.003	0.002	0.002
$m_{1,5}$	0.188	0.089	0.047	0.019	0.012	0.040	0.024	0.020	0.015	0.010	0.011	0.006	0.004	0.002	0.002	0.002
$m_{1,6}$	0.182	0.088	0.051	0.016	0.013	0.040	0.023	0.019	0.014	0.012	0.011	0.007	0.003	0.003	0.002	0.001
$m_{1,7}$	0.207	0.081	0.046	0.021	0.014	0.041	0.029	0.021	0.015	0.011	0.001	0.005	0.004	0.003	0.002	0.002

$m_{2,3}$	0.207	0.078	0.038	0.013	0.014	0.041	0.026	0.024	0.018	0.014	0.011	0.007	0.004	0.003	0.002	0.002
$m_{2,4}$	0.198	0.072	0.035	0.015	0.016	0.039	0.026	0.025	0.018	0.014	0.012	0.007	0.004	0.003	0.001	0.002
$m_{2,5}$	0.197	0.082	0.044	0.015	0..014	0.039	0.022	0.023	0.018	0.014	0.012	0.007	0.004	0.003	0.002	0.002
$m_{2,6}$	0.187	0.081	0.047	0.014	0.015	0.040	0.022	0.022	0.017	0.018	0.012	0.007	0.005	0.003	0.001	0.002
$m_{2,7}$	0.206	0.074	0.042	0.016	0.016	0.014	0.027	0.024	0.018	0.016	0.011	0.006	0.003	0.003	0.002	0.002
$m_{3,4}$	0.216	0.075	0.028	0.017	0.012	0.040	0.031	0.019	0.016	0.009	0.008	0.006	0.003	0.002	0.002	0.002
$m_{3,5}$	0.209	0.086	0.036	0.017	0.011	0.041	0.027	0.019	0.016	0.009	0.009	0.006	0.003	0.002	0.002	0.002
$m_{3,6}$	0.204	0.087	0.039	0.015	0.011	0.042	0.027	0.018	0.016	0.011	0.009	0.007	0.004	0.002	0.002	0.001
$m_{3,7}$	0.224	0.079	0.035	0.018	0.012	0.043	0.033	0.019	0.016	0.010	0.008	0.005	0.004	0.002	0.002	0.002
$m_{4,5}$	0.206	0.081	0.041	0.021	0.013	0.039	0.027	0.019	0.017	0.010	0.009	0.006	0.004	0.023	0.002	0.002
$m_{4,6}$	0.202	0.081	0.044	0.018	0.014	0.040	0.027	0.019	0.016	0.012	0.009	0.007	0.004	0.023	0.002	0.002
$m_{4,7}$	0.221	0.071	0.039	0.022	0.015	0.415	0.034	0.021	0.016	0.010	0.009	0.005	0.003	0.023	0.002	0.002
$m_{5,6}$	0.191	0.091	0.048	0.018	0.012	0.041	0.023	0.017	0.016	0.012	0.009	0.007	0.004	0.003	0.002	0.001
$m_{5,7}$	0.211	0.083	0.044	0.021	0.013	0.042	0.029	0.019	0.017	0.010	0.009	0.005	0.004	0.003	0.002	0.002
$m_{6,7}$	0.206	0.082	0.047	0.019	0.014	0.043	0.029	0.018	0.016	0.012	0.009	0.006	0.004	0.003	0.002	0.002

The next step is to determine the total score (TS), the crisp, fuzzy scores of data and the normalized weight of sub-criteria total scores do obtain by matrix operation.

i) Total Score Matrix for structural indicators of Flexible pavement (Academicians Expert 1 and Expert 2)

$$\begin{array}{c} \\ TS_{FP} = \end{array} \begin{array}{c} \begin{array}{ccccc} R_1 & R_2 & R_3 & R_4 & R_5 \end{array} \\ \begin{bmatrix} 1.000 & 0.794 & 0.950 & 0.0031 & 0.037 \\ 1.000 & 0.160 & 1.000 & 0.181 & 1.000 \\ 1.000 & 0.027 & 0.006 & 0.008 & 0.009 \\ 0.101 & 0.027 & 0.008 & 0.001 & 0.001 \\ 0.311 & 0.276 & 0.049 & 0.278 & 0.270 \end{bmatrix} \end{array} \begin{array}{c} W_{C_k} \\ \begin{bmatrix} 0.148 \\ 0.082 \\ 0.047 \\ 0.014 \\ 0.011 \end{bmatrix} \end{array} \left| \begin{array}{l} LC \\ TC \\ FC \\ BC \\ Def \end{array} \right.$$

ii) Total Score Matrix for Functional indicators of Flexible pavement (Academicians Expert 1 and Expert 2)

$$\begin{array}{c} \\ TS_{FI} = \end{array} \begin{array}{c} \begin{array}{ccccc} R1 & R_2 & R_3 & R_4 & R_5 \end{array} \\ \begin{bmatrix} 0.030 & 0.020 & 0.001 & 0.000 & 0.011 \\ 0.005 & 0.033 & 0.003 & 0.002 & 0.001 \\ 0.159 & 0.279 & 0.019 & 0.024 & 0.012 \\ 0.157 & 0.083 & 0.045 & 0.046 & 0.254 \\ 0.075 & 0.009 & 0.004 & 0.011 & 0.002 \\ 0.005 & 0.033 & 0.003 & 0.002 & 0.001 \\ 0.024 & 0.019 & 0.016 & 0.004 & 0.013 \\ 1.000 & 1.000 & 1.000 & 1.000 & 0.000 \\ 0.027 & 0.005 & 0.005 & 0.004 & 0.005 \\ 0.046 & 0.127 & 0.076 & 0.147 & 0.313 \\ 0.024 & 0.013 & 0.009 & 0.002 & 0.001 \end{bmatrix} \end{array} \begin{array}{c} W_{C_k} \\ \begin{bmatrix} 0.036 \\ 0.025 \\ 0.019 \\ 0.019 \\ 0.011 \\ 0.012 \\ 0.003 \\ 0.004 \\ 0.001 \\ 0.001 \\ 0.001 \end{bmatrix} \end{array} \left| \begin{array}{l} R \\ C \\ S \\ Po \\ Pa \\ Ra \\ B \\ Pu \\ Do \\ Pag \\ De \end{array} \right.$$

Using the simple additive weighing method (Hwang and Yoon, 1981), the total scores (TS), for each road project, of structural and functional parameters are calculated separately using Equation 4 as given below, with usual notations.

$$TS_{mi} = \sum \left[X_{mk} \cdot W\left(C_{mk}\right) \right] \text{ for } k = 1, 2, \ldots n \qquad (4)$$

As a sample calculation, the total score for sub-indicators of structural indicators for road project1 using Equation 4 (Academicians) is given below;

$$TS_{SI} = \left(1.00\times 0.151+1.00\times 0.084+1.00\times 0.053+0.101\times 0.014+0.311\text{x}0.011)\right) = 0.293$$

The total score for sub-indicators of structural and functional indicators for all five road projects are given in Table 7.

Table 7. Total Score (Academicians Expert 1 and Expert 2)

ROAD	Total Score (TS_{mi})		SUM $\sum TS_{mi}$	WEIGHT ($W(C_{mi})$)	
	SI	FI		SI	FI
R1	0.293	0.012	0.304	0.961	0.039
R2	0.138	0.013	0.151	0.916	0.084
R3	0.228	0.005	0.233	0.978	0.022
R4	0.023	0.005	0.029	0.816	0.184
R5	0.093	0.006	0.099	0.942	0.058

The next step is to determine a Pavement Condition Distress Index (PCDI). The total score and the weight of indicators are operated by a matrix for obtaining PCDI, as shown below. The weight of indicators is calculated by using Equation 5.

$$W\left(C_{mi}\right) = TS_{mi}/\Sigma TS_{mi} \tag{5}$$

- ***PCDI Matrix for Road Projects (Academicians Expert 1 and Expert 2)***

$$\begin{matrix} & TS & W \\ PCDI_{R1} = & \begin{bmatrix}0.293\\0.012\end{bmatrix} & \begin{bmatrix}0.961\\0.039\end{bmatrix}\end{matrix};\ \begin{matrix} & TS & W \\ PCDI_{R2} = & \begin{bmatrix}0.138\\0.013\end{bmatrix} & \begin{bmatrix}0.916\\0.084\end{bmatrix}\end{matrix};\ \begin{matrix} & TS & W \\ PCDI_{R3} = & \begin{bmatrix}0.228\\0.005\end{bmatrix} & \begin{bmatrix}0.978\\0.022\end{bmatrix}\end{matrix};\begin{matrix} & TS & W \\ PCDI_{R4=} & \begin{bmatrix}0.023\\0.005\end{bmatrix} & \begin{bmatrix}0.816\\0.184\end{bmatrix}\end{matrix};\begin{matrix} & TS & W \\ PCDI_{R5}= & \begin{bmatrix}0.093\\0.006\end{bmatrix} & \begin{bmatrix}0.942\\0.058\end{bmatrix}\end{matrix}\begin{matrix}SI\\FI\end{matrix}$$

Using a simple additive weighing method (Hwang and Yoon, 1981), PCDI for the road projects is calculated using Equation 6 as given below, with usual notations.

$$PCDI_{mi} = \sum\left[TS_{mi} \cdot W\left(C_{mi}\right)\right] \text{ for } i = 1, 2, ...n \tag{6}$$

As a sample calculation, a PCDI for road project 1 (Academicians) is given as follows;

$$\begin{aligned} PCDIR1 &= \left(0.293\times 0.961+0.012\times 0.039\right) \\ &= 0.282 \end{aligned}$$

From PCDI value, Pavement Condition Index (PCI) can be calculated as;

PCI = 1- PCDI

PCI= 1- 0.282

PCI = 0.718

Similarly, the PCI for all the roads is calculated and shown in table no. 8.

Table 8. Pavement Condition Index and Pavement Condition Rating of all Road Projects (Academicians Expert 1 and Expert 2)

Road Projects.	Pavement Condition Index (PCI)		Pavement Condition Rating
	Academicians	Professionals	
1	0.718	0.736	5
2	0.873	0.847	3
3	0.777	0.747	4
4	0.979	0.979	1
5	0.912	0.913	2

Similarly, the PCI of roads is calculated based on the combination of opinions of other experts. Figures 3 and 4 shows the PCI of all roads based on the combination of views of all experts' with each other.

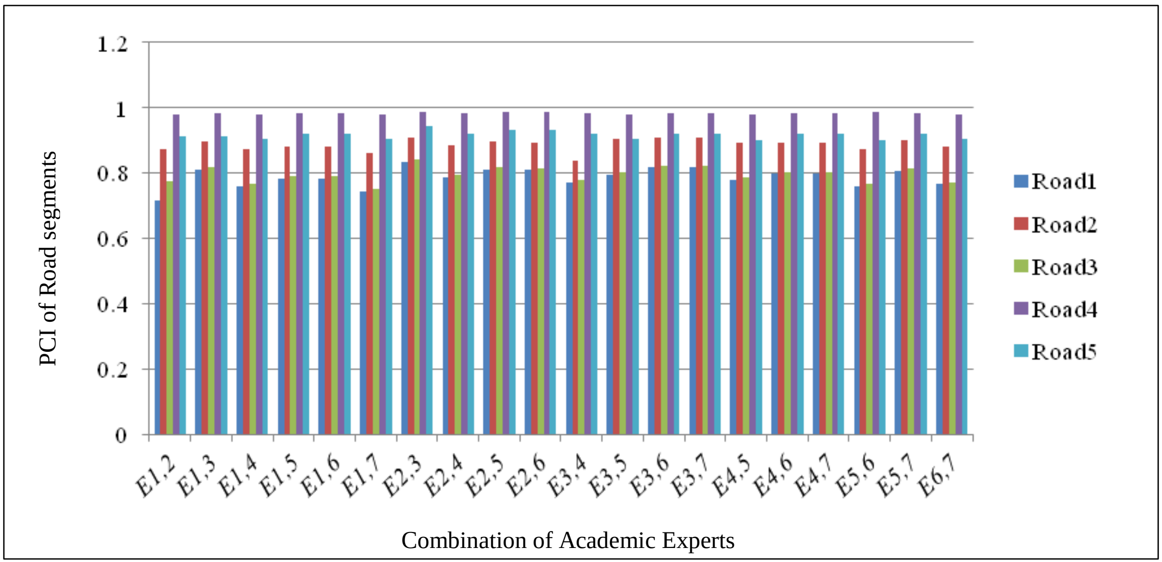

Figure 3. PCI of Road for combination of academician experts

Figure 4. PCI of Road for combination of professional experts

4. Validation of Method

In the IRC 82-2015 [22], pavement distress based rating for urban pavement is given. For the assessment purpose major distresses considered are Cracking, Raveling, Potholes, Settlement and Rut depth. Rating of selected road segments are done by using IRC-82-2015 and compared with the result obtained by the fuzzy evidence theory weightage method. Table 9 shows a comparison of IRC -82-2015 and fizzy evidence theory weightage method results.

Table 9. Comparison of Result by IRC-82-2015 and Expert System

Road	Result by IRC 82-2015		Result by Expert System	
	Rating of Road	Ranking	PCI (Range)	Ranking by Expert System
1	1.59	5	0.6128 to 0.7524	5
2	1.732	3	0.7732 to 0.8059	3
3	1.699	4	0.6632 to 0.7592	4
4	2.212	1	0.9074 to 0.9364	1
5	1.954	2	0.8139 to 0.8772	2

From the Table 9, it is observed that ranking of road segments by both the methods are same.

5. Discussion

In the present study total 42 combinations of experts, 21 for academicians and 21 from industry were taken. From all the combinations, the following points are observed:

- The final rating of roads did not change with the linguistic opinion of the experts (Academicians and Professionals). However, the total score for the roads marginally changed. This is mainly due to the change in the weighting factors derived based on the linguistic term assignment by the experts.
- The structural indicator score is more than functional indicators.
- Road project 4 rated first out of five, and it showed a higher pavement condition index while road project 1 rated 5 with the lowest pavement condition index.
- The result of IRC-82-2015 rating method and defined method is very close to each other. The ranking of selected road segments by both methods is the same.

6. Conclusion

Performance assessment of road pavements includes uncertain data and also the expert's views are considered in the linguistic language. To analyse such uncertain data and ambiguity in the expert's opinion, the fuzzy evidence theory weightage method is used effectively in this study. In this method to nullify the effect of ignorance, all the indicators are considered separately and their combined effect is also considered. Weightage of all the indicators are determined by considering the combination of different experts' opinion. For the assessment purpose total of 16 distresses are identified as pavement performance indicators which are occurred frequently in the flexible pavements to achieve accuracy in the assessment. Structural capacity of the road is determined by deflection and cracking which includes fatigue cracking, longitudinal cracking, transverse cracking and block cracking. Functional condition is determined by using the parameters like rutting, corrugation, shoving, potholes, patching, raveling, bleeding, pumping, drop-off, polished aggregates and depression. By considering the economic importance of the industrial area, road segments in MIDC Chakan area is considered for the assessment purpose. PCI of selected road segments is determined by using the defined methodology. The distresses on the road segments are identified and measured by using IRC recommendations. From the PCI it is observed that the final rating of road segments is not changed but the index value has a marginal variation. This is because of the weighting factors derived from the linguistic opinion of experts. The comparison of results with IRC-82-2015 rating results shows that the result of both the methods are close to each other. From the result, it is observed that this method can be used effectively for the rating of flexible pavements as per their performance condition index. From the obtained rating prioritization of road segments for maintenance scheduling can be done effectively.

7. Conflicts of Interest

The authors declare no conflict of interest.

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