Fuzzy Model for Road Roughness Index

Praveen Aggarwal[1], and Naveen Kumar[2]

***Abstract*—** Pavement deterioration is the root cause for affecting the road roughness, riding quality, comfort to the passengers and safety which leads to distresses such as rutting, cracking, potholes, reveling etc. In the present study, a model is developed between roughness index and distresses using its five distress parameters i.e. Rut depth, Total area of cracks, Area of potholes, Area of patchwork and Reveling. Fuzzy Logic technique, in MATLAB which is an advance technique of soft computing, is used to estimate the values of roughness index considering distress parameters as input parameter and roughness index as output parameter. All the related data to distresses and roughness is collected on the National Highway (NH-15) of the Northern region (Bikaner to Jaisalmer) of Rajasthan state in India to develop a suitable model. A fuzzy rule based model is developed between the input and output parameters. From collected data Coefficient of determination (R2), Standard Error of Estimate (SEE) and Root Mean Squared Error (RMSE) values are determined in support of the model which shows that model is valuable and reliable to use. Results of the developed model are also compared with the results quoted using an Artificial Neural Network (ANN) technique and found higher level of satisfaction.

***Keywords*—**Roughness Index; MATLAB; Fuzzy Logic; Highways and Roads; Pavements; Distress Parameters

I. Introduction

THEmaintenance and management of pavement is of greater concern in pavement engineering as they should be chosen very carefully considering the financial resources and distress existing. There are five types of distresses in pavement which are taken care as they influence the ride quality and smoothness of the pavement which in turn leads to the roughness. The main reasons behind these distresses are heavy traffic, pavement structure, climatic conditions, pavement age etc. and also the condition of the base layer.

It is a well-established fact that the individual pavement distress parameters and the roughness complement each other [2, 11]. Pavement roughness is an overall indicator of the quality of a pavement and it adversely affects not only the vehicle ride quality but also the road user costs [1]. Universally, roughness is expressed as International Roughness Index (IRI) and it is usually manifested as a combined effect of different individual pavement deterioration parameters such as cracking, potholes, raveling and rutting [4, 12].

Pavement roughness is generally defined as an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle (and thus the user) [9].

Roughness is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs [9, 13].

OR

Roughness is the measurement of the unevenness of the pavement in the direction of travel. It is measured in units of IRI, inches per mile or meter per kilometer, and is indicative on the scale of ride comfort. Major factors affecting the roughness are as follows:

1. Rutting
2. Total cracks (Transverse, Fatigue and Longitudinal Cracking)
3. Patchwork
4. Potholes
5. Reveling

Roughness can be evaluated on behalf of many theories or models, among which use of fuzzy logic concept for modeling is a prominent one. While other modeling techniques like linear regression, Non-Linear regression, Neural Network Model etc. as reported in earlier works [9, 11, 12, 13] can also be employed.

The Fuzzy Logic, a mathematical tool for dealing with uncertainty was introduced in 1965 by LotfiZadeh and proposed that it provides an inference structure that enables appropriate human reasoning capabilities [7]. It uses probability theory to explain, if an event will occur, it measures the chance with which a given event is expected to occur. On the contrary, the traditional binary set theory describes crisp events, events that either do or do not occur as in L. A. Zadeh (1965).

Fuzzy logic provides a solution as Principle of Compatibility, the complexity and the imprecision are correlated which adds closer look at a real world problem [8]. In present study, Roughness Index values are predicted by selecting the Fuzzy Logic System for modeling.

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of aninput data set to a scalar output data [5, 6]. A FLS consists of four main parts: fuzzifier, rule base, inference engine, and defuzzifier. These components and the general architecture of a FLS is shown in Figure 1 [15].

The process of fuzzy logic can be explained in Algorithm [5, 15] in following way:

1. A crisp set of input data are gathered and converted to a

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fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification.

2. Afterwards, an inference is made based on a set of rules.

3. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the difuzzification step.

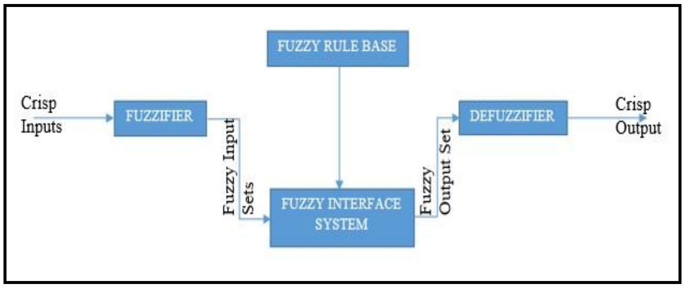

Fig. 1 A Fuzzy Logic System

II. Proposed Fuzzy Model

Proposed fuzzy model have following five input parameters:

1. Rut depth (in millimeter),
2. Total crack (in square meter),
3. Area of pothole (in square meter),
4. Patch work (in square meter), and
5. Raveling (in square meter).

And only one output obtained is Roughness Index (m/km).

After various trials, to fuzzify the crisp values of input parameters, triangular membership function (trimf) [16] is chosen and different number of membership function (MF) are defined for each input parameter and output which is mentioned in table 1 below.

TABLE I
NUMBER OF MEMBERSHIP FUNCTIONS OF PARAMETERS

Parameters	Category	Number of MF
Rut depth (in millimeter)	Input	148
Total crack (in square meter)	Input	32
Area of pothole (in square meter)	Input	08
Patch work (in square meter)	Input	55
Raveling (in square meter)	Input	52
Roughness Index (m/km)	Output	119

The basic rules play an important role in manipulating the output results. The Rule Editor helps to modify these basic rules [10]. To modify the basic rules AND function is selected between three available functions namely AND, OR and NOT. These modified basic rules are used to predict the output results with the help of Rule View. Rule Editor and Rule View of the output i.e. roughness index are shown in figure 3 and figure 4 respectively.

For better results, out of Centroid, Bisector, Medium of Maximum (MOM), Largest of Maximum(LOM) etc., Medium of Maximum (MOM) difuzzification method is used to defuzzify the output i.e. revert to the crisp value.

III. Methodology

In the present study, data obtained for 210 km of stretch of the National Highway (NH-15) is used in which IRI and other distress parameters are compiled kilometer wise.

a) A set of 211 values are taken for each parameters as inputs.
b) Mamdani Fuzzy Interface System is used for predicting the output values using the rule base [3].
c) All the input parameters and output are fuzzified.
d) 211 set of possible combination are considered.
e) The roughness index in all 211 cases of combination is defined by 119 MF as shown in figure 2 and these combinations define the rules for the fuzzy model shown in figure 3.
f) All the 211 rules are inserted and created on the basis of which a rule will be fired for a particular set of inputs.
g) Using the rule viewer, output i.e. Roughness Index for road is observed for a particular set of inputs using the MATLAB Fuzzy toolbox [14].
h) The output is compared with the quoted results.

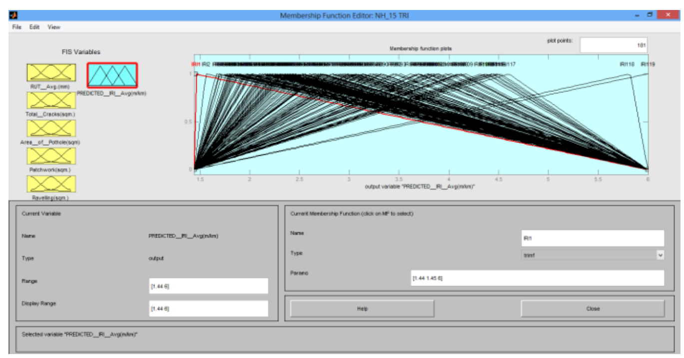

Fig. 2 Membership Function Editor

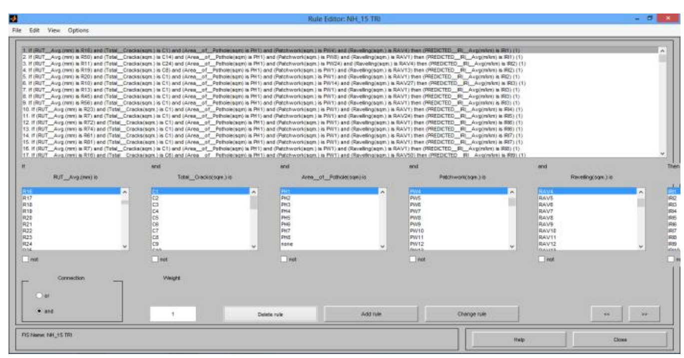

Fig. 3 Rule Editor of the output

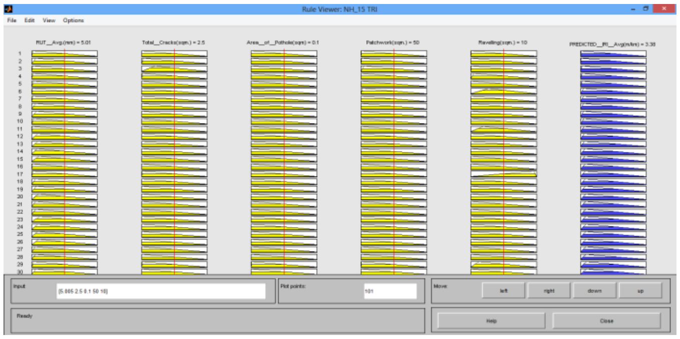
Fig. 4 Rule View of Output

IV. Results and Discussions

Roughness values are predicted by selecting the different data ranges for each parameter given in table 2 and the results of the developed fuzzy model is compared with the results given by the neural network model.

Degree of correlation and R2 values are calculated between the fuzzy model result and the quoted neural network results and it is observed that high degree of correlation and R2 exists between the modeled and quoted results and shown in table 3.

TABLE II
Number of Membership Functions of Parameters

Parameters	Category	Data Range
Rut depth (in millimeter)	Input	0.011-10
Total crack (in square meter)	Input	0-5
Area of pothole (in square meter)	Input	0-0.2
Patch work (in square meter)	Input	0-100
Raveling (in square meter)	Input	0-20
Roughness Index (m/km)	Output	1.44-6

TABLE III
Correlation and R2 Values of Results

Output Parameter	Level of Correlation between Quoted and Modeled Results	R^2 value between Quoted and Modeled Results	SSE	RMSE
Roughness Index (m/km)	0.983	0.966	3.67	0.15

In a previous study [12] an artificial neural network (ANN) model is developed for four highways namely NH-49, NH-205, NH-6 and NH-15. Coefficient of determination (R2) obtained in the quoted ANN model and predicted (for present study only NH-15) fuzzy logic system (FLS) model are compared in table 4.

TABLE IV
Comparison between ANN and FLS model

Model / Model Coefficient	R^2 Value
ANN	0.86
FLS	0.96

A graphical representation of result behavior between the quoted and modeled results of FLS is also shown in figure 5.

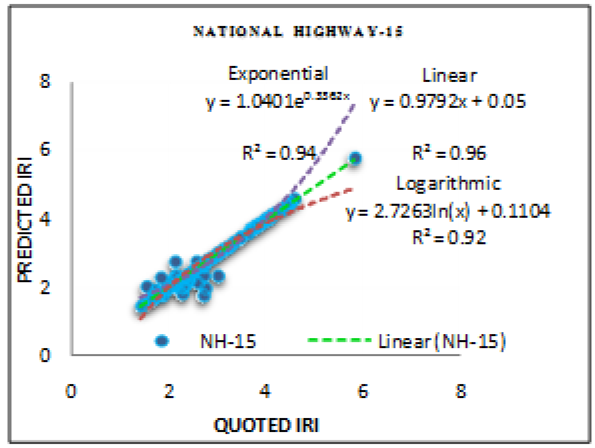

Fig. 5 Graph between Quoted IRI and Predicted IRI

V. Conclusion

In the present study a Fuzzy Logic Model is developed to predict IRI for NH-15 with five affecting input parameters and following conclusions are drawn:

1. As there is no set relationship in the input and output parameters, fuzzy is the best solution for this type of problem.
2. Three different forms of relations are attempted between Predicted IRI and Quoted IRI namely exponential, logarithmic and linear with R2 values 0.94, 0.92 and 0.96 respectively.
3. It has been observed that developed Fuzzy Logic model shows better results as compared to previously developed ANN model.

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