Application of Fuzzy Theory to Radiological Emergency Preparedness

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1. Introduction

Emergency preparedness for nuclear facility is considered as an important part for public health and safety. In an emergency, it is not easy to get the information which is needed for the operation of an emergency system. Even though the lack of the information, decision-maker should make an early decision for the public. And the real situation is often not crisp and deterministic.

The concept of fuzzy set provides the mathematical formulations which can characterize the uncertain variables in the models related to radiological emergency preparedness. And it provides a method which can describe the characteristics of uncertain variables represented by the fuzzy membership functions, and the effects of distribution can be handled with the fuzzy relation and the fuzzy reasoning. By the application of linguistic variables and fuzzy algorithms, it is possible to provide an approximate and effective tool to describe the system which is too complex or ill defined to use precise mathematical analysis [1].

2. Methods

2.1. Fuzzy Reasoning

Inference engine of a fuzzy system operates on a series of statements known as production rules, which connect antecedents with consequences, premises with conclusions, or conditions with actions [2]. The relationship between input variables and output variables can be represented by "if – then" rule which must be determined by experts with a full understanding of a real phenomenon [3,4]. Fuzzy relations are fuzzy subsets of A x B, that is, mappings from A → B. If there is a relationship between A and B, it can be represented by the ordered pair (x, y). Here x and y are the elements of fuzzy set A and B, respectively.

$$(x,y) \in R \quad \text{or} \quad x\,R\,y \tag{1}$$
$$\mu_R \,|A \times B \rightarrow [0,1] \tag{2}$$

The membership grade μ_R means the strength of relation, and it is a useful measure for representing our knowledge.

2.2. Gaussian Plume Model

The spatial concentration distribution on the surface is given as follows:

$$C_{(x,y,0)} = \frac{Q}{\pi u \sigma_y \sigma_z} \exp(-\frac{y^2}{2\sigma_y{}^2}) \exp(-\frac{h^2}{2\sigma_z{}^2}) \tag{3}$$

where Q is the source rate, u is the wind speed, h is the release height and σ_y and σ_z are the horizontal and vertical standard deviations at a downwind distance x, respectively. The amount of mixing affected by the weather conditions is empirically classified into six atmospheric stability classes. Atmospheric stability can be categorized by the measured data of wind speed and solar radiation, and it might results in the occurrence of uncertainty. In this study, fuzzy membership functions have been applied for the categorization of atmospheric stability.

2.3. Estimation of Evacuation Time

The effect of protective actions may be dependent on the site-specific conditions such as population density, road conditions and the characteristics of the behavior of the residents. The variables representing these conditions have a wide distribution of values due to the complexity of real situation in emergency. Representative values of these variables are used in most existing countermeasure models for simplicity and tractability. The variables related to evacuation such as population density, local jurisdictions were represented by fuzzy membership functions.

3. Results and Discussions

3.1. Gaussian Plume Model

For the representation of fuzzy membership functions, wind speed was transformed linearly by the Eq. (4) with the maximum value of 1 and the minimum value of 0,

$$Z = (Z - Z_{min}) / (Z_{max} - Z_{min}) \tag{4}$$

where Z_{max} and Z_{min} represent the maximum and the minimum wind speed, respectively. Figure 1 shows the membership functions for wind speed. Table 1 represents the fuzzy rule based on stability classes which was used in fuzzy reasoning. And the membership of the stability was constructed by Gaussian shaped function as shown in Figure 2.

Figure 3 shows the process of defuzzification by the method of center of area for the case of the low wind speed and moderate solar radiation. The figure shows that the output of stability is 0.605 which is near to the maximum value of B class as shown in figure 2. The developed method was applied to the estimation of the

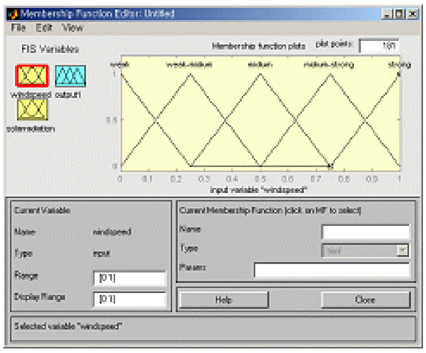

Fig.1. Membership function for wind speed.

concentration by Gaussian plume model. For the application study, the conditions of 68 meter of release height, 3.0E+11Bq/sec of release rate, 2.0±0.2m/sec of wind speed and slight/moderate solar radiation were assumed. The concentration was calculated at 500m down wind distance. The defuzzified result of atmospheric stability was 0.605, between the stability class B and C in Figure 2. This value is more close to B than C. Authors gave weighting 80% to B and 20% to C to reduce the uncertainty in the process of discontinuous classification of stability. The developed method results in the concentration of 4.19E+6Bq/m^3 by weighting the value of 4.53E+6 Bq/m^3 the case of B and 2.84E+6 Bq/m^3 in the case of C.

Table 1.Fuzzy knowledge base for inferring stability class.

Wind speed	Solar radiation	Stability class
low	strong	A
”	moderate	B
”	slight	B
low/moderate	strong	A
”	moderate	B
”	slight	C
moderate	strong	B
”	moderate	B
”	slight	C
moderate/fast	strong	C
”	moderate	C
”	slight	D
fast	strong	C
”	moderate	D
”	slight	D

3.2. Estimation of Evacuation Time

Fuzzy knowledge base for the estimation is shown in Table 2. The developed method was applied to Uljin

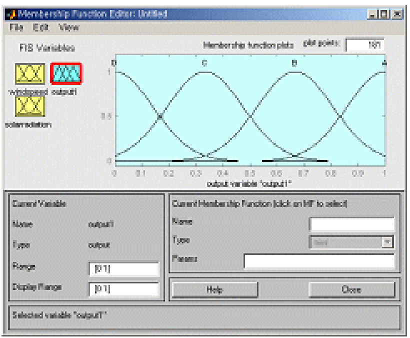

Fig.2. Membership function for stability class.

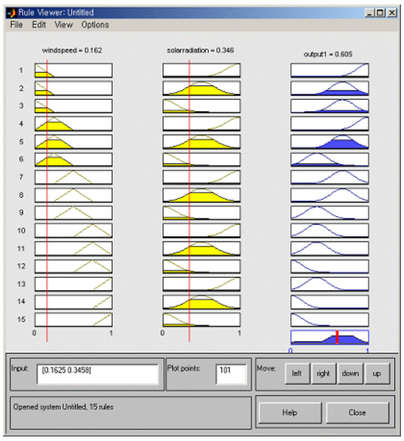

Fig. 3. Defuzzification Process

Table 2. Fuzzy knowledge base for inferring required evacuation time

Population density	Road condition	Evacuation time
Low	-	Short
Medium	-	Medium
High	-	Long
-	Bad	Long
-	Medium	Medium
	Good	Short

site. And the results show that the developed method could estimate the evacuation time which is similar to the results of the existing study [5].

3. Conclusion

In this study, fuzzy theory was applied to radiological emergency preparedness. The obtained results show that the potential applicability of fuzzy theory to describe uncertain variables related to radiological emergency preparedness. The main advantage of the proposed method is that it can reflect the effect of related variables in a continuous manner and the opinions of experts. Therefore, the loss of information due to the process of assumption might be minimized.

REFERENCES

[1] L.A. Zadeh, Outline of a New approach to the analysis of complex systems and decision process, IEEE Transactions on Systems, Man, and Cybernetics, SMC-3, pp.28-44, 1973.

[2] G.J. Klir and T.A. Folger, Fuzzy sets, uncertainty, and information, Prentice-Hall Inc., 1988.

[3] C.V. Negoita and D. Ralescu, Simulation, Knowledge-based computing, and fuzzy statistics, Van Nostrand Reinhold, New York, 1987.

[4] A. Kaufmann and M.M. Gupta, Fuzzy mathematical models in engineering and management science, North-Holland co., Amsterdam, 1988.

[5] I.G. Jeon and J.K. Lee. Prediction of evacuation time for emergency planning zone of Uljin nuclear site, Jr. of Korea Association of Radiation Protection, 27. pp. 89-198, 2002.