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METHOD OF DETERMINING THE RISK OF AN EMERGENCY SITUATION AT THE FACILITIES OF PORT INFRASTRUCTURE

В статье предлагается методика оценки риска аварийной ситуации на объектах портовой инфраструктуры, основанная на методе экспертных оценок и теории нечетких множеств.

Ключевые слова: *риск, аварийная ситуация, экспертные оценки, нечеткие множества.*

У статті пропонується методика оцінки ризику аварійної ситуації на об'єктах портової інфраструктури, що ґрунтується на методі експертних оцінок і теорії нечітких множин.

Ключові слова: *ризик, аварійна ситуація, експертні оцінки, нечіткі множини.*

The article offers a method for the assessment of the risk of an emergency situation at the facilities of port infrastructure, based on the method of expert assessments and fuzzy set theory.

Keywords: *risk, emergency situation, expert assessments, fuzzy sets.*

Introduction. Define ***the risk of an emergency situation (ES)*** at the facilities of port infrastructure as a quantitative characteristic of the probability of such a situation under the influence of hazards.

In the absence of sufficient statistical information on the impact of individual factors on the probability of occurrence of an ES is appropriate to use methods of expert assessments and fuzzy sets.

In [1] have been classified and identified the major risk factors of different nature, occurring during port infrastructure exploitation, namely factors of the technical state of object, technological factors, external factors (environment) and the human factor. In general terms, each risk factor is a function of several parameters that can be measured (quantitative) and not directly measurable (qualitative). Values of quantitative parameters are transformed into a dimensionless quantity that characterizes the degree of deviation from normative value of the parameter. Qualitative parameters are presented as a text description or expert estimates range from 0 to 1.

The purpose of the article is the development of method for determining the risk of an ES at the facilities of port infrastructure on the basis of expert assessments and fuzzy set theory.

The basic material. Fuzzy description of parameter values appear in connection with uncertainty that arises in the course of various types of clas-

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sifications [2, 3]. For example, when you cannot clearly distinguish "high" and "very high" probability. Then use fuzzy descriptions means the following:

– introduction of linguistic variable with its term-set values. For example: the variable "factor parameter level" can have a set of values-term "very low, low, medium, high, very high".

– constructive description of linguistic variable by selecting the corresponding quantitative trait – for example, a specially designed indicator of the probability that takes values from 0 to 1.

– comparison of each value of linguistic variable of the membership function to a particular fuzzy subset. Commonly used functions in this case are trapezoidal membership functions (Fig. 1). Upper base of the trapezoid corresponds to the full confidence in the correctness of classification, and the lower – to the full confidence that no other values of the interval (0-1) do not belong to the selected fuzzy subset.

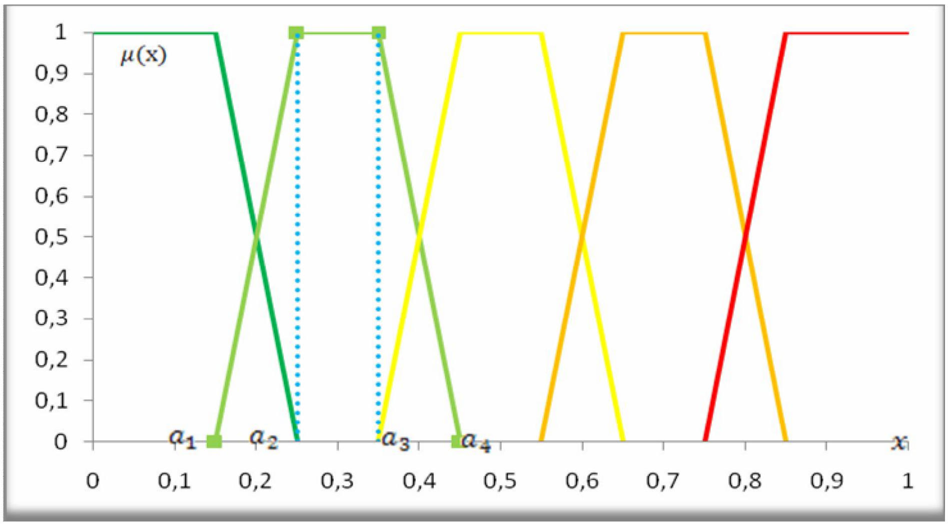


Fig. 1. Trapezoidal membership function

To describe subsets of the term-set enter system of the five relevant membership functions of the form

$$\mu_1(x)=\begin{cases}1;\ 0\le x\le 0{,}15\\ 10(0.25-x);\ 0.15<x<0.25\\ 0;\ 0.25\le x\le 1\end{cases}$$

$$\mu_2(x)=\begin{cases}0;\ 0\le x\le 0.15\\ 10(x-0.15);\ 0.15<x<0.25\\ 1;\ 0.25\le x\le 0.35\\ 10(0.45-x);\ 0.35<x<0.45\\ 0;\ 0.45\le x\le 1\end{cases}$$

$$\mu_3(x)=\begin{cases}0;\ 0\le x\le 0.35\\ 10(x-0.35);\ 0.35<x<0.45\\ 1;\ 0.45\le x\le 0.55\\ 10(0.65-x);\ 0.55<x<0.65\\ 0;\ 0.65\le x\le 1\end{cases}$$

$$\mu_4(x)=\begin{cases}0;\ 0\le x\le 0.55\\ 10(x-0.55);\ 0.55<x<0.65\\ 1;\ 0.65\le x\le 0.75\\ 10(0.85-x);\ 0.75<x<0.85\\ 0;\ 0.85\le x\le 1\end{cases}$$

$$\mu_5(x)=\begin{cases}0;\ 0\le x\le 0.75\\ 10(x-0.75);\ 0.75<x<0.85\\ 1;\ 0.85\le x\le 1\end{cases}$$

For a compact description of the trapezoidal membership function $\mu(x)$ it is convenient to describe them by trapezoidal numbers of the form

$$\beta\ (a_1, a_2, a_3, a_4),$$

where a_1 and a_4 – abscissa of the lower base of the trapezoid;

a_2 and a_3 – abscissa of the upper base of the trapezoid.

This trapeze sets $\mu(x)$ in area of a non-zero carrier of value x to corresponding fuzzy subset.

Also the formal introduction of the classifier involves the introduction of a set of nodes. For example, a standard five-level classifier has 5 symmetrically arranged on the 01-carrier nodal points {0.1, 0.3, 0.5, 0.7, 0.9}, that is, on the one hand, the respective maxima of membership functions abscissas on the 01-carrier and the other side uniformly are spaced apart on 01-carrier and are symmetric about the node 0.5. Then entered linguistic variable "degree of probability" defined at 01-carrier, together with a set of nodal points, hereinafter will be called the standard five-level classifier. The constructed fuzzy classifier is of great importance for further discussion. The bottom line is that if nothing is known about the factor, except that it can take any value within the 01-carrier (principle of equal priority), and it is necessary to carry out the association between qualitative and quantitative assessment of the factor proposed classifier makes that with maximum reliability. The sum of all the membership functions for each x is equal to 1, indicating the consistency of the classifier.

Enter the following base sets and subsets:

1. The complete set of values of the linguistic variable F "level of influence of the integral factor" is divided into five subsets:

G_1 – a subset of "very low"
G_2 – a subset of "low"
G_3 – a subset of the "average"
G_4 – a subset of "high"
G_5 – a subset of the "very high".

2. Corresponding to the set G the complete set of values of the linguistic variable "level of influence of the factor" is divided into five subsets:

E_1 – a subset of "very low"
E_2 – a subset of "low"
E_3 – a subset of the "average"
E_4 – a subset of "high"
E_5 – a subset of the "very high".

3. For the linguistic variable "parameter level" of a single risk factor parameter the complete set of its values B_{ni} is divided into five subsets:

B_{ni1} – a subset of "very low"
B_{ni2} – a subset of "low"
B_{ni3} – a subset of the "average"
B_{ni4} – a subset of "high"
B_{ni5} – a subset of the "very high".

By default, assume the additional condition matching sets B, E and G. If, during the classification parameter p_{ni} refers to the subset B_{nik}, then the level of the corresponding factor is classified as E_k, and the level of integral factor – respectively as G_k.

Building a classifier of current value F of an ES integral index as a criterion for splitting this set into fuzzy subsets (Table 1). Consider the case when this classifier is a standard five-level classifier on the 01-carrier.

Table 1

Classification of current value F of an ES integral indicator

Interval of values F	Classification level of the parameter	Degree of estimated confidence (membership function)
$0 \leq F \leq 0.15$	G_5	1
$0.15 < F < 0.25$	G_5	$\mu_5 = 10 \times (0.25 - F)$
	G_4	$1 - \mu_5 = \mu_4$
$0.25 \leq F \leq 0.35$	G_4	1
$0.35 < F < 0.45$	G_4	$\mu_4 = 10 \times (0.45 - F)$
	G_3	$1 - \mu_4 = \mu_3$
$0.45 \leq F \leq 0.55$	G_3	1
$0.55 < F < 0.65$	G_3	$\mu_3 = 10 \times (0.65 - F)$
	G_2	$1 - \mu_3 = \mu_2$
$0.65 \leq F \leq 0.75$	G_2	1
$0.75 < F < 0.85$	G_2	$\mu_2 = 10 \times (0.85 - F)$
	G_1	$1 - \mu_2 = \mu_1$
$0.85 \leq F \leq 1.0$	G_1	1

Table 2

Compliance with the quantitative value of the qualitative syntactic rule G,
by which new terms are generated

Interval of values F	A subset
$0.8 < F < 1$	G_1
$0.6 < F < 0.8$	G_2
$0.4 < F < 0.6$	G_3
$0.2 < F < 0.4$	G_4
$0 < F < 0.2$	G_5

If there is additional information about the behavior of the parameter (e.g., histogram), the parameter classification in general will not have a standard form, as the nodal points and respective membership functions will lie asymmetrically on the 01-carrier of the respective factor.

The risk factor indicator characterizes the degree of influence of this factor on the probability of an ES.

Calculation of a particular risk factor indicator is carried out by the matrix method, the essence of which is a double convolution of the data provided in Table 3. Indicator F_n of n-th risk factor is determined by the formula

$$F_n = \sum_{j=1}^{5} m_j \sum_{i=1}^{N} w_{ni} \mu_{ij} ,$$

where m_j – a set of nodal points;

w_{ni} – the importance of i-th parameter of n-th factor;

From the formula becomes clear designation of nodal points in a fuzzy classifier. These points act as weights in aggregating the system parameters at the level of their qualitative states. Thus, the nodal points carries out mixing set of non-standard classifiers (with its asymmetrically located nodal points) into a single classifier standard form, with a simultaneous transition from a set of non-standard carriers of particular parameters to the standard 01-carrier.

The inner summation is performed, taking into account the weights of parameters and the outer summation – on five-level classifier node points of the probability of an ES.

Table 3

The levels of carriers to fuzzy subsets

Name of a parameter	**The current value**	**The weight**	**The result of the classification of subsets**				
			very low	**low**	**average**	**high**	**very high**
			Nodal points				
			m_1	m_2	m_3	m_4	m_5
Parameter *n1*	p_{n1}	w_{n1}	μ_{11}	μ_{12}	μ_{13}	μ_{14}	μ_{15}
Parameter *n2*	p_{n2}	w_{n2}	μ_{21}	μ_{22}	μ_{23}	μ_{24}	μ_{25}
Parameter *n3*	p_{n3}	w_{n3}	μ_{31}	μ_{32}	μ_{33}	μ_{34}	μ_{35}
Parameter *n4*	p_{n4}	w_{n4}	μ_{41}	μ_{42}	μ_{43}	μ_{44}	μ_{45}
…	…	…	…	…	…	…	…
Parameter *nN*	p_{nN}	w_{nN}	μ_{N1}	μ_{N2}	μ_{N3}	μ_{N4}	μ_{N5}

The table contains a column with the values of the parameters and a row with the nodal points of five-level classifier and is the result of modeling, sufficient to determine the indicator of a particular factor.

Weights of parameters are typically calculated by using a simple ranking, proportional method or method of pairwise comparison.

If it is possible to rank all parameters of a single factor in descending order of importance $\left(w_{n1} > w_{n1} > \ldots > w_{nN}\right)$, then the weight of i-th parameter can be determined by Fishburne’s rule [4]

$$w_{ni} = \frac{2(N-i+1)}{N(N+1)},$$

where N – number of parameters of a single factor.

For example, in case of 4 parameters the allocation diagram of their weights will be as follows

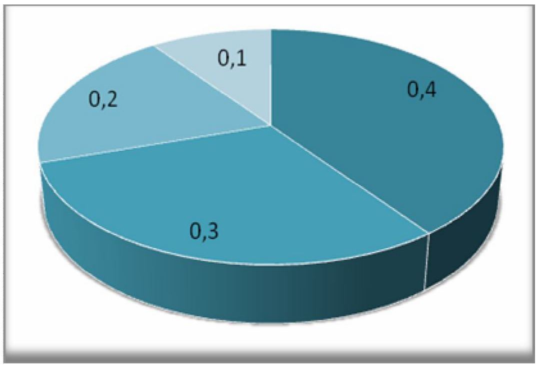


Fig. 2. Allocation diagram of parameter weights in case of using Fishburne's rule

If all parameters are of equal importance (or the system of preferences isn't present), the value of each parameter is determined by the formula

$$w_{ni} = \frac{1}{N}.$$

For case with 4 parameters the allocation diagram of their weights will be as follows

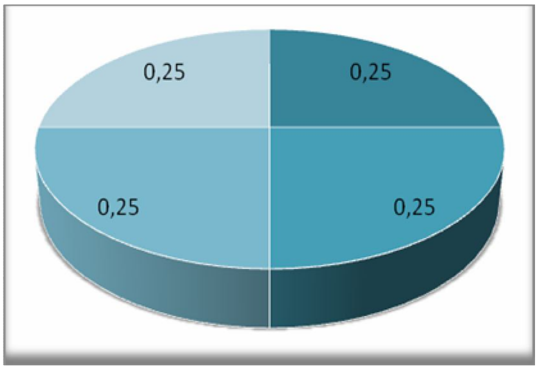


Fig. 3. Allocation diagram of parameter weights in case of equal importance

Fishburne's rule reflects the fact that if the level of significance of the parameters is nothing but the order of their importance, the resulting score is the maximum entropy of available information uncertainty concerning the object of research, i.e. allows you to make better decisions in a bad information environment.

Integrated indicator characterizes the degree of influence of all risk factors for the occurrence of an ES.

Most probable value of the integral index of the influence of all factors on the occurrence of an ES can be represented as a weighted average value of the indicators analyzed factors of the situation

$$F = \sum_{i=1}^{n} F_i \cdot w_i ,$$

where F_i – the degree of probability of an ES on the *i*-th factor;

w_i – the weight of *i*-th parameter;

n – number of factors.

Previously allocated 4 hazards (factors of danger), so the formula becomes

$$F = F_1 \cdot w_1 + F_2 \cdot w_2 + F_3 \cdot w_3 + F_4 \cdot w_4 .$$

Risk factors weights w_i can be determined by any method from among those that are used in calculating parameters weights within a single factor.

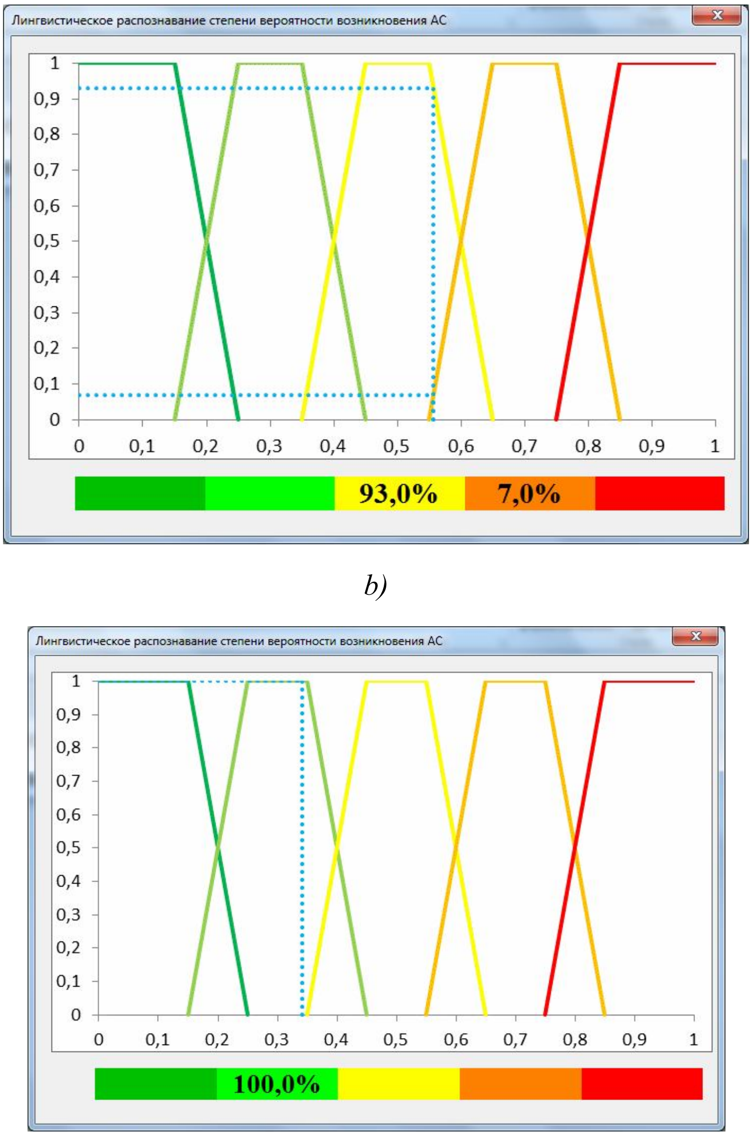
Recognize the obtained value of integral indicator of an ES based on the selected classifier. The result of the classification is a linguistic description of the risk of an emergency situation and the degree of certainty the outcome of such recognition.

For example, for the value $F = 0.557$ linguistic recognition with 93.0 % certainty determines the degree of the risk of an ES as "average", and for the value $F = 0.342$ linguistic recognition with certainty 100.0 % determines the degree of the risk of an ES as "low" (Fig. 4).

Table 4

Linguistic characteristic of risk

The linguistic characteristic of risk	The value of integral indicator of risk factor, F	The probability of occurrence of an emergency situation, P_i
very low	0 – 0.2	$< 10^{-6}$
low	0.2 – 0.4	$10^{-5} – 10^{-6}$
average	0.4 – 0.6	$10^{-4} – 10^{-5}$
high	0.6 – 0.8	$10^{-3} – 10^{-4}$
very high	0.8 – 1.0	$10^{-2} – 10^{-3}$



a)

Лингвистическое распознавание степени вероятности возникновения АС

93,0% 7,0%

b)

Лингвистическое распознавание степени вероятности возникновения АС

100,0%

Fig. 4. Examples of linguistic recognition
of the received value of risk degree

Define from the following table the probability of occurrence of an emergency, depending on the value of the integral indicator of risk factor.

Conclusion

1. The method of determining the probability of an ES at the facilities of port infrastructure allows us to estimate the influence of individual hazards of different nature and determine the integral indicator of safety of port infrastructure as a whole.

2. Definition of risk of an ES at the facilities of port infrastructure will allow the technician to assess the probability of occurrence of an accident in a complex technical system, whether it a pier, dock equipment, manufacturing process or even a person, under the influence of both internal (violation of the working discipline, low qualifications, etc.) and external (natural phenomena, sabotage, etc.).

This will provide a timely opportunity to make appropriate adjustments in the activities related to improving the safety of port infrastructure and to create an effective portfolio of projects for a specific port in conditions of insufficient volume and uncertainty of source information.

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