2008-5435/11/32-49-55
INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE

IJOH 3: 49-55, 2011

ORIGINAL ARTICLE

Fuzzy Logic Method for Assessment of Noise Exposure Risk in an Industrial Workplace

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Received January 28, 2011; Revised May 3, 2011; Accepted May 26, 2011

This paper is available on-line at *http://ijoh.tums.ac.ir*

ABSTRACT

At present, conventional methods of noise exposure assessment utilize in industrial workplaces. In the classical area assessment method, noise exposure assessment depends on sound pressure level measurement results that expressed numerically and indicated harmful areas. This paper proposes an exposure assessment method of occupational noise based on Fuzzy sets. The noise assessment by Fuzzy logic method involves the primary investigation of the workplace, determined inputs and output variables, Fuzzification, Fuzzy rules, Fuzzy inference method and Defuzzification. This assessment method considered a function consists of Noise level, the number of exposed workers, exposure duration and noise reverberation time. Suggested method makes possible to evaluate unconsidered cases in order to assess of noise exposure risk. Fuzzy logic assessment results are more useful and flexible for analysis than conventional assessment. Fuzzy logic provides the opportunity to obtain risk model of noise exposure based on noise parameters, dimension of workplace and human perceptions.

Keywords: *Noise exposure, Fuzzy logic, Assessment method, Industrial workplace*

INTRODUCTION

Noise is defined as unwanted sound [1]. Noise pollution is one of the important issues of pollutant in workplaces and is almost one of the harmful agents for workers [2]. Most particularly, it can result in damage to the audio sensory mechanism and lead to premature and permanent loss of hearing [3]. For example, in Sweden 9% of the workforce exposed to hazardous noise level at workplace, and 100 million dollars paid for compensation (1992) [4].

Noise assessment in workplace has consequential and requires considering. The goal of assessment is to assess the workplace noise and to determine some effective variables in the workplace and compare to exposure limits. Today, conventional methods of environmental noise exposure assessment employ in industrial workplaces. In the classical area assessment method, noise exposure assessment depends on sound pressure level measurement results that expressed numerically and indicated only harmful areas [5].

The exposure limit of sound pressure level (SPL_{TWA}) in workplace in Iran, defined 85 dB (A) for 8 hours in a day and 44 hours per week [5]. This permitted level adopted as a criterion for judgment of the obtained results in the working environment. For example, the noise level 85.5 dB is determined as risk region, and noise level 84.5 dB considered as caution region, while it differs only 1 dB between these levels. This approach performed cheap and simply applicable to presents of noise pollution description. Those consider only noise level for assessment and ignore other essential aspects of risk variables such as; number of workers involved in the workplace, duration of noise exposure and acoustic

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Table1. Inputs and output variables with their associated Fuzzy values

System's variables	Number	Linguistic variables	Linguistic values	Fuzzy intervals
Inputs	1	Noise level	Low	<75
			Medium	72-85
			High	80-90
			Very high	85-95
			Extra high	>90
	2	The number of workers exposed in each($100m^2$)	Few (<4)	0-0. 4
			Average(2-7)	0.2-0.7
			Many(>6)	>0.6
	3	Duration of workers exposing in each shift (h)	Short	<3
			Average	2-6
			Long	>4
	4	Reverberation time (s)	Short	<1
			Average	0.5-2.5
			Long	>2
Output	5	Noise risk assessment	Extremely Low	0-0.1
			Extra Low	0.05-0.15
			Very Low	0.1-0.25
			Small Low	0.2-0.35
			Low	0.3-0.45
			A Little High	0.4-0.55
			Medium Low	0.5-0.6
			Medium	0.55-0.7
			Medium High	0.65-0.75
			High	0.7-0.8
			Very High	0.75-0.9
			Extra High	0.85-0.95
			Extremely High	0.9-1

properties. Consequently, that needs a pervasive method for noise assessment in workplaces that take consideration of some variables that effect on noise pollution.

Fuzzy logic theory emerged during the twentieth century and predicted to apply extensively in many fields [6]. During the past two decades, Fuzzy logic has successfully applied to many real world problems in various branches of science and engineering [7]. Today, this method is highly accepted in industrial applications; it has considered applications on the ergonomic aspects such as noise control and illumination [3]. In the Classical Crisp theory clearly determined whether an item belongs to the set (one) or not (zero) [8]. That is not always sure which things were true and false, but that is sure all of things that either true or false [9]. A Fuzzy set is a class of objects with a continuum of grades of membership. Membership grades each object exist between zero and one [10]. This theory is introduced as a standard tool for dealing with systems that are too complex or too ill defined to be susceptible to analysis by conventional techniques [11]. Fuzzy set techniques provide a methodology for computing with words, which mimics human reasoning [12]. This logic assessment is flexible and provides many assessment options, while the classical method adheres to constant mathematical calculation [6].

The purpose of this paper is to determine risk assessment of noise exposure using an adjusted pervasive method instead of conventional method. In order to reveal the proposed method in this paper, assessment of occupational noise exposure risk consist of essential measurements and calculations of room acoustic properties and number of workers involved in an industrial glass factory in Hamadan (west of Iran) to carry out a field study.

MATERIALS AND METHODS

Application of Fuzzy method comprised in three stages:

1. Fuzzification (input and output variables).

2. Fuzzy rules, Fuzzy inference methods.
3. Defuzzification ;(converts the Fuzzy number to crisp value by Center of Area technique) [13].

For risk assessment of noise exposure by Fuzzy logic method, measurements of noise variables Including noise level, number of workers and reverberation time were considered. The main steps taken in the design of the present Fuzzy method explained by the following structure [7, 14, 15]:

1. Identification of the input and output variables (the system's variables).
2. Determination of the ranges of input and output variables.
3. Determination of the membership functions for selected input and output variables.
4. Formation of the set of linguistic rules that represent the relationships between the system variables.
5. Selection of the appropriate reasoning mechanism to the formalization of the Fuzzy model (Mamdani inference technique).
6. Defuzzification.

The number of input variables and their associated membership functions determine the number of rules [3]. This rule table can reflect experiences of the human experts [7]. Each rule reflects a non-linear relationship between independent variables (inputs) and dependent variables (outputs) of the process or system under consideration. All rules together define a linguistic model [3]. The correlation among two inputs and one output graphically represented with a specific 3D shape - assessment surface by Matlab software [16]. In this study reverberation time was estimated by the common equation (T(s) =0.16V/A) [5].

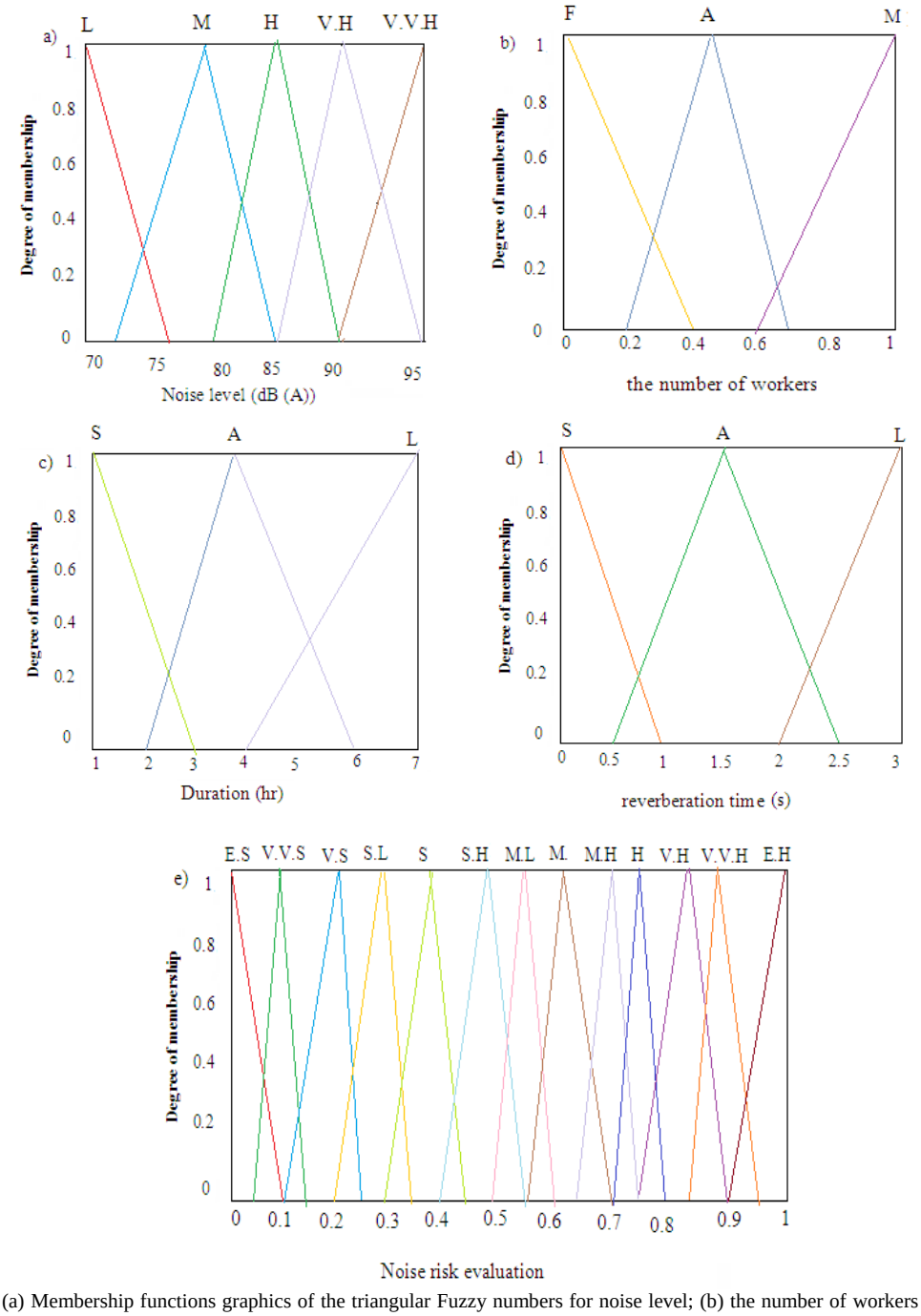

Fig 1 (a-e). (a) Membership functions graphics of the triangular Fuzzy numbers for noise level; (b) the number of workers exposing in each shift (c) duration of exposed; (d)) reverberation time; e) membership functions for noise risk assessment.

Table 2. Sets of If-Then rules

	IF				THEN
Rules	Noise level	Number of workers	Reverberation time	Duration	Risk assessment
1	Low	Few	Short	Short	Extremely low Risk
2	Low	Few	Short	Average	Extra low risk
3	Low	Few	Short	Long	Very low risk
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.					
21	Low	Many	Short	Long	Small low risk
22	Low	Many	Average	Short	Very low risk
23	Low	Many	Long	Short	Small low risk
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33	Medium	Few	Average	Long	Small high risk
34	Medium	Few	Long	Short	low risk
66	High	Average	Short	Long	High risk
67	High	Average	Average	Short	Medium high risk
68	High	Average	Average	Average	High risk
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73	High	Many	Short	Short	Medium risk
74	High	Many	Short	Average	Medium high risk
75	High	Many	Short	Long	High risk
76	High	Many	Average	Short	Medium high risk
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132	Very Very High	Many	Average	Long	Extremely high risk
133	Very Very High	Many	Long	Short	Very high risk
134	Very Very High	Many	Long	Average	Extra high risk
135	Very Very High	Many	Long	Long	Extremely high risk

RESULTS

Noise assessment results by means of Fuzzy method presented in this section. In the first stage of this method, the system's variables, inputs, and output were determined. According experts view went through questionnaire and Delphi method. It is characterized the effective principal factors on the assessment. Finally, four inputs and an output were selected. As revealed in Table 1, the input variables were noise level, the number of workers exposed, duration, reverberation time and the output variable is risk assessment of noise exposure.

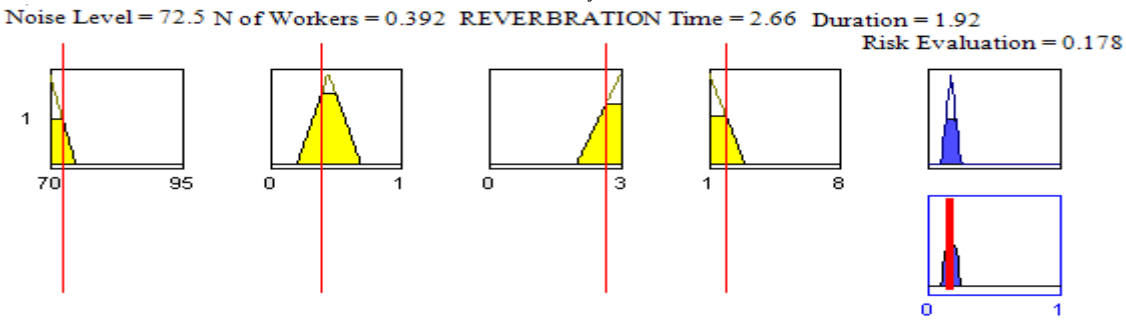
The second step was to determine linguistic values of system variables (inputs and output) in the form of words and natural language. Then Fuzzy intervals of the input and output variable characterize. According experts poll by using Fuzzy Delphi method and based on obtained data of the measurement and calculation in the workplace, their membership function and other parameters obtained. The linguistic variables, their linguistic values and related Fuzzy intervals illustrates in Table 1. The triangular membership functions for all inputs and output revealed in Figure 1(a-e).

After determining variables and their membership function, the next step was to create the rules of "if - then". The rules collected based on views of noise engineering experts. In this study, there were four inputs contain of; noise level, the number of workers exposed in each $100m^2$, duration of workers exposing in each shift and estimated reverberation time [5]. Total number of rules obtained by multiply inputs membership functions is equal 135 rules. A set of rules showed in Table 2. Two rules based on Mamdani inference approach with their graphic representations have represented in Figure 2(a-b). The risk assessment results by using Matlab software summarized in 3-D plots in Figure 3(a-d). These figures show the effects of the inputs to the output.

DISCUSSION

In the classical area assessment method, noise exposure assessment depends on sound pressure level measurement results that expressed numerically and indicated only harmful areas. One of the disadvantages of using conventional approaches is that only one parameter (noise level) interpreted for determined noise exposure risk region. To overcome the problems of the

a) Rule: IF noise level is low, AND number of workers is few, AND exposed duration is short AND reverberation time is long THEN risk assessment is very small risk



b) Rule: IF noise level is high, AND number of workers is average, AND exposed duration is long AND reverberation time is average THEN risk assessment is high risk

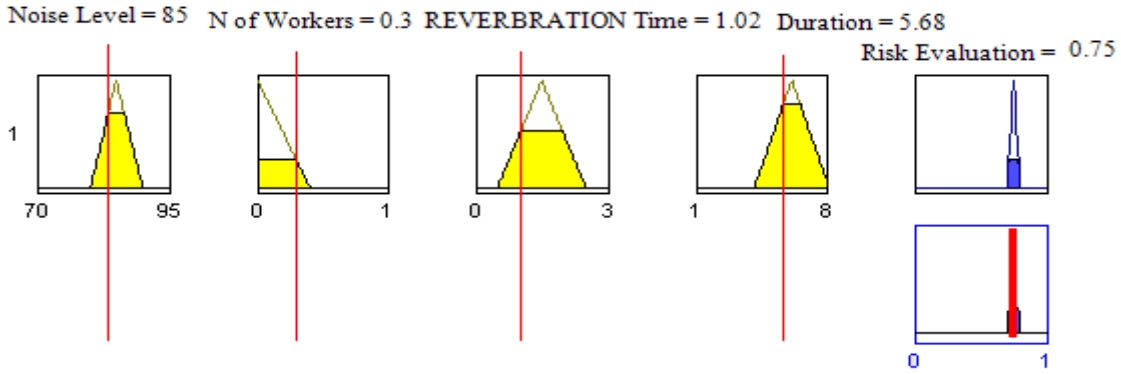


Fig 2 (a-b). IF-THEN rules and their graphic representations in Mamdani inference approach

traditional approach, Fuzzy method has broadly used in risk assessment which uses Fuzzy linguistic terms to describe the variables of system. In practice, decision should been taken about variables which have not been considered in conventional evaluating. Fuzzy logic makes possible for experts to estimate unconsidered cases in order to noise risk assessment. Fuzzy logic provides the opportunity to model physical and technical parameters with human opinions. Risk assessment of noise exposure (output variable) calculated to a function of the noise level, the number of workers exposing in each shift, duration of exposure in 100 square meter and reverberation time. 3-D plots (Figure 3) shows noise risk assessment as a function of noise level and number of workers whereas two other inputs not considers. In addition, Other Figure showed noise risk assessment as a function of two inputs workers whereas two other inputs not considers.

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 [7]. Benetto (2006) used Fuzzy-Sets Approach to Noise Impact Assessment [8]. The obtained results showed the use of Fuzzy intervals and numbers in comparison with Crisp number present more exact analysis, which is somewhat verifier of present research. Peng (2007) assessed the traffic noise impact based on probabilistic with Fuzzy approach. The obtained results showed Fuzzy set and Fuzzy relation applied to identify the predicted noise impacts in qualitatively and quantitatively [17]. The results of this study showed the Fuzzy method could use as an effective method in evaluating of noise exposure risk with consideration of qualitative and quantitative variables. In conventional method, only noise level (Quantity variable) used for assessment. In fact, evaluation of the noise risk exposure of the industrial workplace can be affected by several variables Such as the number of the workers (quality variable), reverberation time (Quantity variable). Fuzzy logic provides an effective way to consider Quantity and quality variables and helps to make a perfect evaluation.

This paper presents a method of fuzzy logic for the risk assessment of noise exposure in industrial workplace. The obtained results used to assist professional health experts with recognition of the critical regions to priority and control. These results demonstrate that the fuzzy logic is a useful method for assessing and not enforced to evaluate with a crisp number.

The use of the fuzzy logic needs excellent expert knowledge about the assessment and the situations of the industrial workplace. Expert views aimed to find out the input variables that affect output variable, using fuzzy Delphi method, and give a perfect evaluation in order to help health experts to determine the critical areas as well as their importance. The importance issue is to allocate the company's budget to the critical

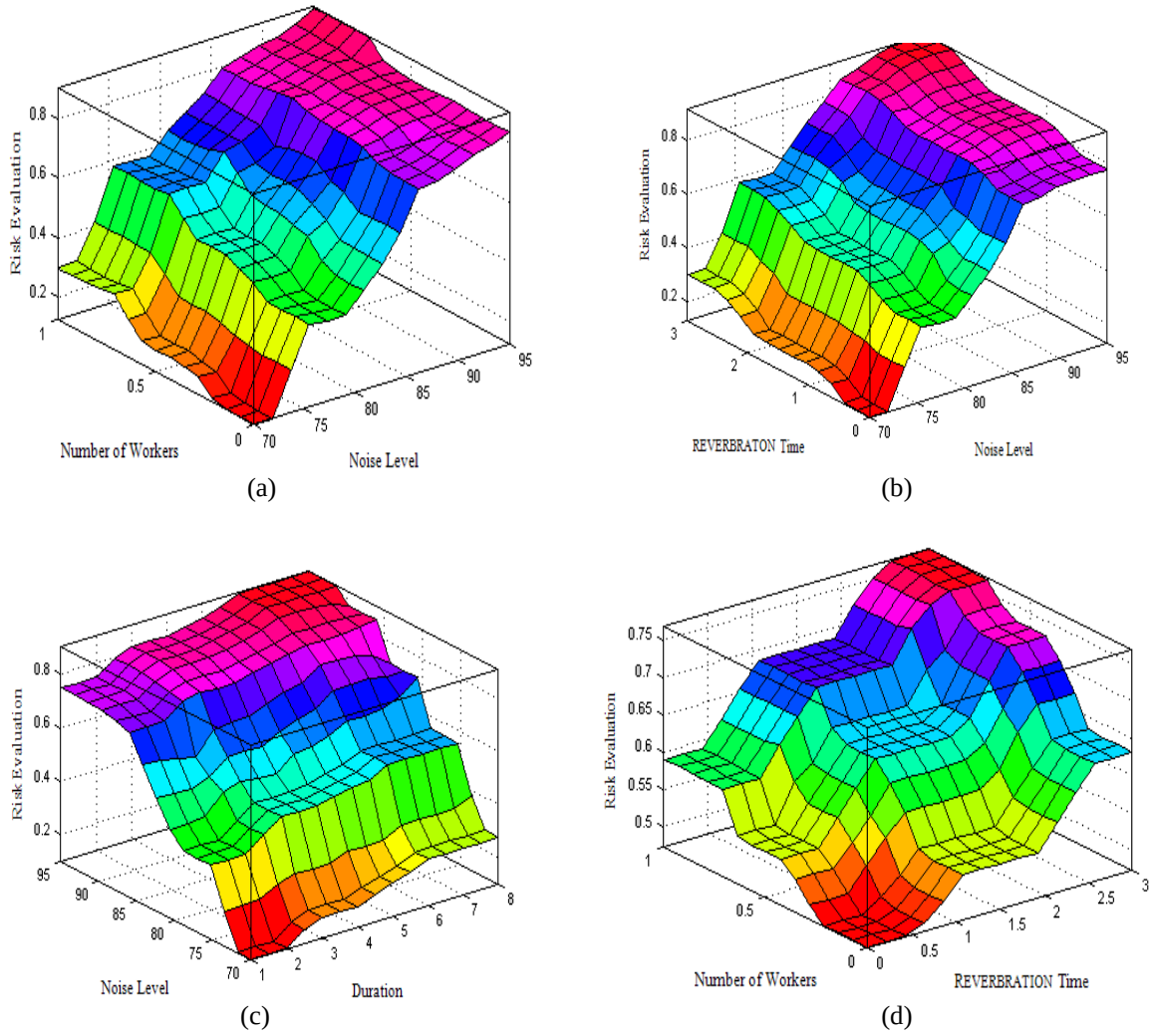


Fig 3 (a-d). Output (noise risk assessment) in the form of 3-D illustration with noise level and number of workers (a); noise level and reverberation time (b); duration ad noise level (c); reverberation time and number of workers (d) as the inputs.

sections so fuzzy is used to priority for helps in the judgments made.

CONCLUSION

Our current work is focusing on risk assessment of noise exposure based on fuzzy logic. It is believed that the Fuzzy method assist to obtain a clear and integrated approach to risk assessment of noise exposure. In future studies, expect to reach a more logical and real judgment with applying more comprehensive inputs which consider all noise assessment aspects. It suggests that with applying new method such as neural networks and fuzzy neural networks increase the ability of explaining and the reality of the assessment.

ACKNOWLEDGEMENTS

The authors declare that there is no conflict of interests.

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