Fuzzy Aggregation Approach for Estimating Severe Accident Phenomenon Probability

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1. Introduction

The purpose of this research is to apply fuzzy aggregation technique for estimating severe accident phenomenon probability.

Severe accident phenomena in nuclear power plants (NPPs) have large uncertainties because of the lacks of the experience and difficulties of the experiments, so U.S.NRC performed expert elicitation method to obtain the severe accident probability used in the Level 2 PSA. This value has been still used worldwide. However, knowledge on severe accident phenomena is likely to show a significant difference compared to the results from the past results. In addition, the severe accident probability from U.S.NRC research results may not suitable in case of Korea NPPs. Thus, a need of new values of severe accident phenomenon probability has been identified.

As the understanding of severe accident phenomenon deepens and experts in Republic of Korea (ROK) increase, the demand of a new revision probability is growing. This study conducted surveys of experts in severe accident in ROK using Delphi's technique. Based on the collected data, this paper applied a fuzzy aggregation method to derive the opinions of various experts into a consensus one.

Conventional mathematical ways cannot handle natural linguistic expression efficiently because of its vagueness. However, fuzzy approach is useful to solve fuzzy phenomena that exist in real world situations such as uncertain, unspecific and subjective evaluation situation as it is capable of measuring the concept of ambiguity associated with subjective human judgment. Fuzzy elicitation methods act as initiators to make decisions in the presence of complete and accurate information.

2. Data collection

A panel size of 26 was selected from different fields, such as research or academic institute, regulatory body, operation and management of nuclear power plant, to judge the probability of severe accident phenomenon. Due to the depth of knowledge by experts, a basic status of expert is considered as weighing factor. The expert status to be evaluated includes the professional characteristics and track record of the person, the qualifications, and experience [1].

A literature [2] suggested that determining whether expert judgment can be better elicited in a probabilistic or fuzzy framework. Since severe accident phenomenon is too complex to be reasonably described in conventional quantitative expressions, investigators asked linguistic expression of answer to the experts. However, there is uncertainty of linguistic imprecision or vagueness called fuzzy uncertainty [3]. The vagueness connected with linguistic terms which were 'Certain (C)', 'Highly Likely (HL)', 'Very Likely (VL)', 'Likely (L)', 'Fully Possible (FP)', 'Unlikely (U)', 'Very Unlikely(VU)', 'Highly Unlikely (HU)', and Impossible (I) in this study. It is treated with fuzzy quantifiers.

Chen [4] proposed a numerical approximation system (called as the fuzzy quantifiers) to systematically convert linguistic terms to their corresponding fuzzy numbers. A linguistic value can be represented by approximate reasoning of fuzzy number. In this paper, the Chen conversion Scale 8 was used to represent assessment of the experts shown in Fig. 1.
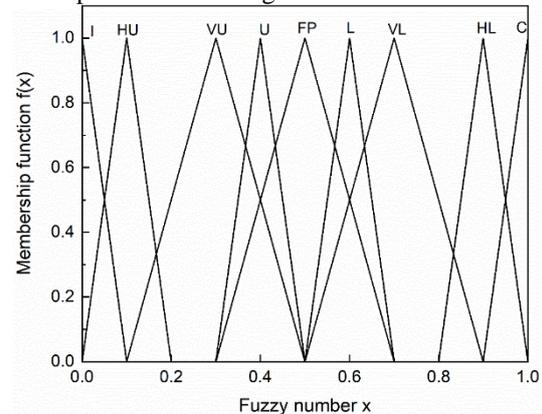
Fig. 1. Schematics of fuzzy number membership function

3. Fuzzy Aggregation

The fuzzy aggregation is the process of consensus of expert opinion. Due to different opinion of probability of each severe accident phenomenon, it is necessary to combine the opinion into a single one. A typical approach is the linear opinion pool [5]:

$$M_i = \sum_{i=0}^{m} w_j A_{ij} \quad j = 1,2,\ldots,n \text{ (1)}$$

Where A_{ij} is the linguistic expression of a basic event i given by expert j. m is the number of basic event. n is the number of experts, w_j is a weighting factor of the expert j and M_i indicated the aggregated fuzzy value of the basic event i.

Using α-cut of different membership functions of Eq(1), the corresponding membership function of above fuzzy number f(x) in question 1-1 could be obtained as:

$$\mu_N(x) = \begin{cases} \dfrac{x - 0.22}{0.15}, & 0.22 \leq x < 0.37 \\ \dfrac{0.52 - x}{0.15}, & 0.37 \leq x < 0.52 \\ 0, & otherwise \end{cases} \quad \ldots(2).$$
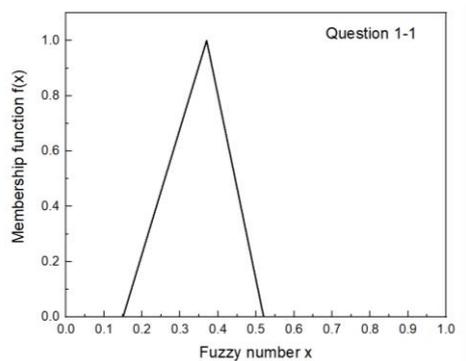
Fig. 2 Result of fuzzy aggregation in question 1-1.

4. Defuzzification

Defuzzification extracts a precise value of the range of fuzzy set to the output variable. This paper used Center of Sum(CoS) which is the one of the most popular defuzzification methods and is simply explained as calculating the center of area under the curve.

If the output fuzzy set $C = C_1 \cup C_2 \cup \ldots C_n$, then mathematically, this CoS [6] can be express as:

$$CoS = \frac{\sum_{i=1}^{n} x_i A_{C_i}}{\sum_{i=1}^{n} A_{C_i}} \quad \ldots (3)$$

Here, A_{C_i} denotes the area of the region bounded by the fuzzy set is C_i and x_i is the geometric center of the area A_{C_i}.

Table 1 indicates the fuzzy aggregation value after the defuzzification process. It also compared to an original value which currently used in Level 2. Question 1-1 is involved in reactor coolant system (RCS) failure. The question is: if RCS pressure is high and status of in-cavity injection is flooded, mode of induced primary system failure is no RCS failure.

The result is a little similar but a percentage change is -22%. It may explain as 1) improving the knowledge of severe accident phenomenon, 2) reliability of existing OPR1000 data, and 3) including biases due to subjective expert judgement.

Table 1. Comparison between original and fuzzy aggregation values.

	Question 1-1
Original value (Current Level 2)	0.48
Fuzzy aggregation value	0.37

A percentage change	-22%

5. Conclusion

This paper applied fuzzy aggregation and centroid defuzzification techniques into estimating the severe accident phenomenon probability. The result itself can bring much controversy. However, it is still meaningful that the probability of severe accident phenomenon was derived based on knowledge of serious accidents accumulated over 30 to 40 years by a network of Korean experts.

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