RISK ANALYSIS SYSTEM

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Abstract. Nowadays uniting the efforts of all interested parties and authorities in preparation and making informed decisions in the field of public safety, government, territories, natural environment acquires special actuality. Systematic logically reasonable construction of failures of system elements that can lead to a failure requires a full understanding of the nature and operation of the system of possible failures of its elements.

The purpose of the study is to identify a system of related methodic materials (approved methods) that define the stages and their corresponding methods of assessing the risks of emergencies associated with exposure to damaging factors caused by fires, explosions and releases of toxic substances used in the risk assessment techniques and tools and set standards acceptable levels of risk of emergencies.

Research methods. The article considers the possibility of using logical-graphic schemes (dendrograms) for correct identification of the dangers of objects. The task of deciding to assess the risk of an emergency in the context of financial damage caused can be solved on the basis of a fuzzy game model.

The main results of research. Systematic logically reasonable construction of failures of system elements that can lead to a failure requires a full understanding of the nature and operation of the system of possible failures of its elements. Inclusion into the tree of failures the external causes further requires the understanding of the connection of the analyzed system with other technical systems and natural events. Together, this causes the involvement of special experts into the construction and analysis of fault trees. The task of deciding to assess the risk of an emergency in the context of financial damage caused can be solved on the basis of a fuzzy game model.

Scientific novelty. The system is based on the principle of developing a compromise between accuracy and ease of assessment calculations, so there is a possibility of simplified calculation of the maximum possible number of victims in emergency situations (number of people killed or damage to health) without significant loss of accuracy.

Practical significance. Nowadays uniting the efforts of all interested parties and authorities in preparation and making informed decisions in the field of public safety, government, territories, natural environment acquires special actuality.

Keywords*: risk, optimization, emergency situations, fuzzy game model.*

Problem Statement. Nowadays uniting the efforts of all interested parties and authorities in preparation and making informed decisions in the field of public safety, government, territories, natural environment acquires special actuality. This is also the work in increasing public awareness, public authorities and the analysis of the organization, risk control, risk acceptance. This is also the independent examination and the development of programs, projects, promising ideas, technical solutions, regulatory documents. As well as these are scientific and research activities.

Review of the Literature. The issues of management in emergency situations and the construction of information systems for decision-making in emergency situations are devoted to the study and publication of many scientists and specialists – A.N. Yelokhina, A.V. Izmalkov, V.V. Kulby, V.I. Vasilyeva, B.N. Porfiriev, R.Z. Khamitova, M.A. Shakhramanyan, I.Yu. Yusupova, V.G. Krymsky and others.

In recent years, scientific and practical developments in the field of risk management have been actively developed abroad, among which are the works of J. Apostalakis, L. Gossen, S. Guaro, R.C ook, H. Kumamoto, F. Lissa, Marshall, G. Saver, E. Henley and others.

Nevertheless, the range of unresolved problems in this area is still quite wide. The difficulty of solving the problem of modeling and management in emergency situations is due to the fact that the nature of the development of a particular emergency situation is purely individual, and its development takes place under conditions of uncertainty.

The aim of the paper is to identify a system of related methodic materials (approved methods) that define the stages and their corresponding methods of assessing the risks of emergencies associated with exposure to damaging factors caused by fires, explosions and releases of toxic substances used in the risk assessment techniques and tools and set standards acceptable levels of risk of emergencies. The system is based on the principle of developing a compromise between accuracy and ease of assessment calculations, so there is a possibility of simplified calculation of the maximum possible number of victims in emergency situations (number of people killed or damage to health) without significant loss of accuracy.

Presentation of research material. Critically important objects may be at risk and endangered danger (as you can see at figure 1).

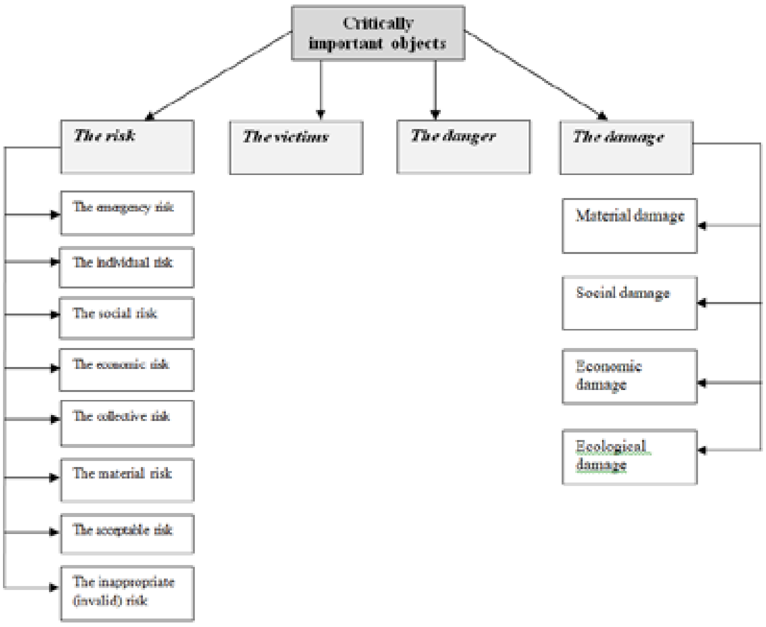


Fig. 1. Threats to critical facilities [1; 4]

The specific part of the territory, depending on the degree of risk can be attributed to one of the four types of risk areas:

· unacceptable risk zone (prohibitive) - this is the territory where the presence of people is not permitted, except for persons providing an appropriate organizational, social and technical actions (special construction of engineering structures, the introduction of additional protection, monitoring, alerts, etc.), aimed at reducing the risk to an acceptable level. New construction is not allowed, regardless of the possible economic and social benefits of a particular type of economic activity, with the exception of defense facilities, the state border guarding or objects functioning automatically. The relocation of people to safe areas is routinely performed.

· high-risk area - a territory which allowed temporary staying of limited number of people associated with the performance of official duties. New residential and industrial construction is allowed in exceptional cases by the decision of the heads of the administration or executive with mandatory implementation of a set of special measures to reduce risk to an acceptable level, mandatory risk control and prevention of emergency situations.

· conditionally acceptable risk zone - the area where construction and the location of new residential, social and industrial facilities is allowed, in case of obligatory performance of a complex of additional measures to reduce the risk.

· acceptable risk zone - territory on which any construction and location of population is allowed.

Determination of risk factors in the operation of critical facilities (CEP) is based on the result analysis of certification or declaration of safety of the facility. Depending on the result of a critically important object can be in one of three areas of risk:

· unacceptable risk area (area of strict regulation and risk control) - optional quantitative analysis of risk, requires special measures to ensure protection of critical facilities;

· high risk area (area of economic regulation and risk management) - a quantitative risk analysis is mandatory, requires to take certain measures to ensure the security of the object;

· acceptable risk area (area with no need of risk management) - analysis and the adoption of special additional security measures are required.

The risk assessment of an emergency is divided into five consecutive steps (fig.2):

- identification of dangers;
- construction of damaging factors fields;
- selection of defeat criteria;
- assessment of the effects of exposure to damaging factors;
- calculation of risk indicators.

Danger identification.

The task of this stage - to identify and clearly describe all the dangers sources and ways (scenarios) of their implementation. This is crucial stage of the risk assessment, since not identified at this stage dangers are not exposed to the further consideration and disappear from view.

The results of dangers identification stage are:

· a list of adverse events;

· description of hazards, risk factors, conditions of occurrence and development of adverse events (e.g., scenarios of possible accidents), including an assessment of implementation of the frequency of occurrence of each of the scenarios and the development of the accident;

· preliminary hazard and risk assessment. When dangers identification of the object performed, which is not a complex technical system, it is acceptable to use a method of quality dangers assessments, detailed in [2,10].

The emergence and development of emergencies in objects of a complex technical system, is determined by a combination of random events occurring at different rates and at different stages.

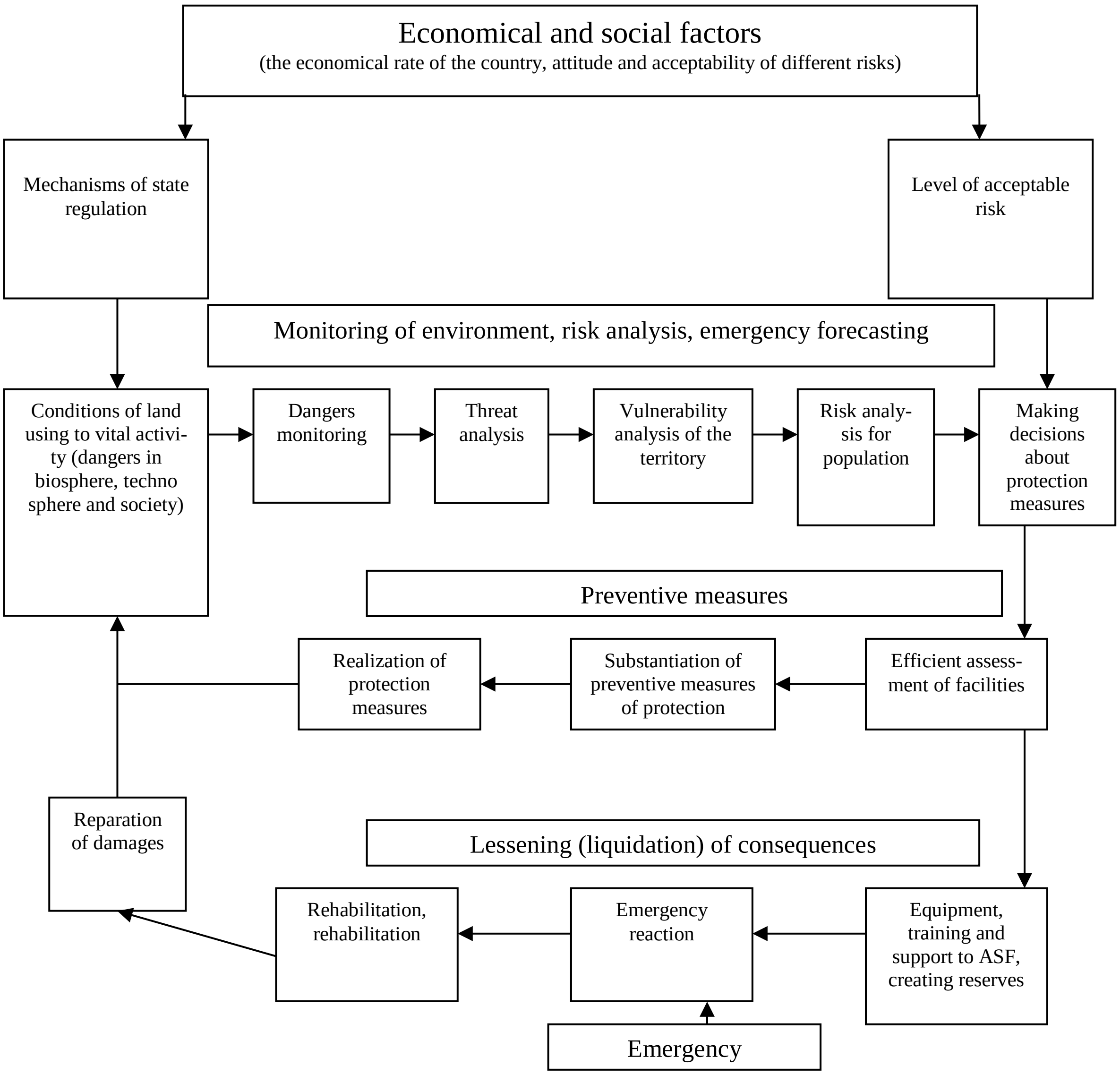


Fig. 2. The structure of control system of the natural and technogenic risks [4]

Correct identification of the dangers of this type of objects is possible in the case of quantitative risk analysis, based on the use of logical-graphic schemes (dendrograms):

- “fault trees” identify the causal chain of events that led to the appearance of an emergency;
- “trees of events” identify the sequence of the outgoing head events determining the feasibility of a scenario of an emergency.

Evaluation of the frequency of occurrence of different scenarios and the development of the accident presupposes data on the frequency of primary failures (triggering events), the mutual influences of element failures and other similar information that can be obtained from:

- the technical documentation (for components and assemblies);
- statistics (for accident and reliability of technological systems and natural phenomena);
- expert specialists assessment.

Construction of damaging factors fields.

The main parameters affecting the factors taken into account when calculating the risk markers of emergency due to fires, explosions and releases of toxic substances, presented in [4]. Also, in [4], the sources are recommended for use in constructing the fields affecting factors in the case of propagation of the shock wave thermal radiation and pollutants in three-dimensional space (the atmosphere).

To calculate the damaging factors fields in the development of emergency in a two-dimensional or one-dimensional space (for example, filling of oil on the surface or contact with soluble emergency chemically hazardous substances in open watercourses) qualitatively different mathematical models needed. Some of them are presented in the relevant teaching materials for assessment of impacts [4].

Selection criteria for the lesion

In assessing the effects of damaging factors on a man, the environment and the different objects can be used as deterministic destruction criteria and probability.

When calculating on the basis of risk indicators lesion fields constructed in accordance with recommended [6] sources probabilistic metrics used. Guidelines for the selection criteria of probability of adverse effects of assessment factors are presented in [3,5].

Deterministic criteria destruction used, including when assessing the effects of damaging factors in the environment, are also presented in the relevant methodic materials [6].

Assessment of the impacts of the damaging factors

The effects of an emergency situation refer to:

· the number of victims among the staff and the population living on the territory adjacent to the fire and explosion danger and chemically dangerous objects or routes of transportation of dangerous loads;

· material and environmental and economic damage associated with exposure to damaging factors of an emergency on the property of the state, individuals and legal entities, and the environment.

The number of victims - is the number of people killed and/or received health damage by the emergency, i.e. the amount of irrecoverable loss and health [11-12]. Estimation of the number of victims in emergency situations of technogenic character can be done, following [4].

The calculation of risk indicators

The main risk factors are:

- individual risk;
- collective risk;
- social risk;
- material risk;
- economic risk.

The physical meaning of individual risk can be expressed as the frequency of lesions of separate person as a result of the impact of the total of the studied danger factors at a given point of space. Individual risk - a function defined on a surface adjacent to a dangerous object.

Through individual risk, knowing the density of the population distribution and / or staff at the surface adjacent to the risk, collective risk can be expressed. [9]. Collective risk so, in fact, is the math expectation of a discrete accidental human values. By analogy with the collective risk, the material risk determined - the expectation of a discrete random variable material damage.

Guidelines for the construction and analysis "fault trees"

1. General characteristics of the method

The method of quantitative risk analysis, based on logic-graphic circuit "fault tree" is used to analyze the possible causes and underlying causes of an emergency (accidental) situation and calculate its frequency.

The tree of faults - a graphical representation of logical connections between emergency situations and events, initiating them. Fault Tree Construction is a process of "reverse comprehension", that is, since the accident, or other undesirable event (often referred to as the upper undesirable event and / or the parent event) covers development that may lead to its realization. Then we study the causes of these events, and so on, until you have identified all of the primary initiating events. The result of applying this method is to determine the frequency of emergency (accidental) situations. It is also recommended to determine the minimum combination of events that determine the occurrence of an accident, or the inability (minimum bandwidth and a combination of interception, respectively).

2. Fault Tree Structure

Fault tree structure includes one parent event (accident, incident), which connects with a set of relevant previous events (failures errors, adverse external influences), which form a causal chain. For communication between the events in the "nodes" of trees used logical signs "AND" and "OR". Logic symbol "AND" means that the higher-level event occurs during the lower occurrence of events (equivalent to multiplying their probability to estimate the probability of a superior event). The sign "OR" means that the higher-level event may occur due to the occurrence of one of the lower-level events.

Fault tree elements can be divided into three groups:

- primary failures or triggering events;
- secondary failures;
- control failures.

The primary failures are events that took place under conditions that normally function in considered technical system. Secondary failures occur due to changes in operating conditions of the equipment, in particular due to the deviation from production schedules. Management faults occur, even when the equipment is functioning normally doesn't receive for some reason the control signals that ultimately leads to its malfunctioning. All three types of failure may be present in the fault tree structure. One of the fault tree analysis tasks is to determine the list of the primary failure, leading to the creation of an emergency. Secondary failures and management failures are intermediate events that require further analysis, to identify leading to the emergence of the primary events.

3. Triggering event

Many causes of emergency (triggering events) can be divided into three classes:

- equipment failures;
- staff actions, which led to a deviation from production schedules;
- external causes.

External events can initiate accident at the various sites. Although the frequency of such events is small enough, they can lead to large-scale consequences. External events can be divided into two categories:

- natural phenomena: earthquakes, floods, storms, high temperature, lightning, etc.
- effects resulting from human activities: crash, work of neighbor industrial facilities, sabotage, etc.

4. The minimum bandwidth and a combination of interception

Failure analysis of the tree allows you to select the signal branch to main event and indicate related:

- Minimum bandwidth combination.
- Minimum shut-off combinations.

Minimum bandwidth combinations - a set of initiating events, mandatory (simultaneously) the occurrence of which is sufficient for the occurrence of main events (accidents). Such combinations are used primarily for the detection of "weak points".

Minimum shut-off combination – a set of initial events that guarantees absence non-arising of main event, provided none of the components of this set of events. Such combinations are mainly used to determine the most effective measures to prevent accidents.

5. An example of design and analysis of fault tree

When analyzing the occurrence of a failure, a failure tree consists of sequences and combinations of violations and malfunctions, and thus it represents a multi-level graphological structure of causal relationships obtained by following dangerous situations in reverse order to find possible causes of their occurrence (Fig. 3).

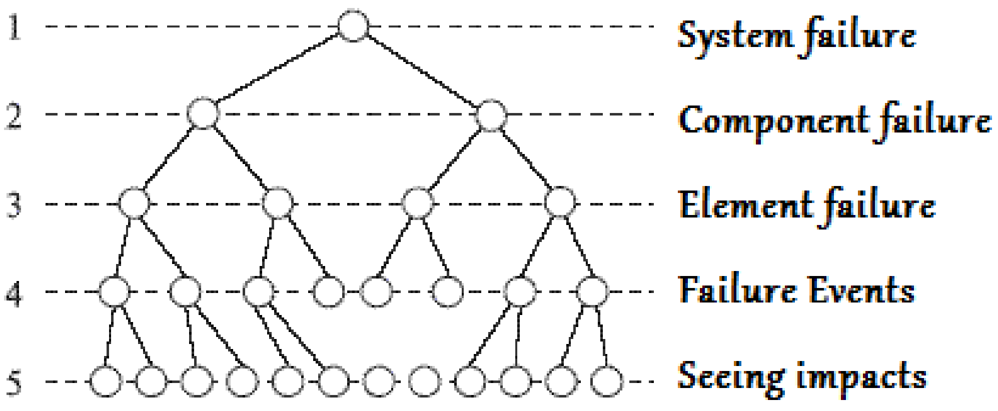


Fig. 3. Conditional scheme of building a tree of failures

The advantages of a fault tree are as follows:

- analysis focuses on finding failures;
- allows you to show explicitly unreliable places;
- is provided with graphics and provides visual material for the part of IT professionals who are involved in system maintenance;
- makes it possible to perform a qualitative or quantitative analysis of the reliability of the system;
- the method allows specialists to focus on individual specific system failures in turn;
- provides a deep understanding of the system behavior and penetration into the process of its work;
- are a means of communication of specialists, as they are presented in a clear visual form;
- helps to deductively detect failures;
- gives designers, users and managers the opportunity to visually justify design changes or establish the degree of compliance of the system design with specified requirements and analysis of trade-off decisions;
- facilitates the analysis of the reliability of complex systems.

The main advantage of the fault tree (compared to other methods) is that the analysis is limited to identifying only those elements of the system and events that lead to this particular system failure or accident.

The disadvantages of the fault tree are as follows:

- implementation of the method requires a significant investment of funds and time, since an increase in the detail of the infrastructure under consideration leads to a geometric increase in the number of influencing events;
- the fault tree is a scheme of Boolean logic, which shows only two states: working and failed;
- it is difficult to take into account the state of partial failure of elements, because when using the method, as a rule, it is considered that the system is either in good condition or in a state of failure;
- difficulties in the general case of an analytical solution for trees, containing backup nodes and reestablished nodes with priorities, not to mention the significant efforts that are required to cover all types of multiple failures;
- requires reliability specialists to have a deep understanding of the system and specific consideration of each time only one specific failure;
- the fault tree describes the system at a certain point in time (usually in the steady state), and the sequence of events can be shown with great difficulty, sometimes it is impossible. This is true for systems with complex control loops, in such cases, as a rule, they refer to methods based on stochastic (random) processes.

Emergency Risk Assessments

The task of deciding to assess the risk of an emergency in the context of financial damage caused can be solved on the basis of a fuzzy game model. Such tasks are considered when making decisions about participation in an investment project under risk conditions, as models reflecting risk, classic matrix game models are used with the search for solutions in the class of mixed strategies, i.e. based on a probabilistic approach [6, 7]. We use the approach proposed in [8] for risk assessment.

Emergency:

1) relatively satisfactory condition, no emergencies - d_1;
2) emergencies with minimal damage - d_2;
3) catastrophic emergency - d_3.

Income values are taken into account with a "+" sign, losses - with a "-" sign. The numerical values of d_1, d_2 and d_3 are known (or at least their estimates are known). To prevent an emergency, you can carry out various activities, spending on it certain funds.

Because the emergency is unique, the decision maker (DM) can choose one of two behavioral strategies:

1) decides to invest in preventing emergencies;
2) decides not to invest in disaster prevention.

It is necessary to choose the strategy of behavior of the decision maker, in which his gain would be at least non-negative, and the worst case losses would be zero. This situation is described by the player *A* matrix *A* (DM) of the two-player matrix game (Table 1).

Next, we bring the matrix model to a fuzzy mind [6–8]. Experts can determine the degree of belonging to alternatives of "nature" - the degree of confidence that nature will choose the option B_1. Expert estimates are selected according to the E. Harrington scale [6] for the formalization of heuristic information.

Table 1

Decision maker winnings matrix

	B_1 (relatively satisfactory condition, no emergencies)	B_2 (emergency with minimal damage)	B_3 (catastrophic emergency)
A_1 (DM decides to invest in preventing emergencies)	D_1	D_2	D_3
A_2 (DM decides not to invest in emergency prevention)	0*	0*	0*

* - the decision maker does not lose anything and does not gain

If model A chooses alternative A1, interpretation of the model is reflected in this case by a set of fuzzy production rules:

R_1: if x is B_1, then y is d_1,

R_2: if x is B_2, then y is d_2,

R_3: If x is B_3, then y is d_3.

Here, the variable x represents the state of player *B* (“nature”), and y - the gain (loss) of player *A* (DM). The degree of truth of the premise of the first rule (R_1) is obviously equal g_1 to that of the second - g_2 and third - g_3.

At the same time, the set of reduced fuzzy rules together with the accepted conditions form the model of Wang – Mendel fuzzy inference [4], according to which the clear value of the output variable (in this case, the gain value Q_1) is determined by the formula:

$$Q_j = \frac{\sum_{j=1}^{3} a_j \cdot g_j}{\sum_{j=1}^{3} g_j} \qquad (1)$$

When player *A* chooses strategy A_2, it is obvious that the proceeds (losses) of the decision maker are equal to zero $Q_2 = 0$.

The question of choosing a strategy is now solved by checking the inequality: $Q_1 > Q_2$ or $Q_1 > 0$. If this inequality holds, then the strategy (risk level) should be accepted, if not executed, discard.

In our case, the losses, as well as the degree of confidence for the alternatives of “nature” are given in table 2 (the sum of the alternatives is not necessarily 1).

Table 2

Baseline for decision making

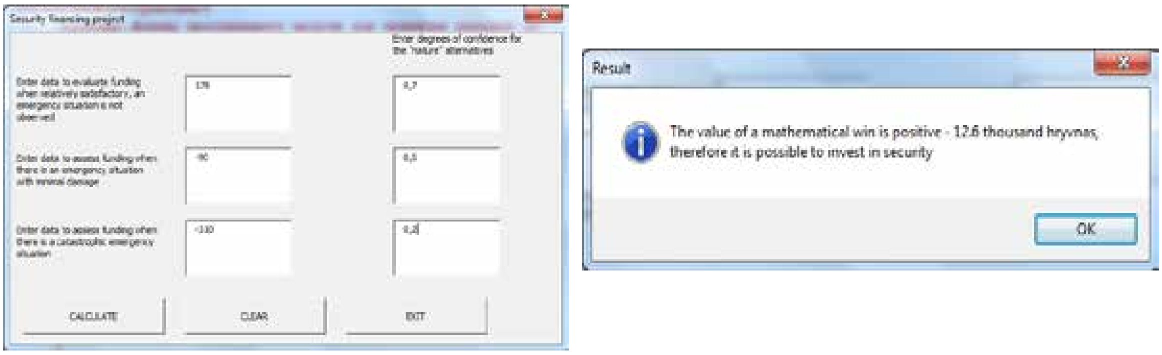
	B_1 (relatively satisfactory condition, no emergencies)	B_2 (emergency with minimal damage)	B_3 (catastrophic emergency)
A_1 (DM decides to invest in preventing emergencies)	Proceeds– 178 000 UAH	Loss – 90 000 UAH	Loss – 310 000 UAH
A_2 (DM decides not to invest in emergency prevention)	0	0	0
Degree of confidence for the alternatives of “nature”	0,7	0,5	0,2

The choice of the optimal solution of investment of material means for prevention of an emergency:

$$Q_1 = \frac{178 \times 0{,}7 - 90 \times 0{,}5 - 310 \times 0{,}2}{0{,}7 + 0{,}5 + 0{,}2} \approx 12{,}6$$

thousand UAH - the value is non-negative, it means that you can invest money in security. 12,6 thousand UAH - the value, the sign of which determines the choice of one or another alternative [3].

The screen forms of the program module for making decisions on security financing and disaster prevention are shown in Fig. 4.



Enter degrees of confidence for the "nature" alternatives

Enter data to evaluate funding when relatively satisfactory, an emergency situation is not observed: 178 | 0,7

Enter data to assess funding when there is an emergency situation with minimal damage: -90 | 0,5

Enter data to assess funding when there is a catastrophic emergency situation: -130 | 0,2

The value of a mathematical win is positive - 12.6 thousand hryvnas, therefore it is possible to invest in security

Fig. 4. The screen forms of the program module for making decisions on security financing and disaster prevention [3]

Conclusions. Systematic logically reasonable construction of failures of system elements that can lead to a failure requires a full understanding of the nature and operation of the system of possible failures of its elements.

Inclusion into the tree of failures the external causes further requires the understanding of the connection of the analyzed system with other technical systems and natural events. Together, this causes the involvement of special experts into the construction and analysis of fault trees.

The task of deciding to assess the risk of an emergency in the context of financial damage caused can be solved on the basis of a fuzzy game model.

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Аннотация. В наше время объединение усилий всех заинтересованных сторон и органов власти по подготовке и принятию обоснованных решений в области общественной безопасности, управления государством, территориями, природной средой приобретает особую актуальность. Систематически логически обоснованное построение элементов системы, которые могут привести к отказу, требует полного понимания характера и функционирования системы возможных отказов ее элементов.

Методы исследования. В статье рассматривается возможность использования логико-графических схем (дендрограмм) для правильной идентификации опасностей объектов. Задача принятия решения об оценке риска возникновения чрезвычайной ситуации в контексте причиненного финансового ущерба может быть решена на основе модели нечеткой игры.

Основные результаты исследования. Систематически логически обоснованное построение элементов системы, которые могут привести к отказу, требует полного понимания характера и функционирования системы возможных отказов ее элементов. Включение в дерево отказов внешних причин дополнительно требует понимания связи анализируемой системы с другими техническими системами и природными явлениями. В совокупности это вызывает привлечение специальных экспертов к построению и анализу деревьев отказов.

Научная новизна. Система основана на принципе выработки компромисса между точностью и простотой расчетов, поэтому существует возможность упрощенного расчета максимально возможного числа жертв в чрезвычайных ситуациях без значительной потери точности.

Практическая значимость. В наше время объединение усилий всех заинтересованных сторон и органов власти по подготовке и принятию обоснованных решений в области общественной безопасности, управления государством, территориями, природной средой приобретает особую актуальность.

Ключевые слова: *риск, оптимизация, чрезвычайные ситуации, нечеткая игровая модель.*

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Анотація. Сьогодні особлива актуальність набуває об'єднання зусиль усіх зацікавлених сторін і органів влади у підготовці та прийнятті обґрунтованих рішень у сфері громадської безпеки, уряду, територій, природного середовища. Систематична логічно обґрунтована конструкція елементів системи, що може призвести до відмови, вимагає повного розуміння природи і функціонування системи можливих відмов її елементів.

Методи дослідження. У статті розглядається можливість використання логіко-графічних схем для правильної ідентифікації небезпечних об'єктів. Завдання прийняття рішення про оцінку ризику надзвичайної ситуації в контексті фінансової шкоди може бути вирішено на основі нечіткої ігрової моделі.

Основні результати дослідження. Систематично логічно обґрунтована побудова елементів, системи, які можуть привести до відключення, вимагає повної розуміння характеру і функціонування можливих відказів її елементів. Включення до дерева відмов зовнішніх причин додатково вимагає розуміння зв'язку аналогічно-рухових систем з іншими технічними системами і природними явищами. В сукупності це викликає притягання спеціальних експертів до побудови і аналізу дерев відмов.

Наукова новизна. Система, заснована на принципах вираження компромісу між точністю і простотою розрахунків, тому існує можливість спрощеного розрахунку максимально можливого числа жертв у надзвичайних ситуаціях без значної втрати точності.

Практична значимість. У наш час об'єднання зусиль всіх зацікавлених сторін і органів влади з підготовки та прийняття обґрунтованих рішень в галузі громадської безпеки, управління державою, територіями, природним середовищем набуває особливої актуальності.

Ключові слова: *ризик, оптимізація, надзвичайні ситуації, нечітка ігрова модель.*

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