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Operating readiness evaluation method of first level information distribution AFES equipment at facilities of fuel and energy complex in special conditions

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ABSTRACT

Introduction. The necessity of obtaining by decision makers (DM) of complete information on first level information distribution equipment operating readiness of Automated Process Control Systems (APCS) at any time. Data on the pre-fire condition at a facility of the fuel and energy complex (FEC) is transmitted using the control elements of Automated Fire and Explosion Safety Systems (AFES) as a part of the APCS. The connection of determining the state of readiness of the AFES equipment with the degree of preventive maintenance is shown. The aim of the study is to obtain a scientifically based tool for determining AFES equipment operating readiness.

Research methods. In order to solve the problem, there was selected a six-level graph of strategic planning model that is offered to a DM for use while evaluating the first level information distribution AFES equipment operating readiness. The hierarchy is based on the implementation of plans for the maintenance, repair and replacement of equipment. There were simulated verification measures and remedial procedures by using the method of successive increments. Two problems of mathematical programming are proposed — linear and nonlinear one. In the first case, a new form of the objective function was obtained, taking into account the maximum efficiency of plans implementation. In the nonlinear formulation in different forms, the criterion search function is considered to estimate the maximum efficiency. Optimal task solving is a conclusion about the use of a certain resource for one specific event.

Study results. The conclusion was made about the feasibility of using the entire resource for a specific event. When solving the optimization problem in the nonlinear formulation, the dynamism of the parameters of the planned work vector to bring the first level AFES information sources in the required state, as well as the work performance intensity vector, is noted. As a result, there was proposed an AFES equipment integral operating readiness formula for a certain number of remedial measures.

Conclusion. A method for evaluating the effectiveness of remedial measures for AFES, taking into account the resource limited by special conditions, is obtained. The use of the method gives an opportunity for on-duty shifts of the fuel and energy complex facility to promptly respond to pre-fire situations.

Keywords: automation; fire safety; automated process control systems; fire and explosion safety systems; fuel and energy complex; integral index; analysis; hierarchy; readiness status; strategic planning; significance; fires; explosions.

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Introduction

The facilities of the fuel and energy complex (FEC) are a constant source of security threat, including fire, the environmental safety. In this regard, an important task is to predict the readiness of fire equipment to perform its functions [1]. However, having strategic significance, fuel industry enterprises need preliminary planning and actual control of sustainable and safe operation [2, 3]. It is extremely important to be able to anticipate and timely prevent the occurrence of a fire and explosion hazard situation at a fuel and energy complex of any scale. A rather difficult task is to determine the scope of monitoring of security systems and fire protection at such facilities. According to [4], the definition of this volume should be carried out on the basis of expert evaluations of employees participating in the operation of these systems. If there are restrictions on obtaining information, estimates may not be performed correctly. As an example of the process of obtaining such evaluations, one can cite a detailed data analysis [5] received from expert staff at various levels working in fire hazardous areas of oil and gas facilities. Decision makers (DM) at the fuel and energy facilities need prompt (real-time) confirmed information on the state of readiness for operation and reliability of fire automatics systems, gas fire detectors [6], environmental status sensors and other fire alarm systems or pre-fire devices [7, 8]. The decision making time required by DM to take the right decision in terms of fire safety (FS) [9] largely depends on the completeness of the information. All of these information sources for decision makers in Automated Process Control Systems (APCS) are the first level information distributors. As a rule, Automated Fire and Explosion Safety Systems (AFES) are built into the control system facilities at the fuel and energy complex facilities. The principles of their work are based on timely informing the decision maker of possible dangerous situations [10]. To find out the operating readiness state of first level AFES equipment, it is necessary to plan activities for bringing it in a ready state in dangerous situations. In this case, the priority task for the decision-maker is to evaluate the degree of implementation of certain components of these plans and the possibility of carrying out and the importance of some of the activities included in them with the help of monitoring tools or special embedded AFES software [11]. The number of fires and explosions prevented at fuel and energy facilities depends on the success of such evaluations [12].

Preventive maintenance by the repair and maintenance team at the fuel and energy complex to identify the required repair or replacement of AFES equipment is a priority and strategic goal in evaluating its operating readiness. The heterogeneity of such equipment and its maintenance, repair and replacement activities is of secondary importance. The main evaluation criterion is the possible influence of one or another unit of first level information distribution AFES equipment on the strategic goal of decision makers to provide fire safety at a facility of the fuel and energy complex.

Today, many enterprises of the fuel and energy complex use control systems and ensure fire safety of foreign production [13, 14]. In [15] it is claimed that 80 % of this market is occupied by foreign manufacturers. In terms of the volume of this product, PE Arton takes the leading position (36 %), followed by Beijing PT Security Technology (33 %) and Wizmart Technology (11 %). In terms of value, the shares occupied by manufacturers on the market for this product are distributed as follows: Bosch — 11 %, Hekatron — 9 %, Honeywell — 8 % [15]. Recently, due to sanctions on fuel and energy facilities, difficulties have arisen with the supply of imported equipment for AFES intended for sending information to decision makers, as well as for upgrading the process control system at infrastructure facilities. Thus, for example, when designing the modernization of a fuel and energy complex facility according to [16], the wear of the originally supplied and non-replaced process equipment was about 80–100 %. This is partially due to the fact that the replacement process is complicated due to significant restrictions on the required supplies. In this regard, it should be noted that the identification of the most important elements of the equipment is of paramount importance. The conditions of operation of fuel and energy facilities, under which there are restrictions on the supply, timely replacement and verification of equipment, will be called special ones. If it is impossible to conduct separate planned activities, it is advisable to develop new models for providing fire safety at the fuel and energy complex facilities, changing, for example, the nature of information transfer inside the facility or the mounting points of sensors and detectors. Although the latter measure does not seem to be very appropriate, as it may cause violation of the general fire and explosion alarm scheme.

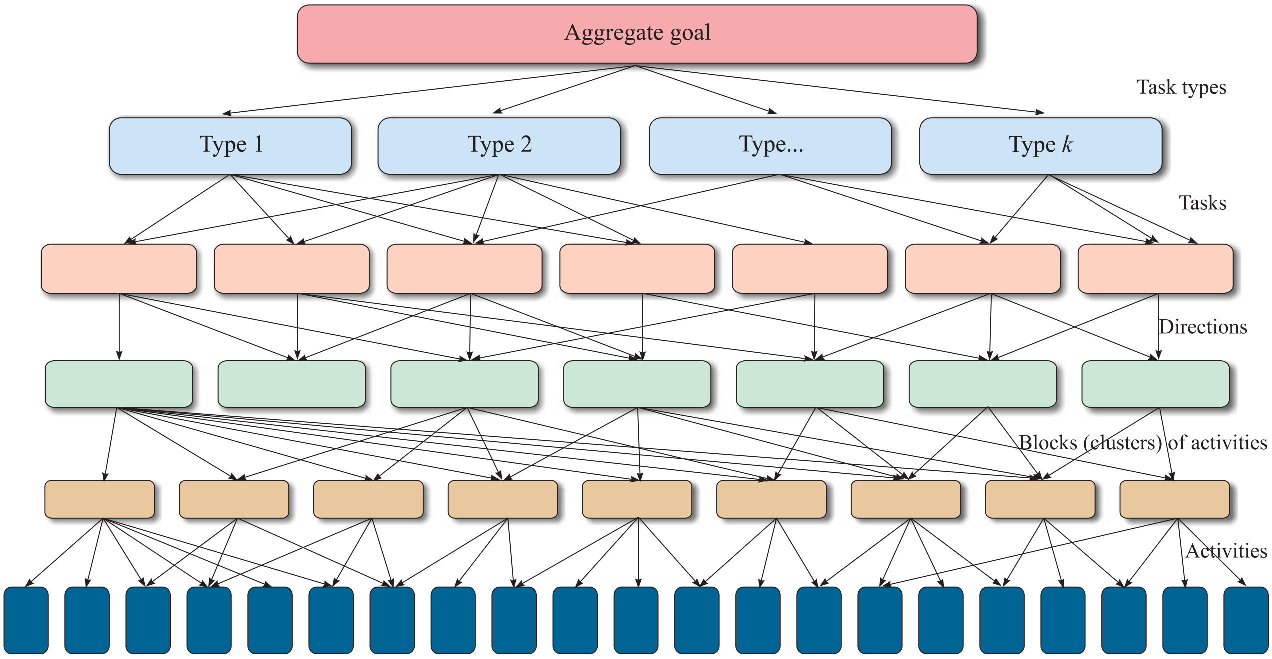
The purpose of this article is to obtain a reasonable tool for evaluating the effectiveness of planned measures for the restoration of low-level AFES equipment. To achieve it, the authors have set the task of analyzing and identifying the equipment operating readiness for ensuring fire and explosion safety in an automated way at fuel and energy facilities. Simulation of remedial measures is performed by the method of successive increments when considering two problems of mathematical programming — linear and nonlinear one. Obtaining their optimal solutions is described, which consists in recommending the use of a certain resource for one specific event.

Research methods

In order to simulate the importance of individual measures, strategic planning was used in evaluating first-level AFES equipment operating readiness [17, 18]. The basic rule described in [17, 18] is a graph of strategic planning based on a hierarchy of goals, objectives, directions, clusters, events, etc. Its analysis in conducting the evaluation of first level AFES equipment operating readiness is the main method that should be used by a DM to achieve the desired goal.

Let us consider an analogue of the specified graph. Let us construct a similar graph based on the hierarchy of the implementation of the plans for the maintenance, repair and replacement of the specified equipment (see Figure). Let us call it a graph of strategic planning for evaluating the first level AFES equipment operating readiness of a fuel and energy complex facility. The goal of the DM and the quality indicator for the entire group of these activities will be the DM's evaluation of AFES equipment operating readiness in an automated mode.

The maximum level of AFES equipment operating readiness will be its state that will let eliminate any dangerous or potentially dangerous situation before the onset of dangerous consequences. In order to do this, it is necessary to have the resources to bring the first-level information distribution AFES equipment in the best condition. Inspections and planned measures for the remedial procedures as for the equipment can be simulated differently.



Six-level graph of strategic planning for evaluating the first level AFES equipment operating readiness of a fuel and energy complex facility

If we use the method of successive increments in order to do this [19], then we can consider at least two problems of mathematical programming to determine the AFES equipment operating readiness. The first one is a linear programming problem with one constraint. The main idea is to find the maximum of the additive objective function $\psi(x_e)$ for readiness parameters, the values of which can be determined by plans for the repair, maintenance, restoration or replacement of information sources of first level AFES, with a limit on the specified resource type b due to special conditions. At the same time, the overall integral readiness index for all the required AFES equipment will be determined.

In this formulation the problem can be considered as

$$\psi(x_e) = \max_{\psi} \psi(x) = \max_{\Sigma} \left\{ \sum_{i=1}^{u} \alpha_i \cdot x_i \right\}; \quad (1)$$

$$g(x) = \sum_{i=1}^{n} \beta_i \cdot x_i, \quad (2)$$

where x_e is a vector value at which the objective function $\psi(x)$ takes the maximum value;

x — vector of independent parameters (of planned work to bring information sources of first level AFES in the “correct” state);

$$x = \{x_1, x_2, \ldots, x_u\}; \quad (3)$$

u — the number of units of required equipment;

$\alpha_i \geq 0 \ \forall \ i = 1, \ldots, u$ — coefficients of elements importance in the goal; are determined in accordance with the constructed decision matrix for the hierarchy selected in the graph of strategic planning [20];

$\beta_i > 0 \ \forall \ i = 1, \ldots, n$ — resource utilization factors for performing work in accordance with plans;

x_i — a certain value of an independent parameter (of planned work to bring information sources of first level AFES equipment to “correct” state) corresponding to a certain number of unit of equipment;

$$g(x) \leq b, \ b > 0; \quad (4)$$

b — the maximum permissible value of a certain resource taking into account special conditions;

n — the total number of activities carried out according to the plans (in general u and n are not equal, as in accordance with the graph of strategic planning for its levels, which are higher than the lower one, we should also take into account the significance; they will not be equal even if the planned activities will not be fully implemented).

At the same time

$$\sum_{i=1}^{u} \alpha_i = 1; \quad (5)$$

$$\sum_{i=1}^{n} \beta_i = 1. \quad (6)$$

Condition (2) regulates the loading of personnel, the availability of financial or material resources taking into account (6) in accordance with the action tree described in the plans. At the same time, it is considered that during their implementation, the DM seeks to achieve the aggregate goal set in a certain direction (see Figure), in this case, this goal is the maximum readiness of AFES equipment to work in special conditions.

The maximum efficiency of activities in accordance with the plans in solving this problem (formulas (1)–(4)) is realized with equality of the left and right parts in (4). Otherwise, reaching a maximum $\psi(x)$ leaves the rest of the resource, which makes it possible to get new increments of any component x_i, for which $\alpha_i > 0$, and the increment of the objective function (1), that does not fit into the original formulation of the problem.

If it is obtained from the condition (2) x_i and consider that for some k a ratio α_k/β_k will take the greatest value in comparison with other values α_i/β_i, then the objective function $\psi(x)$ and the condition will take this form [21]:

$$\psi(x) = \frac{\alpha_k}{\beta_k} b + \sum_{i=1}^{u} \beta_i \left\{ \frac{\alpha_i}{\beta_i} - \frac{\alpha_k}{\beta_k} \right\} x_i; \tag{7}$$

$$\beta_i \left\{ \frac{\alpha_i}{\beta_i} - \frac{\alpha_k}{\beta_k} \right\} \le 0. \tag{8}$$

In this case, the linear programming problem is solved for an unconditional extremum, because for all $i \ne k$ the values x_i must be zero. This follows from the new condition (8), according to which at $x_i > 0$ $\forall$ $i \ne k$ the value $\psi(x)$ will be less than the maximum.

It follows from this conclusion that the resource b should be directed to conduct only one event, i. e. to increase one parameter of the vector (3). This is true for any and not only for nonnegative values α_i if there is at least one positive one among them.

In the second variant of the problem, when the function $\psi(x)$ is not linear and is a concave function, and the limitation is linear, the criterion search function for evaluating maximum efficiency can be written as [22]:

$$\psi(x_e) = \max_x \psi(x) \tag{9}$$

with the same limitations (see formulas (2) and (4)):

$$\begin{cases} g(x) = \sum\limits_{i=1}^{n} \beta_i \cdot x_i; \\ g(x) \le b, b > 0. \end{cases} \tag{10}$$

The solution to this problem, as well as to the previous one, is on the boundary determined by the restrictions (10). The class of these problems is usually solved by the Lagrange method [23], but in this case it is appropriate to resort to another solution of the problem.

Let us suppose that by dividing a resource b into parts Δb, appropriate to its use in individual events, we will be able to distribute them consistently. At the same time the use of each share of the resource will not be of fundamental importance, as well as the use of these components. Then for small sections corresponding to Δb, the problem in the nonlinear formulation can be solved as a linear one.

By analogy with it, we need to find such a value $\psi(x)$, for which the partial derivative with respect to one of the parameters (see formula (3)) is maximum taking into account multiplication by the coefficient $1/\beta_k$. Then, after choosing an event x_k, using the resource in such a way that

$$\exists k, \ \frac{\partial \psi(x)}{\partial x_k} = \max_{x_i} \frac{\partial \psi(x)}{\partial x_i}, \tag{11}$$

function (9) should be rewritten as

$$\psi(x) = \psi\left(x_1, x_2, \ldots, x_{k-1}, \frac{b}{\beta_k} - \sum_{i \ne k}^{n} \frac{\beta_i}{\beta_k} \cdot x_{k+1}, \ldots, x_n \right). \tag{12}$$

Therefore, the function increment $\psi(x)$ should be defined as:

$$\begin{aligned} d\psi(x) = {} & \frac{\Delta b}{\beta_k} \frac{\partial \psi(x)}{\partial x_k} - \\ & - \sum_{i=1}^{n} \left\{ \frac{\partial \psi(x)}{\partial x_i} - \frac{\beta_i}{\beta_k} \frac{\partial \psi(x)}{\partial x_k} \right\} dx_i, \end{aligned} \tag{13}$$

or

$$\begin{aligned} d\psi(x) = {} & \frac{\Delta b}{\beta_k} \frac{\partial \psi(x)}{\partial x_k} - \\ & - \sum_{i=1}^{n} \beta_i \left\{ \beta_k^{-1} \frac{\partial \psi(x)}{\partial x_i} - \beta_k^{-1} \frac{\partial \psi(x)}{\partial x_k} \right\} dx_i, \end{aligned} \tag{14}$$

where

$$k = \operatorname{Arg}\left\{ \max_i \left(\beta_i^{-1} \frac{\partial \psi(x)}{\partial x_i} \right) \right\}. \tag{15}$$

Assuming that all values in (13) and (14) under index of summation are not positive, the distribution Δb we can assume, as in the previous formulation, that the optimal solution in this case is to use the entire resource Δb for one event only k.

Results analysis

Consistently pursuing the solution of this problem for various Δb, it can be seen that in each case the value $\max\limits_x \psi(x)$ will be found for various events. And the conclusion about the need to use the entire resource Δb for k event says only that it should not be spread between several events.

It should be noted that in the case of solving the problem of determining the AFES equipment readiness in this formulation, the remedial measures provided for by the plans will be carried out in such a way that the vector itself (3) will change and the number and the nature of the measures will change as well. This is due to the fact that for each of x_k will be its own event, and for the rest ones, the calculation will be performed without it at the next distribution step Δb. In this case, for each step when using a part of the resource Δb one should provide his/her own vector of events x^t:

$$x^t = \{x_1^t, x_2^t, \ldots, x_n^t\}, \tag{16}$$

as well as his/her own intensity vector of their conduction:

$$\beta^t = \{\beta_1^t, \beta_2^t, \dots, \beta_n^t\}. \tag{17}$$

Then, assuming that everything will be distributed T resource portions, where

$$T = b/\Delta b, \tag{18}$$

We can write the following formula for the integral AFES equipment readiness for T remedial measures for which resource b is possible, and its parts Δb will be enough to complete these activities:

$$\mathrm{d}\psi^t(x_e) = \Delta b \sum_{t=1}^{T} (\beta_k^t)^{-1} \frac{\partial \psi(x)}{\partial x_k^t}, \tag{19}$$

where t — step number;

${}^{t}_{k}$ — event index from the plan for which the objective function during the t step takes the maximum value.

Summary

The problem, given in two different productions and with one constraint, shows how, using successive increments the value of the resource, limited by special conditions, one can evaluate the effectiveness of the planned measures for the restoration of the AFES equipment. At the same time, the planning of activities and the evaluation of their significance are carried out taking into account the hierarchy obtained as a result of strategic planning.

The transformations, which are given in this article can be easily applied to the case of dividing this equipment into classes and subclasses, as well as while changing the nature of the restrictions or using several restrictions. Such scaling will allow creating a convenient algorithm for supporting the management of decision makers while dealing with AFES system, which, in its turn, under special conditions, will allow ensuring proper level of fire safety at a facility of fuel and energy complex.

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