

Fuzzy logic-based risk assessment

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Safety and reliability are essential issues in modern sciences. Modern equipment and systems should meet technical, safety and environmental protection requirements. The risk can appear as personal injury or death, mission degradation, property technical damage or destruction. The risk is a measure of harm or loss associated with the human activity. It is the combination of the likelihood and the consequence of a specified hazard being realized. For decision making we need the opinions of other sciences, sometimes we have to consider moral questions. One of them is to manage risk of human activities. To make reliable decision, the risk of the given system or process should be known correctly. Fuzzy logic is a new mathematical tool to model inaccuracy and uncertainty of the real world and human thinking. This paper will show the possibility of use of the fuzzy logic to assess the risk.

1. Introduction

Risk assessment is an important element of risk management. The goal of risk assessment or risk characterization is to determine risk context and acceptability, often by comparison to similar risk.¹ There are many qualitative and quantitative methods to assess risk. In the last case the risk is determined by multiplication of severity and probability measures.^{2,3} Basically the insurance companies and banks use these methods. If the possible loss can be harm to people or death the quantitative risk assessment cannot be used ethically and qualitative ones should be applied.⁴ These methods contain many subjective elements.⁵ Subjectivity of experts can be modeled by fuzzy logic.⁶

Fuzzy Logic is a form of logic used in some expert systems and other artificial-intelligence applications in which variables can have degrees of truthfulness or falsehood represented by a range of values between 1 (true) and 0 (false). With fuzzy logic, the outcome of an operation can be expressed as a probability rather than as a certainty. For example, in addition to being either true or false, an outcome might have such meanings as probably true, possibly true, possibly false, and probably false.

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There are countless fields in the modern engineering and military sciences in which fuzzy used the fuzzy logic. BOWLES and PELÁEZ demonstrate two methods of the fuzzy logic-based assessments of criticality.⁷ XU et al.⁸ presented a fuzzy logic based approach of failure mode and effect analysis.

The paper is organized as follows: Section 2 summarizes the risk management. Section 3 shows the risk assessment. Section 4 presents the development of fuzzy logic-based risk assessment methods. Section 5 shows application of the developed method. Section 6 encompasses the most important findings, conclusions and future works of the author.

2. Risk and risk management

All human activity involves any risk. In our age, experts (called by MICHELBERGER “*homo eticus*”)⁹ have to decide on moral base, during decision-making. It is very important to use risk management methods to investigate and to minimize risks which concomitance of human activity. The risk is the combination of the likelihood and the consequence of a specified hazard being realized.

Risk management is the systematic application of policies, practices, and resources to the assessment and control of risk affecting human health and safety or the environment.¹⁰ A critical role of the safety regulator is to identify activities involving significant risk and to establish an acceptable level of the risk. In most cases, the near zero risk should be not achievable can be very costly.

The goal of risk assessment is to determine risk context and acceptability, often by comparison to similar risks. The type of risk analysis used should be appropriate for the available data and to the exposure, frequency and severity of potential loss. Quantitative risk analysis incorporates numerical estimates of frequency or probability and consequence. In practice a sophisticated analysis of risk requires extensive data which are expensive to acquire or often unavailable. Fortunately few decisions require sophisticated quantification of both frequency and consequences. The relative risk analysis means that a risk is evaluated in comparison to another risk.

The basic principles of the risk management are the following:

- Accept no unnecessary risk;
- Make risk-decisions at the appropriate level;
- Accept risk when benefits outweigh the costs;
- Integrate risk management into planning at all levels.

The risk management process is a continuous one designed to detect, assess, and control risk while enhancing performance and maximizing the capabilities. The specific actions associated with each step of a general risk management process are depicted below.

2.1. Identify the hazards

A hazard can be defined as any real or potential condition that can cause injury, illness, death to personnel or damage to or loss of equipment or property. The purpose of this step is to identify as many hazards as possible.

2.2. Assess the risks

Risk is the probability and severity of loss from exposure to the hazard. The assessment step is the application of quantitative or qualitative measures to determine the level of risk associated with a specific hazard. This step defines the probability and severity of an undesirable event that could result from the hazard identified above.

2.3. Analyze risk control measures

Investigate specific strategies and tools that reduce, mitigate, or eliminate the risk. Only the effective control measures can reduce or eliminate one of the three components (probability, severity, or exposure) of the assessed risk.

2.4. Make control decisions

After controls have been selected to eliminate hazards or reduce their risk, determine the level of residual risk for the selected tasking, mission and/or course of action.

2.5. Supervise and review

Risk management is a process that continues throughout the life cycle of the system, or activity. Leaders at every level must fulfill their respective roles in assuring controls are sustained over time. Once controls are in place, the process must be periodically reevaluated to ensure their effectiveness.

3. Risk assessment

The first step of risk assessment is to assess hazard severity. It is determination of the severity of the hazard in terms of its potential impact on the people, equipment.

Severity assessment should be based upon the worst possible outcome that can reasonably be expected.

Using quantitative risk assessment method, the risk is product of probabilities and calculated “crisp” severity of investigated hazard. This method can be used when the factors mentioned above can be determined unequivocally. For example insurance companies use it.

Often the probability and severity cannot be identified unequivocally. These factors can be determined only by knowledge of experts. In this case we have to use severity and probability categories. In this case the risk is logical combination of them, and we should use fuzzy logic to model inaccuracy and uncertainty human thinking.

But in this case the determination of membership functions raises a problem. Interrogation of users and maintainers of investigated system or executors of given task can solve this problem. It is important to mention that a man of small experience has notable knowledge, but its transformation to numerical data is a very difficult task. The aim mentioned above can be accomplished by so called expert reports and statistical inference of their data. (The author used this method when he investigated pneumatic system of helicopter MI-8 HIP to determine the permissible brake-asymmetry and brake-effort). These data have notable subjectivity because they accrue from interpretation of individual experiences. Therefore these data should be used as fuzzy membership functions.

Table 1 shows the severity categories provide guidance to a wide variety of missions and systems.

The next one is the assess probability. Its goal is to determine the probability that the hazard will cause a negative event of the severity assessed in step above. Generally accepted definitions for probability are given in Table 2.

The complete risk assessment combines severity and probability estimates to form a risk assessment for each hazard. By combining the probability of occurrence with severity, a matrix is created where intersecting rows and columns define a Risk Assessment Matrix. Table 3 is an example of a Risk Assessment Matrix.

4. Fuzzy assessment system development

During risk assessment based upon experiences uncertain categories (see Tables 1 and 2) should be used, which can be investigated by only fuzzy tools.

Firstly the fuzzy membership functions of all input and output parameters and logical rules should be determined. Figure 1 shows the membership functions of

severity categories shown by Table 1. In Figure 2 the fuzzy occurrence (empirical probability) sets (Table 2) can be seen. Figure 3 shows the fuzzy risk sets definition.

The logical rules were determined by Table 3. All use AND logical connection.

Table 1. Severity categories

Catastrophic	Complete mission failure, death, or loss of system
Critical	Major mission degradation, severe injury, occupational illness or major system damage
Moderate	Minor mission degradation, injury, minor occupational illness, or minor system damage
Negligible	Less than minor mission degradation, injury, occupational illness, or minor system damage

Table 2. Probability categories

	Individual soldier	All soldiers	Individual item	Fleet or inventory	Probability density
Frequent	Occurs often in career	Continuously experienced	Occurs often in the life of the system	Continuously experienced	more than 0.1
Likely	Occurs several times in a career	Occurs regularly	Occurs several times in the life of the system	Occurs regularly	0.01 ~ 0.25
Occasional	Will occur in a career	Occurs sporadically	Will occur in the life of the system	Occurs several times in the life of the system	0.001 ~ 0.01
Seldom	May occur in a career	Occurs seldom	May occur in the life of the system	Can be expected to occur in the life of the system	0.0001 ~ 0.01
Unlikely	So unlikely you can assume it will not occur in a career	Occurs very rarely	So unlikely you can assume it will not occur in the life of the system	Unlikely but could occur in the life of the system	less than 0.001

Table 3. Sample Risk Assessment Matrix

	Frequent	Likely	Occasional	Seldom	Unlikely
Catastrophic	EH	EH	H	H	M
Critical	EH	H	H	M	L
Moderate	H	M	M	L	L
Negligible	M	L	L	L	L

EH – Extra High; **H** – High; **M** – Medium; **L** – Low.

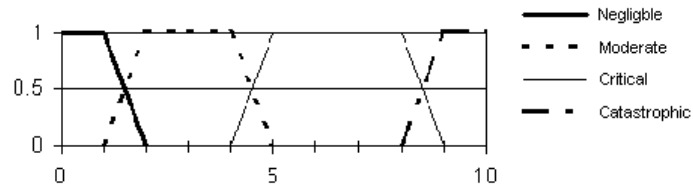


Figure 1. Severity sets definition

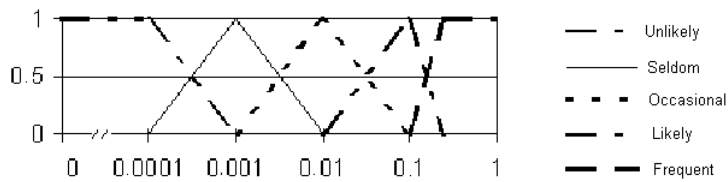


Figure 2. Probability sets definition

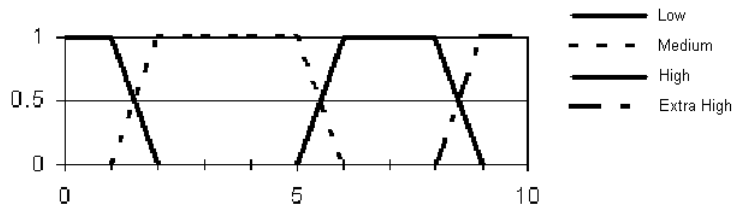


Figure 3. The risk sets definition

5. Fuzzy assessment process application

A fuzzy logic-based decision-making process realizes the following process. This process uses several rules simultaneously. The attribute of set of rules mentioned above is that their solution by classical logic can be different or antinomic at the same time.

Practically, this inconsistency can be (should be) resolved by the fuzzy logic. This process is a combination of four subprocesses: fuzzification, inference, composition, and defuzzification.¹¹

The flow chart of fuzzy logic application is illustrated by Figure 4.¹²

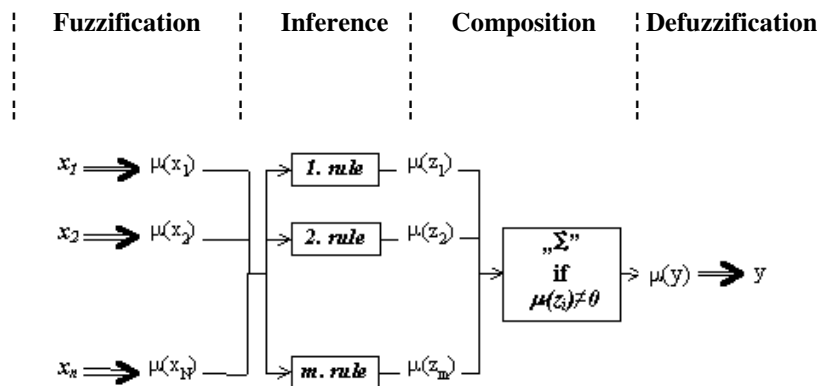


Figure 4. Fuzzy logic application flow chart

To manage a special helicopter mission, the air staff has assessed its risk using the fuzzy logic based risk assessment method. The severity and probability of possible aircrashes have been determined by expert's (pilots') report, result of which are the followings:

- degree of severity is 4.75 in a numeric scale from 0 to 10;
 - probability of occurrence is 0.005,
- as averages of the expert's report.

5.1. Fuzzification

In the fuzzification subprocess, the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth $\mu(x_i)$ for each rule premise.

In our case the degrees of truth of severity sets are (see Figure 5).

$$\begin{aligned} \mu(\text{severity_is_critical}) &= 0.75; \\ \mu(\text{severity_is_moderate}) &= 0.25. \end{aligned}$$

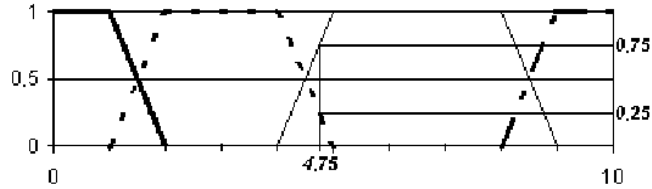


Figure 5. Determination of degree of truth of severity sets

Namely, severity of the investigated event is in some degree critical and moderate too. Degrees of truth of probability sets are (see Figure 6):

$$\begin{aligned} \mu(\text{probability_is_occasional}) &= 0.7 ; \\ \mu(\text{probability_is_seldom}) &= 0.3 . \end{aligned}$$

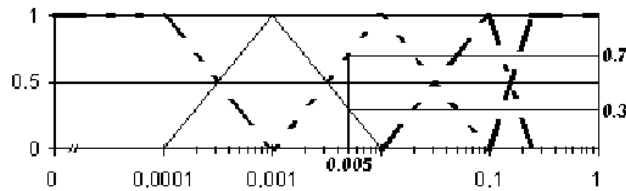


Figure 6. Determination of degree of truth of probability sets

That is, probability of the event's occurrence mentioned above can be occasional and infrequent to some degree.

5.2. Inference

In the inference subprocess, the truth-value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule.

In our example only there is only four logical rules, which are practically used. On the basis of the Risk Assessment Matrix (Table 3), they are the following ones:

- Rule (A): If severity is critical and probability is occasional then risk is high;
- Rule (B): If severity is moderate and probability is occasional then risk is medium;
- Rule (C): If severity is critical and probability is seldom then risk is medium;
- Rule (D): If severity is moderate and probability is seldom then risk is low.

It is very interesting that, using the given rules, the risk – a result of a rule – can be high, medium and low. Only fuzzy logic tools can unwind this conflict! In the fuzzy logic, the minimum operator is used instead AND classical logic connection. Therefore:

<i>Rule (A)</i>	–	risk_is_high:	$\mu(z_A) = \min(0.75; 0.7) = 0.7;$
<i>Rule (B)</i>	–	risk_is_medium:	$\mu(z_B) = \min(0.25; 0.7) = 0.25;$
<i>Rule (C)</i>	–	risk_is_medium:	$\mu(z_C) = \min(0.75; 0.3) = 0.3;$
<i>Rule (D)</i>	–	risk_is_low:	$\mu(z_D) = \min(0.25; 0.3) = 0.25;$

The truth-values of all other rules are zero, therefore there is no need to mind them during composition subprocess.

5.3. Composition

In the composition subprocess, all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable.

Results of two rules are same (namely medium), the degree of membership:

$$\mu(\text{risk_is_medium}) = \max(\mu(z_B); \mu(z_C)) = \max(0.25; 0.3) = 0.3$$

Using the above results:

$$\begin{aligned}\mu(\text{risk_is_high}) &= 0.7; \\ \mu(\text{risk_is_medium}) &= 0.3; \\ \mu(\text{risk_is_low}) &= 0.25.\end{aligned}$$

5.4. Defuzzification

The defuzzification subprocess creates a crisp ranking from fuzzy conclusion set. There are more defuzzification methods.

The Weighted Mean of Maximum (WMoM) method is one of commonly used procedure. This method gives the average, weighted by their degree of truth, of the support values at which all the membership functions that apply reach their maximum value. In case of trapezoidal membership function it is taken as center of the maximal range. Formally, the Weighted Mean of Maximum conclusion Z:

$$Z = \frac{\sum_{i=1}^n \mu_i x_i}{\sum_{i=1}^n \mu_i},$$

where:

- n – number of quantized output conclusions;
- x_i – the support value of the i -th membership function;
- μ_i – degree of truth of the i -th membership function.

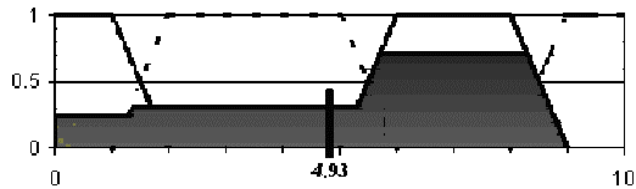


Figure 7. Result of composition

In our example:

$$Z = \frac{0.25 \cdot 0.85 + 0.3 \cdot 3.5 + 0.7 \cdot 7}{0.25 + 0.3 + 0.7} = \frac{6.1625}{1.25} = 4.93,$$

that is, the degree of risk of investigated undesired event is: 4.93.

On the basis of risk sets definitions (see Figure 3), the investigated sortie had medium level risk.

$$\mu(\text{risk_is_medium}) = 1.$$

The air unit commander could use this result to accept the risk during the next step of risk management process. Balancing assessed risk and the probable benefit of the sorti, the leader permitted the mission and did not prescribe to investigate any risk control tools.

6. Future work

This papers shown a fuzzy logic-based risk-assessment method. During prospective scientific research related to this field of mathematics, the author will complete following tasks:

- to investigate fuzzy logic's possibilities of use in the modern aircraft and other technical systems operation and its management;
- to popularize usage of fuzzy logic in the modern technical management decision-making;

- to investigate theory and methodology of working-up of diagnostic and troubleshooting methods based upon fuzzy logic;
- to work up fuzzy logic-based method to investigate integrated systems' parameter uncertainties
- to study methodology and possibilities of use fuzzy tools, during reliability investigation in the modern Hungarian military sciences.

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