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DEVELOPMENT OF A RISK ASSESSMENT MODEL FOR DISASTER MANAGEMENT

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ABSTRACT :
Risk is commonly evaluated using probability, but it is difficult to analyze quantitatively because it is an intrinsically qualitative concept whose factors are enormously complex. Nevertheless, the quantification of risk probability and severity is essential for comprehensive risk assessment. For this reason, an integrated model that utilizes the subjective experience and the skills of experts is needed.
This study attempts to formulate a risk assessment model using opinion based on expert experience and skills. Diverse modeling techniques are considered, and the fuzzy inference technique is selected as an appropriate technique for risk assessment. By adopting an intuitive rather than probabilistic approach, the frequent lack of probabilistic risk assessment data is addressed.
To determine the relationship between conventional fuzzy theory and personal conceptual images of risk, linguistic variables used in risk assessment for probability and severity are identified along with fuzzy membership functions. A formulation of the severity and probability membership functions is then introduced, and fuzzy inference steps are described. In addition, the defuzzification methods to predict the risk assessment results of individuals and groups are analyzed using a case study with 12 participants. Furthermore, prediction is analyzed, with different weights given to individuals based on their characteristics. In addition, sensitivity analysis was reviewed in the aspect of pessimistic or optimistic view.

KEYWORDS:
decision making, fuzzy theory, risk assessment, expert opinion

1. INTRODUCTION

Risk is constant and ubiquitous, and harm causes considerable damage to life and property. Generally, the ISO/IEC Guide defines “harm” as injury or damage to the health of people, or damage to property or the environment, “hazard” as a potential source of harm, and “risk” as a combination of the probability of the occurrence of harm and the severity of that harm.
Conventionally, most studies on risk assessment have concentrated on statistical estimation. However, risk is difficult to analyze quantitatively because it is an intrinsically qualitative concept whose factors are enormously diverse, and related statistical data are often insufficient. However, there exist many situations in which human beings must make a decision without sufficient statistical data.
In such situations, any advice given by experts is of great help to non-experts. However, the decision-making of various experts is affected not only by mental, physical, and psychological factors, but also by psycho-social factors such as work climate, gender, and education. Even though risk is often evaluated using probability, risk assessment factors can be difficult to analyze quantitatively in uncertain environments such as nuclear power plants, where factors are numerous, their relationships are not clear, and observed data are not sufficient. For these reasons, an integrated model that can utilize the subjective experience and judgment of experts is needed.

This study aims to develop a risk assessment model that predicts the decision-making of experts in risky situations. It also compares the assessments of individuals and groups in different fields of study and discusses how an optimism index could be incorporated into the proposed model.

2. DEVELOPMENT OF A RISK ASSESSMENT MODEL

To develop the relationship between conventional fuzzy theory and human conceptual images of risks, modeling techniques are reviewed and linguistic variables used in risk assessment for likelihood and severity are determined. A formulation process for the severity and likelihood membership functions is then introduced, followed by the steps for designing fuzzy inference rules. In addition, we show how defuzzification methods can help decision makers familiar with numerical expressions understand the risk, where the main focus is how to imitate and predict the decision making of experts in risky situations.

2.1 Review of Modeling Techniques

This study briefly reviews several modeling techniques for the purpose of developing risk assessment models: influence diagrams, system dynamics, the analytical hierarchy process, neural networks, and fuzzy inference.
Influence diagrams and system dynamics were originally developed to graphically analyze social phenomena and have been widely applied to human decision-making problems. However, these techniques have the disadvantage that the identification of influence factors is subjective.
The analytic hierarchy process is now a well-known technique for providing a systematic ranking of a problem or system components. This technique is amenable to a wide variety of organizational and non-organizational decision-making problems, but is inadequate for representing causal relations. However, it is useful to determine relative importance or weights consisting of quantitative numerical values.
Neural networks and fuzzy inference are useful techniques for dealing with human-based uncertainty. In particular, fuzzy inference allows vague information to be approximately summarized using natural language, which consists of words used in human communications; hence, it was chosen to develop the risk assessment model proposed in this paper.

2.2 Development of an Individual Fuzzy Risk Assessment Model

Individual fuzzy membership functions were elicited from a questionnaire-based survey of 12 undergraduate students with different majors. Next, a risk membership function was formulated using the elicited membership functions and a fuzzy inference rule was designed. As a result of this process, individual risk assessment results were obtained. In this case study, elicited fuzzy membership functions were analyzed using MATLAB ver.7.10 (R2010a).

2.2.1 Selection of Fuzzy Linguistic Variables

It may seem controversial to apply fuzzy language variables and fuzzy logic to risk assessment. However, almost all decisions in social fields are made by humans, who usually express a large portion of their opinions and feelings using verbal language. Therefore, it is quite natural for there to be a systematic consistency in the use of language variables.
In addition, risk is a combination of the probability of occurrence of harm and the severity of that harm. In this study, the probability of occurrence is defined as likelihood and severity is simply defined as severity. The linguistic variables were selected from the Standard Practice for System Safety (MIL-STD-882E). The likelihood variables are Frequent, Probable, Occasional, Remote, and Improbable. In addition, the severity variables are Catastrophic (I), Critical (II), Marginal (III), and Negligible (IV). For the case study described in this paper, Korean linguistic variables suggested by Jung in previous research were used.

2.2.2 Elicitation of fuzzy membership functions

The elicitation of fuzzy membership functions is the first step to obtaining fuzzy sets. The output of each linguistic variable is expressed as a number between 0 and 1. To obtain fuzzy membership functions in this study, a questionnaire-based survey was carried out that contained 20 risky situations and a 100 mm linear scale. Each linguistic variable was formulated as triangle fuzzy membership function that indicates each individual's opinion. In this study, the x-axis indicates the degree of likelihood or severity and the y-axis indicates the degree of confidence.

2.2.3 Design of fuzzy risk membership functions

The risk is combination of the likelihood and the severity. Individual risk assessment membership functions are combined with the likelihood and severity membership functions for that risk. Thus, likelihood, severity, and risk membership functions were designed as 15 fuzzy inference rules using MATLAB's fuzzy AND-operator. Furthermore, an identification number was given to each risk membership function to design the fuzzy inference rule. Final fuzzy inference rules are expressed as IF <fuzzy proposition 1>, THEN <fuzzy proposition 2>.

2.2.4 Quantification of fuzzy risk assessment results

This step obtains the fuzzy sets of a membership function using linguistic variables. A triangle fuzzy membership function has a minimum value l, median value m, and maximum value u; thus, the membership function is defined as a triplet (l, m, u). For example, the fuzzy membership functions of evaluator 1 regarding the risky situation of setting up a scaffold on a steel bridge was assessed as shown in Figure 1.

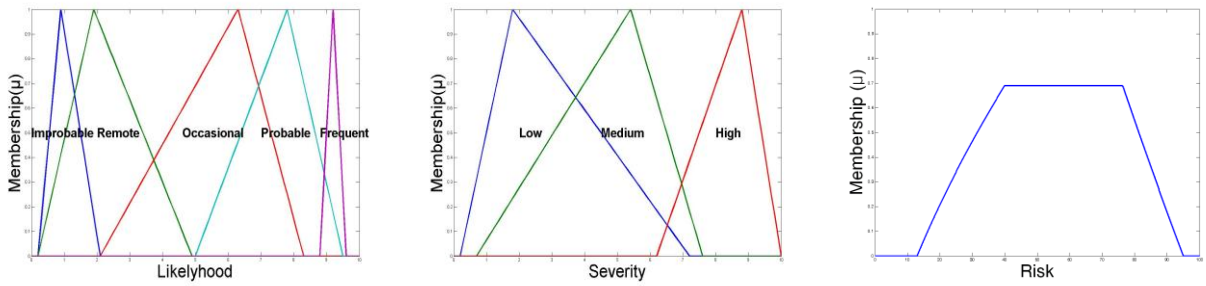


Figure 1 Fuzzy Membership Functions of Evaluator 1

The risk assessment result of evaluator 1 was first expressed using triangle fuzzy membership functions, and then various defuzzification processes could be used to obtain a quantitative value (crisp value). The defuzzification results are shown in Table 1.

Table 1 Defuzzification Results of Evaluator 1

defuzzification process	result of risk assessment
FOM (first of maximum)	41.1
MeOM (mean of maxima)	55.7
LOM (last of maximum)	75.8
COG (center of gravity)	55.4
COA (center of area)	58.4

According to the defuzzification results, the maximum risk assessed by evaluator 1 for the situation of setting up a scaffold on a steel bridge was 75.8 (LOM) and the minimum risk was 41.1 (FOM). The maximum possible value of all scores was 100.

2.3 Development of a Group Fuzzy Risk Assessment Model

Decision-making is affected not only by conventional factors, but also by sophisticated psycho-social factors. For example, Kim analyzed how a leader's opinion affects other group members' opinions in group decision-making. Therefore, risk assessment in uncertainty is difficult to analyze quantitatively. Many researchers have attempted to explain human decision-making problems using fuzzy theory because of the uncertain and inaccurate nature of information involved in the decision-making process. However, most studies using fuzzy theory compare the importance of alternatives, and there has been minimal applied research. In this study, we develop the protocol for a group risk assessment model.
Individual fuzzy membership functions were elicited using a survey for 12 undergraduate students. The study participants were then classified into three groups of four according to major: safety engineering, humanities, and sociology. The group risk membership functions were formulated according to the elicited membership functions and a fuzzy inference rule was then designed.
For example, four evaluators in three groups (12 evaluators total) evaluated the risky situation of setting up a scaffold on a steel bridge. The following is the risk assessment process for three evaluators, each with a different major.

2.3.1 Integration of individual fuzzy risk assessment

Three evaluators assessed the risk. The integrated membership functions with a fuzzy OR-operator are shown in Figure 2. Consequently, the opinions of evaluator 1 (the safety engineering major) and evaluator 3 (the sociology major) are mainly reflected in the risk assessment. Further, evaluator 3's opinion was selected because their degree of confidence was higher than that of evaluator 1 and evaluator 2 (the humanities major).

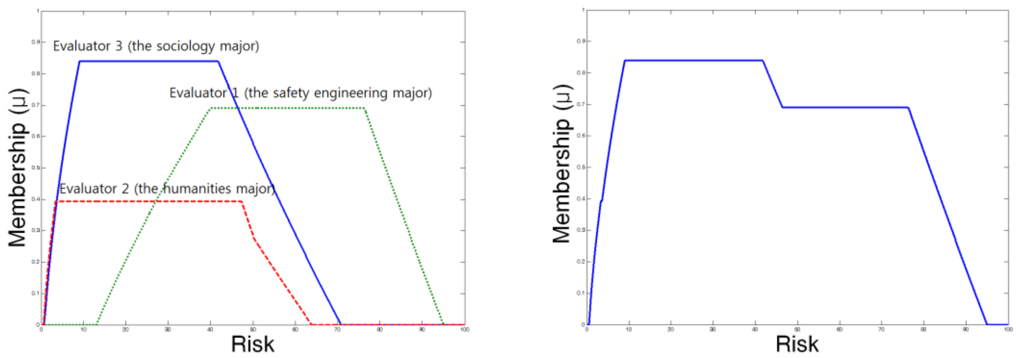


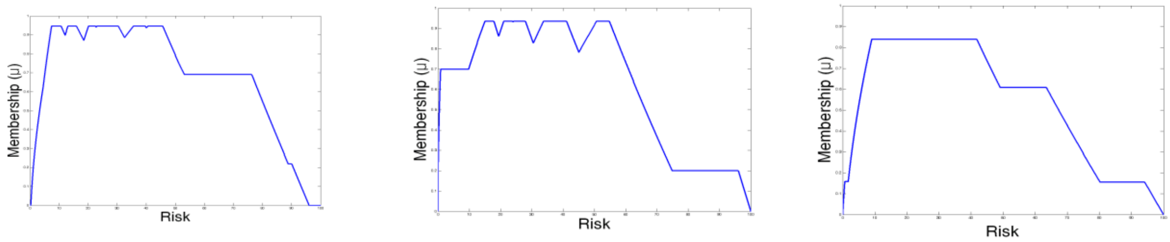
Figure 2 Fuzzy Membership Functions of Three Evaluators

2.3.2 Quantification of group risk assessment

Group risk assessment is a process that gathers and integrates the opinions of several experts in various fields. Therefore, all evaluators' risk membership functions need to be elicited and integrated into a single membership function. In addition, the risk assessment results of a group of three evaluators can be quantified through the defuzzification process. Consequently, the suggested risky situation (setting up a scaffold on a steel bridge) was evaluated from 6.1(minimum) to 22.9(maximum). Among the results, the methods that most broadly reflect the assessment of the three evaluator's opinions are COG = 21.3 and COA = 20.0. However, when assessing risk, we should consider the most pessimistic situation, hence the score of 22.9 obtained by LOM is preferable for risk assessment with respect to disaster management.

2.4 Application of the fuzzy risk assessment model

To further develop the fuzzy risk assessment model, the 12 participants were classified in three groups of four according to major. Figure 3 shows the risk membership functions of each group. The majors in safety engineering, humanities, and sociology are labeled as groups A, B, and C, respectively.



group A group B group C

Figure 3 Fuzzy Membership Functions of Major-based Groups

Using the COG method, the defuzzified result of Group A is 41.7, which is higher than the results of groups B and C (38.9 and 39.0, respectively). Therefore, group A's decision is used as the result. In addition, Figure 4 shows the risk membership function of the 12 evaluators integrated using a fuzzy OR-operation.

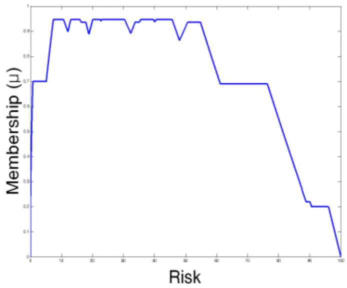


Figure 4 Integrated Fuzzy Membership Function of Major-based Groups

In particular, the defuzzification results of the 12 evaluators and Group A were the same when using the FOM, MeOM, and LOM methods, as shown in Table 2, because Group A had a higher degree of confidence than the other two groups. Therefore, Group A's decisions were used as the risk assessment results of the 12 evaluators.

Table 2 Defuzzification Results of Each Groups

defuzzification process	group A	group B	group C	all subjects
FOM	7.4	15.1	9.0	7.4
MeOM	27.5	33.4	25.4	27.5
LOM	45.6	54.7	41.8	45.6
COG	41.7	38.9	39.0	41.9
COA	39.9	37.3	36.6	40.6

3. INCORPORATION OF AN OPTIMISM INDEX

Predicting the outcome of group decisions, which can be frequently required in real field situations, can be analyzed using different weights for individual assessments based on that individual's characteristics. This section discusses how the optimism index trait of decision makers may be incorporated into the proposed model. Park et al. suggested an optimism index α that reflects an evaluator's perception of risk. This index is expressed as a number between 0 and 1.

If an evaluator's risk assessment results are represented by a triangular fuzzy number (l, m, u), when the evaluator is optimistic, the triangle fuzzy number (m) leans toward the right. In contrast, if the evaluator is pessimistic, the triangle leans toward the left. Hence, risk perception attitude can be denoted as the triangle fuzzy number (l, m′, u).

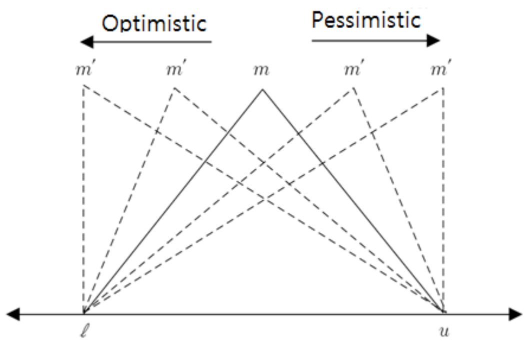


Figure 5 Modification of an Evaluator's Risk Attitude

As shown in the Figure 5, if a particular risk assessment scores high on the the optimism index, m' is larger when close to u and smaller when close to l, as the x-axis indicates the degree of risk. As a result, if an evaluator's risk perception attitude is pessimistic ($\alpha = 0.3$), then the defuzzification results should be increased, and if his/her attitude is optimistic ($\alpha = 0.8$), then the results should be decreased. Consequently, the evaluated value of the risk can be changed according to the risk perception attitude, even though there are no changes in the range of risk. In summary, the risk perception attitude and ambiguity of the evaluator's opinion can be reflected in the risk assessment by using Park et al.'s optimism index.

4. CONCLUSION

The present study focused on risk assessment through individual and group decision-making. In this paper, several techniques were reviewed to determine whether individual or group decisions could be predicted quantitatively. In addition, a schematic model of decision-making was formulated to develop a risk assessment model using fuzzy theory. Using a fuzzy inference-based integration model could help to develop risk assessment models in uncertain situations.

Fuzzy theory could be an appropriate and practical technique for risk assessment because it can reflect uncertainty and each evaluator's experience, pointing out aspects for alternative plans. However, to objectively assess this method, the technique should be supported by a logical basis through empirical study.

The case study in this paper, in which 12 undergraduate students with different majors participated as subjects, obtained positive results. With human responses using linguistic variables and numeric values for conventional illustration, fuzzy membership functions were constructed and expanded to fuzzy membership functions that could predict a group's decision making. If a more sophisticated interview design is employed, this fuzzy risk assessment technique could be of use in situations that are deficient in statistical inference data.

To summarize, if fuzzy theory and expert opinion are used, a practical and effective quantitative risk assessment could be obtained for disaster management.

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