Safety Assessment of Technical Objects and Systems Using Fuzzy Logic Methods

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Abstract. To assess and analyze safety of engineering facilities, systems and the level of risks in the manmade environment, it is often necessary to study the influence of various weakly formalized factors. In this case, when modeling risk, it is advisable to use methods of fuzzy logic. Fuzzy methods make it possible to represent risk, defined as a combination of the probability of an emergency and the measure of its consequences, as a function of fuzzy variable. This makes it possible to develop fuzzy models describing the relationship between parameters of technical facilities and their safety level in accordance with various risk criteria. The paper provides examples of assessing the influence of the reliability of a technical system on the level of societal risk for personnel as well as the influence of the level of facility protection on the level of risk generated by it. The aspects of formalization of indicators characterizing the reliability of the human operator are also considered. These aspects are further used for modeling risk. The considered procedures can be made more sophisticated by expanding the space of factors, taking into account linkages among them and embedding the obtained fuzzy sets into a hierarchical cognitive risk model.

1. Introduction
The development of the main directions of assessment, analysis and modeling of safety is largely determined by the existing risk-based concept in this area. This makes it possible to implement a flexible approach to ensuring safety, in which all the necessary protective measures for a certain class of objects and systems are not strictly regulated, but safety criteria and possible ways of achieving them are substantiated [1]. The values of individual, potential, collective, social, economic, technical and environmental risks of an emergency situation on the territories of the location of technical systems and objects that pose a potential hazard are used as safety criteria [2].

For the analysis of indicators characterizing the level of risks in the manmade environment and the state of safety of technical objects and systems, as a rule, discrete models are used which do not allow taking into account the influence of various weakly formalized factors. To study their influence on the overall level of risk, it is advisable to carry out risk modeling using fuzzy methods (FM).

The use of FM allows one to represent the risk $R$, defined as a combination of the probability of the occurrence of an emergency $P$ and the measure (value) of its consequences $U$ [3], in the form of a combination of fuzzy sets $\mu(P)$ and $\mu(U)$ [4]. In this case, it becomes possible to consider the risk as a fuzzy value with a membership function $\mu(R)$. This, in turn, allows one to obtain a defuzzified risk value, for example, its most possible value, as well as a scatter of values [5].
Possible variants of the model representation of risk in terms of FM are:

- replacing the discrete values of $P$ and $U$ with fuzzy variables, and their combinations – with an extended (according to the principle of generalization) product;
- replacing the values of $P$ and $U$ with fuzzy relations, and combinations (products) – with the composition of these relations;
- generalization of the formula using fuzzy integrals.

Representation of risk in the form of a fuzzy value allows one to create a family of fuzzy models describing the relationship between various characteristics (parameters) of a technical system (object) and the safety level of this system in accordance with various criteria. Thus, FM provide the opportunity to assess the influence of such characteristics as reliability, the level of facility protection, the human factor, etc. on the overall level of risk.

2. Assessment of the influence of the system reliability on the level of societal risk

The following procedure can be proposed to assess the influence of the state of reliability of a technical system on the level of societal risk for the personnel with the help of FM.

Reliability is a complex property, which, depending on the purpose of technical system and the conditions of its application, may include non-failure operation, maintainability, recoverability, durability, storability, availability, or certain combinations of these properties. Let in the considered example the reliability of technical system is determined by its non-failure operation, which is estimated by the indicator of probability of no-failure operation [6]. A fuzzy linguistic variable characterizing the reliability level of a system is given in Table 1.

| Characteristic of the state of reliability of system | Probability of no-failure operation | System reliability level |
|------------------------------------------------------|------------------------------------|-------------------------|
| The reliability of system does not meet the necessary technical requirements and conditions | 0 – 0.45                           | Low                     |
| The reliability of system mainly meets the necessary technical requirements and conditions | 0.46 – 0.75                        | Medium                  |
| The reliability of system fully meets the necessary technical requirements and conditions | 0.76 – 1                           | High                    |

The consequence of system failure is possible damage to personnel, population, property (equipment, structures, buildings, products, etc.), and the environment [7].

| Characteristics of possible harm to life and health of personnel | Score assessment of the damage | Damage level |
|------------------------------------------------------------------|------------------------------|--------------|
| Very low probability of harm to health, very low probability of death | 0 – 12                       | Very low     |
| Low probability of harm to health, very low probability of death | 13 – 37                      | Low          |
| Probability of minor harm to health, low probability of death | 38 – 62                      | Medium       |
| High probability of serious harm to health, low probability of death | 63 – 87                      | High         |
| High probability of serious harm to health, high probability of death | 88 – 100                     | Very high    |
The damage from system failure to life and health of personnel can be estimated, for example, using the fuzzy linguistic variable given in Table 2.

The result of system failure is, among other things, the emergence of societal risk for personnel [8].

The above two fuzzy linguistic variables, obtained by the method of expert assessments, constitute the factor space of the simplest fuzzy model of the influence of system reliability on the level of societal risk.

The characteristics of the output variable «Level of societal risk» are given in Table 3.

Table 3. Assessment of societal risk.

| Score assessment of the level of societal risk | Level of societal risk   |
|-----------------------------------------------|-------------------------|
| 0 – 10                                        | Insignificant           |
| 11 – 25                                       | Moderate                |
| 26 – 50                                       | Medium                  |
| 51 – 75                                       | Significant             |
| 76 – 100                                      | High (large)            |

When using the classic Mamdani’s fuzzy logical inference method, the base of fuzzy production rules in the considered example consists of 15 rules. The considered procedure can be made more sophisticated by expanding the space of factors and taking into account linkages between them.

3. Assessment of the influence of the level of protection of the facility on the magnitude of risk generated by the facility

The following procedure can be proposed to assess the influence of the level of protection of the facility on the magnitude of risk triggered by it.

Let there be a set of indicators \{X\}, which, using procedure \(\psi_1\) (function or algorithm), describe the condition of protection of the object by a complex indicator \(A\). After the formation of the complete set \(A\) of object protection states, one can introduce a linguistic variable \(Z\), which divides the set \(A\), for example, into five in general case intersecting subsets \(Z_1, \ldots, Z_5\), which correspond to the following values of the fuzzy linguistic variable: \{Unprotected, Low, Insufficient, Sufficient, High\}. Each of the subsets \(Z_1, \ldots, Z_5\) correspond to their own membership functions \(\mu_1(Z), \ldots, \mu_5(Z)\).

A similar procedure can be implemented to form the linguistic variable \(R\) «Level of risk» with the values \{Highest, High, Medium, Low, Insignificant\}. In this case, procedure \(\psi_2\) is used, which brings the set of indicators \(\{Y\}\), characterizing the level of risk, to a complex indicator \(B\). To assess the level of risk, depending on the specific task, various criteria can be used.

Let the fuzzy factor space of the linguistic variable \(R\) also consist of five subsets \(R_1, \ldots, R_5\), which correspond to their membership functions \(\mu_1(R), \ldots, \mu_5(R)\). Let us also establish that there is a one-to-one correspondence between the linguistic variables «Level of protection» and «Level of risk» (see Table 4).

Table 4. Correspondence between the linguistic variables.

| Level of protection of facility | Level of risk generated by facility |
|--------------------------------|-----------------------------------|
| Unprotected                    | Highest                           |
| Low                            | High                              |
| Insufficient                   | Medium                            |
| Sufficient                     | Low                               |
| High                           | Insignificant                     |
The presence of a one-to-one correspondence between the variables $Z$ and $R$ makes it possible to obtain two related fuzzy sets characterizing the condition of protection of the facility and the level of risk generated by it, which opens up the possibility of their joint use in the data mining system. In the general case, the procedure can be made more sophisticated, since the correspondence of the output linguistic variables may not be one-to-one.

4. Assessment of the influence of the reliability of the human operator on the risk level

When assessing the influence of the human factor on the level of risk, it is important to take into account in the model being formed the factors that determine the reliability of the human operator. The use of FM is an effective way to assess the reliability of an operator, since some indicators of the reliability of the human operator can only be formalized using fuzzy methods [9].

In the most general form, the factors that determine the reliability of a particular operator can be divided into three groups [10, 11]: qualifications, availability of practical work experience, individual psychological features.

The dependence of risk generated by the facility on the operator's qualification level can be presented in the form of the correspondence of linguistic variables and assessed according to Table 5.

| Level of operator qualification | Level of risk |
|--------------------------------|---------------|
| Insufficient                   | High          |
| Appropriate                    | Medium        |
| Fully compliant                | Low           |

When solving a particular problem it is possible to detail the specified variable (consideration of the main components of the operator's qualification level, such as basic education, familiarity with the software used, the degree of training, etc.), which ensures the construction of the goal tree and the formation of the corresponding fuzzy inference procedure.

The presence of practical work experience of the operator can be assessed, for example, by using a linguistic variable with the values {None, Insufficient, Acceptable, Large}, as well as by using a time scale that takes into account the operator's work experience (see Table 6).

| Operator work experience | Time scale (years) | Level of risk |
|--------------------------|--------------------|---------------|
| None                     | Less than 1 year   | Very high     |
| Insufficient             | 1 – 3 years        | High          |
| Acceptable               | 3 – 5 years        | Medium        |
| Large                    | More than 5 years  | Low           |

Depending on the specific task, the time scale for assessing the operator's work experience may provide for a larger number of intervals.

The individual psychological features of the operator, as a rule, include long-term endurance, endurance to emergency strain and overstrain, interference tolerance, spontaneous distractibility, reaction to unforeseen stimuli, switchability, resistance to external factors. The study of this group of factors involves their formalization, the study of the correlation between them, as well as the relationship with the characteristics that determine the overall level of safety and risk. A possible way to solve this problem is to develop a cognitive risk model in the form of a complex hierarchical structure of fuzzy sets.
5. Conclusions
Fuzzy methods and models can be effectively used for solving problems related to the analysis of the influence of various weakly formalizable factors on the overall level of risk and safety of technical objects and systems.

Representation of risk by a fuzzy value allows one to develop a family of fuzzy models describing the relationship between various characteristics of an object or a technical system and the safety level of this system in accordance with various risk criteria.

FM allows one to assess the influence of such important characteristics of an object or system as reliability, condition of protection, human factor on the overall level of risk. As examples, the following procedures are considered:

- a procedure for assessing the influence of technical system reliability on the level of societal risk for the personnel;
- a procedure for assessing the influence of the level of facility protection on the magnitude of risk induced by it;
- a procedure for assessing the influence of factors determining reliability of the human operator.

The considered procedures, depending on specific tasks, can be made more sophisticated by expanding the space of factors, taking into account linkages among them and embedding the obtained fuzzy sets into a hierarchical cognitive risk model.

6. References
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