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Application of Fuzzy Logic in Prevention of Road Accidents Using Multi Criteria Decision Alert

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Authors' contributions

This work was carried out in collaboration between both authors. Author RG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author OKC managed the analyses of the study. Both the authors managed the literature searches, read and approved the final manuscript.

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ABSTRACT

With development and growth of technology, there has been an upsurge in number of vehicles on the street globally, which has resulted in increase of traffic jams and road accidents. This growing problem is being studied by researchers to find the solution. Fuzzy logic method is widely used in Intelligent Transportation Systems (ITS). In our study, considering various parameters required to control the vehicle safety, a fuzzy logic model was developed for automatic speed alert, brake alert with sensors and cameras in vehicles. For intelligent transport, Fuzzy Interface System (FIS) is developed to support drivers' decision making and alert them to control speed and brake so as to avoid accidents. The Rule Based System was established using various linguistic rules. Accordingly, 50 effective IF—Then rules were generated in the present study. In conclusion, this model can be inbuilt in the vehicles, with different number of inputs and outputs and for a fully automated system, to reduce the road accidents and traffic jams. The outcome of the research would lead to reduction road accidents.

Keywords: Fuzzy logic; Intelligent Transportation Systems; Fuzzy Interface System; speed alert; brake alert; sensors; vehicle safety.

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1. INTRODUCTION

Transportation and traffic is one of the most dynamic and random phenomena in the daily life. The experience of driving varies with each and every outing, hence it is one of the most difficult aspects of computing and controlling mathematically. For traffic control there has been a lot infrastructural development to maintain steady flow of traffic like multiple lane highways, roads with slip lanes, roundabouts, diamond interchange highways and stacked interchanges etc.

Despite of all of the development in recent years, accidents continue to rise by the day. The main reason for this is due to the control of vehicles residing ultimately at the driver. So, reduction of mishaps can be achieved by making the driver more aware of his travel environment. The aim of this research is to provide means to the driver to increase his awareness, by the use of alert systems.

Decision making is broadly defined to include proper choice or selection of constraints under condition of uncertainty. The decision may involve the simple optimization of output function under various constraints or an optimization with multiple criteria which corresponds to mathematical programming and multi criteria - multi objective decision making respectively. Fuzzy logic system is defined as a mode to map an input space to an output space in order to determine the level of membership of a variable to a system. The fuzzy model is easy to perceive and its mathematical perceptions are simple. Hence, fuzzy logic can be used for modeling the complicated and non-linear perceptions. Literature reviews demonstrate that there are many uses of fuzzy logic system in different regions.

The concept of Fuzzy set and Fuzzy logic was introduced by Zadeh [1,2,3], Professor in Computer Science at University of California in Barkley. Bellman and Zadeh [4], suggested a model of decision making in which relevant goals and constraints were stated as fuzzy sets, and a decision was determined by an appropriate aggregation of these sets.

Chaudhari, et al. [5], in their paper, described use of fuzzy logic in decision making to enhance the profit in the field of rice farming. This paper also helped to make the necessary arrangements of farm cultivation in advance and quantify amount of seed, fertilizers, manure, insecticides, labor expenses, machinery etc. before rainy season or sowing. Wang et al. [6], developed a model for traffic accidents prediction, based on fuzzy logic. In this paper, fuzzy statistics theory and 133 Harbin arteries accidents data were used to ensure the fuzzy sets of each variable and its corresponding membership functions.

Terzi et al. [7], established fuzzy logic model for prevention of accidents by controlling brake rate from speed and distance data. They have developed a model to vary the vehicle pursuit distance automatically to reduce the rate of accidents. Rehman et al. [8], developed a fuzzy logic approach model for smart intelligence transport system. It consists three inputs Distance between Vehicles, Vehicle Speed and Static Friction Coefficient and one output was Brake Rates.

Massami et al. [9], studied fuzzy comprehensive technique to evaluate traffic accidents risk on road. They formed the Pairwise Comparison Matrix to determine the normalized weights. Compared the weights by fuzzy approach and non-fuzzy approach by fuzzy pairwise comparison method. Haoran Wu Yan Li et al. [10], discussed a longitudinal minimum safety distance model based on driving intention and fuzzy reasoning for the longitudinal minimum safety distance, and can improve the reliability, timeliness and accuracy of collision warning.

Drivers are vulnerable to musculo-skeletal and psychological disorders because of substantially harmful agents in this stressful occupation, Ali Karimi et al. [11], presented a fuzzy logic based, road accident model on physical and mental health of drivers. This study aimed to investigate the influence of driver's physical and psychological health on the risk of road accidents using fuzzy logic approach.

Elda Maraj and Shkelqim Kuka [12], developed a model that can predict the traffic accidents specifically in Albania. Because of the random character of traffic accidents, the existing methodology will not be efficient in predicting the exact number of traffic accidents. The fuzzy logic model is practical in predicting traffic accidents. They have used fuzzy logic toolbox of MATLAB.

Globally, accidents are increasing day by day due to traffic and many people die or get injured. To check these accidents, many institutes and organisations are working on it. It was noticed that human error was the main factor behind these accidents. By using new technology in vehicles, such accidents can be prevented. Fuzzy logic can help an individual in decision making at several stages while driving in an uncertain environment.

In this paper, a fuzzy logic model was developed to take a proper decision for speed alert & brake alert in uncertain conditions so that a vehicle can be driven safely considering different constraints like Distance, Crowd on Road, Zebra Crossing, Time of Driving, Age of Driver & Road Condition.

2. FUZZY TRANSPORTATION PROBLEM

In the field of transportation, traffic density, planning and engineering architecture plays a very important role for proper execution and analysis. Measure of performance is dependent on the level of congestion in observed traffic volumes. Kikuchi and Dragna, [13], have proposed the approach for variety of problems such as observed counts and the relationship among the true values for the formulation of fuzzy linear programming problem. Due to complexity and uncertainty of transport systems, the consideration of simplified traffic scheduling plays very important role.

In the past several decades, a variety of deterministic and stochastic models have been developed to solve complex traffic and transportation engineering problems. These mathematical models use different formulae and equations to solve such problems.

During their education and training, engineers are most often directed to the use of exclusively objective knowledge (formulae and equations). However, when solving real-life engineering problems, linguistic information is often encountered that is frequently hard to quantify using 'classical' mathematical techniques. This linguistic information represents subjective knowledge (linguistic information). The fuzzy logic is a useful technique in real life transportation problems.

3. FUZZY MODEL FOR THE PRESENT STUDY

Concentrating on the drivers performance based on the various components required for avoiding accidents and soft driving experience, we feel that it is important to consider the influence of factors with uncertainties that may occur during driving vehicles. The parameters like Distance, Crowd on Road, Zebra Crossing, Time of Driving, Age of driver and Road condition have valuable contribution for safe driving and to control the rate of accidents through Speed alert and Brake alert.

Fig. 1 shows the model of fuzzy system which computes the safe driving by the drivers considering the alerts on output driving speed and brake on road.

In view of the selection of various input variables & output variables they are subdivided into linguistic terms as shown in Table 1 and Table 2. Trapezoidal membership function is used for their linguistic terms with degree of membership given by equation 1. These linguistic terms and ranges of the membership functions are decided on the discussion with experts in the field of transportation and traffic controls.

MATLAB R 2013a is used for the determination of output on the basis of the various defined rule base. The rules are framed by considering all input variables with real life & practical difficulties occur in the field of transportation and discussion with the experts. After finalizing the rules, by fuzzy rule inference the data is tuned in MATLAB to get the output in terms of crisp values.

3.1 Membership Functions for Input Variables

The membership functions play vital role in the overall performance of fuzzy representation. The MFs are the building blocks of fuzzy set theory, that is, fuzziness in a fuzzy set is determined by its MF. Accordingly, the shapes of MFs are important for a particular problem since they effect on a fuzzy inference system. They may have different shapes such as triangular, trapezoidal, Gaussian, and so forth. The only condition a MF must really satisfy is that it must vary between 0 and 1.

Membership function parameters, specified as the vector [a b c d]. Parameters b and c define the shoulders of the membership function whereas a and d define its feet. The shape of the membership function depends on the relative values of b and c.

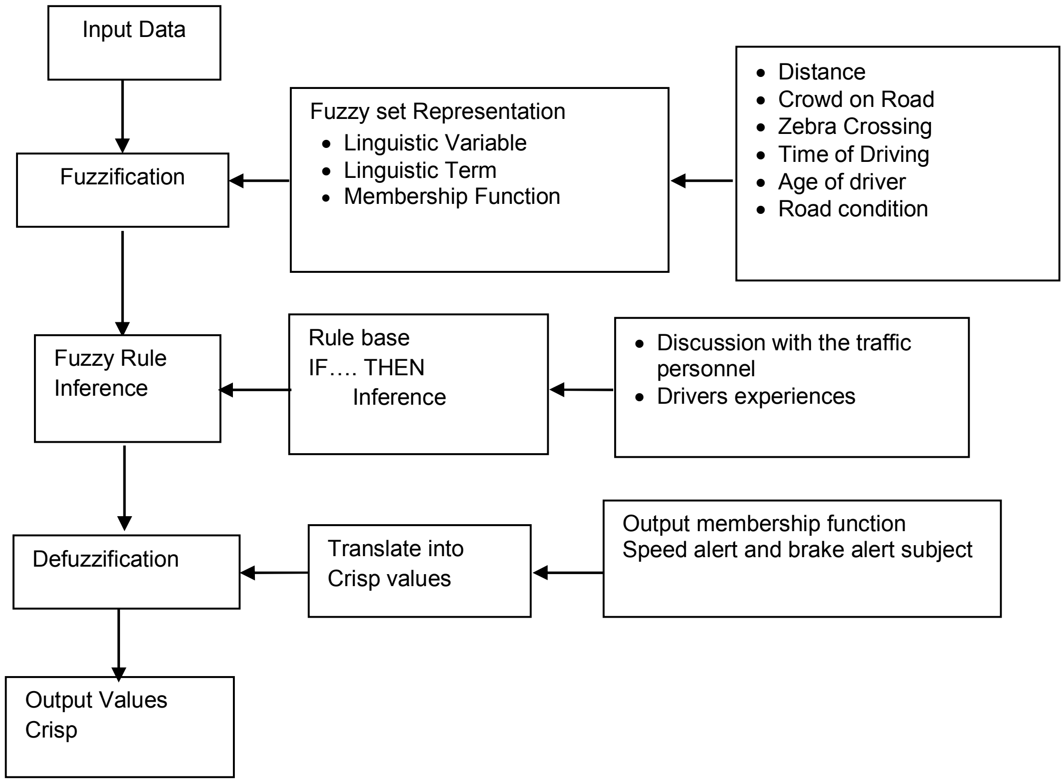

Fig. 1. Basic elements of fuzzy logic

The inputs of fuzzy system Distance, Crowd on Road, Zebra Crossing, Time of Driving, Age of driver and Road condition fuzzified crisp input range into linguistic variables by using trapezoidal membership function for converting the crisp set into fuzzy set as in equation 1. The fuzzified values are symmetrically distributes according the universe of discourse.

$$\mu_f(y) = \begin{cases} 0, & y < a \\ \dfrac{y-a}{b-a}, & a \le y \le b \\ 1, & b < y < c \\ \dfrac{d-y}{d-c}, & c \le y \le d \\ 0, & y > d \end{cases} \quad (1)$$

Input Variables, Fuzzy Linguistic Variables and corresponding Crisp Input Range of the study are given in the Table 1.

The following tools are used to build, edit, and view fuzzy inference systems:

- Fuzzy Logic Designer to decide the number & name of input and output variables.
- Membership Function Editor to state, display and edit the shapes of all the membership functions related with all input and output variables.
- Rule Editor to edit the list of rules which describes the performance of the system.
- Rule Viewer to view the fuzzy inference diagram and to see, which rules are active, or how individual membership function shapes influence the results.
- Surface Viewer to view the dependency of one of the outputs on any one or two of the inputs; that is, it creates and plots an output surface map for the system.

Figs. 2, 3, 4, 5, 6 and 7 show the trapezoidal membership functions for input variables distance, crowd on road, zebra crossing, time of driving, age of driver and road condition respectively. There are five Fuzzy Linguistic Variables for each input variable, therefore it shows five trapezoids in each figure as given below.

Table 1. Linguistic variable ranges for input variable

Input Variable	Fuzzy Linguistic Variable	Crisp Input Range
Distance	Very Less	[0 0 50 100]
	Less	[50 100 150 200]
	Comfortable	[150 200 250 300]
	More	[250 300 350 400]
	Far	[350 400 500 500]
Crowd on Road	Very Negligible	[0 0 10 20]
	Negligible	[10 20 30 40]
	Moderate	[30 40 50 60]
	Crowded	[50 60 70 80]
	Over Crowded	[70 80 100 100]
Zebra Crossing	Very Close	[0 0 50 100]
	Close	[50 100 150 200]
	Watchable Distance	[150 200 250 300]
	Far distance	[250 300 350 400]
	Long Distance	[350 400 500 500]
Time of Driving	Early Morning	[0 0 7 8]
	Morning	[7 8 11 12]
	Noon	[11 12 13 14]
	Afternoon	[13 14 16 17]
	Evening	[16 17 20 20]
Age of driver	Very young	[0 0 16 18]
	Youngest	[16 18 21 24]
	Young	[21 25 36 40]
	Old	[36 40 46 50]
	Oldest	[46 50 60 70]
Road condition	Worst	[0 0 50 55]
	Average	[50 55 60 65]
	Good	[60 65 70 75]
	Very Good	[70 75 85 90]
	Excellent	[90 95 100 100]

Input variable distance, is divided into linguistic terms as- very less, less, comfortable, more and far according to the distance between vehicles in feet with the crisp ranges 0-100, 50-200, 150-300, 250-400 and 350-500 respectively. For example, if distance is 323 feet, it belongs to the linguistic term ‘More’ and its degree is 1 as shown in the Fig. 2.

Input variable crowd on road, is divided into linguistic terms as- very negligible, negligible, moderate, crowded and overcrowded. On the basis of crowd on road in terms of the percentage the crisp ranges are considered as 0 – 20, 10 – 40, 30 – 60, 50 – 80 and 70 – 100 respectively. For example if crowd on road is 50%, it belongs to the linguistic term ‘Moderate’ with degree 1 and belongs to the linguistic term ‘Crowded’ with degree 0 as shown in the Fig. 3.

Input variable zebra crossing, is divided into linguistic terms as - very close, close, watchable distance, far distance and long distance. On the basis of distance of zebra crossing from the vehicle, the crisp ranges are considered in terms of feet as 0 – 100, 50 – 200, 150 – 300, 250 – 400 and 350 – 500 respectively. Now consider Zebra crossing is 75 feet far away from the vehicle then it belongs to linguistic term ‘Close’ with degree 0.5, as shown in Fig. 4. The degree of membership function can be determined by equation 1 also. It is $\mu_f(y) = \frac{75-50}{100-50} = 0.5$ as Crisp Input Range [50 100 150 200].

Input variable Time of Driving, is divided into linguistic terms as early morning, morning, noon, afternoon and evening. On the basis of Time of Driving, the clock timings, in terms of the crisp ranges, are considered as 0 – 8, 7 – 12, 11 – 14, 13 – 17 and 16 – 20 respectively. As shown in the Fig. 5, if we consider Time of Driving 6 AM then it belongs to linguistic term ‘Early Morning’ with degree 1.

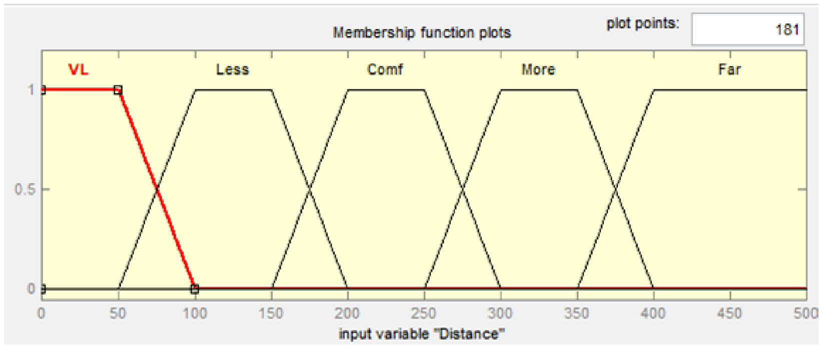

Fig. 2. Membership function of input variable distance

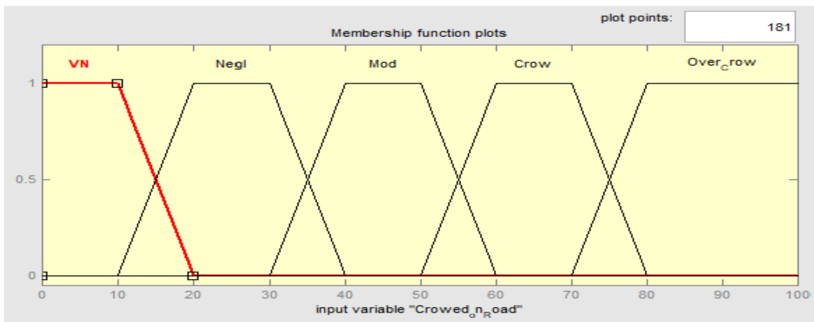

Fig. 3. Membership function of input variable crowd on road

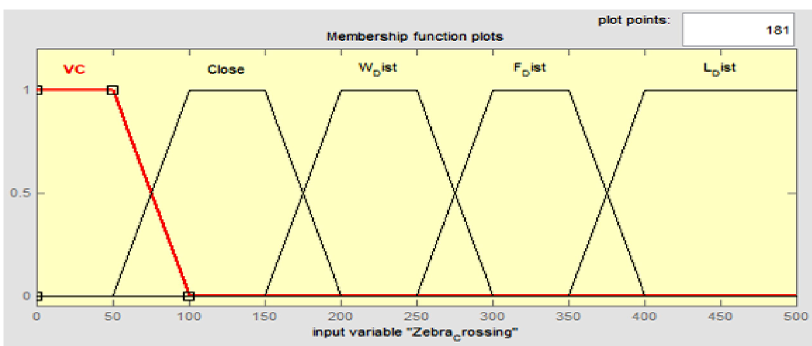

Fig. 4. Membership function of input variable zebra crossing

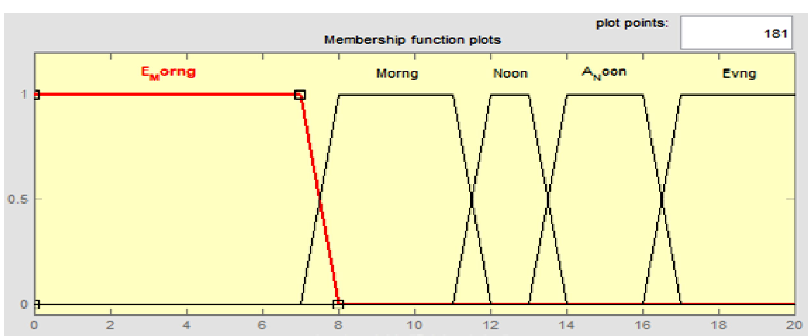

Fig. 5. Membership function of input variable time of driving

Age of driver is consider as the important parameter for the study. It is divided into various linguistic terms as- very young, youngest, young, old and oldest according to their age as 0-18, 16-24, 21-40, 36-50 and 46-70 respectively. It is clear from the Fig. 6, that if the age is 36, then it belongs to linguistic term 'young' with degree 1 and to linguistic term 'old' with degree 0.

The input variable road condition, is subdivided into various linguistic terms defining the road condition as worst, average, good, very good and excellent with the ranges in terms of percentage as 0–55, 50–65, 60-75, 70-90 and 90-100 respectively as shown in the Fig. 7. If road condition is 57% then it belongs to linguistic term 'average' with degree 1

3.2 Membership Functions for Output Variables

Output of the current system are speed alert & brake alert, and are divided into various linguistic terms such as very slow, slow, average, above average and high, in case of speed alert and similarly defined for brake alert as no brake, brake push, brake, urgent brake, peak, using trapezoidal membership function for changing the crisp set into fuzzy set as in equation 1. The crisp output range is given as percentage for the respective linguistic terms. The membership function and linguistic term for above output variables of the study are given in the Table 2.

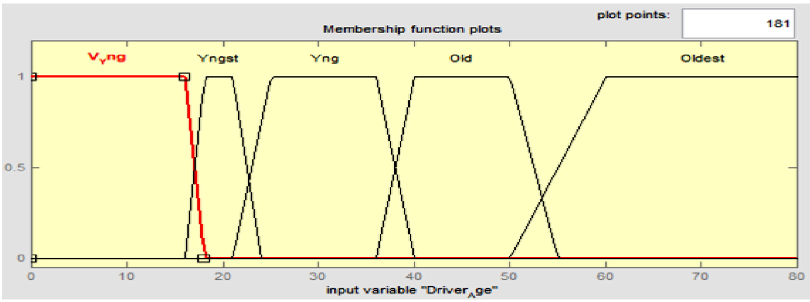

Fig. 6. Membership function of input variable age of driver

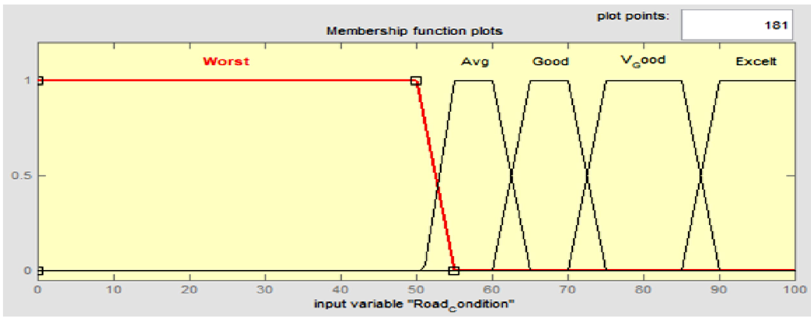

Fig. 7. Membership function of input variable road condition

Table 2. Linguistic variables for output variables

Output Variable	Fuzzy Linguistic Variable	Crisp Output Range
Speed alert	Very Slow	[0 0 10 20]
	Slow	[10 15 25 30]
	Average	[25 30 40 50]
	Above Average	[40 50 60 70]
	High	[70 80 100 100]
Brake Alert	No Brake	[0 0 10 20]
	Brake Push	[10 15 25 30]
	Brake	[25 30 40 50]
	Urgent Brake	[40 50 60 70]
	Peak	[70 80 100 100]

Figs. 8 and 9, show the trapezoidal membership functions for output variables speed alert and brake alert respectively. There are five Fuzzy Linguistic Variables for each output variable, therefore it shows five trapezoidal shape graph in each figure as given below.

The speed limits is subdivided into various categories in linguistic variables as - very slow, slow, average, above average and high. Speed limit keeping very slow or slow is the need according to the alerts at zebra crossing, crowd on the road, road condition, etc. on the road. The crisp ranges of the linguistic variables are considered in terms of percentages as 0-20, 10-30, 25-50, 40-70 and 70-100 as shown in the Fig. 8. If the Speed alert is 25% it belongs to linguistic term 'average' with degree 0, as Crisp output range [25 30 40 50] and belongs to linguistic term 'slow' with degree 1 as Crisp output range [10 15 25 30].

Brake of vehicle in the linguistic terms is categorized as- No Brake, Brake Push, Brake, Urgent Brake and Peak with the ranges in terms of percentages i.e. 0-20, 10-30, 25-50, 40-70 and 70-100 respectively. As shown in the Fig. 9, if the Brake alert is 55% it belongs to linguistic term 'urgent brake' with degree 1, as Crisp output range [40 50 60 70].

3.3 Fuzzy Rule Base and Rule Viewer for Trapezoidal Membership Function

The inputs and outputs of fuzzy system are defined in terms of fuzzy variable. Fuzzy rule based system was developed based on the experience of the experts in the state traffic department. Fuzzy Rule Base Modelling is significant specifically where relations between the components of the system are not exactly known, if there is inadequate statistical data for study and if the data is ambiguous about a particular thing which the user wants. The Rule Based System can be established using many linguistic rules, which can be formulated with "IF—THEN" along with some fuzzy mathematical operators. We have generated 50 IF—Then rules in the present case, some of them as sample rules are listed below:

1. If, Distance is Very Less and Crowd on Road is Very Negligible and Zebra Crossing is Very Close and Time of Driving is Early Morning and Driver Age is Very Young and Road Condition is Worst; then, Speed Alert is Slow and Brake Alert is Brake.
2. If, Distance is Less and Crowd on Road is Negligible and Zebra crossing is Close and Time of Driving is Morning and Driver Age is Youngest and Road Condition is Average; then, Speed Alert is Slow and Brake Alert is Push.
3. If, Distance is Comfortable and Crowd on Road is Moderate and Zebra Crossing is Watchable Distance and Time of Driving is Noon and Driver Age is Young and Road Condition is Good; then, Speed Alert is Average and Brake Alert is Push.
4. If, Distance is More and Crowd on Road is Crowded and Zebra Crossing is Far Distance and Time of Driving is After Noon and Driver Age is Old and Road Condition is Very Good; then, Speed Alert is Average and Brake Alert is Brake.
5. If, Distance is Far and Crowd on Road is Over Crowded and Zebra Crossing is Long Distance and Time of Driving is Evening and Driver Age is Oldest and Road Condition is Excellent; then, Speed Alert is Average and Brake Alert is Push.

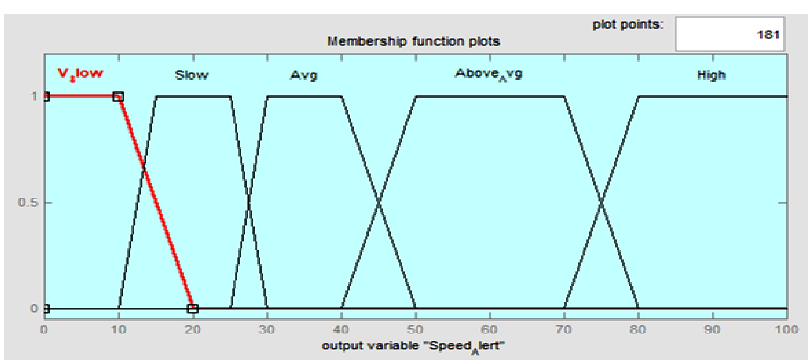

Fig. 8. Membership function of speed alert

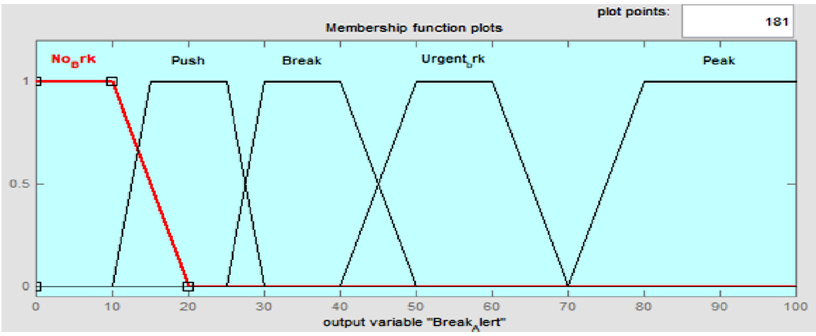

Fig. 9. Membership function of output brake alert

Rule viewer of the suggested fuzzy expert system for the input and output variables and the membership grades assigned as shows in Figs. 2 to 9, fuzzified and fuzzy rules defined above, the rule base is generated by MATLAB and the output variables speed alert and Brake alert are as shown in Fig. 10.

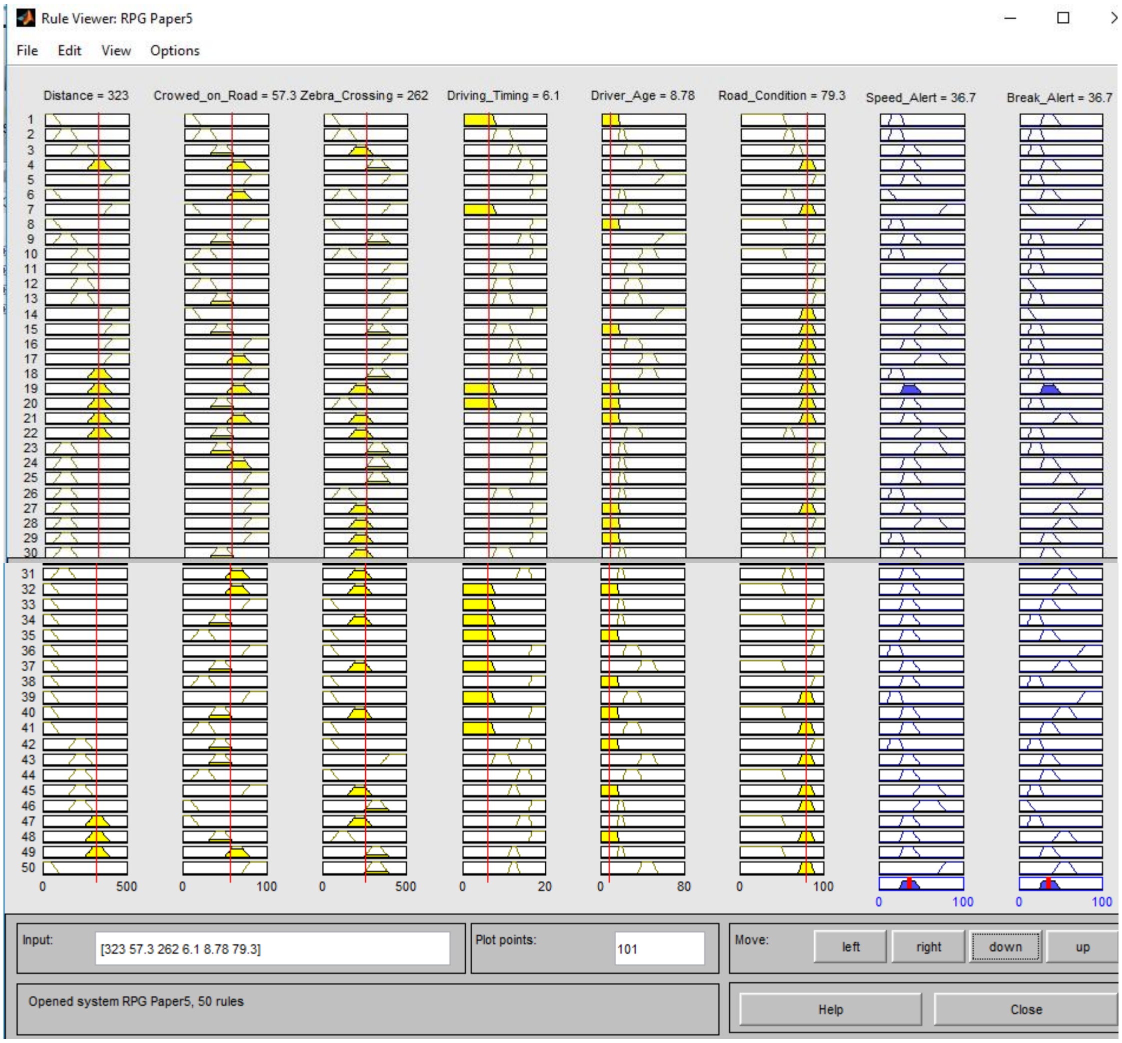

Fig. 10. Rule viewer of the fuzzy rule

Each rule is a row of plots, and each column is a variable (input & output). The rule numbers are displayed on the left of each row. You can click on a rule number to view the rule in the status line. The first six columns, of fifty plots each show the membership functions referenced by the antecedent, or the if-part of each rule. The last two column, of fifty plots each show the membership functions referenced by the consequent, or the then-part of each rule. The last plot, in the seventh and eighth column, represents the aggregate weighted decision for the given inference system. This decision will depend on the input values for the system. The defuzzyfied output is displayed as a bold vertical red line on this plot.

Optimizing the parameters of the fuzzy controller through tuning we can find optimized output value which will be the best option for driver to take decision or controlling the vehicle to avoid the accidents on road.

Surface viewer for the input variables Driver Age, Distance and output variable Speed Alert is given below Fig. 11. We have a six – input and two-output system and would like to see the output surface. The Surface Viewer can generate a three - dimensional output surface where any two of the inputs & one of the output vary, but the other inputs and outputs must be held constant and we get a three dimensional view. The surface plot updates automatically if we change the input or output variable selections or the number of grid points.

4. RESULTS AND DISCUSSION

Terzi et al. [7], developed a fuzzy model for Intelligent Transportation Systems (ITS) by using two input variables speed (velocity of the vehicle) and distance for getting an alert on output as brake rate automatically. On the basis of the alert, the brake pedal can slow down speed. So, in this model they have used two input variable and one output variable for decision making to avoid the accidents.

We have developed the fuzzy logic interface system for Intelligent Transportation Systems (ITS) by using six input variables Distance, Crowd on Road, Zebra Crossing, Time of Driving, Age of driver and Road condition and two output variables speed alert and brake alert.

Based upon the experience of the experts in the traffic department, Fuzzy rule based system was developed, which is significant specifically where relations between the components of the system are not exactly known, if there is inadequate statistical data for study and if the data is ambiguous about a particular thing which the user wants. The Rule Based System was established using various linguistic rules. Accordingly, 50 effective IF—Then rules were generated in the present study. It is a multi-objective fuzzy model which works simultaneously on two variable controls. Thus this model can effectively be used in automated vehicle.

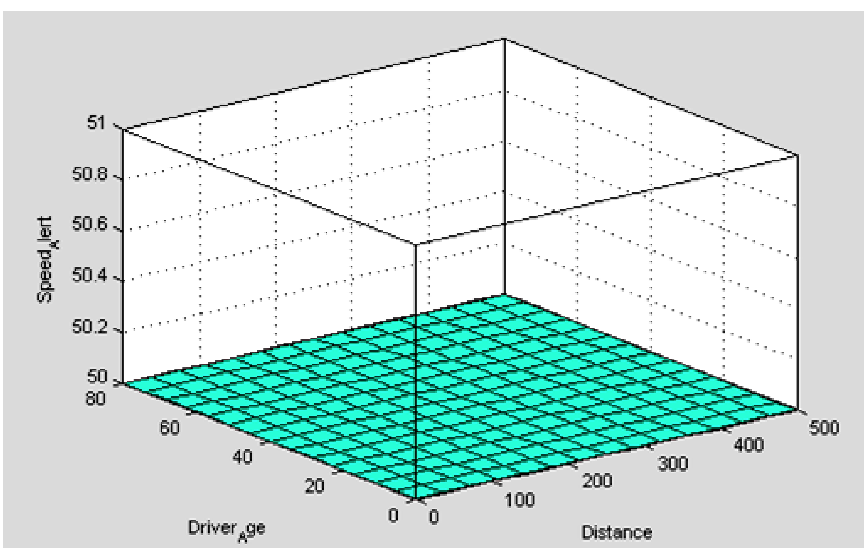

Fig. 11. Surface view

5. CONCLUSION

In India, due to high traffic density on road and unawareness of drivers many people die or get injured in traffic accidents. Many reasons like drivers' fault, lack of infrastructure, environment, weather conditions etc. contribute to these accidents. Intelligent Transportation Systems (ITS) can help to reduce this accident rate up to some extent. In this chapter, a model of Fuzzy Expert System (FES) is proposed for estimation of alert to drivers for controlling speed and use of proper brake system through speed alert and brake alert. The various parameters used for estimation of these alerts are as- Distance, Crowd on Road, Zebra Crossing, Time of driving, Age of driver and Road condition. The results have been validated previously through experts in the field of traffic control. So, this fuzzy logic approach can effectively be used to reduce rate of traffic accident on road. This model can be inbuilt in vehicles with different number of input and output, for fully automated system. This study can also help for fully automated driverless vehicles as per the requirement of manufacturer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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