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ON THE QUESTION OF REDUCING THE RISK OF UNTIMELY DETECTION OF AN AEROLOGICAL EMERGENCY IN THE VENTILATION NETWORK OF A COAL MINE

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Abstract. The risks of an aerological emergencies can be of different nature, namely:

a) a working with a fire source can have a significant length and ramifications after it, so the signal from the sensor can provoke the introduction of a emergency elimination plan position that is different from the planned one;

b) if there are enough sensors, it is possible to reduce the risk by placing the sensors at intermediate points in order to ensure a predetermined fire detection time;

c) if there are not enough sensors, it is possible to reduce the risk by reducing the fire detection time by controlling several fire-hazardous areas with one sensor (although a certain risk remains).

Direct factors for calculating the risk of an event (the probability of its occurrence and the magnitude of the consequences) are unsuitable for assessing the risk of incorrect selection of the basis for emergency detection sensors, since they cannot be determined in advance. Therefore, in order to reduce it, it is necessary to proceed to assessing the risk using indirect factors that do not have a probabilistic form. The use of such indirect factors is the purpose of solving the problem of improving the assessment of the emergency risk of emergency control. This is precisely the novelty of the proposed approach.

The purpose of the article is to characterize methods for reducing the risk of untimely detection of an aerological emergency in the ventilation network of a coal mine. According to this purpose, the following tasks will be solved:

a) fire detection under the condition of a given detection time and the presence of an unlimited number of sensors in order to optimize it;

b) fire detection under the condition of a given available number of sensors and places for their possible installation in order to reduce the time for detecting an emergency.

Two possible statements of tasks for reducing the risk of untimely detection of an aerological emergency are characterized and methods for solving them are given. The presentation of the material is illustrated by control examples.

The indicator of risk reduction on the mine scale will be the maximum sensor response time in the event of an emergency in all mine workings that are dangerous by carbon monoxide. All other values will obviously be smaller. If this indicator exceeds the acceptable one, additional measures must be taken.

Keywords: aerological emergency, exogenous fire, indirect risk factors, carbon monoxide sensor, sensor basis.

1. Introduction

The task of detecting a fire, as the most common aerological emergency accompanied by the release of carbon monoxide [1], by fire gas detectors is part of the functioning of the emergency protection system (EPS) in the normal mode of coal mining, that is, at the time of the occurrence of a mine emergency. In the following, only exogenous fire will be considered.

For successful extinguishing of a fire and the use of other emergency measures, it is important to detect the focus of its development at the earliest possible stage. This requires sensors with high sensitivity, and therefore with a low threshold of operation and independence from the properties of the emergency gas-air environment [2–5].

Since the principle of operation of automatic fire detection devices is to measure physical quantities associated with the manifestation of its damaging factors, this can be most effectively carried out not by measuring the parameters of heat and mass transfer, but by the content of toxic volatile substances in the ventilation stream. Such properties are attributable for sensors-detectors that detect fires by changing of carbon monoxide concentration in the ventilation flow entering the sensor [1, 6–8]. It should be noted that the solution of the fire detection problem can be facilitated by assessing the changes in other components of the air-gas environment (carbon dioxide, hydrocarbons and other combustion products) [9 and others], however, such sensors have not found wide application in the mining industry. The same applies to determining the local change in the refractive index of air, the presence of smoke (aerosols), the attenuation and scattering of light rays, as well as changes in the optical background of the fire detection object, etc. [10 and others]. These factors can mainly be noted only by a person directly at the point of the mining operation under consideration, and do not belong to the category of research devoted to the creation of automatic (automated) fire detection means.

At present, the location of fire detection devices is carried out according to the principle: the sensor is installed at the final node of the working, where a fire may occur. Thus, the place of fire is determined with accuracy to a specific working and, based on this, measures are taken in accordance with the corresponding position of the emergency elimination plan (EEP).

However, this approach is not free from various types of risk of complicating the emergency situation, and therefore - from worsening the safety of miners working within the emergency area. The risks can be of different nature, namely:

a) the working with the source of the fire may have a significant length and ramifications after it, so the signal from the sensor may provoke the introduction of an EEP position different from the planned one;

b) if there are enough sensors - it is possible to reduce the risk by placing sensors at intermediate points in order to ensure a predetermined time for fire detection;

c) if there are not enough sensors, it is possible to reduce the risk by reducing the time to detect a fire by monitoring several fire-hazardous areas with one sensor (although a certain risk remains).

Direct factors of calculating the risk of an event (the probability of its occurrence and the magnitude of the consequences) are unsuitable for assessing the risk of incorrect selection of the basis of emergency detection sensors, since they cannot be determined in advance. Therefore, in order to reduce it, it is necessary to proceed to assessing the risk using indirect factors that do not have a probabilistic form. The use of such indirect factors is the goal of solving the problem of improving the assessment of the emergency risk of emergency control. This is precisely the novelty of the proposed approach. If standard risk assessment methods are not always sufficiently justified (it is difficult to explain an average user the difference in the probability of danger of 10^{-6} and 10^{-5} - both are too small), it will be much clearer to assess indirect factors, namely:

a) the amount of air $Q(i, j)$ entering the sensor installation site in the working (i, j). It is known in advance from the materials of air-depression surveys or current measurements in the period between their conduct. $Q(i, j)$ together with the length of the working $L(i,j)$ and its cross-sectional area $S(i, j)$ determines the air velocity $v(i, j)$ in the working;

b) the concentration $C(i, j)$ of carbon monoxide in the working. The possibility and time of the sensor operation depends on the correctness of its determination, that is, directly, the risk of taking erroneous emergency measures. After all, the sensor will operate if the carbon monoxide concentration exceeds its sensitivity threshold, which depends on the speed *v(i, j)* of reaching the sensor by fire gases with a critical concentration.

It should be noted that indirect risk factors can also include the flow rate of gases coming from the emergency site. Thus, a ventilation stream with a flow rate greater than in normal ventilation mode will reach the sensor. On the one hand, this will accelerate the sensor operation, and on the other hand, there are currently no (and are unlikely to ever appear) measuring devices for this emergency application. Therefore, this indirect factor will be necessarily disregarded.

The use of indirect risk factors is more justified and understandable to the user. Their optimal values obtained according to a certain criterion will correspond to the minimum risk value in a given situation (possibly not optimal: this depends on the selected optimality criterion). Their use provides a qualitative assessment of risk, contributing to the subsequent quantitative assessment of risk (although they do not provide an opportunity to obtain a specific value of the latter).

The purpose of the article is to characterize methods for reducing the risk of untimely detection of an aerological emergency in the ventilation network of a coal mine. According to this purpose, the following **tasks** will be solved:

a) fire detection under the condition of a given detection time and the presence of an unlimited number of sensors in order to optimize it;

b) fire detection under the condition of a given available number of sensors and places of their possible installation in order to reduce the time of emergency detection.

Solving both problems will help to reduce the risk of untimely emergency detection using indirect risk factors.

2. Methods

To solve the problems, methods of approximate calculations, mathematical programming, fuzzy set theory and fuzzy logic will be used. Experimental studies were conducted on control examples.

3. Theoretical part

The problem of detecting the place of occurrence of an emergency, depending on the available information in the design conditions of this element of the EPS, can be formulated in different statements.

Problem 1. Let the time required for fire detection τ_{det} and the list of mine shafts in which carbon monoxide detectors can be installed be given for practical reasons. It is necessary to find the places for installing the sensors that minimize their number.

Problem 2. Let the total number N of fire gas detectors and the list of mine shafts in which they can be installed be given. It is necessary to find the locations of the sensors that provide the minimum τ_{det} and the value of this time.

In this case, the following assumptions are made:

a) since the emergency detection is carried out in the initial period and precedes the adoption of measures to establish an emergency ventilation mode, the emergency detection time is determined by *υ(i, j)* in the emergency working under normal ventilation mode at the time of the emergency;

b) the flow structure of the graph describing the mine ventilation network (MVN) and determined by the directions of air movement is unchanged when solving the problems;

c) the emergency is considered detected when an air jet gassed with carbon monoxide with a critical concentration crosses the cross-section of the working at the sensor installation location;

d) the air-gas distribution in the network is calculated according to two Kirchhoff laws.

In the above assumptions, the task of synthesizing a system of fire gas detection sensors is to determine the locations of their installation, which will reduce the risk of untimely detection of an emergency within a given time by a minimum number of them.

Analysis of the processes of liquidation of exogenous fires that occurred in mines of the Ministry of Coal Industry of Ukraine in 2020–2023 showed that the time τ_{det} in a number of cases exceeds 30 min. Then gaseous products can penetrate into potentially non-threatening areas of the mine, the emergency evacuation of people from which is provided for by the EEP, differs from what is required in the current situation. As the analysis showed, in most cases $0 \leq \tau_{det} \leq 30$ min is acceptable (most often the left boundary of the interval is within 18 min). In real conditions, a certain basis of sensors-detectors in mines exists, therefore task 2 is more relevant for this case. Actually, it can be considered a design task.

Direct task of choosing the basis of sensors-detectors of fire gases

A number of works is devoted to the issue of detecting the ignition source in an exogenous fire. They were mainly reduced to solving the problem when the required time for detecting a fire in the mine and the place of possible installation of CO detectors are given, and it is necessary to determine their number. At the same time, a number of issues of changing the speed of air flows due to the entry of technogenic methane and fire gases into the ventilation stream, which comes from the emergency area, were not taken into account. The proposed methods also did not take into account the change in the cross-section of mining workings as they are driven and used, which also causes a change in the speed of gas flow to the sensor and, as a result, the time of detection of the ignition source. These factors can significantly affect the level of risk of taking erroneous emergency measures.

MVN may contain workings of the following types:

a) workings, in which a fire may occur and the installation of sensors is possible - set Θ_1

b) workings, in which a fire may occur but the installation of sensors is impossible - set Θ_2;

c) workings, where a fire cannot occur and sensors cannot be installed – set Θ_3 It includes workings impassable for people: wells, some rising ones, etc.;

d) workings, in which a fire cannot occur, but the installation of sensors is possible (some workings from among those that are not fixed or fixed with non-combustible fasteners) – set Θ_4,

In specific mines, one or another set, except for Θ_1, may be absent.

The listed sets satisfy the following conditions:

$$\Theta_1 \cup \Theta_2 \cup \Theta_3 \cup \Theta_4 = \Theta;$$

$$\Theta_i \cap \Theta_j = \varnothing, i, j = 1, 2, 3, 4.$$

Note that the workings $(i,j) \in \Theta_3$ can be excluded from consideration as not subject to control, and $(i, j) \in \Theta_4$ (their sensors can be replaced with sensors in the workings $(i', i) \in \Theta_1$,, or $(j, j') \in \Theta_1$ (the direction of air movement in the working is taken from the first node to the second), which, without changing their total number, only minimizes τ_{det}

It is advisable to start calculating the location of the sensors from the general outlet stream of the mine and conduct it against the direction of the ventilation stream. The first sensors will then be installed at the end of $(i, j) \in \Theta_1$, $j \in M_1$ – the set of terminal nodes of the ventilation shafts (suction ventilation mode). In the future, the location of the next sensor will be determined by fulfilling the following conditions:

a) if $L(i, j) / \upsilon(i, j) > \tau_{det}$, where $\upsilon(i, j)=Q(i, j) / S(i, j)$, $L(i, j) / \upsilon(i, j) > \tau_{det}$ where $\upsilon(i, j)=Q(i, j) / S(i, j)$, then the sensors are installed along the length of the working with a step $D = \upsilon(i, j)\tau_{det}$, until

$$\tau(i, j^{(\partial)}) = \frac{L(i,j) - \left[\frac{L(i,j)}{\upsilon(i,j)\tau_{det}}\right]D}{\upsilon(i,j)} \le \tau_{det}, \quad (1)$$

where $j^{(\partial)}$ is the location of the next sensor. Square brackets mean taking the integer part of the expression enclosed in them. Otherwise, in expression (1) we take $D = 0$;

b) when passing through node i, the location of the next sensor is determined by time

$$\tau' \le \tau_{det} - \tau(i, j(\partial)), \quad (2)$$

where $\tau(i, j^{(\partial)})$ is the distance from the beginning of the working to the place of installation of the previous sensor. The absence of exact equality is caused by the possibility of two situations. In the first case (i, j) is the only one that comes out of i working. If at the same time $\forall (i', i) \in \Theta_1$, then the places of installation of the sensors in (i', i) are determined from the expression (2), in which exact equality takes place, taking into account the fact that

$$\frac{L(i^{(\partial)},i)}{\upsilon(i',i)} = \tau'.$$

If under the same condition $\exists\,(i'', i)$, that

$$Q(i',i) << Q(i',i), \tag{3}$$

then during a fire in (i'', i) a situation may arise

$$\frac{\Sigma C(i_k,i)Q(i_k,i)}{\Sigma Q(i_k,i)} < C_\partial,$$

where C_∂ is the sensitivity threshold of the sensor used. In this case, the sensor in (i, j) will not work and the fire in the interval $(i^{(\partial)}, i)$ will not be detected. It is necessary to install the sensor at the end of $(i^{(\partial)}, i)$ and perform further calculations with respect to it.

If $\exists(i', i) \in \Theta_2$, then $i^{(\partial)} = i$ (before merging with fresh jets) and consideration in the direction (i', i) is terminated.

In the second case $\exists(i, j') \neq (i, j)$. In this case, in expression (2) there is an inequality, which can be replaced by

$$\tau' = \tau_{det} \min_k \left\{ \frac{L(i, j_k^{(\partial)})}{v(i, j_k)} \right\}$$

Regarding the sensors located at points $i^{(\partial}$ of the workings $(i_\kappa, i) \in \Theta_1$, the consideration continues according to the described scheme. The calculation ends when all

$$\frac{L(i_k, j_k^{(\partial)}}{\upsilon(i_k, j_k)} \le \tau_{det},\ i_k \in M_2,$$

where M_2 is the set of initial nodes of the air supply trunks.

Studies showed that there is a single functional dependence that allows finding the installation locations of the following sensors L_j based on the known installation locations of the previous ones with automatic fulfillment of the conditions listed above. It has the form

$$L_j = \upsilon(i^{(\partial)},i)\tau_{\text{det}} + \min_{\tau_k}\left(1 - \frac{\upsilon(i',i)}{\upsilon(i_k,j_k)}\right)\left(\sum_{(i_k,j_k)\in\mu} L(i_k,j_k) - \sum_{k\in\mu} L_k\right), \tag{4}$$

where $\mu(i,j)$ – the route of movement of fire gases from i to j ; τ_κ – the time of operation of the nearest sensor in case of fire occurrence in node i; $\mu=\min_{\tau^*} \mu(i,j)$, $j \in M_1 \cup M_3 \setminus (M_1 \cap M_3)$; τ^* – the time of movement of fire gases from node i to node j; M_3:{i', $(i', j') \in \Theta_2$,}.

This dependence satisfies all the above conditions. Namely, by accepting that $\upsilon(i', i) = \upsilon(i, j_\kappa)$, we have $L_j = \upsilon(i', i)\tau_{det}$, $L_j = \upsilon(i', i)\tau_{det}$,, which corresponds to the placement of sensors along the length of the working, The presence of condition (3) corresponds to the case

$$L'_j = \lim_{\upsilon(i,j)\to 0} L_j = \min_{\tau_k}\left(\sum_{(i_k,j_k)\in\mu} L(i_k, j_k) - \sum_{k\in\mu} L_k\right);$$

but the expression in parentheses is the distance from the previous sensor to the beginning of the working in which it is installed; therefore, the next sensor is installed at node i. If there is only one working (i, j) coming from node i, expression (4) takes the form

$$L_j = \upsilon(i',i)\tau_{\det} + \left(1 - \frac{\upsilon(i',i)}{\upsilon(i,j)}\right)\left(\sum_{(i_k,j_k)\in\mu} L(i_k, j_k) - \sum_{k\in\mu} L_k\right). \tag{5}$$

Using the given relations, it is possible to determine the location of all sensors in the MVN by means of similar calculations. It is just necessary to take into account that if the MVN has the workings $(i,j)\in\Theta_2$, $\frac{L(i,j)}{\upsilon(i,j)} > \tau_{\det}$ the solution to the problem will be inaccurate, since

$$\tau_{\det}^{real} = \max\left\{\tau_{\det}\frac{L(i,j)}{\upsilon(i,j)}\right\}, \quad (i,j)\in\Theta_2. \tag{6}$$

Selection of the basis of sensors when limiting its dimensionality

The simplest and most acceptable method for solving the problem is the analog method of random search, the essence of which is as follows.

The initial value τ_{det} is selected and problem 1 is solved for it. Let N_1 sensors be needed. If $N_i = N$, this is the solution to the problem. If $N_1>N$, then it is necessary to increase, and if $N_L < N$ - to decrease τ_{det} and repeat the calculations τ_{del}. The number of steps of such an iterative method is determined by the accuracy of the initial approximation, the accuracy of the calculation and the principle of choosing the next value of τ^1_{det}.The initial approximation can be chosen by the formula

$$\tau_{det} = \left(\sum_{(i,j)\in\Theta_1} \frac{L(i,j)}{\upsilon(i,j)}\right) : N. \tag{7}$$

However, it is not accurate enough. Namely, let the sensor (i_l, j_1) (i_l, j_1) be installed at the point i_2 and $\exists(i_3, i_1) \in \Theta_2$, $\exists(i_4, i_1) \in \Theta_2$. If $\frac{L(i_1, i_2)}{L(i_1, j_1)} < \tau_{det}$., then the sensor will monitor the sections of the workings (i_3, i_1) and (i_3, i_1) with length

$$L\left(i_3^{(\partial)}, i_1\right) = \left[\tau_{det} \frac{L(i_1, i_2)}{\upsilon(i_1, j_1)}\right] \upsilon(i_3, i_1);$$

$$L\left(i_4^{(\partial)}, i_1\right) = \left[\tau_{det} \frac{L(i_1, i_2)}{\upsilon(i_1, j_1)}\right] \upsilon(i_4, i_1).$$

In this case, for the three workings under consideration, in formula (7) it is possible to replace $L(i_l, j_1) + L(i_3, i_1) + L(i_4, i_1)$ with a smaller value

$$L(i_1, j_1) + L(i_3, j_1) + \left\lfloor L(i_4, j_1) - L\left(i_{4(\partial)}, i_1\right)\right\rfloor \tag{8}$$

Similarly, if $\exists(i_1, j_2) \in \Theta_2$,, which has a sensor at the point $\frac{L(i_1.i_7)}{\upsilon(i_1, j_2)} < \tau_{\det}$, then

$$L(i_3^{(d)}, i_1) = \left[\tau_{det} - min\left\{\frac{L(i_1, i_2)}{v(i_1, i_2)}, \frac{L(i_1, i_7)}{(i_1, j_2)}\right\}\right] v(i_3, i_1)$$

and the sum included in (7) has the form (8). If there are many such nodes, which is typical for the MVN, the minimization of the numerator (7) will be significant and the degree of accuracy of the initial approximation is high. But the analytical definition of segments $(i_3^{(\partial)}, i_1)$ and $(i_4^{(\partial)}, i_1)$ impossible, because when solving the problem, value of τ_{det} is unknown. One should limit oneself to the initial approximation (7), compensating for its insufficient accuracy with an effective method of calculating the correction $\Delta\tau_{\det}^i = \left|\tau_{\det}^{i-1} - \tau_{\det}^i\right|$ in order to obtain a solution in the minimum possible number of steps. $\Delta\tau^{\kappa}_{det}$ meets these requirements well enough and is calculated by the formula

$$\Delta\tau_{det}^k = ((N_k - N) \sum_{(i,j) \in \Theta} \frac{L(i,j)}{\upsilon(i,j)}) : 2NN_k, \tag{9}$$

where k is the iteration number.

The minimum number of sensors required to detect a fire is equal to the dimension of the set M_1. The time for detecting a fire is

$$\tau_{det} = \max_m \left\{ min \sum_{(i_k, j_k) \in \mu(i^m, j^l)} \frac{L(i_k, j_k)}{\upsilon(i_k, j_k)} + \frac{L(i^m, j^l)}{\upsilon(i^m, j^l)} \right\} \upsilon(i_3, i_1); \tag{10}$$
$$j^l \in M_1; (i, i^m) \in \Theta_2.$$

Routes $\mu(i^m, j^l)$ in the case under consideration are minimal in terms of the time of movement of fire gases along them. The second term in formula (10) may be absent.

4. Results and discussion

The presented method for solving the first problem can be illustrated by a control example of the MVN presented in Fig. 1.

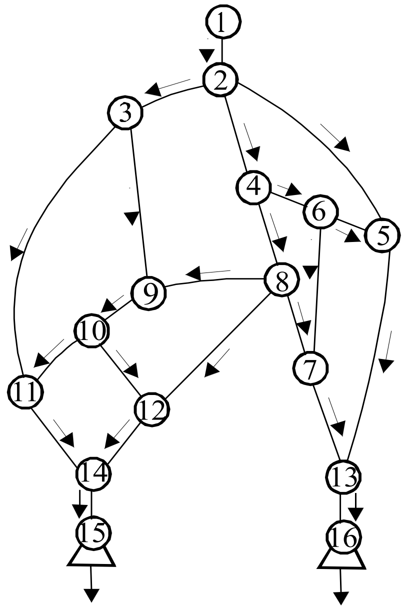

Figure 1 – Determining the installation locations of fire gas sensors

The initial data are given in Table. 1.

Table 1 – Input data for solving the first problem

Starting node	End node	Product length, m	Cross-sectional area, m^2	Air consumption in production, m^3
1	2	500.0	45.2	3000.0
2	3	500.0	25.2	1400.0
2	5	650.0	20.0	600.0
2	4	400.0	10.5	1000.0
3	9	50.0	10.5	100.0
3	11	740.0	8.0	1300.0
4	8	610.0	8.2	600.0
4	6	600.0	6.4	400.0
6	5	550.0	6.5	380.0
6	7	400.0	0.5	20.0
8	9	50.0	0.4	20.0
9	10	1100.0	6.2	120.0
10	11	100.0	0.1	5.0
8	12	1192.0	6.5	280.0
8	7	288.0	6.0	300.0
5	13	540.0	7.4	980.0
7	13	250.0	10.0	320.0
10	12	300.0	5.5	115.0
11	14	1200.0	10.1	1305.0
12	14	180.0	10.0	395.0
14	15	100.0	18.5	1300.0
13	16	100.0	18.5	1700.0

Let us also assume that C_{∂} = 0,005%, τ_{det},=5 min. , θ_2: (4, 8), (6, 5), (9, 10); $\theta_3 = \varnothing$: θ_3: (6,7), (8,9); θ_1: remaining workings.

The first sensors are installed in nodes 16 (sensor No. 1) and 15 (sensor No. 2). The time of passage of fire gases through the workings (14, 16) is 1.073 min.

Since there is no change in concentration in node 14, the sensors are installed in the workings (11, 14) and (12, 14) at a distance from the first sensor *L*3 = 606 m, *L*4 = 255 m. Similarly, *L*2 (13, 15) = 1.406 min and *L*5 = 214 m, *L*6 = 574 m. Thus, sensor No. 1 monitors the workings (14, 16), 506 m of the workings (11, 14) and 155 m of the workings (12, 14), etc.

The results of calculations for determining the location of other sensors are summarized in Table. 2.

Table 2 - Results of solving the problem

Sensor number	Installation location	Controlled area	Notes
3	(11, 14)	646 m (11, 14)	
4	(12, 14)	25 м (12, 14), 91 m (10, 12), 188 m (8, 12)	
5	(7, 13)	136 m (7, 13), 38 m (8, 7)	(6, 7) is not controlled
7	(5, 13)	66 m (5, 13), 135 m (2, 5)	
8	(11, 14)	48 m (11, 14), (3, 11)	
9	(10, 12)	104,5 m (10, 12)	
10	(8, 12)	226 m (8, 12)	
11	(8, 7)	250 m (8, 7)	
12	(2, 5)	150 m (2, 5)	
	(6, 5)	(6, 5)	Sensor at node 5
13			$\tau_{\det}^{real}$ = 9.4 min
14	(4, 6)	312 m (4, 6)	Sensor at node 6
15	(10, 12)	104,5 m (10, 12)	
16	(10, 11)	(10, 11)	Sensor at node 11
17	(9, 10)	(9, 10)	
18	(8, 12)	226 m (8, 12)	
19	(8, 12)	226 m (8, 12)	
20	(4, 8)	(4, 8)	Sensor at node 8
			$\tau_{\det}^{real}$ = 8.3 min
21	(3, 9)	48 m (93,90	Sensor at node 9
22	(2, 5)	150 m (2, 5)	
23	(2, 5)	150 m (2, 5)	
24	(2, 5)	65 m (2, 5), 188 m (1, 2)	
25	(4, 6)	288 m (4, 6), 37 m (2, 4)	
26	(2, 4)	363 m (2, 4), 2 m (3, 9)	
27	(3, 9)	2 m (3, 9), 272 m (2, 3)	
28	(2, 3)	228 m (2, 3)	
29	(1, 2)	312 m (1, 2)	

The real time of fire detection in the MVN is 9.4 min.

The control example, of course, does not correspond to the conditions of real mines; it is used just to improve the quality of illustrative material and prove the universality of the method. No one will undertake to monitor a fire-hazardous section of a mining workings with an accuracy of up to 2 m, or to install several sensors along the length of one working (with rare exceptions). τ_{det} deliberately underestimated, and the lengths of the workings, on the contrary, are overestimated.

The method allows to control fire-hazardous sections of the MVN with any degree of accuracy; to achieve an acceptable result, it is just necessary to change τ_{det} An illustrative example is also the finding of an uncontrolled working (6, 7); it indicates the need to revise the organization of fire detection in the MVN section under consideration.

Let us consider the application of the method for solving problem 2 on the example described above at $N = 8$. For simplicity, we will assume that all workings belong to $\Theta_{1.}$ According to (7), τ_{det} will be approximately equal to 22.5 min. Using the algorithm for solving the first problem, we can form table 3, similar to table 2.

Table 3 – Results of solving problem 2

Sensor number	Installation location	Controlled area
1	(14, 16)	(14, 16), (11, 14), (3, 11), (12, 14), (10, 12), 737 m (8, 12), (10, 11), 195 m (9, 10)
2	(13, 16)	(13,16), (7, 13), (8, 7), (6, 7), (5, 13), (6, 5), 491 m (4, 6), 510 m (2, 5)
3	(9, 10)	434 m (9, 10)
4	(9, 10)	434 m (9, 10)
5	(9, 10)	33 m (9, 10), (3, 9), (2, 3), (8, 9), (4, 8)
6	(8, 12)	455 m (8, 12)
7	(4, 6)	109 m (4, 6), (2, 4)
8	(2, 5)	140 m (2, 5), (1, 2)

Since the first iteration of sensors requires less than what is available, it is necessary to adjust τ_{det}. From expression (9), it will be equal to $\tau^2_{det}=\Delta\ \tau^2_{det}+\ \tau^1_{det}$ = 19.7 min.

Repeating the calculations similar to those carried out to form Table 2, we obtain the solution to the problem; τ_{det}.can be taken equal to 19.7 min.τ 5.

5. Conclusion

Reducing the risk of taking erroneous emergency measures during the occurrence of an abnormal aerological situation consists in optimizing the time of its detection. If there are enough sensors that can be installed in the mine workings, this time can be reduced as much as possible. Otherwise, the risk depends on implicit factors (in particular, the speed of ventilation flows in the workings and the concentration of carbon monoxide in them), which will allow determining the locations of sensor installations in such a way that fire detection occurs as quickly as possible. The maximum sensor response time will be an indicator of risk reduction on a mine scale. All other values will obviously be smaller. If this indicator exceeds the acceptable one, additional measures must be taken.

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ДО ПИТАННЯ ПРО ЗНИЖЕННЯ РИЗИКУ НЕСВОЄЧАСНОГО ВИЯВЛЕННЯ АЕРОЛОГІЧНОЇ АВАРІЇ У ВЕНТИЛЯЦІЙНІЙ МЕРЕЖІ ВУГІЛЬНОЇ ШАХТИ

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Анотація. Ризики аерологічної аварії можуть мати різну природу, а саме: а) виробка з джерелом пожежі може мати значну протяжність і розгалуженість після нього, тому сигнал з датчика може провокувати введення до дії позиції ПЛА, відмінної від запланованої; б) якщо датчиків достатньо – можливе зниження ризику за рахунок розташування датчиків у проміжних точках з метою забезпечення заздалегідь заданого часу виявлення пожежі; в) якщо датчиків недостатньо – можливе зниження ризику за рахунок зниження часу виявлення пожежі шляхом контролю одним датчиком кількох пожежонебезпечних ділянок (хоча певний ризик при цьому залишається).

Прямі чинники розрахунку ризику події (імовірність її виникнення і величина наслідків) для оцінки ризику неправильного вибору базису датчиків виявлення аварії непридатні, оскільки не можуть бути завчасно визначені,. Тому з метою зниження його необхідно переходити до оцінки ризику за непрямими чинниками, що не мають ймовірнісної форми. Використання таких непрямих чинників і є метою вирішення задачі вдосконалення оцінки аварійного ризику контролю аварійної ситуації. Саме у цьому і полягає новизна пропонованого підходу.

Метою статті є характеристика методів зниження ризику несвоєчасного виявлення аерологічної аварії у вентиляційній мережі вугільної шахти Згідно цієї мети вирішуватимуться наступні задачі:

а) виявлення пожежі за умови заданого часу виявлення і наявності необмеженої кількості датчиків з метою її оптимізації;

б) виявлення пожежі за умови заданої наявної кількості датчиків і місць їх можливого встановлення з метою скорочення часу виявлення аварії.

Охарактеризовано дві можливі постановки задач зниження ризику несвоєчасного виявлення аерологічної аварії і наведено методи їх вирішення. Викладення матеріалу ілюстровано контрольними прикладами.

Показником зниження ризику у масштабі шахти буде максимальний час спрацьовування датчика за умови виникнення аварії в усіх аварійно небезпечних за оксидом вуглецю виробках шахти. Усі інші значення будуть, очевидно, меншими. Якщо цей показник перевищує прийнятний – необхідне залучення додаткових заходів.

Ключові слова: аерологічна аварія, екзогенна пожежа, непрямі чинники ризику, датчик оксиду вуглецю, базис датчиків.