



# Relationship between Pavement Roughness and Distress Parameters for Indian Highway Using FLS in MATLAB

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**Abstract:** The relationship between the road roughness and its distress parameters such as rut depth, total cracks, area of potholes, patchwork and releveling, is presented in this paper with the help of the Fuzzy Logic technique in MATLAB (2010). Pavement roughness and distress parameters data are collected from the National Highway (NH-205) over the span of Madanpalle to Anantpur, Southern cities of Andhra Pradesh in India, to develop a user friendly, efficient and precise model for the roughness and distress parameters.

A Fuzzy Logic model is developed in MATLAB for IRI (International roughness index), using five pavement distress parameters namely Rutting, Total cracks (Transverse, Fatigue and Longitudinal Cracking), Patchwork, Potholes and releveling as input parameters. Analysis in the model indicates that a non-linear relation is good as coefficient of determination ( $R^2$ ), Standard Error of Estimate (SEE) and Root Mean Squared Error (RMSE) value and Percentage Error supports the model substantially. Model is developed using 60% data for model development and training purpose and remaining 40% data is used for the testing purpose. The  $R^2$  value showed that the model performance is satisfactory both in training and testing stages.

The output results of the Fuzzy Logic model is compared with Artificial Neural Network (ANN) model results available in literature.  $R^2$  value between them shows that Fuzzy Logic model yields a better forecast of the road roughness for the distress parameters than Artificial Neural Network (ANN) model.

**Index Terms - Road Roughness; MATLAB; Fuzzy Logic; Highways and roads; India; Pavements; Parameters; Rut Depth.**

## I. INTRODUCTION

The maintenance and management of pavement is of greater concern of 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; 6]. 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 [3]. 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 [4:15].

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) [5]. Roughness is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs [5; 7].

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 [5]:

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

There are many more affecting factors like Corrugation, Man-holes, Stripping, and bleeding etc.

Roughness can be manipulated on behalf of many theories or models given by different person's likely linear regression, Non-Linear regression, Neural Network Model etc. In present study Roughness Index values are predicted by selecting the Fuzzy Logic System (FLS) for modeling.

From various literature sources, fuzzy logic is justified in different manner. Dr. Lotfi Zadeh, Principle of Compatibility, the complexity, and the imprecision are correlated and adds the closer look at a real world problem, the fuzzifier becomes its solution [10]

The Fuzzy Logic tool was introduced in 1965, also by Dr. Lotfi Zadeh, is a mathematical tool for dealing with uncertainty [9]. In general; the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities [9]. On the contrary, the traditional binary set theory describes crisp events, events that either do or do not occur. It uses probability theory to explain if an event will occur, measuring the chance with which a given event is expected to occur.

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data [8; 12]. A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier. These components and the general architecture of a FLS is shown in Figure 1 [13].

The process of fuzzy logic can be explained in Algorithm in following way:

1. A crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification [12; 13].
2. Afterwards, an inference is made based on a set of rules [12; 13].
3. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step [12; 13].

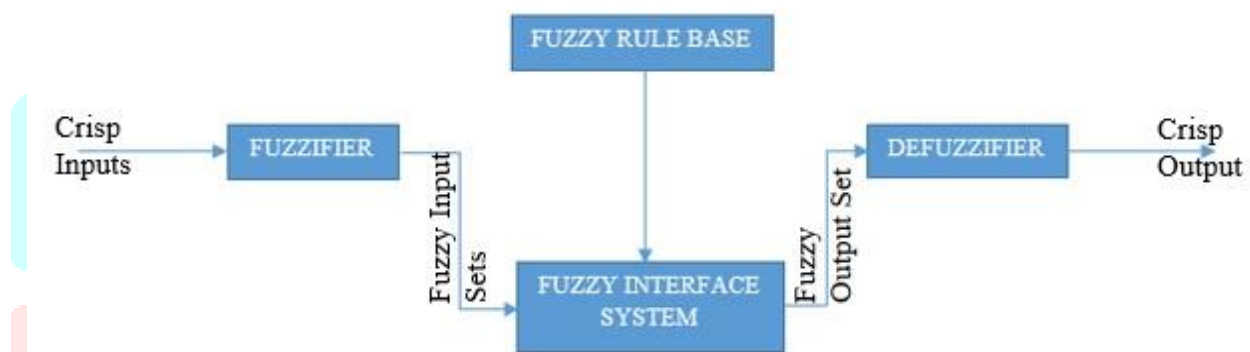


Figure 1: A Fuzzy Logic System

## II. RESEARCH METHODOLOGY

### Proposed Fuzzy Model:

Proposed fuzzy model have five input parameters as follows [4]:

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).

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

To fuzzified the crisp values of input parameters, triangular membership function (trimf) [14] is chosen and different number of membership function (MF) are defined for each input parameter and output which are mentioned in table 1 below.

**Table 1:** Number of Membership Functions of Parameters

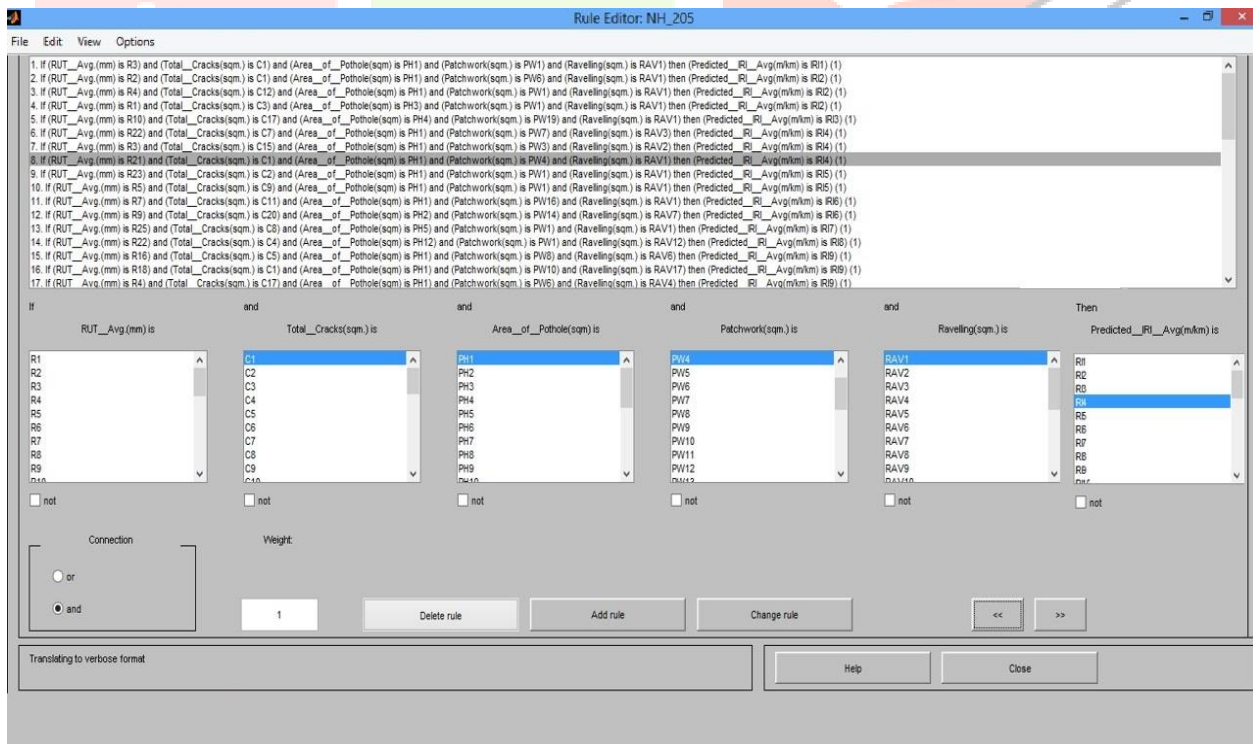
Parameters	Category	Number of MF
Rut depth (in millimeter)	Input	32
Total crack (in square meter)	Input	34
Area of pothole (in square meter)	Input	22
Patch work (in square meter)	Input	28
Raveling (in square meter)	Input	21
Roughness Index (m/km)	Output	31

The basic rules play an important role in manipulating the output results. The Rule Editor helps to modify these basic rules [1]. 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 manipulate the output results with the help of Rule View [1]. Rule Editor and Rule View of the output i.e. roughness index are shown in figure 2 and figure 3 respectively.

To Defuzzified the output results i.e., back to the crisp value, Mean of Maximum (MOM) defuzzification method is used.

### Methodology:

- Total 48 values are taken for each parameter as inputs.
- Mamdani Fuzzy Interface System is used for predicting the output values using the rule base [11].
- All the input parameters and output are fuzzified.
- 50 set of possible combination are considered.
- The roughness index in all fifty cases of combination is defined by Thirty one MF and these combinations define the rules for the fuzzy model shown in figure 2.
- All the Fifty rules are inserted and created on the basis of which a rule will be fired for a particular set of inputs.
- Using the rule viewer, output i.e. Roughness Index for road is observed for a particular set of inputs using the MATLAB Fuzzy toolbox [16].
- The output is compared with the quoted results.

**Figure 2:** Rule Editor of the output

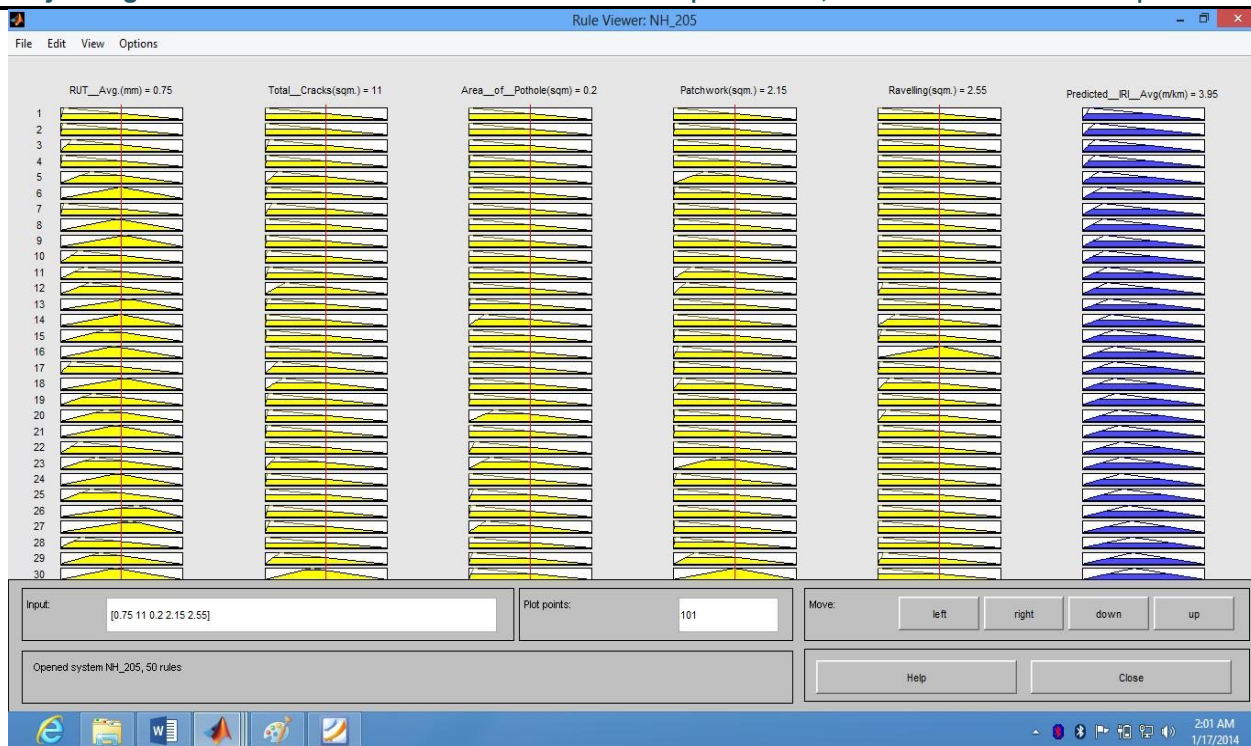


Figure 3: Rule View of the output

IV. RESULTS AND DISCUSSION

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 R<sup>2</sup> values are calculated between the fuzzy model result and the quoted neural network results and it is observed that high degree of correlation and R<sup>2</sup> exists between the modeled and quoted results and shown in table 3.

Table 2: Data Ranges of Parameters

Parameters	Category	Data Range
Rut depth (in mm)	Input	0-1.5
Total crack (in square meter)	Input	0-22
Area of pothole (in square meter)	Input	0-0.4
Patch work (in square meter)	Input	0-4.3
Raveling (in square meter)	Input	0-5.1
Roughness Index (m/km)	Output	2-5.2

Table 3: Correlation and R<sup>2</sup> Values of Results

Output Parameter	Level of Correlation between Quoted and Modeled Results	R <sup>2</sup> value between Quoted and Modeled Results	SSE	RMSE	%age Error
Roughness Index (m/km)	0.9934	0.9869	0.2687	0.07643	0.16

A paper on “Relationship between Pavement Roughness and Distress Parameters for Indian Highways” is published [4]. In this paper four highways namely NH-49, NH-205, NH-6 and NH-15 are taken and broadly categorized into two Southern (NH-49 and NH-205) and Northern Region (NH-6 and NH-15) for study of roughness based on distress parameters. They worked for the R<sup>2</sup> value with the help of ANN [4]. The R<sup>2</sup> values for Southern and Northern region were found to be 0.757 and 0.826 respectively [4].

For present study only NH-205 is taken for comparison between ANN and FLS model. The values of  $R^2$  have been calculated in different model coefficients. Only the Exponential, Logarithmic and Power models are considered. The comparison between ANN and FLS model is shown in table 4.

**Table 4:** Comparison between ANN and FLS model for NH-205

Model / Model Coefficient	$R^2$ Value		
	Exponential	Logarithmic	Power
ANN [4]	0.927	0.934	0.897
FLS	0.972	0.982	0.985

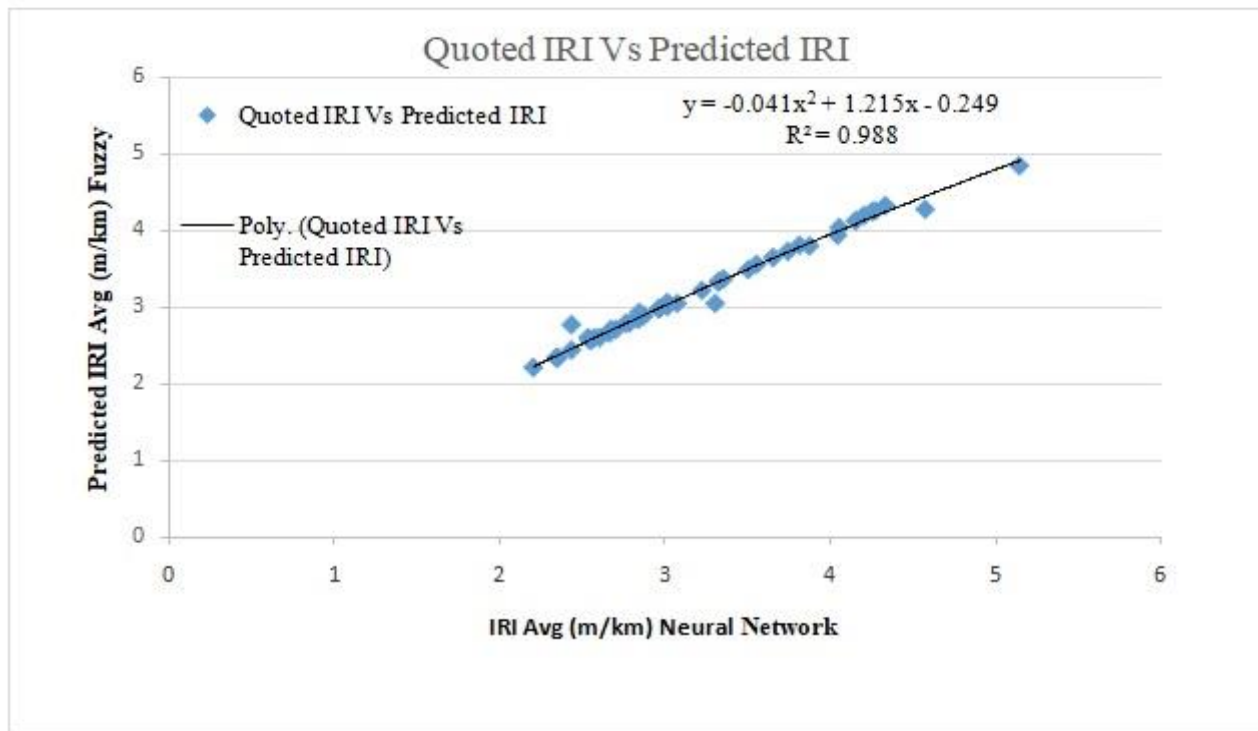
A graph showing the result behavior between the quoted results of ANN [4] and modeled results of FLS is also drawn as shown in figure 4.

### Conclusion:

The following conclusions are drawn from the present Fuzzy Logic Model:

1. Five different forms of relations are attempted between Predicted IRI and Quoted IRI namely exponential, logarithmic, polynomial, power and linear with  $R^2$  values 0.9715, 0.982, 0.988, 0.9857 and 0.9869 respectively.
2. The best two relations are polynomial and linear with  $R^2$  0.988 and 0.9869 respectively.
3. The Fuzzy Logic model shows an approximately  $R^2$  value of 0.98.
4. The limitations of traditional regression models can be overcome by latest tools such as Fuzzy Logic models.
5. It has been identified that Fuzzy Logic models are superior to other statistical models.
6. The relations between pavement distress data and roughness are developed considering the FLS and the performance of model is compared with the ANN model. It is observed that it is a better and significant way to find out the results by FLS model than the others.
7. The correlation and  $R^2$  values shown in table 5 also shows that the model is also worked at higher level in training and testing both which support the model very substantially.

Output Parameter	Level of Correlation between Quoted and Modeled Results in Training	Level of Correlation between Quoted and Modeled Results in Testing	$R^2$ value between Quoted and Modeled Results in Training	$R^2$ value between Quoted and Modeled Results in Testing
Roughness Index (m/km)	0.9615	0.9859	0.9245	0.9681

**Table 5:** Correlation and R<sup>2</sup> Values of Training and Testing Data**Figure 4:** Graph between Quoted IRI and Predicted IRI.**REFERENCES**

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