Searching the Optimal Combination of Fire Risks Reducing Measures at Oil and Gas Processing Facilities with the use of Genetic Algorithm

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Abstract: The search for the combination of fire risk-reducing measures at oil and gas processing facilities is a complicated task. There may be a large number of measures to reduce fire risks which need to be optimized, both technically and economically. The analysis of the existing programs for risk assessment has been conducted. The structure of database with the values of risk-reducing measures has been worked out. To reduce the time required for this task, a genetic algorithm approach has been proposed.

1 INTRODUCTION

At present, there are a lot of quantitative risks assessment systems, which can qualitatively determine explosion and fire dangerous factors in the territory of oil and gas processing facilities. As a rule, after risks assessment procedures, risk values are inappropriate. In these cases, some measures for reducing risk values are required. There can be a lot of measures for reducing risk values (installation of alarm system, automatic fire extinguishing system, a decrease in stored material, etc.). In most cases, one measure is not enough. It is necessary to find a set of measures that maximally reduce fire risk values and do not require a lot of expenses. Fire risks values may be different in each case of a combination of risk values reducing measures. Each situation requires risk assessment procedures, but risk assessment procedure requires a lot of operations and time. So, the number of the procedures of risks assessment will grow in geometric progression with the amount of objects on the territory (figure 1). Special algorithm for optimization of combinations of measures for reducing risk values has been developed. In the paper presented, the risk acceptance criteria approach when using genetic algorithms for searching optimal combination of fire risk-reducing measures at oil and gas processing facilities.

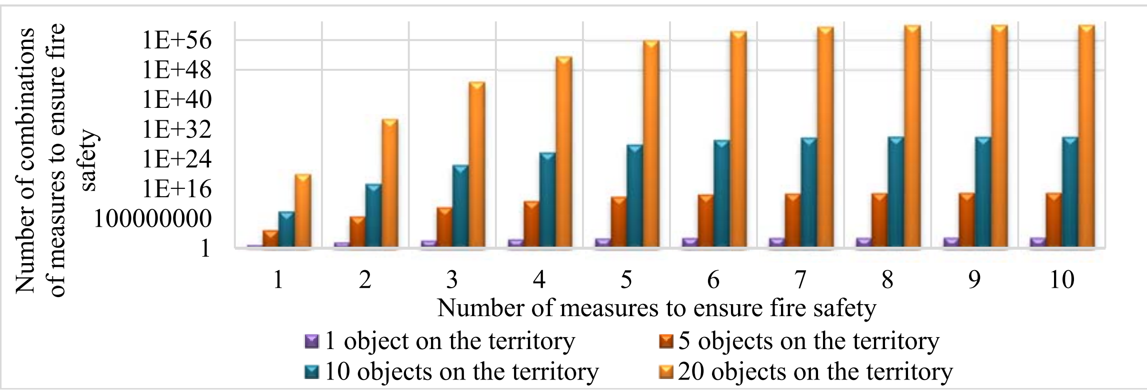

Figure 1: Number of combinations of measures to ensure fire safety.

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2 RELATED WORKS

Risk management has become a vital topic both in academia and practice during the past several decades(Desheng, Shu-Heng, David, 2014). When evaluating safety of projects, it is common to use risk acceptance criteria to support decision-making (Abrahamsen and Aven, 2008). However, the analysis of the existing fire risk estimation software (Gudin and Khabibulin, 2015) showed that the systems of fire risks assessment do not contain special methods and algorithms, which make it possible to find a combination of measures for reducing fire risk values.

One of the existing methods for solving optimization problems is genetic algorithms used to solve a lot of decision-making problems with great amount of information (Xuancai et al., 2016). Many scientists came to the conclusion that genetic algorithms can be used in solving complex tasks (Martorell et al., 2005; Ramirez et al., 2009). Besides, their effectiveness as to the optimization were highlighted in many studies (Panov and Shary, 2011; Schaefer, 2012; Sergienko, 2009).

One of the methods of using genetic algorithms has been already presented (Caputo et al., 2011). This method is used in searching for the economic optimum risk level. It is based on the minimization of total expenses. After the experiments, the authors show that he can solve that problem quite well. Reduction in expenses is an important task, but the first task is to provide fire safety, because it directly influences the safety plant workers and people living in residential areas.

Upon the review of the related works, it was identified that genetic algorithm can solve the problem of searching for the best combination of measures for reducing fire risk values with risk acceptance criteria.

3 GENETIC ALGORITHM FOR FINDING COMBINATIONS IN ORDER TO REDUCE RISK VALUES

For the purposes of analysis of most of the events stored in the database, comprehensive assessment of fire risks should be conducted when analyzing each event, except for specific associated cases. For example, with the time that people spend in the building, when the values of individual fire risk would change only by factoring the probability of the people being there. In such cases, comprehensive risk estimation is not required, and such exceptions should be included into the program code separately.

In general, the genetic algorithm model proposed by John Holland (Holland, 1975) was used. For crossing of chromosomes a method with a single point of exchange was used. Mutation procedure was slightly modified for searching the combination of fire risk-reducing measures.

First of all, after crossing, there may be identical gens in the chromosome. It is necessary to have only unique gens in the chromosome. So, all identical gens are going to mutate, except for one.

To add more, a special method was invented to form the first population. It consists of 2 steps:

1) Evaluating the effectiveness of measures;

2) Generation chromosomes by using the roulette wheel method.

To create combinations with different number of measures added the operation for accidentally deleting of chromosome.

3.1 Objective Function

One of the obligatory criteria of the genetic algorithm use is an objective function presenting quantification of the efficiency of computed solutions. The suggested objective function consists of three parameters:

1. The amount of fire risks calculated values in the territory of an enterprise, which does not exceed acceptable values (Q).
2. The parameter of average deviation of infeasible calculated values of fire risks in the territory of oil and gas facility and the adjacent residential zone from the acceptable values (D).
3. Reduced cost of measures (P).

The following formula is used for the calculation of the amount of acceptable fire risks values in the territory of oil and gas facility:

$$Q = \sum_{j=1}^{J} \left(\alpha(R_j)\right) + \sum_{m=1}^{M} \left(\beta(I_m)\right) + \gamma(S), \quad (1)$$

Where:

$$\alpha(R_j) = \begin{cases} 1, \; x \leq R_a \\ 0, \; x > R_a \end{cases}; \quad (2)$$

$$\beta(I_m) = \begin{cases} 1, \; x \leq I_a \\ 0, \; x > I_a \end{cases}; \quad (3)$$

$$\gamma(S) = \begin{cases} 1, \ x \leq \ S_a \\ 0, \ x > S_a \end{cases}; \tag{4}$$

R – Final value of an individual fire risk for the workers of the enterprise;
J – Amount of workers on the enterprise;
I – Final value of individual fire risk for people located in housing, social, and business or recreation areas;
M – Amount of facilities with people in residential zone;
S – Final value of social fire risks quantity for people located in housing, social, and business or recreation areas;
R_a – Acceptable value of individual fire risk quantity for the workers of enterprise;
I_a – Acceptable value of individual fire risk quantity for people located in housing, social, and business or recreation areas;
S_a – Final value of social fire risk quantity for people located in housing, social, and business or recreation areas;
α – Acceptable criterion of value as to individual fire risk quantity for the workers of the enterprise;
β – Acceptable criterion of value of individual fire risk quantity for people located in housing, social, and business or recreation areas;
γ – Acceptable criterion of value of social fire risk quantity for people located in housing, social, and business or recreation areas;
Q – Amount of fire risks quantity acceptable within the framework of the given case.

Total costs of procedures implementation are calculated according to the following formula:

$$P_i = K_i \cdot E_{\mathrm{n}} + \mathrm{C}_{ei} \tag{5}$$

where P_i – total costs of i-th procedure, eur/year;
K_i – capital cost for the purposes of the procedure implementation, eur/year;
C_{ei} – exploitation costs of i-th procedure.

Adduction of this set cost parameters to the current period is performed by multiplying them by the coefficient of the relative cost effectiveness of additional capital investments. (E_n).

Parameter (D) reflects average deviation of infeasible calculated fire risks quantities at the protected facility and the adjacent residential area from feasible values. The current parameter takes on the value from 0 to 1, and it is used in cases, where not of all the values of fire risks are feasible, and also used in order to define points in the territory of the facility, where all values will be most designated to feasible values:

$$D = \frac{A + B + C}{Z + Y + \gamma(S)}, \tag{6}$$

Where

$$A = \frac{\sum_{z=1}^{Z} R_a / R_z}{Z}; \tag{7}$$

$$B = \frac{\sum_{y=1}^{Y} I_a / I_y}{Y}; \tag{8}$$

$$C = \begin{cases} \frac{S_a}{S}, S > S_a \\ 0, S \leq S_a \end{cases}; \tag{9}$$

A – Dimensionless parameter of the average infeasible individual fire risks quantities in the territory of the facility (less than R_a) from feasible values (R_a);
R_z – Value of the quantity of infeasible individual risks in the territory of gas distributing plant;
Z – Amount of infeasible values of individual fire risks quantity in the territory of the enterprise;
B – Dimensionless parameter of the average infeasible values of the individual fire risks in the territory of the facility (lesser I_a) from feasible values (I_a);
I_y – Infeasible values of the individual fire risks in residential area;
Y – Amount of infeasible values of individual risks quantity in the residential area;
C – Dimensionless parameter of deviation of social risk in the residential area from feasible value.

The current criteria were correlated in a unified object function. Because of the primary objective within the set of procedures on the optimization of fire risks control is safety, the highest priority goes to parameter K, the next criterion according to priority is economic component (P). Against the backdrop of couple combinations of procedure parameters K and P are equal, and the required values of fire risks are non-subnormal, Q becomes the key parameter that provides rectangular distribution of the risk zones in the territory of gas and oil facilities. Therefore, the object function in the system of fire risks management is presented in the following way:

$$f = (\max(Q), \min(\mathrm{P}), \max(D)) \tag{10}$$

3.2 Generation of the First Population

The logical sequence of actions as to the evaluation of the effectiveness of risk value-reducing measures can be represented as follows:

1. Choosing a fire risk-reducing value measure from the database.

2. Analysis of the application with regard to the objects in the territory.
3. Calculation of fire risks values for each suitable object with the selected measure.
4. Save results to the specified massive.
5. If all measures are considered, go to the end, or go to step 1.

The first population is generated by using the approach that called the "roulette wheel" (Gen and Cheng, 1997). The value of the effectiveness of each measure is expressed by fitness function ($eval(M_k)$). The next step after the assessment of the effectiveness of measures is to calculate the overall function of all measures:

$$F = \sum_{k=1}^{\text{number of measures}} eval(M_k) - min\{eval(M)\} \quad (11)$$

3. Calculate the probability of selection (P_k) for each measures M_k:

$$P_k = \frac{eval(M_k) - \min\{eval(M)\}}{F} \quad (12)$$

k =1,2,…,*number_of_measures*

4. Calculate the total probability P_k for each measure (M_k):

$$q_k = \sum_{k=1}^{\text{Number of measures}} M_k \quad (13)$$

Each measure is one gen in the chromosome, so chromosome consists of many measures.

$$v = ([M1], [M2], [M3], \dots [Mk]) \quad (14)$$

where *M1*, *M2*, *M3*, *Mk* – measures for reducing fire risks values.

A chromosome consists of k measures. The selection process begins with rotation of a wheel for k times; each time, one chromosome's gen is selected by the following algorithm:

1. Generate a random number r from the interval [0, 1].
2. If $r \leq q_1$, then select the first measure M_1; otherwise, go to the k-th measure ($2 \leq k \leq$ count_of_mesuares) such as $q_{k-1} \leq r \leq q_k$.
3. If the selected chromosome has already been chosen, go to step 1 or choose this measure.

The above procedures are to be repeated while counting the population not equal to the required number.

3.3 Fitness Function

Evaluation function matching of chromosomes is performed in two steps:

1. Implementation of all measures contained in the chromosome.
2. Calculate the parameters of the goal function.

Fitness function plays the role of environment and evaluates chromosomes according to their capability to perform optimization criterion.

3.4 Selection

For the selection, the roulette wheel approach was chosen. The roulette wheel can be constructed as follows:

1. Calculate the value of the function of compliance $eval(v_k)$ for each chromosome v_k.
2. Calculate the overall function of the population concerned:

$$F = \sum_{k=1}^{pop_{size}} eval(v_k) - \min_{j=1,pop_{size}}\{eval(v_j)\} \quad (15)$$

k =1,2,…,pop_size

3. Calculate the probability of selection (P_k) for each chromosome v_k:

$$P_k = \frac{eval(v_k) - \min_{j=1,pop_{size}}\{eval(v_j)\}}{F} \quad (16)$$

k =1,2,…,*pop_size*

4. Calculate the total probability (q_k) for each chromosome (v_k):

$$q_k = \sum_{j=1}^{k} P_j, k = 1,2,\dots,pop\_size \quad (17)$$

The selection process begins with the rotation of a wheel *pop_size* times; each time one chromosome is selected by the following algorithm:

1. Generate a random number r from the interval [0, 1].
2. If $r \leq q_1$, then select the first chromosome v_1; otherwise choose the k-th chromosome ($2 \leq k \leq$ *pop_size*) such that $q_{k-1} \leq r \leq q_k$.

3.5 Crossing and Mutation

For crossing of chromosomes, a method with a single point of exchange is used. In accordance with this method, one point of exchange is randomly selected, with respect to which parts of chromosomes are swapped-parents. For this purpose, it generates the integer in the interval [1, *count_of_chromosomes*], which is the point of gene exchange.

Mutation consists of the change in one or more genes with mutation probability equal ratio. If we suggest different number of measures in combinations, there is a little probability of removing one gen from a chromosome.

4 ANALYSIS

The analysis of the received model was performed on the basis of estimating the fire risk of a standard facility in gas and oil industry (gas distribution plant), in the territory of which propane-butane fraction was major circulated substance.

In order to create the model of enterprise optimization combination according to the reduction of fire risks calculated values on the territory of the current oil and gas enterprise, the list of suggested procedures to reduce fire risks with provisional capital and exploitation total costs from base value has been formed (table 1).

Efficiency analysis as to the model has been conducted in several stages, with the use of the presented object function. During the first stage, Q and D parameters of the object function, along with the use of each procedure separately, were estimated (table 2).

On the next stage the search of procedures combinations with the help of suggested model was conducted in order to analyze and select the best parameters. As search stopping criterion was chosen situation when combination includes only one procedure. After the range of computing experiments the following optimal parameters where defined:

–crossing percentage: 80;
–mutation percentage: 30;
–possibility of gene deletion from the chromosome (procedures from the set): 75.

In order to create high variability of procedures combination high crossing (80%) and mutation (30%) percentage was chosen (figure 2, 3). After the range of experiments it was discovered that possibility of gene deletion from the chromosome (procedures from the set) significantly influence the time of selection and in this case the quality of the selected combinations do not change up to the particular moment (figure 4). Therefore the possibility of gene deletion from the chromosome was defined equal to 75%.

Mutation of 30% of specimens was chosen, because in this value, the variability of the suggested combination of the procedures significantly increases and causes the increase in the quality of the algorithm work results. The use of value under 30% causes the decrease in the observed combinations variability and the quality of results. According to the increase in the variability, the decrease in the algorithm quality is also observed (figure 3).

Table 1: Procedures of value of fire risks quantity reduction in the territory of gas distribution plant.

№	Procedure of reduction of value of quantity of fire risk	K, run	C_{ei}, eur/year	P, eur/year
1	Reduce filling degree on 15 %.	0	X	X
2	Reduce the probability of unstable unit presence by 20%	0	0.3X	0.3X
3	Install automatic fire alarm unit	0.3X	0.1X	0.16X
4	Install automatic fire extinguishing unit or water spray unit under the control by independent organization (irrespective of the type of the fire extinguishing unit)	X	0.3X	0.5X
5	Install automated automatic fire extinguishing unit (water or foam) or waterspray unit without control of performance capability by independent organization	0.6X	0.15X	0.27X
6	Install other types of automatic fire extinguishing unit without the control of performance capability by independent organization	0.5X	0.1X	0.2X
7	Install flanging 30 m^2	0.15X	0.01X	0.04X

Table 2: List of possible procedures and parameters of object function using Q and D parameters.

№	Procedure	Object	Q	D
1	Reduce possibility of the object's presence by 20 %	Road tank	16	781561535748
2		Railway tank	16	779786139413
3	Reduce filling degree by 15 %.	Road tank	16	779307110031
4		Railway tank	16	779307110031
5		Separator	16	779307110031
6		Tank 100 m^3	16	779307110031
7		Tank 50 m^3	16	779307110031
8		Tank 100 м^3 (group 2)	16	779307110031
9	Install automated automatic fire extinguishing unit (water or foam) or water spray unit without the control of performance capability by independent organization	Road tank	16	779307110031
10		Railway tank	16	779307110031
11		Separator	16	779307110031
12		Tank 100 m^3	16	779307110031
13		Tank 50 m^3	16	779307110031
14		Tank 100 m^3 (group 2)	16	779307110031
15	Install automatic fire alarm unit	Road tank	16	788404842408
16		Railway tank	16	781226809106
17		Separator	16	790786801193
18		Tank100 m^3	17	870910212155
19		Tank 50 m^3	17	953271699395
20		Tank 100 m^3 (group 2)	17	974221794362
21	Install automatic fire extinguishing unit or water spray unit under the control by independent organization (irrespective of the type of fire extinguishing unit)	Road tank	16	779307110031
22		Railway tank	16	779307110031
23		Separator	16	779307110031
24		Tank100 m^3	16	779307110031
25		Tank 50 m^3	16	779307110031
26		Tank 100 m^3 (group 2)	16	779307110031
27	Install other types of automatic fire extinguishing unit without the control of performance capability by independent organization	Road tank	16	779307110031
28		Railway tank	16	779307110031
29		Separator	16	779307110031
30		Tank100 m^3	16	779307110031
31		Tank 50 m^3	16	779307110031
32		Tank 100 m^3 (group 2)	16	779307110031
33	Install flanging 30 m^2	Road tank	16	779307110031
34		Railway tank	16	779307110031
35		Separator	16	779307110031

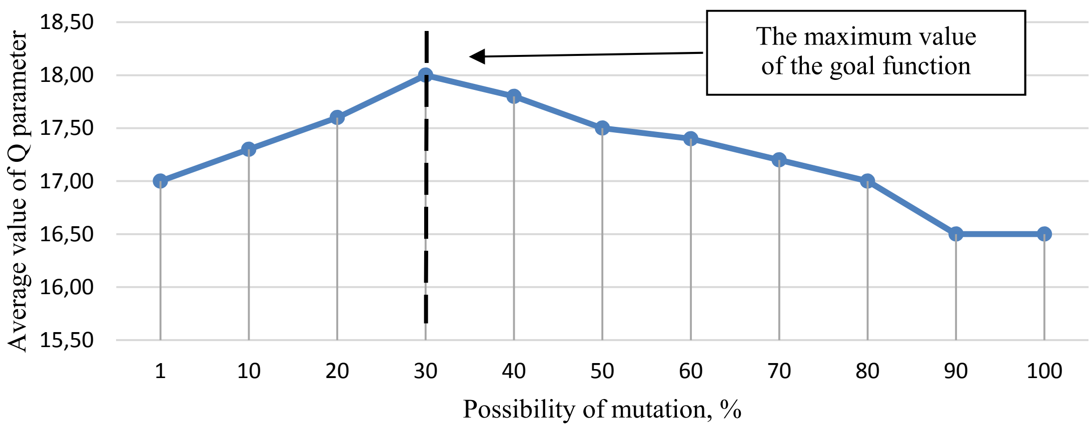

Figure 2: Correspondence of Q parameter average value with mutation possibility.

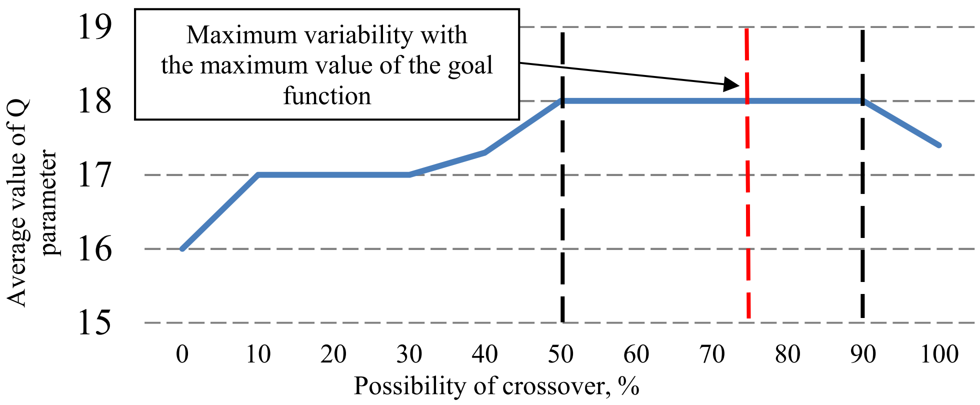

Figure 3: Correspondence of Q parameter average value with crossover possibility.

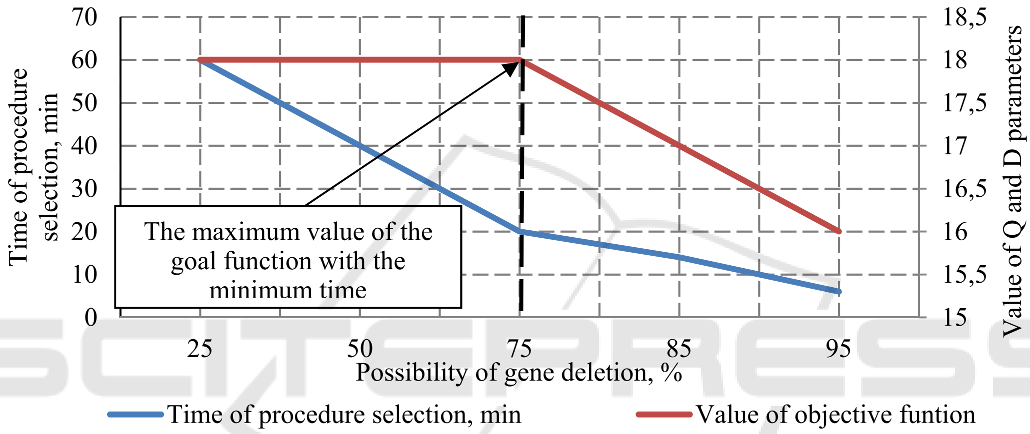

Figure 4: Correspondence of procedures combinations and number of feasible risks on the territory of the enterprise (Q) selection with possibility of their chromosome gene deletion.

After selecting the procedures as to the reduction of fire risks of the calculated values with the use of the suggested model, the list of possible combinations was defined. A table was formed with the lists of the most efficient combinations with various quantity of procedures (table 3).

Procedures selection time amounted a little bit more than *21* min. The suggested model was always finding procedures combination with high value of objective function, though during the process of combination selection options are possible with greater amount of procedures, but with lower value of objective function. For example: when procedures No. 3, 4, 5, 6, 1, 16, 21, 24, 10, 11 were combined, then the parameters of the objective function were equal to: Q=16, D=0,78, P=3,2X. Despite the fact that in table 4 with various quantity of procedures only one option of a procedure set is presented, the program can output multiple alternate options of combinations with high value of objective function according to the required quantity of procedures in one combination.

Table 3: Rating of procedures combinations as to the decrease in fire risks calculation values at various quantities of solutions in them.

Quantity of solutions	Numbers of solutions according to table 3	Q	D	P
10	7, 8, 1, 2, 15, 18, 19, 26, 27, 33	18	0	2,42X
9	7, 8, 1, 2, 15, 18, 19, 26, 27	18	0	2,38X
8	5, 1, 15, 17, 18, 19, 22, 24	18	0	2,24X
7	7, 1, 2, 15, 18, 19, 26	18	0	1,88X
6	5, 1, 15, 18, 19, 22	18	0	1,58X
5	5, 16, 18, 20, 10	18	0	1,05X
4	1, 15, 16, 19	18	0	1,03X
3	5, 15, 16	18	0	0,62X
2	7, 15	17	0,98	0,46X

5 CONCLUSIONS AND FUTURE WORK

The model of procedures for the management of fire risks at oil and gas facilities was presented with the use of genetic algorithms with modifications for solving the assigned task:

1. Instead of the use of binary row, the chromosome is used, the genes of which serve as identifier of the procedures.
2. The primary population is generated according to a specific algorithm.
3. In order to create the set from various quantity of procedures, a changed mutation operation is used consisting of random deletion of one of the chromosome-s gene.

The efficiency of the model obtained was tested in information system “FireRisks”. As a result, it was concluded that one of the main advantages of the suggested approach is the significant decrease in calculation operations, which, in turn, solves the issue of optimizing fire risks management procedures at the facilities with the use of modern information systems.

The offered model also possesses high variability of suggested variants, except for the significant reduction in the required time for conducting the variable combination of procedures on fire risk calculated values decrease.

At present, unification is conducted of the created models into a single system of intellectual support of decision-making in the field of fire risks management at oil and gas complex facilities.

The way forward is to create algorithms using CMA Evolution Strategy, Differential evolution and Simulated Annealing to compare the effectiveness of the obtained models in the management of fire risks in the oil refining facilities.

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