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Quantifying the Likelihood of SAMG Decision-Making Actions using a Fuzzy Logic Model

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1. Introduction

Conventional Human Reliability Analysis (HRA) methods have not dealt with a decision-making part of human activities in a serious way because most of the actions required in Emergency Operating Procedures (EOP) belong to a rule-based actions, which do not require a serious decision-making function of human operators in Nuclear Power Plants (NPPs) [1]. However, the decision-making activity by the Technical Support Center (TSC) plays a crucial role in implementing Severe Accident Management Guidelines (SAMG), thus the likelihood of a decision-making activity of SAMG based on a sound model of SAMG decision-making needs to be quantified in HRA for Level 2 PSA [2].

When entering the SAMG, the TSC evaluates negative impacts associated with each SAM strategy of the Severe Accident Guideline (SAG), compare the positive and the negative impacts of implementation of the SAG, and decide whether each SAG should be implemented or not. Since this process has a high-level complexity and uncertainty in knowledge, a Fuzzy Logic Model (FLM) is suggested modeling and quantifying the likelihood of a TSC's SAMG decision-making.

The FLM is useful to model a complex system using qualitative and uncertain information [3]. In addition, the FLM is being spotlighted as a means dealing with fundamental limitations of HRA such as insufficient data, subjectivity and uncertainty. Thus, this study suggests a reasonable FLM for SAMG decision action.

The purpose of this study is to suggest a FLM for quantifying a SAMG decision-making action. To identify suitable parameters for FLM, systematic trial and error is implemented based on the Fuzzy Logic Toolbox from MATLAB. Data from expert judgment is used in this paper. Based on the FLM, this paper shows the quantified result for decisions of SAM strategies. The values can be used in part of Level 2 HRA as the likelihood of SAMG decision actions.

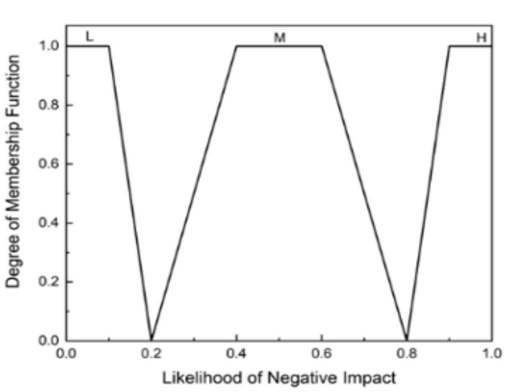
2. Fuzzy Logic Model

FLM can be categorized into three steps: Fuzzification, Fuzzy Inference System (FIS), and Defuzzification. This study used Mandani's FIS for developing FLM. Fuzzification is the process of transformation from crisp data to fuzzy set using fuzzy linguistic term (i.e. Low, Medium, High). Fuzzy operators (AND or OR) and fuzzy rules (if-then rules) are applied in the FIS. Logical operators represent that AND/OR as selecting a minimum/maximum value among input values, respectively. Fuzzy rules are expressed in human words, and usually used in form of If-then rules. For example, this format is '*If* input 1 is Low and/or input 2 is High, *then* output is Medium'. Membership Functions (MFs) as parts of fuzzification in addition to fuzzy rules are identified by expert judgement since this is based on knowledge. Finally, the result of output is defuzzified using the centroid method to get a crisp value. These steps can be done by using the fuzzy logic toolbox simulator of MATLAB [4].

3. Development of FIS for a SAMG Decision Action

3.1. Fuzzification

Based on expert judgement, input parameters associated with the decision of a SAM strategy were identified as shown in Fig.1. Input1 and input2 are related to the TSC's perception on negative impacts of SAGs; while input3 and input4 are selected for evaluation of mitigative actions. Input 1 is the likelihood of negative impacts, and input2 is the evaluation complexity of negative impacts. Input3 is the implementation complexity of mitigative actions against a negative impact and input4 is the decision burden from the consequences of mitigative actions. The output is the likelihood of a final decision on whether to implement the strategy or not. These variables are formed by trapezoid MFs resulted from a numerous trial and error applications.



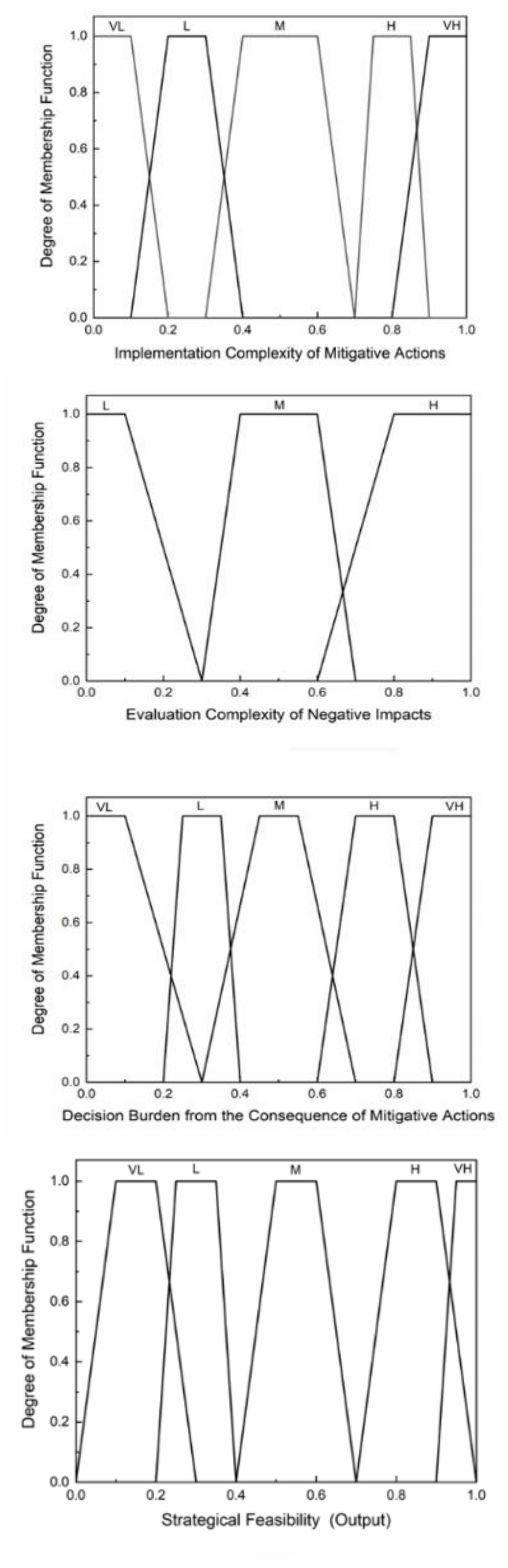


Fig.1. Identified fuzzy set for developing FIS of SAMG decision-making.

3.2. Fuzzy rule comparison

As mentioned before, fuzzy rules are established by the knowledge evidence. However, SAMG decision-making has been little studied so far, thus fuzzy rules for SAMG decision-making were set-up in this study based on expert judgment. Four experts participated in making the rules.

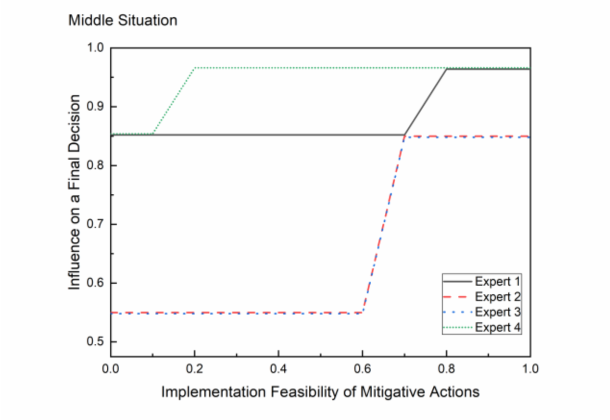


Fig.2. Comparison of results by different rules from experts

Fig.2 shows a different result between experts for representing the relationship between input 3 and the output, when the other condition of inputs 1, 2 and 4 are all situated under a moderate condition, i.e., the values are set to be 0.5. The output value from expert1 is higher than the other experts. When the implementation feasibility of mitigative action is in middle situation, expert 2 and expert 3 synchronized their opinions, whereas expert 4 is too much positive result than expert 2 and expert 3. Considering these results, this paper focused on expert 2 fuzzy rules which has slightly, followed a reasonable pattern of a logical rule.

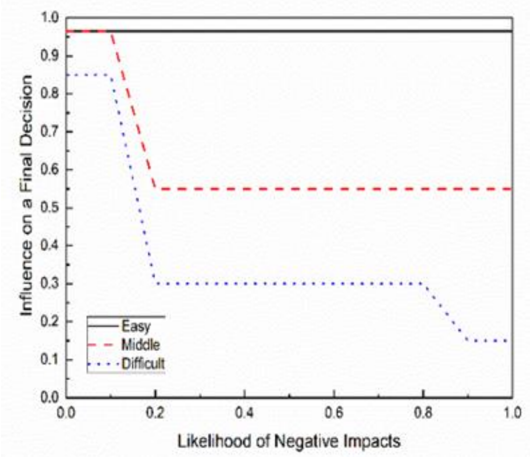
3.3. The Fuzzy inference system and relationship between input parameters and output

Fig.3 describes the capture of our FIS using MATLAB simulator. Fig.4 depicts the results from FIS and it explained the relationship between input variables and output in different situations. It is difficult to intuitively introduce the relationship between input and output and impacts on the output because of the complexity of four inputs. Thus, the decision situation was categorized into easy, middle, and difficult. In easy situation, excepting from the input in X-axis, the other input variables have values and the impact of these values on decision will be negligible. For example, input 1 is Low; Input 2 is Low; and input3 is Very High; and input 4 is Very Low in easy situation.

Fig.3. Developed FIS (Capture)

TSC might easily decide the implementation of strategy in a 0.964 - 1 probabilistic value regardless of the variation of one input (x-axis). In a Middle situation, the initial values are different by input parameters (x-axis). This result showed that likelihood of Negative impact (input1) is the most important value as 0.964 for TSC decision making. Likelihood of negative impact was also the most significant factor in difficult situation. Decision burden have little impact on influence on a final decision in a 0.175 value in difficult situation. The ranking between inputs having significant impact on output are as follows: 1) likelihood of negative impact, 2) implementation feasibility of mitigative actions, 3) evaluation complexity, and 4) decision burden.

In summary, TSC might decide a strategy mainly based on the likelihood of negative impact and the implementation feasibility of mitigative actions, but both the evaluation complexity and the decision burden also act importantly in middle situation. This result implies the importance of improvement of TSC's decision-making capability through training for the understanding of accident progression and reducing a TSC's decision burden.



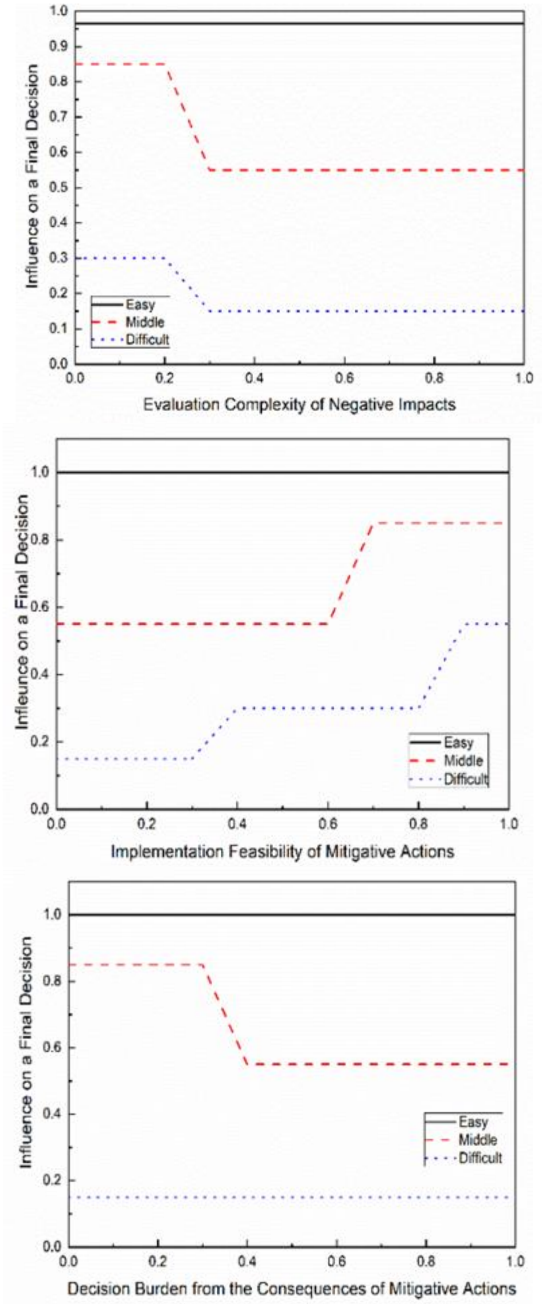


Fig.4. Relationship between four input parameters and influence on a final decision in three different situations

3.4. Quantifying of SAMG decision action

Table I summarized the quantified output from fuzzy model of SAMG decision action. This table can be interpreted that the fraction of deciding a strategy belongs to the range of 0.955 and 0.964 if a TSC decides to implement a SAG in a very high probability. This results will be helpful to perform the detailed task analysis for SAMG. The results in Table I can be used to calculate human error probability with multiplying decision action of implementing the strategy.

Table I. Fuzzy output as quantified values

Fuzzy Value	Crisp value
VH	0.955-0.964
VH-H	0.855-0.874
H	0.85
H-M	0.7-0.725
M	0.5-0.55
M-L	0.443-0.451
L	0.3
VL	0.15-0.3

4. Summary

The aim of this paper is to develop a reasonable FIS for quantitatively express SAMG decision-making. Based on expert judgement, fuzzy rules and input parameters for SAMG decision-making were established. Using Fuzzy Logic Toolbox in MATAB, the FIS was developed, and quantified values from the FIS were provided in Table I. This study revealed that fuzzy concept is useful for the decision making action as well as general HRA.

Unanswered issues remained such as practical application of FIS into case studies of severe accidents and the consensus of fuzzy rules and other parameters. These problems will be solved in the future study.

Despite of these limitations, this result showed the possibility of quantification of SAMG decision action in the decision complexity. This result can be applied to perform detailed task analysis for SAMG. Moreover, this results will support modeling of SAMG actions into Level 2 PSA to adequately evaluate the effect of SAM strategy on the risk of an NPP.

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REFERENCES

[1] P. Pyy. An approach for assessing human decision reliability. Reliability Engineering & System Safety 2000;68(1):17-28. 2000.

[2] Kim J., Cho J. Technical challenges in modeling human and organizational actions under severe accident conditions for Level 2 PSA. Reliability Engineering & System Safety. 2018.

[3] Konstandinidou, M., Nivolianitou, Z., Kiranoudis, C., & Markatos, N. A fuzzy modeling application of CREAM methodology for human reliability analysis. Reliability Engineering & System Safety 2006; 91(6):706-716. 2006.

[4] Mathworks. Fuzzy Logic Toolbox User's Guide, MATLAB. Mathworks, inc. 2019.