Yuriy Abramov* – Oleksii Basmanov**

OPTIMAL DISPOSITION OF MAN-POWER AND TECHNICAL FACILITIES FOR FIRE LOCALIZATION AT FUEL TANK STORE

ABSTRACT

The problem of optimal disposition of high-pressure fire fighting hose units for fire confining at fuel tank store is posed. It is considered the determined and stochastic formulation of the problem. The algorithm of finding the solution that includes both of these cases is proposed.

INTRODUCTION

The urgent task for fire-brigades, when confining fire at fuel tank store is cooling of the burning tank and the next ones. Apparently, there are many possible positions of the high pressure fire fighting hose units for cooling the tanks. Thus there is a problem of their disposition with best cooling efficiency. The model of heating of the fuel tank under an exposure from torch of the burning tank is built up in [1, 2].

THE PROBLEM OF OPTIMAL HOSE UNITS DISPOSITION

The main purpose of this work is the formulation of problem of optimal disposition of forces for fire localization at fuel tank store and construing the algorithm of its solving.

The estimation of the effectiveness of the disposition of hose units is based on the following factors.

1. Cooling efficiency.
2. Safety concerning possible detonation or overboil of petroleum.
3. Water hitting range of tank.
4. Heat flow from the burning tank must not exceed critical value.
5. Presence of obstacles (tanks or other buildings) between a hose unit and cooled tank.
6. Other limitations based either on tactical and technical characteristics of operated hose units or on regulations of safe codes.

The factors 2-6 are limitations, and 1 is criteria of the problem of optimal disposition of hose units for cooling of tanks. In other words, we want to achieve

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* Professor / Academy of Civil Protection of Ukraine, Kharkiv, Ukraine
** Doctorant / Academy of Civil Protection of Ukraine, Kharkiv, Ukraine

the best cooling effect by using available man-power and technical facilities so that limitations 2-6 will be satisfied.

The main assumptions of the model are the following.

1. There are m hose units with times of their deployment t_1, t_2, …, t_m. The different time for their preparing is related to non-simultaneous arriving of fire-brigades to the site of fire or tactical and technical characteristics of the hose units. Assume, $t_1 \le t_2 \le ... \le t_m$, otherwise we can renumerate hose units so that the inequality will be satisfied. Every hose unit has its own tactical and technical characteristics, therefore limitations 2-6 for each hose unit can be peculiar.

2. The size of hose unit is too small comparing to tanks. So two hose units can be disposed as close as we wish to each other or to others objects of fuel tank store.

3. The shape of a torch above the flaming tank can be approximately described as a cone inclined by wind. This assumption can be deleted in the stochastic model of a fire [2]. Stochastic model assumes only normal distribution of pulsation of flame and its temperature.

4. The heat processes in burning tank and the nearest tanks can be described by models presented in [1, 2].

5. Fire scenario does not change during preparation of man-power and technical facilities: there is no new ignition, explosion, petroleum overboil.

6. The task of each hose unit remains constant through all considered interval of time.

Fire brigades must cool the walls of burning tanks and the nearest ones. Let's consider cooling of a group of N tanks. The group has both burning and not burning tanks. Assume that H is the criterion function. Its arguments describe the state of the tank. These characteristics can be determined (e.g. temperature) or stochastic (e.g. distribution law of temperatures). The type of criterion function depends on a method of forecasting of chain fire spread. This method can be determined [1] or stochastic [2]. Now we consider only necessity of minimization of the criterion function:

$$H \to \min . \tag{1}$$

Each tank can be divided on n identical segments by vertical intersecting planes passing through axis. All physical characteristics (e.g. temperature) within each segment are thought to be identical. Task of the hose unit k can be described by three integer numbers (r_k, s_k, f_k), $1 \le r_k \le N$, $1 \le f_k \le n$, $1 \le s_k \le n$, where r_k is ordinal number of cooling tank, s_k is the first cooling segment, r_k is the last cooling segment of tank r_k. Task $0_k = (0,0,0)$ means that hose unit k is not used for cooling of any tank. Therefore task of all hose units can be described by vector of dimension $3m$ with integer coordinates:

$$(r_1, s_1, f_1, r_2, s_2, f_2, ..., r_m, s_m, f_m).$$

The set of all such vectors makes a set of the tasks Z. However, not all of the tasks are feasible operational tasks. For example, from geometrical considerations it is clear, that one hose unit is able to cool not more than the half-perimeter of the tank, i.e. $\|s_k - f_k\| < n/2$, where $\|s - f\|$ is quantity of cooled segments:

$$\|s - f\| = \begin{cases} f - s + 1, & f - s \geq 0 \\ f - s + n + 1, & f - s < 0. \end{cases}$$

The above mentioned conditions 2-6 grant an additional limitation on set of feasible operational tasks $\Omega \subset Z$.

As the area of feasible decisions Ω of the problem (1) is not convex (moreover, it can be incoherent), and the criterion function also may not to be convex, classical methods of optimisation are impracticable to the problem (1). The quantity of feasible decisions is finite, but it is too great: the complete enumeration of possible tasks will take about $(Nn/2)^{2m}$ alternatives.

Z_k is identified as the set of all tasks for hose unit k. Consider the activization of the first hose unit. For each task $\left(r_1^{(i)}, s_1^{(i)}, f_1^{(i)}\right) \in Z_1$ calculate a value of criterion function $H_i(\tau)$. Also, consider additionally 0_1 – the hose unit which is not used, and calculate criterion function for it. The obtained alternatives form a set $\Omega_1 \subset Z_1$ involving the tasks that have minimal value of criterion function:

$$\Omega_1 = \left\{\left(r_1^{(i)}, s_1^{(i)}, f_1^{(i)}\right) : H_i(\tau) = H_{\min}(\tau)\right\}.$$

This set is not empty because it contains at least a task 0_1 (hose unit which is not used).

Let's select task for the second hose unit. For each task $\omega_1 \in \Omega_1$ we consider possible tasks Z_2 for the second hose unit, including its inactive mode 0_2, and calculate values of criterion function $H(\tau)$. The obtained alternatives form a set $\Omega_2 \subset \Omega_1 \times Z_2$ involving tasks that have minimal value of criterion function:

$$\Omega_2 = \left\{\left(r_1^{(i)}, s_1^{(i)}, f_1^{(i)}, r_2^{(i)}, s_2^{(i)}, f_2^{(i)}\right) : H_i(\tau) = H_{\min}(\tau)\right\}.$$

After that we can select a task for the next hose unit. We continue this process until the last hose unit will be considered. It allows to form a set $\Omega_m = \Omega_{m-1} \times Z_m$:

$$\Omega_m = \left\{\left(r_1^{(i)}, s_1^{(i)}, f_1^{(i)}, r_2^{(i)} s_2^{(i)}, f_2^{(i)}, \ldots, r_m^{(i)} s_m^{(i)}, f_m^{(i)}\right): H_i(\tau) = H_{\min}(\tau)\right\}.$$

The obtained set of alternatives Ω_m has tasks which are equivalent according to criterion function (1). It is necessary to select such an alternative of tasks distribution among the hose units, which requires the minimal quantity of the hose units.

DETERMINED MODEL OF FIRE SCENARIO

The determined model of chain fire spread at the fuel tank store is based on forecasting temperature of tanks heated under the fire [1]. Let us suppose $T_{rk}(t)$ is temperature of segment k of the tank r at the time t. Consequently, we can introduce a function:

$$H(T) = \begin{cases} 0, T < T_{cr} \\ (T - T_{cr})^2, T \geq T_{cr}, \end{cases}$$

where T_{cr} is a critical temperature. The critical temperature of the burning tank is temperature under which the steelworks lose its hardness. For the neighbour tanks this is a temperature of spontaneous combustion of the petroleum. Applying function $H(t)$ to all tanks at the interval of time $[0, t_0]$, $t_0 > t_m$, gives the following criterion function:

$$H = \int_0^{t_0} \sum_{r=1}^{N} \sum_{j=1}^{n} H\left(T_{rj}(t)\right) dt \to \min_{\Omega}.$$

Usage of this type of criterion function means tendency to exceed critical values minimally.

STOCHASTIC MODEL OF FIRE SCENARIO

The stochastic model of chain fire spread [2] considers probabilities of achieving some temperature values. It results in another type of criterion function:

$$H_p = \prod_{r=1}^{N} \prod_{j=1}^{n} P\left(T_{rj} < T_{cr}\right) \to \max_{\Omega} .$$

The probability $P\left(T_{rj} < T_{cr}\right)$ means that temperature of segment j of tank r will be less than critical level T_{cr} through out the interval of time $\left(0, t_0\right)$. The critical temperature means the same as in the previous case. The stochastic criterion function maximizes the probability that temperature of any tank will be less than the critical one.

CONCLUSIONS

The algorithm does not depend on type of criterion function and limitations, therefore similar approach can be used for optimization of hose unit distribution not only for fuel tank store, but for other areas as well.

The formulated solution can be used both for the development of the fire response plan and plan of fire fighter action at fuel tank store and for the location of the stationary hose units when designing the fuel tank store.

REFERENCES

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