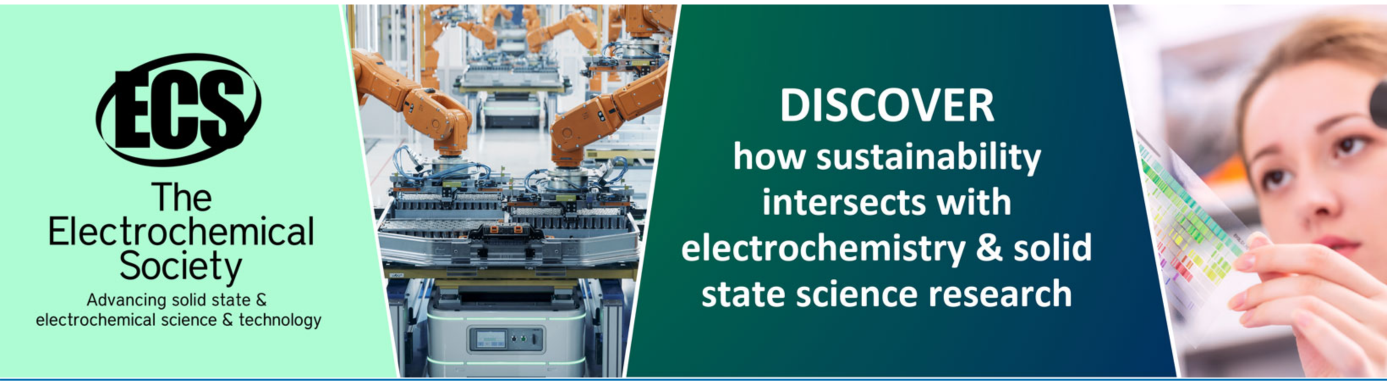
Risk Assessment of Accidents at Coal Mining Enterprises, Using the Automated System of Calculation of Fault Tree and Event



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Risk Assessment of Accidents at Coal Mining Enterprises, Using the Automated System of Calculation of Fault Tree and Event

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Abstract. The article deals with the methodological approach to the qualitative and quantitative analysis of the risk of a hazardous production facility, which is regulated by the current legal documentation in Russia. In this case, quantitative methods of failure tree analysis and event tree analysis are highlighted. The article shows possible variants of construction of listed trees for coal mines. The description of the automated system of calculation of trees of failures and events developed in Novokuznetsk Institute (branch) of Kemerovo state University is given. This software product allows you to build these trees with the help of Microsoft Visio, and then calculate the probability of failures and events that caused the accident at each site of the mine and the entire enterprise as a whole and draw up the results of the calculation in the form of a table in automatic mode. Examples of trees construction and results of calculation of probability of occurrence of failures and the events received with use of the described automated system for the concrete enterprise are resulted.

1. Introduction

An accident risk analysis is a process of identifying hazards and risk assessments of an accident at a hazardous production facility (HPF) for individuals or groups of people, property or the environment.

In accordance with the normative and legal documentation currently in force [1-5], the methodological approach to qualitative and quantitative risk analysis [7-9], as well as its estimations for HPF, including coal mines [9], provides the possibility of using of various tools (usage theory [10], probability theory methods and mathematical statistics [11, 12], checklist method and “What if ...?” method, method of species analysis, method of the consequences and criticality of failures, method of analysis of the danger and operability [13], method of studying hazards and performance [14], method of event trees and fault trees [6, 14 - 18], etc.) to identify and quantify all paths of occurrence of triggering events. In assessing risk it is also necessary to take into account cause-effect relationships (the “Domino” principle) [19]. Therefore, very often the most expedient in this case is the use for this purpose of the method of expert assessments [16, 20].

2. Material and methods

In accordance with the Safety Guide [3], the Fault Tree Analysis (FTA) method is used to analyze the possible causes of an accident and calculate its frequency (based on knowledge of the frequencies of the source events) .The structure of the failure tree includes one head event (usually an accident and /

or an incident), which is combined with a set of relevant downstream events (errors, failures, unfavorable external influences) forming causal chains (accident scenarios) .For links between events in “nodes” of trees one can use signs “AND” and “OR”. The AND sign means that the parent event occurs when the downstream events occur simultaneously (corresponds to the multiplication of their probabilities to evaluate the probability of the upstream event.) The OR sign means that a parent event can occur due to the occurrence of one of the subordinate (downstream) events. In the analysis of the failure tree, it is recommended to define the minimal combinations of events that determine the occurrence or impossibility of an accident (minimum throughput and cut-off combinations respectively).

The method of “Event tree analysis” (ETA) is a quantitative or semi-quantitative method, including the construction of a sequence of events outgoing from the main event, usually an accident at the HPF. The ETA method is used to analyze the development of an emergency situation. The frequency of each emergency scenario is calculated by multiplying the frequency of the main event by the conditional probability of the final event [3].

When assessing the risk of accidents at a coal-mining enterprise, it is necessary first to identify and describe the production and technological facilities that are part of this enterprise, for example: tunnel slaughter, mining slope, ventilation shaft, conveyor drift, etc. For each object, you need to specify dangerous factors and build failure and event trees. The number of trees is different for each object - from 2 to 20. One of the possible variants of the failure tree "Inadmissible gas accumulation" for a coal mine is shown in figure 1.

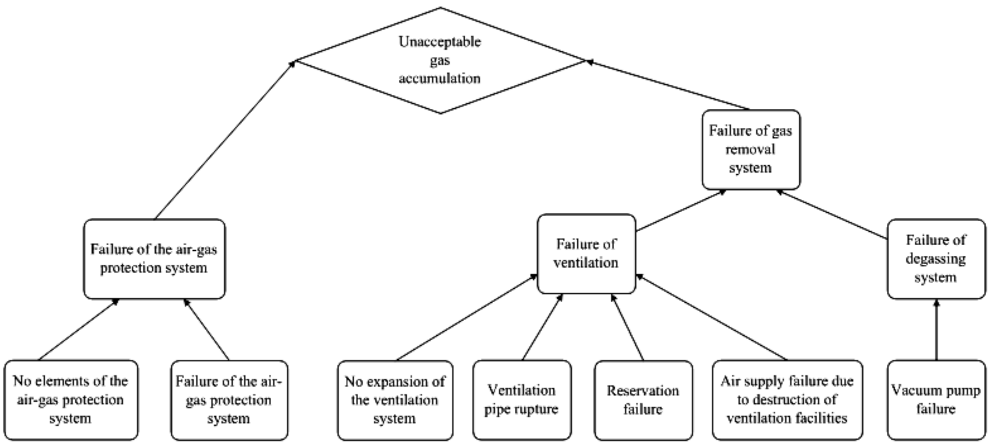

Figure 1. Failure tree “Inadmissible gas accumulation”.

Any scenario describing an emergency situation begins with an initiating event (sparking, short circuit, heating insulation, sensor failure, etc.), which may occur at some frequency. The following sources and methods can be used to determine the frequencies of initiating events:

-statistical assessment of the causes of accidents on the considered or similar objects;

-expert evaluation.

The probability of failures for each object in this case is calculated by the formula

$$P_{failure\ N} = 1-(1-P_1)\cdot(1-P_2)\cdot\ldots\cdot(1-P_m),$$

where $P_{failure\ N}$ is the probability of occurrence of initiating events on a specific object N, $P_1, P_2, \ldots, P_m$ are the total probabilities for a particular class of initiating events (for example, broken support, unacceptable gas accumulation, etc.)

Figure 2 shows an example of the event tree "The origin of a burning source" for a particular object.

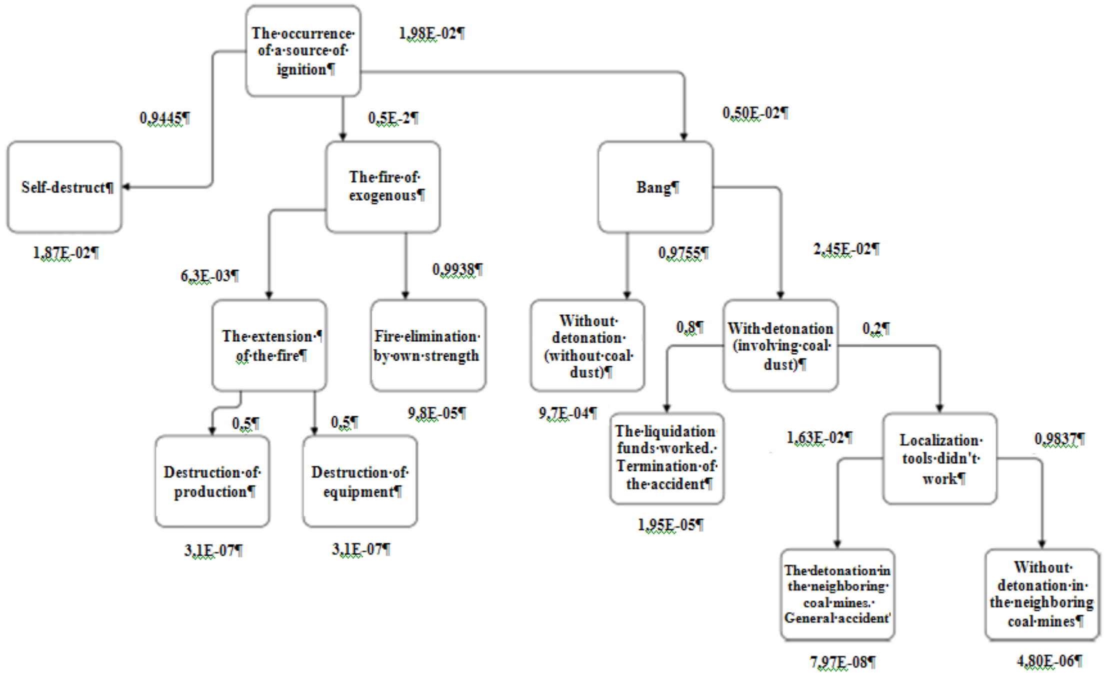

Figure 2. Event tree “The origin of an ignition source”.

3. Results and discussion

Obviously, carrying out calculations of failure trees and event trees manually is an extremely laborious operation, the execution of which can be accompanied by a large number of errors.

To eliminate this problem, the team of authors of the article developed an automated system for calculating failure trees and event trees. It allows you to build a tree using Microsoft Visio tools (figure 3), creating tree nodes and transitions between them with the parameters of each node (name, description and probability of the initiating event).

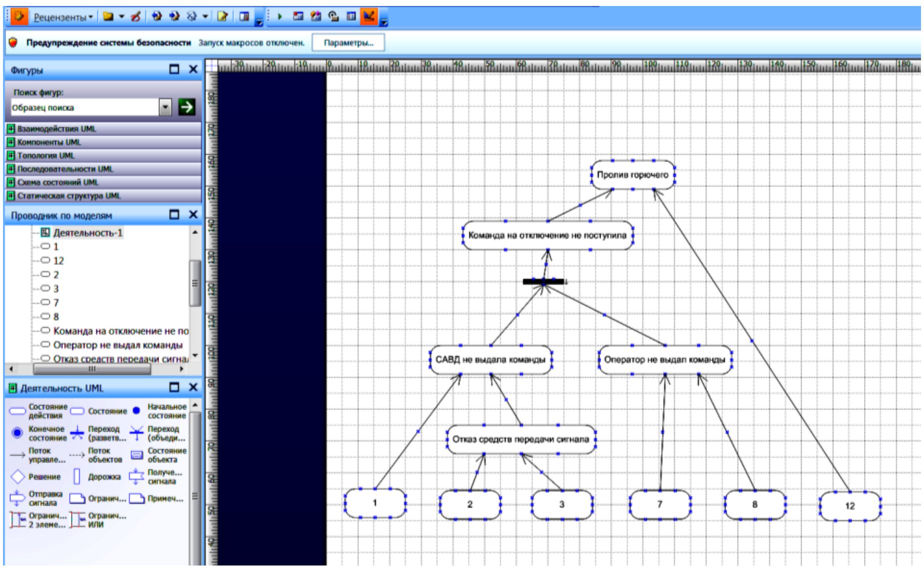

Figure 3. The result of creating a tree of failures using Microsoft Visio.

After building the tree, the system automatically calculates the probability of failure on each object and prepares its results in the form of a table (table 1).

Table 1. Result of calculating the probability of failure “Fire source” for a particular facility.

№	Combination	Probability
1	Failure of spark protection in electrical equipment P = 0,011111 Heating of cables and other equipment P = 0,001	1,11E-05
2	Failure of spark protection in electrical equipment P = 0,011111 Use of combustible materials P = 0,018182	2,02E-04
3	Failure of spark protection in electrical equipment P = 0,011111 Destruction of container P = 0,066667	7,40E-04
4	Heating of cables and other equipment P = 0,001 Use of combustible materials P = 0,018182	1,82E-05
5	Heating of cables and other equipment P = 0,001 Destruction of container P = 0,066667	6,67E-05
6	Use of combustible materials P = 0,018182 Destruction of container P = 0,066667	1,21E-03
	The total probability	2,25E-03 Average probability

Then, after establishing the links between technological objects and failures (figure 4), the probability of failures and their initiating events on the objects and the enterprise as a whole is calculated. The results of calculations are automatically processed in the form of tables (table 2 and table 3).

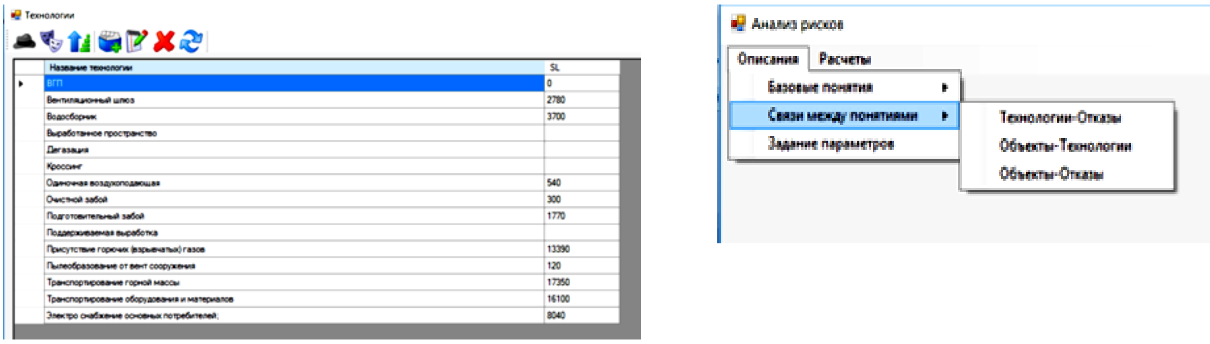

Figure 4. The sequence of creating links between technologies, objects and failures.

Table 2. The probability of failure on the objects and the enterprise as a whole.

Failure	Object 1	Object 2	Object …	Object 7	For the enterprise as a whole
Broken support		1,00E-03	…		2,89E-03 Average probability
Origin of fire	1,12E-05	2,66E-04	…		1,77E-03 Average probability
Inadmissible accumulation of gas	1,00E-08	7,57E-03	…	4,00E-06	3,64E-02 High probability
Inadmissible suspension of dust		5,71E-07	…		1,14E-06 Lowh probability
Inadmissible deposition of dust		2,75E-02	…		5,42E-02 High probability
Fire in the working space			…	2,13E-05	4,26E-05 Lowh probability
Relapse of exogenous fire			…	2,12E-05	4,86E-01 High probability
Fire/flash of methane			…	3,98E-06	2,62E-03 Average probability
Electric shock	1,00E-06	1,00E-06	…		5,00E-06 Lowh probability
Fall of equipment/stand	1,00E-06	1,00E-06	…		5,00E-06 Lowh probability
Subtotal	1,42E-05	3,60E-02	…	2,92E-05	5,35E-01 High probability

The data presented in this way makes it possible to easily identify the most likely accidents for each individual object and for the enterprise as a whole, as well as identify the objects most dangerous from the point of view of the emergence of conditions for the development of accidents.

Table 3. Probabilities of occurrence of accident initiating events on objects and the enterprise as a whole.

Initiating event	Object 1	Object 2	…	Object 7	For the enterprise as a whole
Failure - Emergence of source of ignition					
Exogenous fire, localized on my own	5,57E-07	1,32E-04	…		2,77E-04 Average probability
Exogenous fire, localized in object (destruction of equipment)	3,50E-09	4,16E-07	…		9,15E-07 Practically incredibly
Exogenous fire with subsequent development (destruction of production)		4,16E-07	…		8,32E-07 Practically incredibly
Gas explosion without coal dust	8,49E-08	2,01E-06	…		4,27E-06 Low probability
Explosion of gas with the participation of coal dust, localized in object		9,21E-13	…		1,84E-12 Practically incredibly
Gas explosion involving coal dust without detonation of dust on adjoining objects		2,14E-13	…		4,28E-13 Practically incredibly
Gas explosion involving coal dust with detonation in neighboring excavations		6,33E-15	…		1,27E-14 Practically incredibly
Failure - Ignition in the worked out space					
Endogenous Fire			…	2,13E-10	4,2646E-10 Practically incredibly
Termination of the combustion process			…	2,13E-05	4,2642E-05 Low probability

The automated system described in this article can be used for various hazardous production facilities, since it allows you to add new and edit existing trees, objects and technologies.

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