# MODEL OF CYCLICAL MONITORING AND MANAGING OF LARGE-SCALE FIRES AND EMERGENCIES

# FOR EVALUATION OF THE REQUIRED NUMBER OF UNMANNED AIRCRAFT SYSTEMS

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In this article, based on the forecast of the state dynamics of control systems with the use of cellular automata, we consider the obtained results that provide the theoretical basis for the development of a conceptual model of forming a reserve of fire monitoring tools. The article identifies analytical dependences of the assessment of the limit states of the monitoring system for solving the challenges of planning and organizing the proper fire monitoring in the event of protracted fires. A set of procedures has been developed for solving practical problems of evaluating the necessary number of monitoring tools to perform monitoring tasks in a quality manner. The possibility is envisaged of taking into account the changes occurring in the states of a control system due to the influence of its external environment, which is crucial in assessing the adequacy of modelling results.

**KEYWORDS**

monitoring planning, information support, reserving the monitoring tools

## 1 INTRODUCTION

The general concept of fire preventionand control in the Russian Federation defines a number of practical aspects of managing the elements,scattered both in time and space,of the system intended for forecasting, preventing and eliminating large-scale fires. (Abramov, 2002)

The information support of the system is completely based on monitoring results, which, together with forecasting methods, provide objective information for all stages of fire prevention and control.

The specifics of implementing such monitoring systems depend on the types of monitoring and the specifics of its main functions, namely: collecting information, obtaining forecasts, evaluating safety and effectiveness (GOST P 22.1.12–2005, GOST P 56935–2016)

At another point, the range of methods for monitoring fires varies greatly [6,7,8] and currently unmanned aircraft systems (UAS) are used for monitoring fires and emergencies (http://www.uav.ru, Semenov, 2017)

Modern scientific methods have determined that the scientific analysis of unmanned aircraft systems used asfire monitoring tools requires a system of quantitative indicators, such as the speed of monitoring systemdeployment, the quality of information transmittedduring monitoring, and the economic component: the cost of monitoring tools.

However, the development of digital technologies has determined the objective necessity to validatethe monitoring results obtained as the information component of control, through intellectual analysis of such monitoring results as the analytical component of control.Therefore, at the present stage, the existing information and analytical control systems need to be developed.An important line for improving information and analytical control systems in the field of fire control is a comprehensive assessment of their organization and functioning, for which it is necessary to have an array of reliablequalitative and quantitative tools.

One of such tools canbe a model of cyclic monitoring which is based on the principles of continuous receipt of information from the scene of a fire or emergency [9].When planning the cyclic monitoring using a UAV-based monitoring system, the entire process of collecting information necessary for decision-making is decomposed into cycles.At the same time, a cyclogram consisting of some stages is formed for each monitoring tool.A sequence diagram of monitoring is a diagramof time,of implementation of the operation stages of monitoring tools when performing the task of collecting information from the scene of an emergency and of the stagesof recovery of monitoring tools, including the maintenance thereof.

## 2 MAIN BODY

Preferably Let’s consider the following monitoring scheme.
Suppose the duration of one monitoring cycle is T (min), including the following steps (Bozek, 2017; Dorschky, 2020) :

- T1 is the duration of the travel of a monitoring tool to the emergency location (min);
- T2 is the duration of on-site emergency monitoring (min);

- T3 is the duration of the travel of the monitoring tool to the place of its restoration (monitoring arrangement place) (min);
- T4 is the duration of recovery of the monitoring tool (min).

The structure of the monitoring scheme is shown in Figure 1.

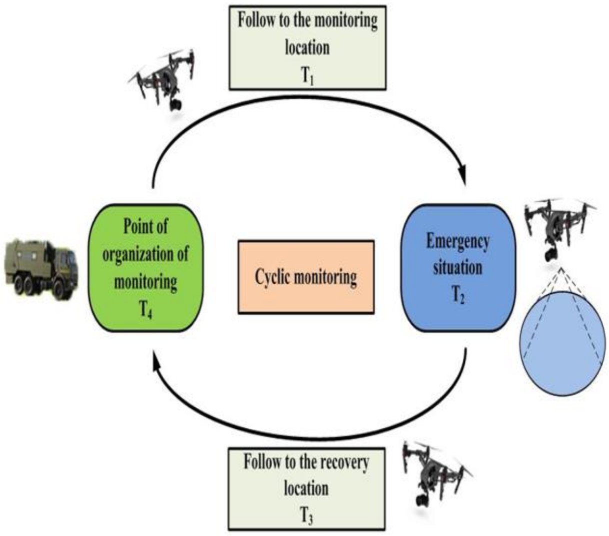

**Fig. 1.Schematic Structure of Cyclical Monitoring (T1- travelling to emergency location; T2- emergency location; T3 – travelling to recovery station; T4 – recovery station)**

According to this scheme, let's suppose that the entire duration of a monitoring cycle shall be equal to the sum of its stage durations, i.e. (Blistan, 2019; Zhu, 2020):

$$T = T1 + T2 + T3 + T4 \text{ (min.)} \tag{1}$$

Then, if you know the duration of the monitoring cycle T, and T1 and T3 mean the time of travelling to the monitoring location and therefrom as determined based on the technical characteristics of each monitoring tool: its speed and operating time, it is necessary to determine the duration of the monitoring and recovery stages of the monitoring tools involved for a given number of monitoring tools N providing continuous and stable monitoring. (Bakanov, 2016; Kilin, 2017)

Here, continuous monitoring shall mean a process characterized by the constant presence of one monitoring tool in the monitori ng location. Monitoring stability is achieved by implementing measures that ensure continuous monitoring in case of unforeseen situations, which is achieved by having at least one monitoring tool at the recovery station.
Then, to ensure the continuity of cyclic monitoring, the required number of monitoring tools shall be determined by the following formula (Bozek, 2016; Tatarinov, 2017; Štroner, 2019) :

$$m = M\left(\frac{T}{T_2}\right) = M\left(\frac{T_1+T_2+T_3+T_4}{T_2}\right) \rightarrow m = M\left(\frac{T_1+T_3+T_4}{T_2}\right)+1 \tag{2}$$

where M is the operator of rounding to the larger integer.

If the duration of the stage of travelling to the monitoring location and duration of the stage of travelling back to the recovery station are equal, i.e. T1=T3, then the required number of monitoring tools can be determined by the following formula (Hu, 2020; Polovinchuk, 2017) :

$$m = M\left(\frac{2T_1 + T_4}{T_2}\right) + 1 \tag{3}$$

providing thatT4 ≥ T2.
To maintain the proper stability of monitoring, the decision on the use a backup monitoring toolmust be made.The decision-making procedure is based on an assessment of the probability of sucheventwhen there are no monitoring tools available at a certain recovery station.

To do this, we use the developed model:

<Tр, Tв, α, m, Pm, P*>

where Tр is the duration of actual operationof monitoring tools, min; TV is the duration of stay of monitoring tools atthe recovery station, min; α is monitoring parameter; m isthe number of monitoring toolsrequired for continuous monitoring; Pmis the probability of an event when all monitoring tools are actually in operation; P* is the limit value of such probability.

For modeling the current states of monitoring, a system of equations similar to the Erlang equations with recovery (Abramov, 2002) is proposed, which can be represented as follows:

$$\begin{cases} \dfrac{dP_0(T)}{dT} = -\dfrac{1}{T_P}P_0(T) + \dfrac{1}{T_B}P_1(T) \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ \dfrac{dP_k(T)}{dT} = -\dfrac{1}{T_P}P_k(T) - \dfrac{1}{T_B}P_k(T) + \dfrac{1}{T_P}P_{k-1}(T) + \dfrac{1}{T_B}P_{k+1}(T) \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ \dfrac{dP_m(T)}{dT} = -\dfrac{1}{T_B}P_m(T) + \dfrac{1}{T_P}P_{m-1}(T) \end{cases} \tag{4}$$

where k is the number of monitoring tools operating in the air; Pk is the probability of such system state where k of mof monitoring tools is operating in the air.

The decision to attract a reserve monitoring tool is based on a strict inequality:
if Pm< P*, then a reserve is required.
Here P(α, m) is defined by the relation:

$$P_m = \frac{1}{\Delta},\ \Delta_k = \alpha^{m-k},\ \Delta = \sum_{k=0}^{m}\Delta_k,\ k=0,1,\dots,m$$

| Number of Monitoring Tools | m=1 | m=2 | m=3 |
|---|---|---|---|
| **Matrix Determinants** | | | |
| $\Delta_0$ | $\Delta_0=\alpha$ | $\Delta_0=\alpha^2$ | $\Delta_0=\alpha^3$ |
| $\Delta_1$ | $\Delta_1=1$ | $\Delta_1=\alpha$ | $\Delta_1=\alpha^2$ |
| $\Delta_2$ | – | $\Delta_2=1$ | $\Delta_2=\alpha$ |
| $\Delta_3$ | – | – | $\Delta_3=1$ |
| $\Delta$ | $\Delta=1+\alpha$ | $\Delta=1+\alpha+\alpha^2$ | $\Delta=1+\alpha+\alpha^2+\alpha^3$ |
| **Desired Probability of System States** | | | |
| State 0 | $P_0=\frac{\alpha}{1+\alpha}$ | $P_0=\frac{\alpha^2}{1+\alpha+\alpha^2}$ | $P_0=\frac{\alpha^3}{1+\alpha+\alpha^2+\alpha^3}$ |
| State 1 | $P_1=\frac{1}{1+\alpha}$ | $P_1=\frac{\alpha}{1+\alpha+\alpha^2}$ | $P_1=\frac{\alpha^2}{1+\alpha+\alpha^2+\alpha^3}$ |
| State 2 | – | $P_2=\frac{1}{1+\alpha+\alpha^2}$ | $P_2=\frac{\alpha}{1+\alpha+\alpha^2+\alpha^3}$ |
| State 3 | – | – | $P_3=\frac{1}{1+\alpha+\alpha^2+\alpha^3}$ |

Table 1 – Calculation of Monitoring System LimitStates

According to the proposed scheme of cyclic monitoring, the duration of stayof the monitoring tool in the air will be determined by the following formula (min):

$$T_p = 2T_1 + T_2 \text{ (min)}$$

In turn, the duration of stay of the monitoring tool on the ground is the recovery time, i.e. TB=T4 (min).
In this case, the following algorithm is proposed for making decisions about the use of a backup monitoring tool (Fomenko, 2013; Pirnik, 2015):

1. Data entry:
   T, T1, T2, P*
2. Determining the duration of the recovery of a certain UAV-based monitoring tool by the following formula:
   T4 = T – 2T1 – T2 = (min.)
3. Calculating the required number of monitoring tools:

$$m = M\left(\frac{2T_1 + T_4}{T_2}\right) + 1$$

4. Calculating α–parameter for the monitoring scheme:

$$\alpha = \frac{2T_1 + T_2}{T_4} = \frac{2 \cdot 4 + 15}{17} = 1.35$$

5. Assessing the probability of such event when all monitoring tool are in the air:

$$P_m = \frac{1}{\Delta}, \quad \Delta_k = \alpha^{m-k}, \quad \Delta = \sum_{k=0}^{m} \Delta_k, \quad k=0,1,\ldots,m$$

6. Making decisions about the use of a backup monitoring tool provided that Pm<P*, then a reserve monitoring tool is required.
   (Fig. 1. Algorithm for making decisions about using a backup monitoring tool)

The decision to attract a backup monitoring tool shall be made based on the following condition: Pm> P*. However, the lack of a backup monitoring tool can be compensated for by increasing the duration of the travelling stage of monitoring tools to the location of a major fire or emergency. (Bozek, 2015; Slimav, 2020)
Thus, this article reveals some analytical dependences of the assessment of the limit states of the monitoring system for solving a set of tasks of its planning and organizing tin the event of protracted fires. Procedures have been developed for solving practical problems of evaluating the necessary number of monitoring tools for the qualitative implementation of fire and emergency monitoring.

## 3 CONCLUSIONS

Authors As a result of the development of the cyclic monitoring model described and its subsequent implementation in the complex of algorithmic and structural solutions for the design of complex control systems for monitoring large-scale fires on the basis of unmanned aircraft systems, the current level of technology development is taken into account in terms of the quality of information exchange in the control system.

The modernized set of solutions makes it possible to use elements of automata theory in practice, when mathematically describing the states of fire monitoring.

Therefore, it is possible to take into account any changes in the state of the control system due to the influence of its external environment, which is crucial in assessing the adequacy of modelling results. (Aslinezhad, 2020)

The totality of the results obtained provides theoretical basis for developing a conceptual model of forming a reserve of fire monitoring tools based on predicting the dynamics of control system states with the use of cellular automata.

In the future, the results of the study will allow us to develop a method for evaluating the state of a monitoring system in order to predict the effectiveness of its functioning in real time.

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