MODELLING OF TRAFFIC CONSTABLE COMFORT LEVEL VARIATION IN NCR REGION BY FUZZY EXPERT SYSTEM

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Abstract –

During the last five years there had been a rapid change in the population of NCR (National Capital Region, Delhi). This has resulted a substantial change in the traffic density in the commercially developed cities. This traffic growth has made the noise level on the roads beyond the prescribed limits. This paper is an attempt for the measurements of noise levels, under traffic conditions over different time span in NCR zone, to estimate, whether these levels exceeds permissible levels, (65 dB (A)) prescribed by the Central Pollution Control Board, New Delhi, the variation in discomfort of road traffic Police constable was assessed by means of a questionnaire, to develop the relationship between road traffic noise levels and percentage of discomfort of road traffic Police constable using fuzzy expert system. The modelling technique is based on the concept of fuzzy expert system, which offers a convenient way of representing the relationships between the inputs and output of a system in the form of IF-THEN rules. Finally results revels that higher road traffic noise levels lead to the increase of discomfort of traffic Police constable.

Keywords: Road traffic noise, Traffic Police constable, Fuzzy logic, Discomfort, NCR (Delhi)

1. Introduction

Ergonomics (or human factors) is the scientific discipline concerned with understanding of the interactions among humans and other elements of a system. It is also concerned with the profession that applies theory, principles, data & methods to design, in order to optimize human well-being and overall system performance. People in systems operate within an environment and environmental ergonomics is concerned with how they interact with the environment from the perspective of ergonomics. Environmental ergonomics is provided in terms of the effects of heat and cold, vibration, noise and light on the health, comfort and performance of people [1].

The traffic volume was assessed in terms of Passenger Car Units (PCU). It is the scale to convert all vehicles into one category, i.e., passenger car. The PCU values for two wheelers, three wheelers, light commercial vehicles, buses, and heavy commercial vehicles are 0.75, 2, 2.5, 3 and 3, respectively [28].

Table1. Summarized mean noise level for each specified locations

Sr. No.	Locations	Measured value of noise levels(dB (A))			Volume of vehicle per hour (%)				Total no. of vehicles per hours
		L_{eq}	L_{min}	L_{max}	Two wheelers	Three wheelers	Light vehicle	Heavy vehicle	
a	Hapur more	89.1	71.1	91.5	7.74	4.95	58.82	29.721	4845
b	Old bus stand	100.3	74	102.2	26.13	5.57	55.75	12.54	4305
c	Chadhary more	84.5	72.9	88.3	21.6	8.9	48.87	20.63	4135.56
d	Hapur chungi more	96.3	76.4	101.7	28.8	7.54	52.34	11.32	3554.8
e	Delhi meerut more	87.9	72.7	96.8	18.75	6.76	51.8	22.69	4154.8

2. Noise pollution and human work efficiency

The effects of noise on human physical and mental performance can be considered as the effects on non-auditory task performance and effects on auditory task performance (e.g. interference with speech communication, etc.). The effects of noise on non-auditory task performance have been inconclusive, different studies indicating that noise reduces task performance, has no effect on task performance or increases task performance. Noise can interfere with auditory communication of information (speech, warning signals, etc.) and hence can decrease task performance. The human auditory system can detect signals within a background of noise. A practical approach to assessing the noise health & performance hazard is to use the index dB(A) L_{eq} Limiting values of around 85-90 dB(A) L_{eq} have been proposed for 8 hours exposure in industrial environments[3]. During the last four decades, there has been an exponential growth in noise level due to reasons like increase in population, increase in traffic density (both road and air), increase in industrial establishments and increase in the use of various noise producing devices on several occasions. This has necessitated the society to think of the overall effects of noise on humans. The prominent adverse effects of noise pollution on human beings include noise-induced hearing loss, reduction in work efficiency, annoyance responses, interference with communication, the effects on sleep and social behavior. The effects on work efficiency may have serious implications for road traffic constable and other occupations. In the past, many studies have been conducted to determine the effects of noise on human performance involving varieties of tasks. Simple routine tasks usually remain unaffected at noise levels as high as 115 dB (A) or above while more complex tasks are disrupted at much lower levels [4]. Noise causes brief periods of inefficiency when sustained visual attention (e.g., visual target detection) is required without decrement in the overall levels of performance [5].

Impulsive and continuous noise impairs the human performance in signal monitoring and tracking task. The effects of noise on human performance have also been investigated by researchers based on sex [6], laterality, age [7] and extrovert-introvert characteristics. However, these factors do not affect human performance significantly. Therefore, depending on the nature of the task, worker performance gets affected differently under the impact of different levels of noise, age and duration of exposure.

3. Fuzzy expert systems

It is a fact that most of the world's knowledge is uncertain and imprecise and hence the description of all real systems inherently contains incomplete and imprecise information. In order to deal with such situations, a fuzzy approach based on fuzzy sets (Zadeh [8]) is considered to be the most appropriate. The main paradigm of fuzzy rule based system is the fuzzy algorithm, the essential concepts of which are derived from fuzzy logic. It is basically an expert knowledge-based system that contains the fuzzy algorithm in a simple rule base. The knowledge encoded in the rule base is derived from human experience and intuition. The rules represent the relationships between the inputs and outputs of a system. Conceptually, a fuzzy rule-based system consists of five functional blocks as shown in Fig.1.

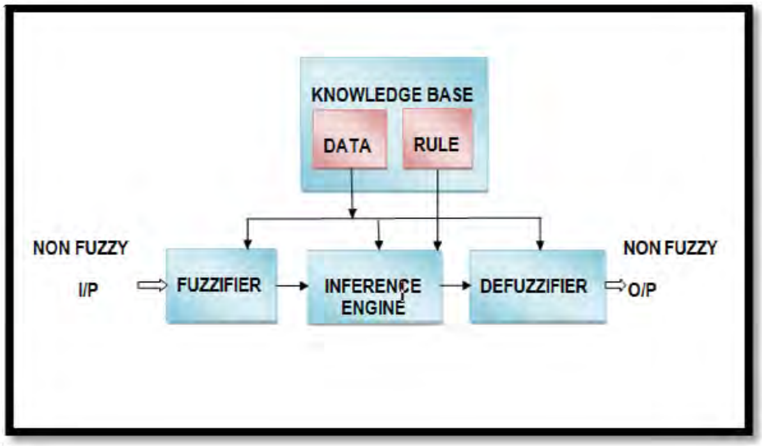

Fig.1.The structure of fuzzy expert systems

(i) ***A fuzzifier***, which converts real numbers of input into fuzzy sets. This functional unit essentially transforms the crisp inputs into a degree of match with linguistic values. Let X is the universe of discourse and x is a generic element of X. A fuzzy set A in a universe of discourse X is characterized by a membership function $\mu_A(x)$ which takes values in the interval I = [0, 1]. If there are m fuzzy sets associated with a given input x, then fuzzifier would produce m fuzzy sets as $A_1(x)$, $A_2(x)$,…..$A_m(x)$ with (m) membership functions $\mu_{Ai}(x)$, i= 1,2,……., m

(ii) ***A database (or dictionary),*** which contains the membership functions of fuzzy sets. The membership functions provide flexibility to the fuzzy sets in modeling commonly used linguistic expressions, such as: -''the noise level is low'' or ''the worker is young'' or "the exposure time is long" or type or "task is complex" etc.

(iii) ***A rule base,*** which consists of a set of linguistic statements of the form, if x is A then y is B, where A and B are labels of fuzzy sets on universes of discourse X and Y, respectively. These labels of fuzzy sets are characterized by appropriate membership function of database.

(iv) ***An inference engine,*** which performs the inference operations on the rules to infer the output by a fuzzy reasoning method. Zadeh [10] proposed the concept of possibility theory as the theoretical foundation for inference mechanism to deal with the uncertainty and imprecision in rule-based systems. The essential rationale behind fuzzy reasoning is the compositional rule of inference

(v) ***A defuzzifier***, which converts the fuzzy outputs obtained by inference engine into a non-fuzzy output z procedure used to derive conclusions from a set of fuzzy if-then rules and from one or more given conditions Zaheeruddin & Jain, [11].

The basic operations of fuzzy reasoning are: -

(i) To compare the input variables with the membership functions on the premise part to obtain the membership values of each linguistic label,

(ii) To combine the membership values on the premise part to get firing strength of each rule,

(iii) To generate the qualified consequent (either fuzzy or crisp) of each rule depending on the firing strength, and

(iv) To aggregate the qualified consequents to produce a crisp output.

Depending on the fuzzy reasoning and fuzzy IF-THEN rules employed, the two most popular fuzzy inference systems are Mamdani fuzzy model and Sugeno fuzzy model. Mamdani fuzzy model (Mamdani & Assilian, [12]) is based on the collections of IF-THEN rules with both fuzzy antecedent and consequent predicates. The advantage of this model is that the rule base is generally provided by an expert and hence to a certain degree it is transparent to interpretation and analysis. Because of its simplicity, Mamdani model is still most widely used technique for solving many real world problems. Sugeno fuzzy model (also known as TSK fuzzy model) was proposed by Sugeno and Kang (1988) and Takagi and Sugeno (1985) in an effort to develop a systematic approach to generate fuzzy rules from a given input-output data. These models are formed by IF-THEN rules that have a fuzzy antecedent part and functional consequent. Usually the consequent is a polynomial function of the input variables. When it is a first-order polynomial, the resulting fuzzy inference system is called a first-order Sugeno (or TSK) fuzzy model, which was originally proposed in Sugeno and Kang (1988), and Takagi and Sugeno (1985). When consequent is a constant, we then have a zero-order Sugeno (or TSK) fuzzy model, which can be viewed as a special case of Mamdani fuzzy inference system, in which each rule's consequent is specified by a fuzzy singleton. Generally, a single spike is used to represent this constant output, also known as a singleton output membership function. Essentially they are a combination of fuzzy and non-fuzzy models. The main advantage of this approach is its computational efficiency.

4. METHODOLOGY

The relationships between various noise-induced effects such as reduction in work efficiency, and input parameters like noise levels frequency, exposure time, type of task and age etc. can in general be represented by multi-inputs multi-outputs (MIMO) system. For the sake of simplicity, if one assumes the noise-induced effects (i.e. outputs) to be independent of each other, the problem of modelling the noise-induced effects reduces to that of a MISO system. The present model shown in Fig. 2 is one such system with noise level, exposure time and traffic density as the input parameters and comfort level of traffic constable as the output. This relationship between inputs and output can mathematically be expressed as:

$$V = f\,(P_1, P_2, P_3)$$

4.1 ALGORITHM

(i) Selection of the input and output variables;
(ii) Determination of the ranges of input and output variables;
(iii) Determination of the membership functions for Various input and output variables;
(iv) Formation of the set of linguistic rules that represent the relationships between the systems variables;
(v) Selection of the appropriate reasoning mechanism for the formalization of the fuzzy model;
(vi) Evaluation of the model adequacy; if the model does results, modify the rules in step 4.

STEP 1: INPUT AND OUTPUT VARIABLES (SYSTEM'S VARIABLES)

The first and most important step in modeling is the identification of system input and output variables. The relationship between them will specify the objective of the model. As shown in Fig. 4.1, the input variables are noise level, Exposure time, and Traffic density. The output variable is comfort level of traffic constable. In order to reduce the complexity of the system, other factors such as place (indoor or outdoor environment), vocal efforts, dialects, humidity, working temperature etc. have been ignored as the inclusion of more inputs adds to the number of rules manifold.

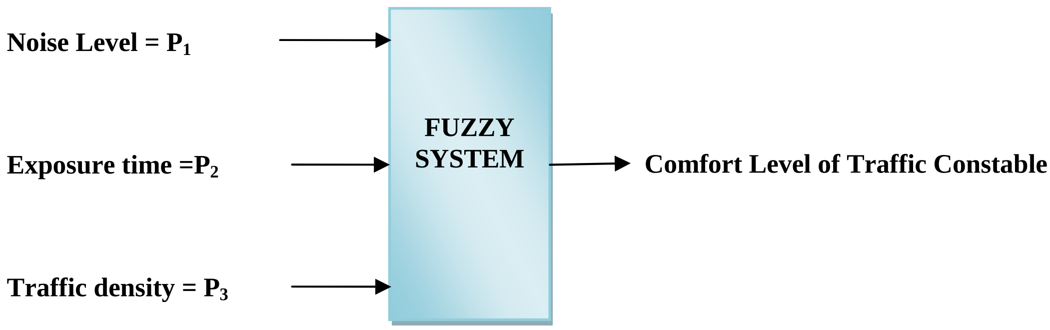

Fig.2. Inputs and output of the system

STEP 2: RANGES OF THE INPUT AND OUTPUT VARIABLES

The second step is to determine the ranges of the input and output variables. The concept of a linguistic variable plays an important role in the applications of fuzzy logic. These variables in fuzzy modelling are defined as linguistic variables whose linguistic values are words or sentences in a natural or synthetic language. A linguistic variable is a variable whose values are words or sentences in a natural or synthetic language. Input and output variables are defined in terms of linguistic values. Each linguistic term is defined by its interval or range. Table 2 shows the linguistic variables, their linguistic values, and associated fuzzy intervals.

Table.2. Inputs and output with their associated fuzzy values

S.N	System's variables	Linguistic variables	Linguistic values	Fuzzy intervals
a	INPUTS	Noise level	Low	55 -65 dB(A)
			Medium	60 -75 dB(A)
			High	70 -90 dB(A)
			Very high	85 -110 dB(A)
			Extremely high	90- 110
		Exposure time	Short	1-2 hours
			Medium	2-4 hours
			High	4-8 hours
		Traffic density	Light	500 -800 vehicle/hr
			Medium	800 -2000 vehicle/hr
			Heavy	1800 -5000 vehicle/hr
b	OUTPUTS	Comfort level	Worst	0-5 %
			Very poor	1-15 %
			Poor	10-25 %
			Acceptable	20-40 %
			Satisfactory	30-60 %
			Fair	50-80 %
			Very good	85-95 %
			Excellent	93-100 %

STEP 3: MEMBERSHIP FUNCTIONS OF THE VARIABLES

The next step is to express linguistic values in the form of fuzzy sets, which are represented by its membership functions. The appropriate choice of the membership functions for each input and output variable is a crucial step in the proper design of the fuzzy model because (1) it determines the complexity of the model, i.e. the number of rules and (2) the performance of the model, i.e. the accuracy of the model results. The membership functions are constructed from several basic functions such as piecewise linear functions, the Gaussian distribution function, the sigmoid curve, quadratic and cubic polynomial curves. The triangular membership function is the simplest one and is commonly used due to its computational efficiency. The membership functions for all inputs and output are shown in figures:

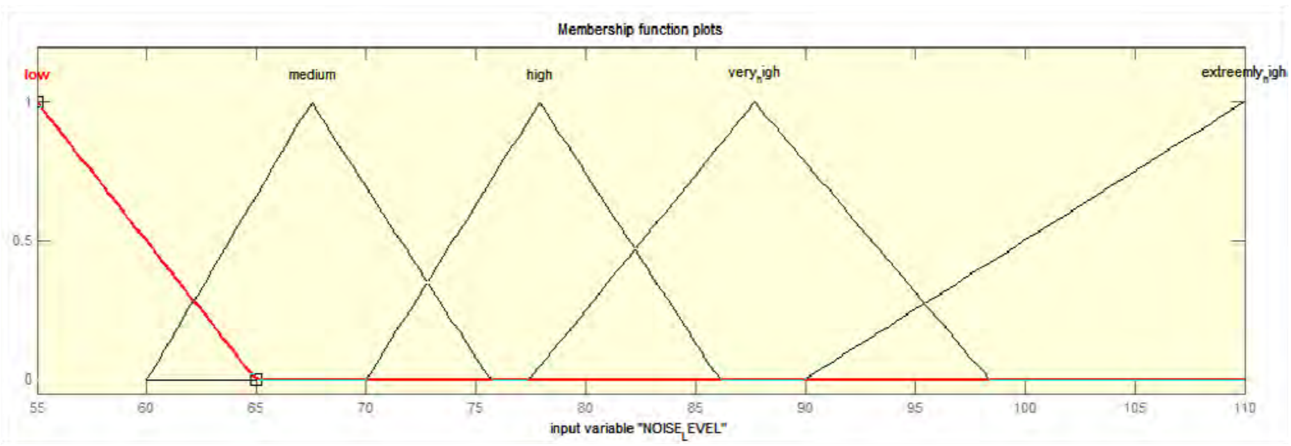

Fig.3 (a). Membership functions for noise level

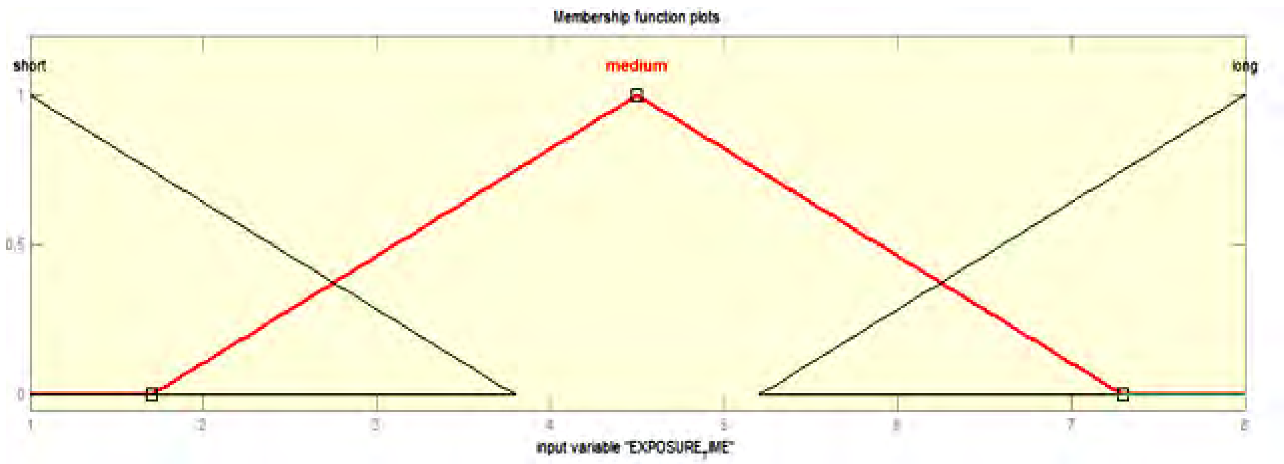

Fig. 3 (b). Membership function exposure time

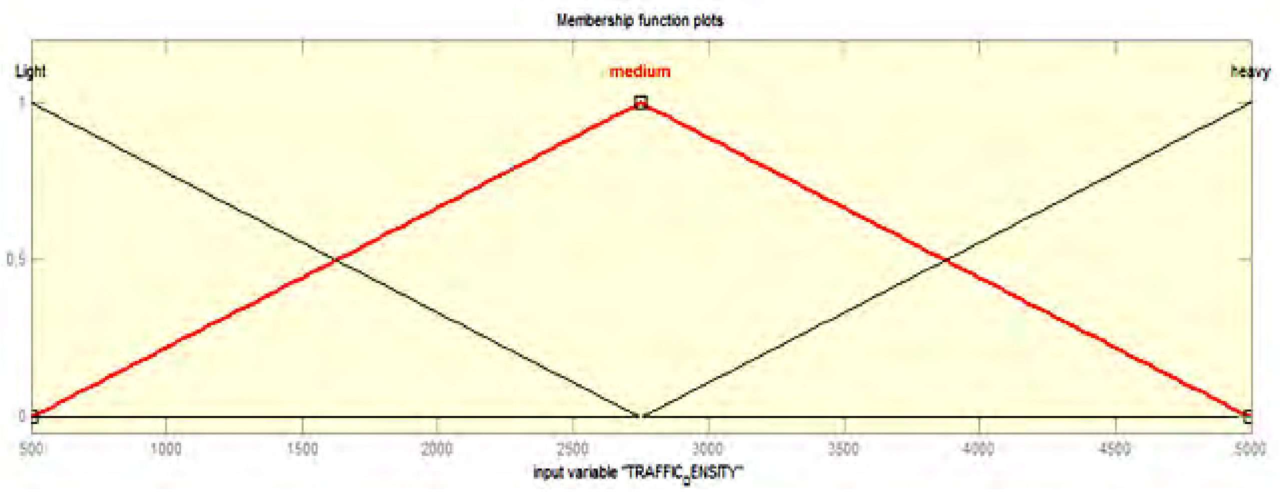

Fig. 3 (c). Membership function for Traffic density

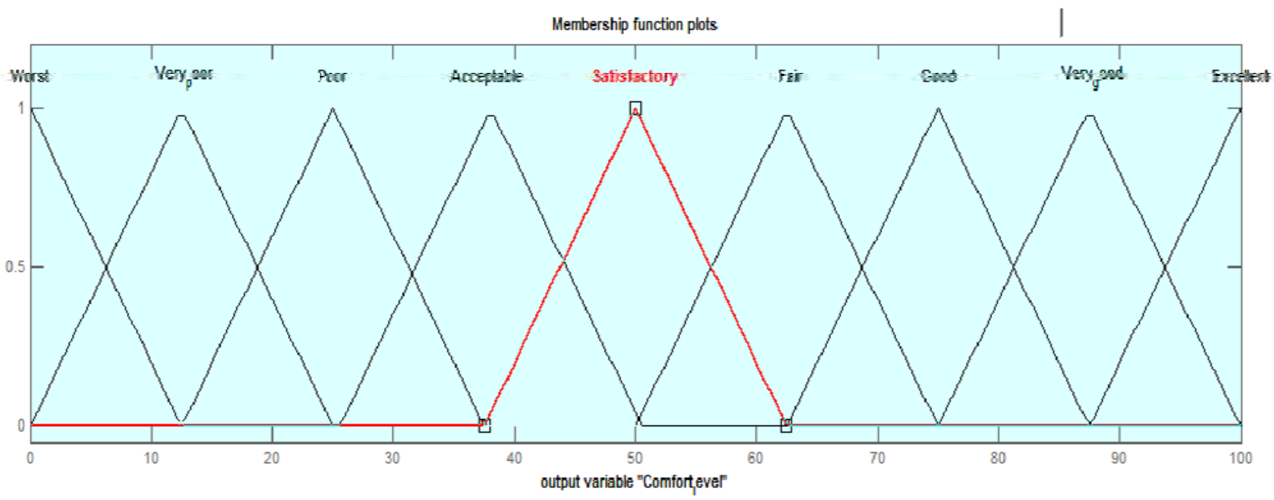

Fig. 3 (d). Membership functions for reduction in work efficiency

STEP 4: LINGUISTIC RULES

The relationships between inputs and output are represented in the form of IF-THEN rules. The knowledge base comprises a database and a rule base. Membership functions of the fuzzy sets are contained in the database. The rule base is a set of linguistic statements with antecedents and consequents respectively connected by AND operator. In general, a fuzzy rule-based system with multi-inputs single-output (MISO) can be represented in the following manner Timoth J.Ross [13]:

IF P_1 is B_{11} AND P_2 is B_{12} AND . . . AND Pr is
B1r THEN Y_1 is D_1
ALSO……………………………………………………...
……………..ALSO
IF P_1 is Bi_1 AND P_2 is Bi_2 AND . . . AND Pr is Bir THEN Ys is Ds,

Where P_1, P_2,……. Pr are the input variables and Y_1, Y_2, ……Ys are the output variables, Bij(i = 1,….., m, j = 1,……, r) and Di (i = 1,….., s) are fuzzy subsets of the universes of discourse U1, U2,…., Ur, and V_1, V_2,…….., Vs of P_1, P_2,……., P_r and Y_1, Y_2,. . ., Ys, respectively. The number of input variables and their associated membership functions determine the number of rules. For example in the present study, there are three inputs. The input data rules & output actions or consequences are generally fuzzy sets, expressed by means of appropriate membership functions defined on an approximate reasoning or interpolative reasoning and is commonly represented by the composition of the fuzzy relations that are formed by the IF-THEN rules. The number of membership functions associated with the first, second and third inputs are three, three, and three, respectively. This yields a total number of rules (4 X 3 X 3 X 3) equal to 108 for both fuzzy model (mamdami & Sugeno).

STEP 5: INFERENCE MECHANISM

The model employs both Mamdani and Assilian (1975) and Sugeno and Kang (1988) fuzzy inference methods. In Mamdani inference method, the membership functions of both the input and output variables are assumed to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. Sugeno-type inference technique, on the other hand, assumes the inputs to be fuzzy sets and the outputs to be constants. Generally, a single spike is used to represent this constant output, also known as a singleton output membership function and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required to find the centroid of a two-dimensional shape. Rather than integrating across a continuously varying two-dimensional shape to find the centroid, we can just find the weighted average of a few data points. As an illustration, two rules for each approach along-with their graphic representations have been given in Figures 4(a) and 4(b), respectively.

Rule: - If noise level is 'very high' & exposure time is 'short' & traffic density is light than reduction in comfort level is "satisfactory".

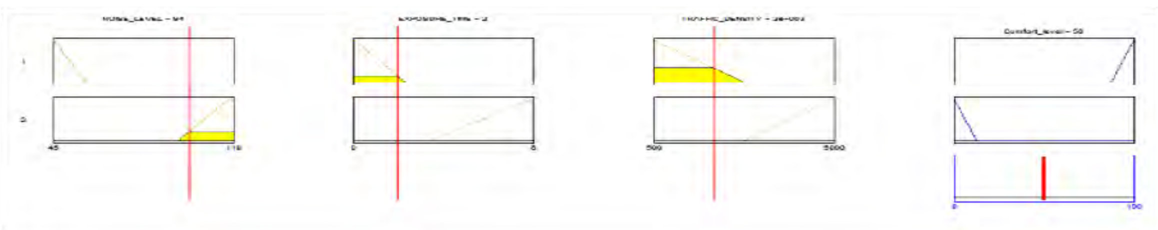

Fig. 4 (a). Typical rules and their graphic representations in Mamdani approach.

Rule: - If noise level is 'very high' & exposure time is 'long' and traffic density is heavy than comfort level is "worst".

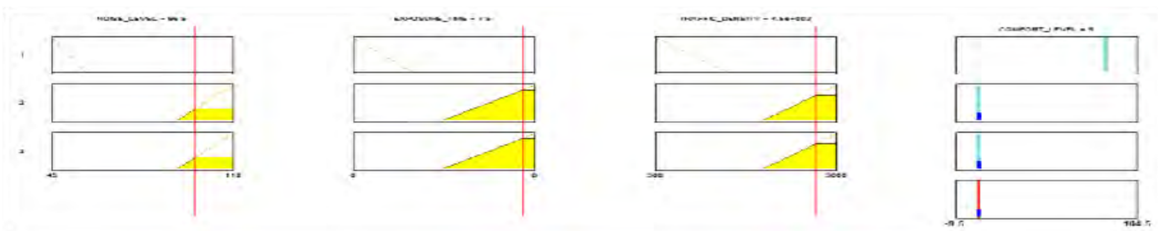

Fig. 4 (b). Typical rules and their graphic representations in Sugeno approach.

STEP 6: EVALUATION OF THE MODEL ADEQUACY

Finally, the model for speech interference expressed in the form of simple IF-THEN rules was implemented on Fuzzy Logic Toolbox of MATLAB (Logic Toolbox for use with MATLAB, 2007). In the initial phases, the developed model generally does not produce the desired results. Hence we have to modify the if-then rules in step 4. In turn, we modify the ranges of the related membership functions. This process is repeated till the desired results are obtained.

5. RESULT & DISCUSSION

The model designed using the IF-THEN rule has been implemented on the Fuzzy Logic Toolbox of MATLAB using both the Mamdani & Sugeno inference technique. The results can be represented either in three-dimensional or two-dimensional. Reduction in comfort level in the present model is considered to be a function of noise level, traffic density and exposure time. The model has been implemented using Mamdani & Sugeno inference techniques, which yield similar results.

Reduction in work efficiency in the present model has been computed as a function of noise level with exposure time, and the traffic density as input parameters. The results can be represented either in 3-D or 2-D plots. The surface representation in 3-D is not easily comprehensible while 2-D representation is more interpretable and understandable. For better visualization and interpretation, model results are summarized in graphical forms in Fig. 5 (a-b) shows the plots of reduction in comfort level (%) versus noise levels for different traffic density & exposure time of traffic constable at various locations in Ghaziabad.

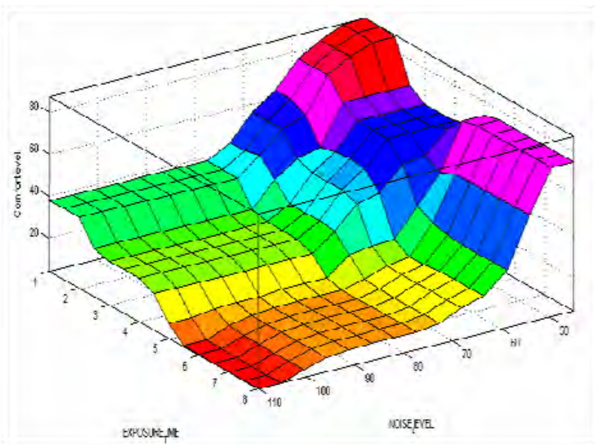

Fig. 5 (a). Output (Comfort Level) in the form of 3-D representations with Noise level & Exposure time

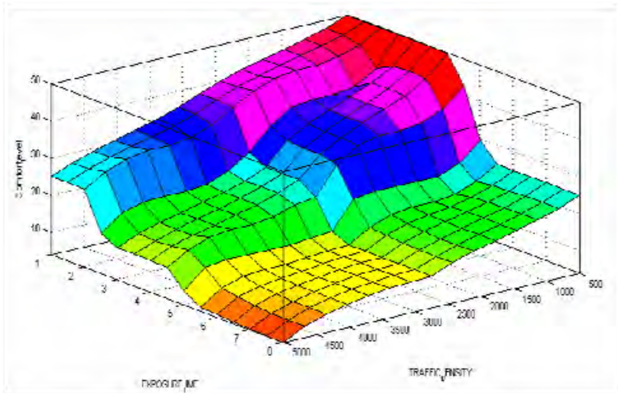

Fig. 5 (c). Output (Comfort Level) in the form of 3-D representations with Traffic density & Exposure time

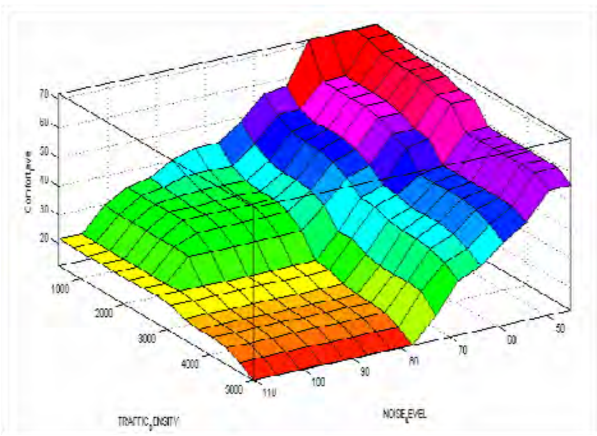

Fig. 5 (b). Output (Comfort Level) in the form of 3-D representations with Noise level & Traffic density

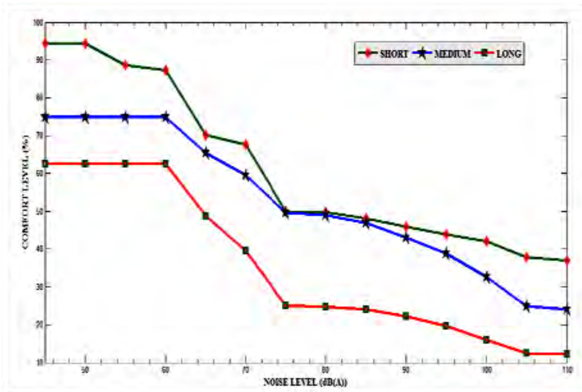

Fig. 6 (a). Reduction in comfort level for traffic constable at various exposure times & traffic density of 500 Vehicles/hr

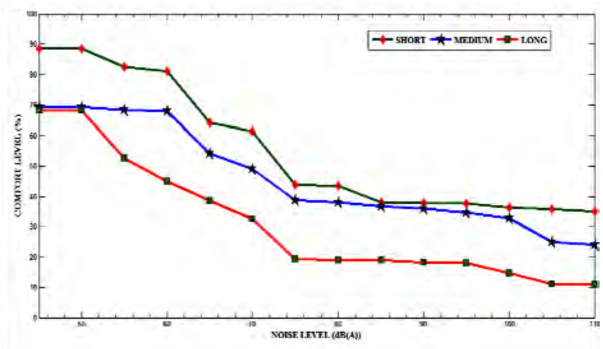

Fig .6 (b). Reduction in comfort level for traffic constable at various exposure times & traffic density of 1500 Vehicles/hr.

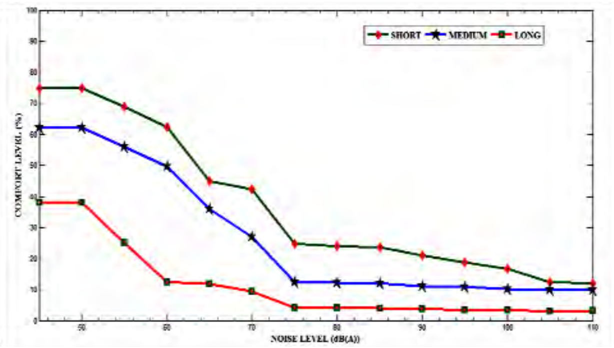

Fig. 6 (c). Reduction in comfort level for traffic constable at various exposure times & traffic density of 5000 Vehicles/hr

It is to be observed from Fig. 5(a) that the comfort level is ‘medium’ affected (45-50%) at ‘very high’ noise levels (90-100dB (A)) for traffic density of about 500 vehicles / hr & exposure time is ‘short’, ‘medium’ & ‘long’. It is also evident that the reduction in comfort level of traffic constable is gradual 55 – 65 dB (A).It is ‘very good (85%)’, ‘good (75%)’, and ‘fair (70%)’ at 60 dB (A) for ‘short’, ‘medium’, and ‘long’ exposure time, respectively. An increase of 5 dB (A) (i.e. at 70 dB (A)) changes its values to ‘good’, ‘fair’, and ‘satisfactory (50 %)’ for different traffic densities. A further increase of 5 dB (A) (i.e. at 70 dB (A)) reduces its values sharply to ‘fair’, ‘satisfactory’, and ‘acceptable (25 %)’, respectively.

However, Fig. 5(b) shows the reduction in comfort level is almost 70%, 90%, and 95% for traffic density 1500 vehicles/hr, respectively at very high noise level 90 dB(A) and above noise levels for ‘short’, ‘medium’ & ‘long’ exposure time. At 75 dB (A), it is ‘satisfactory’, for ‘short’, ‘acceptable’, for ‘medium’, and ‘poor’ (20 %)’ for ‘long’ exposure time, respectively.

Fig. 5(c) shows the reduction in comfort level versus noise level with traffic density 5000 vehicles/hr, The comfort level reduces to almost 80%, 90% & 95% at 100dB(A) noise levels for ‘short’, ‘medium’ and ‘long’ exposure time. In this case, appreciable deterioration in comfort level is observed for ‘short’, ‘medium’, and ‘long’ exposure time. For example, at 75 dB (A), comfort level is 25 %, 15 %, and 5 % for ‘short’, ‘medium’, and ‘long’ exposure time, respectively.

In order to validate the model, we have compared some of our model results with the deduction based on the criterion of Safe Exposure Limit recommended for industrial workers. The Recommended Exposure Limit (REL) for workers engaged in occupations such as engineering controls, administrative controls, and/or work practices is 80 dB(A) for 8 h duration [15]. There is almost no (0%) reduction in work efficiency when a person is exposed to the maximum permissible limit of 80 dB (A) for 8 hours and maximum (100%) reduction in work efficiency for a noise exposure of 95 -115 dB (A) for 8 h [16].

6. CONCLUSION

The main thrust of the present work has been to develop a fuzzy model for the predicting the comfort level on traffic constable as a function of noise level, Traffic density and exposure time at various selected locations of Ghaziabad regions. The model has been implemented on Fuzzy Logic Toolbox of MATLAB. The results obtained from the proposed model are in good agreement with the findings of field surveys conducted by various researchers and reports of International Standard Organization. These reports and surveys are generally available in the form of natural language description. Fuzzy logic is the most convenient framework to transform these natural language descriptions into a fuzzy rule based systems by means of simple IF-THAN rules. It is born out from the present study that for good performance of traffic constable at normal exposure time (‘short’ and ‘medium’) encountered in ambient environment, the noise level should not exceed 80dB(A) for traffic density of 500 and 1500 vehicles/hr. The present effort also establishes the usefulness of the fuzzy technique in studying the ergonomic environmental problems where the cause-effect relationships are inherently fuzzy in nature. Noise map as shown in figure 1.2 indicates that the selected locations are exposed to high level of noise pollution which is well above the safe limits prescribed by National and International standards (CPCB, EU and WHO).

Appendix A

Noise questionnaire for survey in fig.

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Appendix A

Noise level:-	[ ] dB (A)		Location: ……………………..
Temperature & Relative humidity:-	( ) ^{0} C,	( ) %	No of Vehicle/hr:-…………
Age:-	( ) Years		Avg. speed/hr:-……………...
Sex:-	( ) M/F		

S.N.	Questions	Answers/Options			
		A	B	C	D
1	Which one of hazards is the most important in your duty?	Air pollution	Noise pollution	Long term standing	Accidents
2	Which one of noise pollution source is the most important for you?	Traffic	Crowd	Car horns	Others
3	When you are most tensed?	Morning (6-11 am)	Afternoon (12-4 pm)	Evening (5-9 pm)	Both a & c
4	When are you most relaxed?	Morning (6-11 am)	Afternoon (12-4 pm)	Evening (5-9 pm)	Both a & c
5	When you feel most fatigue?	Morning (6-11 am)	Afternoon (12-4 pm)	Evening (5-9 pm)	Both a & c
6	When do you notice most traffic density?	Morning (6-11 am)	Afternoon (12-4 pm)	Evening (5-9 pm)	Both a & c
7	When you consider less traffic density?	Morning (6-11 am)	Afternoon (12-4 pm)	Evening (5-9 pm)	Both a & c
8	What is the type of task you do it in your work?	Manual	Monitoring	Control	Mental
9	If you have another task, what is the type of another one?	Manual	Monitoring	Control	Mental
10	Self-evaluate mood characteristics	Very Patient	Patient	Nervous	Very Nervous