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Fuzzy Inference Based Modelling of Perception Reaction Time of Drivers

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***Abstract*—**Perception reaction time of drivers is an outcome of human thought process, which is vague and approximate in nature and also varies from driver to driver. So, in this study a fuzzy logic based model for prediction of the same has been presented, which seems suitable. The control factors, like, age, experience, intensity of driving of the driver, speed of the vehicle and distance of stimulus have been considered as premise variables in the model, in which the perception reaction time is the consequence variable. Results show that the model is able to explain the impacts of the control factors on perception reaction time properly.

***Keywords*—**Driver, fuzzy logic, perception reaction time, premise variable.

I. Introduction

DRIVERS take a very small time to understand the situation and take appropriate decision regarding overtaking, following other vehicles/s or stopping his/her vehicle. This time is called perception reaction time. This varies with the intensity and experience of driving, driver's age, distance of stimulus (generally, other vehicles) and speed of the vehicle, road edge, rotaries etc. The behavior of a driver can be explained in terms of his/her physiological and psychological characteristics. Both of these characteristics are interrelated and play a vital role in the perception reaction time of a driver.

Perception reaction time is an important factor while designing a road transportation infrastructure or a road transportation management facility. The economy of construction is greatly affected by perception reaction time. For example, considering the design of a vertical curve, the curvature of the same depends upon perception reaction time and the economy of construction depends upon the curvature. Hence, it can be said that to develop a safe, economical and reliable road transportation system, proper understanding of perception reaction time is highly essential.

An essential feature of human driving is a considerable reaction time, which is a consequence of the physiological aspects of sensing, perceiving, deciding, and performing an action [1]. This complex reaction time is of the order of 1 s and varies strongly between different drivers (with different age, gender), different stimuli, and different studies [2]. The reaction time depends on the driving tasks and individual driver characteristics [3]. Driving tasks include car-following, lane-change, left-turn, and right-turn tasks [4]. Driving skills and driving style, or in other words, driver performance and behavior [5] are the two main components of human factors in driving.

The behavior of a driver is highly uncertain because a driver makes his/her decision based on the uncertain information he/she obtains from the environment. For example, an accelerating driver is not aware of the exact distance headway and by pure guess he judges the distance headway, but in most of the cases his/her judgment is correct and he/she safely pursues his/her journey. The conventional mathematics and probability will not be able to explain this kind of traffic scenario. It will be effective and convenient if the factors influencing the behavior of a driver are expressed in terms of linguistic variables. This work is intended to understand the variation of perception reaction time of drivers with age, experience, intensity of driving, speed and distance of the stimulus.

II. Preface to the Presented Model: Review Stage

Before describing the presented model, it is necessary to explain about perception reaction time and stimulus.

A. Perception Reaction Time

The time required by a driver to react for a stimulus is called as perception reaction time. Driver reaction time is defined as the summation of perception time and foot movement time by earlier car-following research [6]. In this work Hopper McGee chain model of perception reaction time [7] will be considered. According to this model the perception time is divided into four components, typical values of the components of the perception time are given in Table I.

TABLE I
Various Components of Perception Time (Adapted from [7])

.no	Component	Time(sec)
1.	Latency	0.31
2.	Eye movement	0.09
3.	Fixation	0.2
4.	Recognition	0.5

B. Stimulus

Stimulus is an object or an event that influence behavior. The stimulus may be a parked car, an accelerating car, a road sign, an obstruction on the road, pedestrians and road features. The behavior and the decision of the driver greatly depend upon different stimuli.

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III. Proposed Model

In the presented model, fuzzy inference system is used to capture vague and imprecise nature of human mind while driving. In an ordinary mathematical model (generally, an equation) we have one or more independent variable/s connected to a dependent variable through the deterministic nature of the equation. In the same line (but in a different fashion), to model any vague and imprecise scenario, some linguistic factors (named as premise variables) are connected to some other linguistic factor (named as consequence variable) through some rules. Similar to different values of independent variables, various instances of premise variables are there named as input condition. In the foregoing subsections various parts of the model are described.

A. Fuzzy Inference System

A fuzzy inference system consists of premise variables and consequence variable connected by some rules. Different instances of the premise variables and consequence variable are called input conditions and conclusion, respectively. The fuzzy inference system considered here is shown in Fig. 1. More details on fuzzy inference system can be found in [8] and [9].

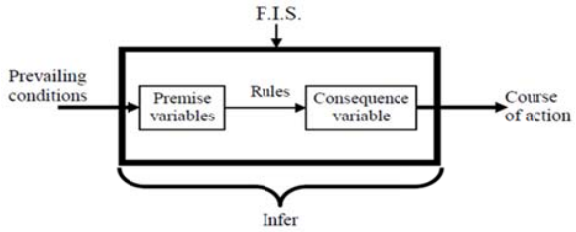

Fig. 1 Fuzzy inference system (adapted from [8])

B. Linguistic Variables (Premise Variables) Considered

Reaction time of a driver depends on a large number of factors. It can be stated that every driver has at least one unique feature. It is really hard and cumbersome to take all the factors that affect the traffic flow. In this work effort has been made to understand the variables that are common in most of the drivers, which are listed as follows:

a) Age
b) Experience
c) Intensity of driving
d) Speed
e) Distance of the stimulus

1) Age

Generally the visual capacity of a driver decreases with age. It is well known and proved that reaction time of a driver depends on his visual ability. Older drivers have problems to adequately detect, perceive and accurately judge the safety of a gap.

An indirect approach is used to consider visual capacity of the driver. By considering age as a premise variable visual ability of the driver is captured indirectly.

The linguistic variable, age (A) is expressed into three groups, namely, very young, young and old.

The membership function of the linguistic variable age is constructed in such a way that it represents the visual ability of the driver.

$$\text{Membership function for age, } \mu\text{age} = \begin{cases} 1; 15 \le A \le 19 \\ 1 - \dfrac{A-19}{11}; 19 \le A \le 30 \\ \dfrac{A-25}{7}; 25 \le A \le 32 \\ 1 - \dfrac{A-32}{13}; 32 \le A \le 45 \\ \dfrac{A-35}{20}; 35 \le A \le 55 \end{cases}$$

Fig. 2 shows the membership functions for different groups of the premise variable, age. The solid line shows the membership function for the age group very young; whereas, the dashed and dotted lines show the membership function for the age groups young and old, respectively.

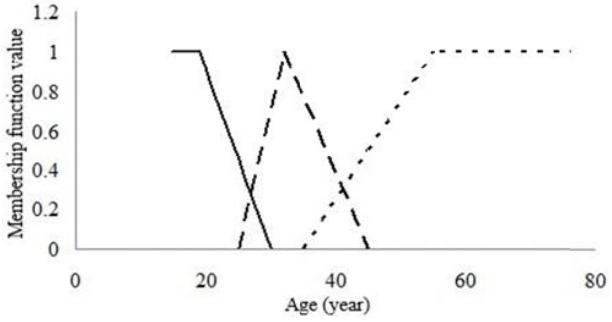

Fig. 2 Membership function for age

2) Experience

The visual field of drivers gets reduced nearly to zero when a driver stares at a single point; a new driver is often distracted which results in increased perception reaction time. Moreover a less experienced driver will not be able to drive the vehicle as versatile as an experienced driver. By taking experience as a linguistic variable we consider the ability of the driver to use the vehicle and perceive the stimulus from his/her environment.

The linguistic variable experience (E) is divided into two groups, less experience and good experience.

$$\text{Membership function for experience, } \mu\text{exp} = \begin{cases} 1; 1 \le E \le 3 \\ 1 - \dfrac{E-3}{15}; 3 \le E \le 18 \\ \dfrac{E-12}{12}; 12 \le E \le 24 \\ 1; E > 24 \end{cases}$$

3) Intensity of Driving

Driving is a complex task which requires a lot of attention, since information is to be perceived and analyzed by the brain, driving causes fatigue to the brain. This results in the increased perception reaction time of drivers. Fatigue may be caused due to long time and monotonous driving. The membership function of the linguistic variable intensity of driving is constructed in such a way that the fatigue of the

driver is taken into account.

The linguistic variable intensity of driving (I) is divided into two groups, low intensity and high intensity

$$\text{Membership function for intensity of drive, } \mu\text{int} = \begin{cases} 1-\frac{l}{40}; 0 \le l \le 40 \\ \frac{l-30}{40}; 30 \le l \le 120 \\ 1; l > 120 \end{cases}$$

4) Speed

With increase in speed the useful visual field of the driver gets reduced. When stopped, a driver's field of vision may be as high as 190 degrees, but for the same person, the angle will be narrowed to 40 degrees at the speed of 60 miles per hour. This reduced visual field causes increase in perception time of a driver. This is the physical effect. But, there is another prominent factor, namely, the psychological factor. At higher speed due to the fear of accident and the severe consequence due to accident at higher speed people become much more alert, i.e., perception reaction time becomes less.

The linguistic variable speed is classified into two groups, low speed and high speed. The membership functions are shown below.

$$\text{Membership function for speed, } \mu\text{speed} \begin{cases} 1; 0 \le u \le 30 \\ 1-\frac{u-30}{20}; 30 \le u \le 50 \\ \frac{u-40}{50}; 40 \le u \le 90 \\ 1; u > 90 \end{cases}$$

5) Distance of the Stimulus

A driver will only be able to perceive a stimulus if the stimulus comes into his/her field of vision. Far the distance of the stimulus, a driver requires more time to perceive the stimulus resulting in increased perception reaction time of the driver.

The linguistic variable distance of stimulus (d) is classified into three groups, low distance, medium distance and large distance. The membership functions are shown below.

$$\text{Membership function of stimulus, } \mu\text{sti} = \begin{cases} 1; 0 < d < 10 \\ 1+\frac{10-d}{25}; 10 \le d \le 35 \\ \frac{d-25}{10}; 25 \le d \le 35 \\ 1-\frac{d-35}{10}; 35 \le d \le 45 \\ \frac{d-35}{45}; 35 \le d \le 80 \end{cases}$$

Membership function relations for the rest four premise variables other than age are not provided here due to lack of space. But, they are constructed in a very similar way.

C. Input

As mentioned earlier, different instances of the premise variables are the inputs for the fuzzy inference system. The inputs can be expressed in the form of a set which is shown below.

Input set = $\{A_k; E_k; I_k; u_k; d_k\}$

where, A_k = Age, exp_k = experience, int_k = intensity, u_k = speed, d_k = distance of the stimulus for the k^{th} driver.

From the definition of membership function it can be found that an element of an input set may belong to two groups hence an input set element may have a maximum of two membership values.

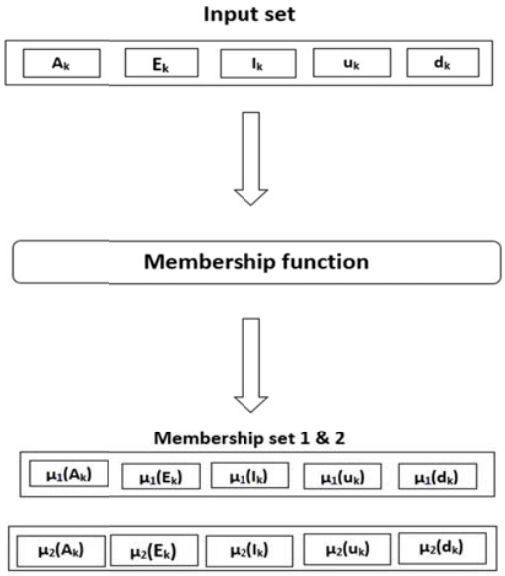

Fig. 3 Schematic for membership function and membership set

Since two membership sets are obtained, combination of the two sets should be done. Applying combination membership set 1 and membership set 2 will produce 32 membership subsets of membership set 1 OR membership set 2. Schematic for membership function and membership set is provided in Fig. 3.

D. Weight of a Membership Subset ($w_{r,k}$)

Since the premise variables are connected using the logical connective AND, the weight of a membership set is the smallest value among the elements in a particular membership subset.

Weight of a membership subset,

$$w_{r,k} = \min\{\mu_r(A_k), \mu_r(E_k), \mu_r(I_k), \mu_r(u_k), \mu_r(d_k)\}$$

where $1 \le r \le 32$.

E. Rules

All the five premise variables are classified into two or three groups. The rules are formed by applying combination of the groups. The number of groups that are to be formed can be determined by multiplying the number of groups in each premise variable (i.e., $3 \times 2 \times 2 \times 2 \times 3 = 72$). The general form of the rules is shown below.

If Age is $\boldsymbol{A}_1$ AND Experience is $\boldsymbol{exp_1}$ AND Intensity is $\boldsymbol{int_1}$ AND Speed is $\boldsymbol{u_1}$ AND Distance is $\boldsymbol{d_1}$ THEN conclusion is $\boldsymbol{P_1}$.

If Age is $\boldsymbol{A_1}$ AND Experience is $\boldsymbol{exp_1}$ AND Intensity is $\boldsymbol{int_1}$ AND Speed is $\boldsymbol{u_1}$ AND Distance is $\boldsymbol{d_2}$ THEN conclusion is $\boldsymbol{P_2}$.
If Age is $\boldsymbol{A_1}$ AND Experience is $\boldsymbol{exp_1}$ AND Intensity is $\boldsymbol{int_1}$ AND Speed is $\boldsymbol{u_2}$ AND Distance is $\boldsymbol{d_1}$ THEN conclusion is $\boldsymbol{P_3}$.
… … … … …
… … … … … …
If Age is $\boldsymbol{A_3}$ AND Experience is $\boldsymbol{exp_2}$ AND Intensity is $\boldsymbol{int_2}$ AND Speed is $\boldsymbol{u_2}$ AND Distance is $\boldsymbol{d_2}$ THEN conclusion is $\boldsymbol{P_{72}}$.

F. Consequence of a Rule

From Hopper McGee chain model of perception reaction time it is found that the smallest value of reaction time is 0.5 sec and the highest value of perception reaction time is 2.7 sec. So, the value of each consequence is suitably interpolated between 0.5 and 2.7. The consequence of each rule is unique.

G. Output (Conclusion, D(k))

Weighted average method is used to obtain the conclusion of the input set. Calculation for the weighted average method is shown below.

Let $D(k)$ be the conclusion of the input set. $D(k)$ is given by:

$$D(k)=\sum_{r=1}^{32}\left(\frac{w_{r,k}}{\sum_{r=1}^{32} w_{r,k}}\right)p_r$$

where, $w_{r,k}$ is the weight of the r^{th} membership subset with input set k (i.e., input set corresponding to k^{th} driver) and p_r is the consequence corresponding to r^{th} membership subset.

IV. Computer Simulation of the Presented Model

To Study the variation of reaction time with age, intensity, experience, speed and distance of the stimulus a program in C language is written. The domain in which the premise variables are defined can be found from the membership functions. Ten values of each premise variable with same step size are selected. Since five premise variables are considered, combination of these selected values of the premise variables must be done. By applying combination 10^5 (= 10 × 10 × 10 × 10 × 10) sets of premise variables are obtained. These sets of premise variables are passed to the membership functions to obtain the membership value and the group to which they belong. Suitable programming is done to obtain the consequence. Using weighted average method the conclusion (Reaction time) of each input set is determined.

V. Results and Discussion

Variation of mean perception reaction time with age is shown in Fig. 4. The graph shows that age has an increasing effect on perception reaction time of drivers, which is as expected; because aged people generally develop physical and nervous weakness. On the contrary, experiences of driving, intensity of driving and speed have a decreasing effect on perception reaction time of drivers, which is as expected due to the following reasons. Very less experienced people cannot fully concentrate due to fear and their perception reaction time gets disturbed and becomes high and random. As their experience increases, the perception reaction time becomes less and stable. Similar explanation is for the effect of intensity of driving (up to a certain threshold value of intensity) due to reason that people, who travel very frequently are much more alert in comparison to those, who travel with a less intensity. Above the threshold value of intensity of driving the effect becomes reverse, i.e., increasing due the reason that excessive fatigue causes raised perception reaction time. Decreasing effect of speed is due to the fact that at higher speed one has to become much more alert, otherwise chances of accident will increase. Again, distance headway has an increasing effect on perception reaction time of drivers, which is as expected; because of the fact that while travelling at smaller distance headway one has to become much more alert, otherwise chances of collision will increase. Graphs corresponding to experiences of driving, intensity of driving, speed and distance headway are not presented here due to space constriction.

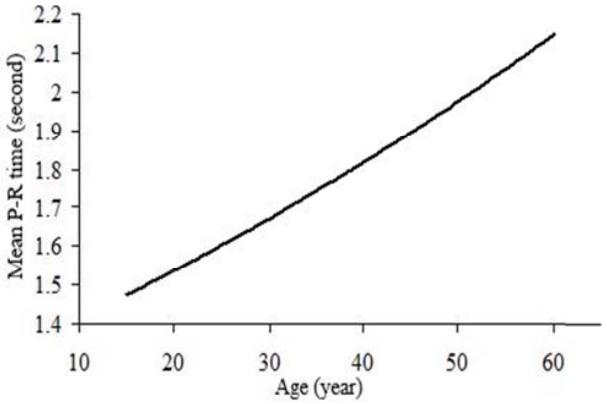

Fig. 4 Mean perception reaction time vs. age

VI. Conclusions

In this study it is tried to model how perception reaction time of drivers varies with different types of stimulus like age, experience of driving etc. Since, this perception reaction time is completely a human psychological process, modeling it by mathematical formula may produce random results. So, fuzzy logic has been used to model the vague and imprecise nature of human mind regarding perception reaction time. Result shows that above a certain age (around 15 years) mean perception reaction time of drivers increases with age. Result also shows that (not presented in this paper) mean perception reaction time of drivers decreases with experience of driving up to a certain extent (approximately 5 years of experience); after that it becomes asymptotic. Intensity of driving has a two-fold effect. Up to a threshold value (40 KM/day) perception reaction time with intensity of driving; beyond which it increases due to fatigue. Whereas, speed has a monotonous decreasing and distance of stimulus has a monotonous decreasing impact on perception reaction time.

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