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Original Article

Expert System for Pavement Condition Assessment and Maintenance Decision: Fuzzy MCDM Approach

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Abstract *- The practice of organizing road network upkeep and repairs to enhance the network's condition is known as pavement maintenance. In order to keep the overall state of the road and the quality of the pavement inventory at a certain level, pavement management includes a wide range of activities. In the past, engineers and maintenance staff planned maintenance using their visual inspection skills and experience. The issue with this technology is that outcomes based on comparable facts frequently differ significantly, and experience is hard to transfer from one person to another..Therefore, an effective pavement management system is one of the most important aspects in the road maintenance phase. In this research, study of expert system with application in pavement management system has been carried out. An expert system is developed to assess the condition of urban pavements and decide repair and rehabilitation strategy. The pavement condition index is developed using the Fuzzy normalized weighting method. An expert system is developed to calculate the pavement condition index and rating of pavement. The author presented a pavement maintenance strategy based on the pavement condition index.*

Keywords *- Pavement Condition Index, User Interface, Repair, Rehabilitation, Strategy*

1. Introduction

The process of planning road network maintenance and repairs to improve the network conditions is known as pavement management. Evaluating good, fair, and poor pavements; assessing the relevance of individual road segments in light of community demand, road functional class, and traffic volume; setting schedules for maintenance on good roads to keep them in better shape; pavement management systems often handle responsibilities including funding permits, scheduling repairs for both fair and poor pavements.. Accurate pavement evaluation is the basis for most of the cost-effective Maintenance and Rehabilitation (M&R) solutions created with the help of the Pavement Management System (PMS).

Expert System is an effective tool for decision making regarding maintenance and administration of pavements.

1.1 Expert System

(Zimmermann, 2001) Expert systems are computer programs that reduce subjectivity, eliminate inconsistency, and handle uncertainty in decision-making processes by relying more on expert heuristics than on logical problem-solving techniques. (Firebaugh & Morris W, 1988) A field of artificial intelligence study called expert systems technologies has many possible uses in civil engineering design. They have a lot of potential to be very helpful tools for transportation experts. It was not new to use expert systems in transportation for a variety of applications. (Hall, K.T.et.al., 1987) Furthermore, it is now possible to develop a knowledge-based expert system that may help other engineers or even train them , especially at the local level, due to advancements in computer hardware and software development. Figure 1 shows the typical processes in the construction of an "expert system."

Fig. 1 Typical processes in the development of a "expert system"

Problem Identification: The problem domain that the expert system will address must be precisely defined in this first step. It's critical to specify which particular decisions or tasks within that area the system will manage.

Knowledge Acquisition: Experts in the field provide information on the problem domain at this step. It is possible to learn this information through documents, interviews, and other sources. The objective is to transfer human specialists' knowledge into a format that the expert system can comprehend and apply.

Knowledge Representation: The learned information is delivered in an organized way that the expert system may use. Conceptual frameworks, rules, facts, frames, and neural networks are examples of common representation techniques.

Inference Engine Design: The brains behind the expert system are its inference engine and reasoning and decision-making processes that rely on the knowledge base. The inference mechanisms are created and put into place in this step. This involves dealing with ambiguity or uncertainty in the knowledge, using inference techniques and comparing the input data to the rules.

User Interface Design: The purpose of the user interface is to make it easier for users and the expert system to interact. In this step, an interface that is easy to use and suited to the needs of user must be created. User requirements, accessibility, and usability principles are required to taken into account.

Integration and Testing: The user interface, inference engine, and knowledge base are incorporated into the expert system, and it undergoes extensive testing. To test whether the system operates as predicted and generates correct answers, sample cases or real-world data are used.

Deployment and Evaluation: The system is deployed in its intended environment after it has undergone testing and validation. To assess how effective the system is, performance is tracked and user input is collected. The system may be enhanced or modified in response to these comments.

Maintenance and Update: The final step involves maintaining the expert system over time. This includes updating the knowledge base, inference engine, or user interface as needed to keep the system relevant and effective. Maintenance ensures that the expert system continues to provide value as changes occur in the problem domain or advancements are made in technology.

In this work author is developed 'Expert System' for pavement condition assessment and decide priority of maintenance.

2. Development of 'Expert System'

A typical process to developed 'Expert System' for pavement condition assessment and decide priority of maintenance is describe in figure 2 The various tools and techniques used for developing expert system are represented in the table 1.

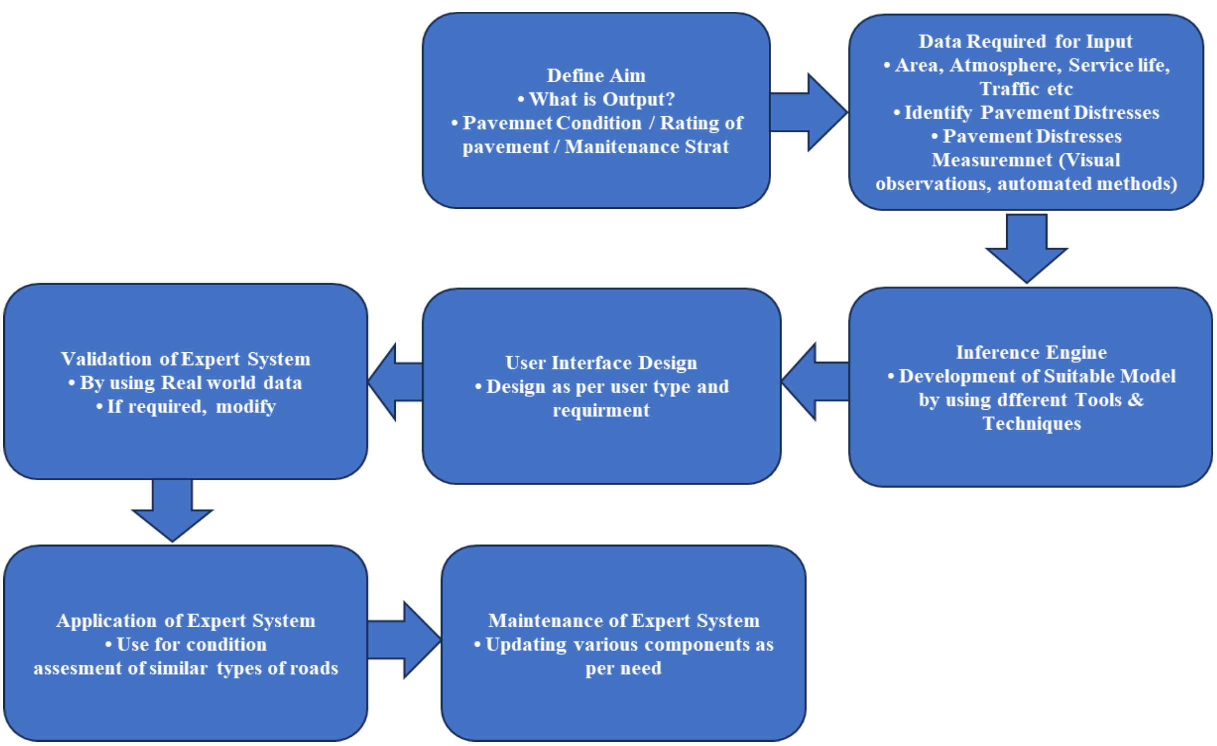

Fig. 2 Typical process to developed 'Expert System' for pavement condition

Table 1. Tools and techniques used for developing expert system in pavement management

Researchers	Techniques	Tools	Remark
Shi et al. (2015) Yang Xuand and Zhanmin Zhang (2022),	Integration of Multiple Data Sources in Pavement Condition Assessment	Visual Inspection Data, Pavement Distress Surveys, Pavement Roughness Measurements,	To identify various distress types, including cracking, rutting, and potholes.
Yang Xuand and Zhanmin Zhang (2022)	Soft computing Techniques	Support vector machines (SVM) and random forests: two machine learning techniques.	To classify pavement distress and prediction, highlighting their effectiveness in analyzing large volumes of pavement data and identifying patterns associated with different distress types.
Shi et al. (2015)		Neural networks	In order to forecast the state of pavement indicators like rutting, cracking, and roughness, input factors like traffic volume, climatic data, and pavement material qualities are used.
Yang Xu and Zhanmin Zhang (2022) Y. Li et al. (2022)		Fuzzy logic systems	To handle uncertainties and imprecisions in pavement condition assessment A novel approach to assessing the quality level of pavement performance is developed by combining the entropy weight-variable fuzzy sets model with the riding quality index (RQI), pavement condition index (PCI), pavement structure strength index (PSSI), skid resistance index (SRI), and antirutting index (ARI).
Chopra, Tanuj, et al (2018) Amr A et al. (2020)		Genetic Programming	To Develop models for predicting pavement distress and condition Proposed a workable model of pavement deterioration using a stochastic Markov chain. An improved TPM that reflects the deterioration of the road network has been developed using field data taken from the LTPP database.
Zhe Li et.al. (2021)		Support Vector Machines (SVM) + Particle Swarm Optimization (PSO)	A pavement performance prediction model was developed using the support vector machine regression (SVR) and particle swarm optimization (PSO) algorithms.
Han C et al. (2019)		Clustering PageRank algorithm (CPRA)	The clustering PageRank algorithm (CPRA) is used to build an intelligent pavement maintenance decision-making system using historical large data.
Zhang et al. (2017)	Artificial Intelligence	Artificial Neural Networks (ANN)	To predicting Pavement Condition Index (PCI) using input parameters such as distress data, traffic data, and pavement age. To create and evaluate prediction models for PCI values Multiple linear regressions (MLR), artificial neural networks (ANN), and fuzzy logic inference (FIS) were some of the techniques employed for flexible pavement sections.

Using the "fuzzy multiple criteria decision-making technique," an expert system for the Pavement Condition Index (PCI) has been built in the current work. The pavement condition index can be used to further rank the roadways. Figure 3 displays the methodology flowchart.

Major environmental factors like temperature changes, rainfall, moisture contents etc. and traffic loading, leading to major structural and functional deterioration of pavement surface. The structural and functional indicators are studied through past research work, IRC codes etc.

The identification of 16 distresses as indicators of pavement condition is complete. These were common in the flexible pavements.Deflection (Df) and cracking determines the road's structural capacity. Cracking includes fatigue (F) ; longitudinal (L) ; transverse (T) ; and block (B) . Rutting (R) ; corrugation (C) ;shoving (S) ; potholes (Po) ; patching (Pa) ; raveling (RAV) ; bleeding (Bl); pumping (Pu) ;drop-off (Do); polished aggregates (Pag) and depression (De) determines the functional condition. In this work, the pavement condition index has been established using fuzzy multiple criteria decision making.

The first step was the identification of Transportation Experts (TEs). Five structural indicators and eleven functional indicators were identified for determining road pavement performance. Normalized weightage technique was used to give an importance weightage. The overview of the fuzzy decision framework for rating the roads is shown in Figure 3. The expert perceptions were interpreted linguistically, with VI denoting "Very important," and I denoting "Important." "Average" was denoted by A, "Least Important" by LI, and "Not Important" by NI. The linguistic phrase depicted in Table 2 is assigned a fuzzy number using the trapezoidal fuzzy scale.

Table 2. Linguistic Terms and Fuzzy Numbers

LINGUISTIC TERMS	FUZZY NUMBER
Very Important, VI	0.77; 0.88;1.00;1.00
Important, I	0.55; 0.66; 0.77; 0.88
Average, A	0.33; 0.44;0.55;0.66
Less Important, LI	0.11; 0.22;0.33; 0.44
Not Important , NI	0.00; 0.00; 0.11;0.22

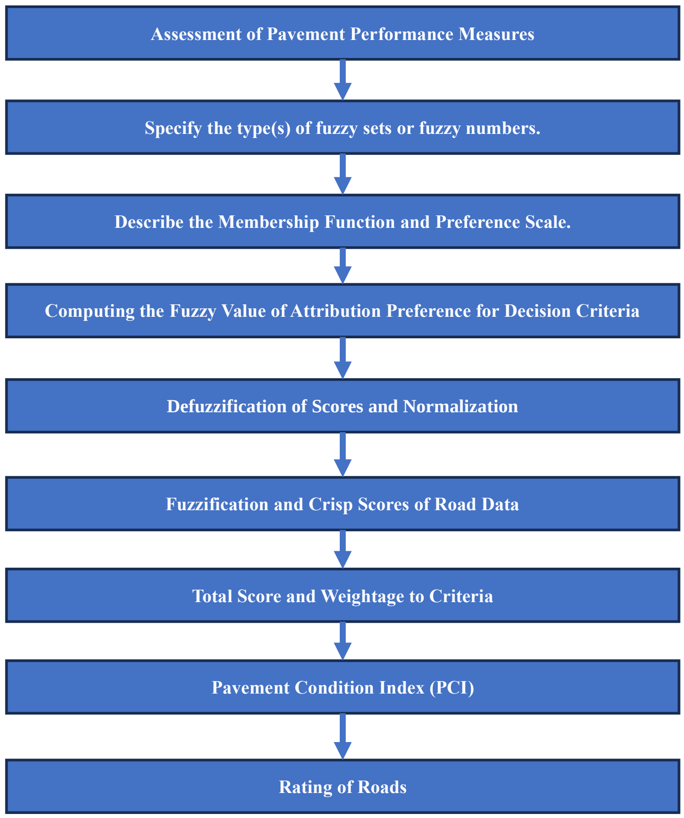

Fig. 3 Fuzzy decision framework for Rating of Road

Transportation engineering experts offered input on eleven sub-criteria of functional indicators and five sub-criteria of structural indicators. The pavement condition index has been calculated by using fuzzy normalized weightage method as per equation

$$PCI = 1 - PDCI \tag{1}$$

The pavement distress condition index (PDCI) for the roads is given in the equation 1.

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

$$TS_{mi} = \sum\left[X_{mk} \cdot W\left(C_{mk}\right)\right] \text{ for } k = 1, 2, \ldots n \tag{3}$$

Pavement distress condition weight of the criterion m (structural or functional indicator) for road i can be calculated as,

$$W\left(C_{mi}\right) = TS_{mi} / \sum TS_{mi} \tag{4}$$

Where,

TS_{mi} = The road's overall score in relation to the criterion m

X_{mk} = The road data's crisp score in relation to the criterion m's subcriterion k

$W(C_{mk})$ = Weight, or significance value, of the criterion m's subcriteria k.

W (Cmi) = Condition of distress on pavement the criterion's weight

Using "MATLAB" software, an expert system has been developed for the above-mentioned methodology, simplifying the process of using personnel in decision-making. Software programming has been done for PCI calculation and rating of program. User friendly interface has been developed. A data base for pavement performance indicators in percentage with their parametric limit and expert‘s opinion on fuzzy scale in excel sheet has been prepared. By using ‘MATLAB’ fuzzy rule and App file ‘User Interface’ (UI) figures have been developed. In 'UI' figure input is given in the form of database described above and output is 'PCI' and rating of road segments.

3. Maintenance and Rehabilitation Strategy for Flexible Pavements

In this work, a maintenance and rehabilitation approach for flexible pavement has been created by a thorough analysis of the literature, IRC-85-2015, and expert opinion.

Table 3 displays the maintenance and repair plan for flexible pavement.. In the given table pavement conditions are classified as good, fair, average, poor and very poor. Based on the condition of pavement a detailed maintenance strategy has given which includes; little maintenance, Routine maintenance, Seal coating, Overlay and Reconstruction.A Pavement Maintenance Strategy can be decided on the basis of Pavement Condition Index calculated in equation 1 which is shown in Table 4.

Table 3. Maintenance and rehabilitation strategy for flexible pavement

Pavement Condition	Pavement Maintenance Strategy	
Good	Little maintenance	Minor Patchwork
Fair	Routine maintenance	Crack sealing, minor patching, Pothole filling
Average	Seal coating	Upper layer Coating
Poor	Overlay	Bitumen overlay
Very Poor	Reconstruction	New road construction

Table 4. Maintenance and rehabilitation strategy for flexible pavement as per PCI

Pavement Condition Index	Pavement Condition	Pavement Maintenance Strategy
0.81-1.00	Good	Little maintenance
0.61-0.80	Fair	Routine maintenance
0.41-0.60	Average	Seal coating
0.21-0.40	Poor	Overlay
0.00-0.20	Very Poor	Reconstruction

4. Validation Expert System

Applicability of Expert system is determined from the case study. Also the validation of Expert System has been done by using work done by researcher in the past. The expert system is applied on the experimentation work of researchers Minu P K and Sreedevi B G 92014) and the results are compared. Data on pavement distress was gathered by IMinu P K and Sreedevi B G (20140) for their study on SH that stretches from Vettu road to Adoor. Roughness surveying was done with an integrator called Bump.

The pavement's deflections were measured using the Benkelman beam. For every segment, the Pavement Condition Indexes (PCI) were ascertained. Pavement sections were categorized as good, fair, etc. based on PCI value. PCI is an assessment method that is used globally to measure pavement quality by taking into account functional factors and the importance of structural performance.

It is established in accordance with the guidelines in ASTM D 5340. A numerical index known as the Pavement Condition Index, or PCI, ranges from 0 (a deteriorating pavement) to 100 (a perfect pavement). A thorough classification is shown in Figure 4. Table 5 displays the researcher's measured level of distress.

Condition Category	Pavement condition Index (PCI)	
	Upper Limit	Lower Limit
Excellent	100	86
Good	85	75
Fair	74	58
Poor	57	40
Failed	39	0

Fig. 4 PCI Chart [9]

Table 5. Measured Distresses by Minu P K and Sreedevi B G

Road Section	Raveling (%)	Cracking (%)	Potholes (%)	Bleeding (%)	Deflection (mm)
1	34.45	1.12	0.006	0.066	0.34
2	32.74	1.28	0.006	0.026	0.29
3	31.30	1.20	0.007	0.069	0.37
4	30.80	1.25	0.007	0.056	0.54
5	30.00	1.12	0.005	0	0.50

Source: Minu P K and Sreedevi B G (2014)

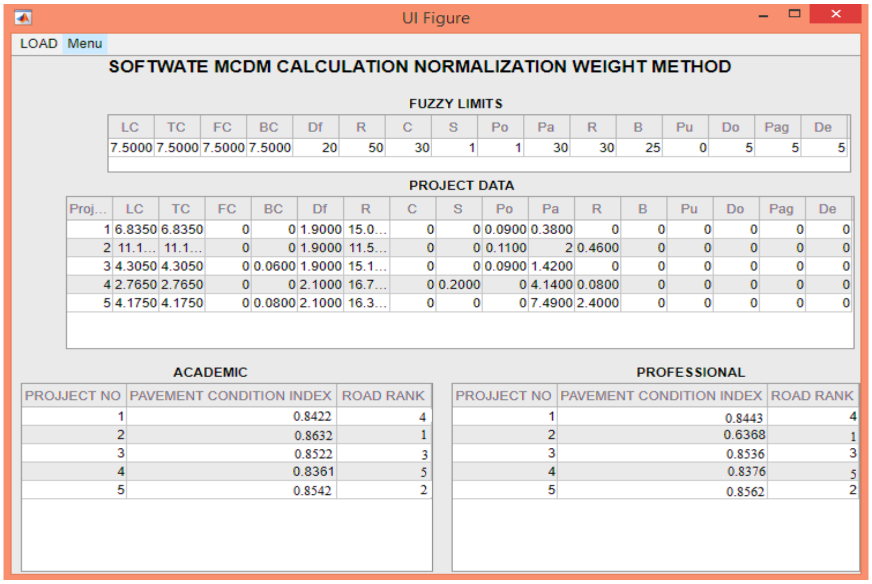

Fig. 5 User Interface for Minu P K and Sreedevi B G (2014)

Table 6. Measured Distresses by Minu P K and Sreedevi B G

Road Section	PCI by Researcher	Condition of Road by Researcher	PCI by Expert System	Condition of Road by ' Expert System'
1	76	Good	0.84	Good
2	78	Good	0.86	Good
3	78	Good	0.85	Good
4	83	Good	0.846	Good
5	80	Good	0.85	Good

The condition of pavement obtained by researchers is compared by condition of pavement obtained by 'Expert System'. The distress data collected by researchers for the study is given as input to the 'Expert System' and output in terms of PCI is obtained. On the value of obtained PCI, condition of pavement is determined. The comparison of Researchers' Result and Expert System Result is shown in Table 6 and it is observed that the condition of road obtained by both the methods was same.

5. Application of Expert System

To ensure that the built expert system is applicable, it has been used on a case study. The MIDC Chakan Industrial sector in the Pimpri Chinchwad Municipal Corporation zone has been taken into consideration for the experimenting. Chakan is a significant car hub. A Special Economic Zone (SEZ) supported by the Maharashtra Industrial Development Corporation (MIDC) is now located there. Production facilities for automobiles from prestigious companies such as Volkswagen Group, Daimler-Benz, Mahindra & Mahindra, Jaguar Land Rover, Bajaj Auto, General Electric, and Hyundai are located in the MIDC, Chakan. This region is home to more than 750 major and minor enterprises, including several producers of auto parts. Therefore, the road condition in this area is evaluated by the expert system based on the area's significance to the nation's economic development. For the aim of rating and assessing pavement condition, five roads from MIDC Phases I and IV are taken into consideration. All of the roadways are made of asphalt with flexible pavement. Road segment details are displayed in Table 7.

Table 7 Details of Road Segments

Road	MIDC Phase	Width of Land (M)	Width of Metal (M)	Length (Km)	Completed Working life (Yrs.)
1	I	20	5.5	2.15	18
2	I	60	16	4.925	18
3	IV	45	7.5	5.3	18
4	IV	20	5.5	2.50	10
5	IV	30	7.5	3.85	10

Experimentation has been done by considering 2.00 km section of road. The total pavement length is divided into 20 sample units of equal size. Each sample unit is of 100 m chainage and distresses are measured in the respective chainage area. Following table gives summary of distress. The values of distresses obtained by experimentation are put in the expert system and PCI and rating of road segments are determined. Figure 6 shows the User Interface. In the figures Fuzzy limits are the input for maximum allowable distresses in the pavement and project data is the input for all the distresses occurs in the pavement.

Data for five projects can be input at a time in the system. Both the values are in percentage. Pavement condition index and road ranking is output obtained for Fuzzy MCDM normalized weightage method. From the result of user interface it is observed that Road 4 rated 1 by the academician as well as by professional opinion. There is marginal variation value of PCI by the opinion of both experts. Similarly Road 5, 3,1 and 2 rated 2,3,4and 5 respectively. Based on the values of PCI obtained for selected road segments, maintenance and rehabilitation decision is shown in Table 9.

Table 8 Percentage of defects for all Road Segments

Defects	ROAD 1	ROAD2	ROAD 3	ROAD 4	ROAD 5
	% OF DEFECTS				
L	9.26	5.95	7.12	0.229	0.28
T	25.44	1.2	37.86	1.356	24.72
F	0.72	0.2	0.05	0.057	0.07
B	0.76	0.2	0.06	0.008	0.01
Df	1.17	5.5	0.97	1.05	1.02
R	1.5	0.99	0.05	0.023	0.55
C	0.14	1	0.08	0.05	0.04
S	0.16	0.28	0.02	0.024	0.01
Po	0.16	0.08	0.05	0.046	0.25
Pa	2.24	0.28	0.11	0.321	0.05
RAV	0.14	1	0.08	0.056	0.04
Bl	0.59	0.47	0.41	0.095	0.33
Pu	0.03	0.05	0	0	0
Do	0.14	0.03	0.02	0.019	0.03
Pag	0.23	0.63	0.38	0.734	1.56
De	0.12	0.07	0.05	0.008	0

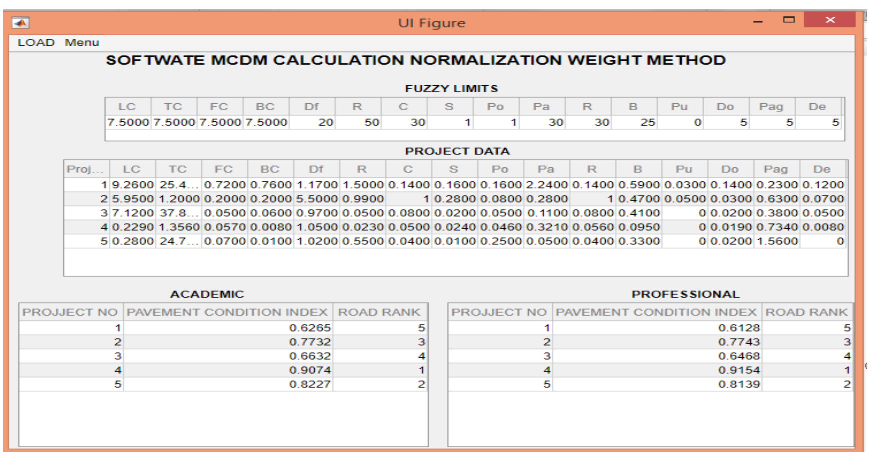

Figure 6 User Interface for Expert System

6. Result and Discussion

The Normalized Weightage Method for Fuzzy Multiple Criteria Decision Making had been used in the development of the expert system. The result of expert system shows that Road 4 rated 1 by the academician as well as by professional opinion. There is marginal variation value of PCI by the opinion of both experts. Similarly Road 5, 3,1 and 2 rated 2,3,4and 5 respectively. Road 1,2and 3 are in fair condition required Routine maintenance and road 4, 5 are in good condition required little maintenance. For the validation expert system the expert system is applied on the experimentation work of researchers Minu P K and Sreedevi B G. The condition of road obtained by both the methods is good.

Table 9 Maintenance and rehabilitation strategy for Selected Road Project

Road	PCI	Pavement Condition	Pavement Maintenance Strategy	
1	0.62	Fair	Routine maintenance	Crack sealing, minor patching, Pothole filling
2	0.77	Fair	Routine maintenance	
3	0.66	Fair	Routine maintenance	
4	0.91	Good	Little maintenance	Minor Patchwork
5	0.82	Good	Little maintenance	

7. Conclusion

This paper the studies of expert system and their application in pavement condition assessment in detail has been done. The Fuzzy MCDM method Expert System In order to assess PCI and assign a condition rating to the road segments, a normalized approach has been developed during this work. In the current study, the repair and rehabilitation strategy is also specified based on PCI value. The results of the present study have been analyzed, leading to the following conclusions:

- The academicians' and experts' linguistic opinions have a slight impact on the PCI number, but the road segment's ultimate rating remains same.
- Based on the classification of roads pavement maintenance decision as minor. Patchwork; potholes filling; upper layer coating; bitumen overlay; and new road construction can be taken effectively. Large data base of expert opinion can be saving effectively in the expert system.
- Simplifies, expedites, realisticizes, transparently, and reliably decision-making.
- Facilitates the quick identification of the optimal pavement maintenance option by an engineer.
- Validation of expert system is done by using data of researcher work. The PCI value marginal change but rating and condition assessment gives same result. Hence, expert system can be used for any type of flexible urban pavement.
- It is found that the fuzzy approach is better suitable for road maintenance than the conventional way.

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