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An Approach to the Drone Fleet Survivability Assessment Based on a Stochastic Continues-Time Model

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Abstract. An approach and the algorithm to the drone fleet survivability assessment based on a stochastic continues-time model are proposed. The input data are the number of the drones, the drone fleet redundancy coefficient, the drone stability and restoration rate, the limit deviation from the norms of the drone fleet recovery, the drone fleet operational availability coefficient, the probability of the drone failure-free operation, time needed for performing the required tasks by the drone fleet. The ways for improving the recoverable drone fleet survivability taking into account amazing factors of system accident are suggested. Dependencies of the drone fleet survivability rate both on the drone stability and the number of the drones are analysed.

INTRODUCTION

Recent development in data management as well as modern solutions in aviation technology makes the exploitation of drones for critical infrastructure (CI) monitoring possible.

According to [1], drones and others unmanned aircraft vehicles have already demonstrated very successful business cases in the following CI areas:

- Power transmission tower and line inspections.
- Cell power inspections.
- Rail line monitoring.
- Bridge inspections.
- Flare stack inspections.
- Pipeline monitoring.
- Wind farm blade inspections.

Drones are also applied for radiation detection and mapping to safely identify irradiated areas in the event of a NPP accident [2, 3]. It can be explained by following their benefits compared to manned aircraft:

- Small-size mobile equipment facilitates effective and timely countermeasures.
- Take-off and landing at user-selected locations (no airfields necessary) and at user-defined times.
- The missions can be carried out safely in remote locations (the operator can stay in an uncontaminated area).
- Small operation costs.
- Cost of fuel, service and maintenance are negligible.

It should also be noted that negative experiences in the Fukushima NPP accident [2] requires an increase of reliability and survivability of monitoring tools, because during the accident a part of data channels will inevitably

fail and it will be necessary to look for ways for redirecting of the information flows. To overcome this situation, additional wireless channels [4-5] should be used. These wireless channels can be part of the drones' equipment. Nowadays, drones are able to provide the necessary data flow in minutes after the accident occurred and are the most profitable platform where repeater modules can be placed.

Thus, it is very important to have survivable drone fleet able to perform the task listed above. The reliability models for drone fleet based systems for NPP accidents monitoring were developed using RBDs and researched in [6, 7].

The aim of this work is to present an approach to the drone fleet survivability assessment based on stochastic continues-time model, considering this fleet as a recoverable multi-state system and taking into account amazing factors of an NPP accident.

DESCRIBING THE PROPOSED APPROACH

If a drone fleet consists of identical drones performing the same task (for example, fleet collects some information from monitoring stations), one can be considered as an associative system (A-system). In this case, the drone fleet ability state depends on the number of its drones. If after exposure to amazing factors (e.g., ionizing radiation) the number of the drones in operational state meets the requirement, the drone fleet will be able to continue being in ability state. To take into account the drone fleet degradation process, the drone fleet damage D is used. The drone fleet is able to perform the required task if:

$$D \leq D_p, \quad (1)$$

where D_p is the drone fleet permissible damage.

D_p is regarded as a criterion to determine the ability states during the process of identifying the drone fleet states. D_p is the permissible number of the failed drones to continue performing the required tasks by the drone fleet.

If drone fleet survivability is ensured not only by redundant drones, but also by carrying out the measures aimed at recovering failed drones, it is necessary to take into account the drone fleet residual damage D_r .

This damage is calculated by the following formula:

$$D_r = D - D_c, \quad (2)$$

where D_c is the drone fleet prevented damage as a result of recovery.

With regard to (1) drone fleet survivability rate can be calculated as the probability that drone fleet residual damage does not exceed the permissible value D_p :

$$G = \int_0^{D_p} f(D_r) dD_r. \quad (3)$$

If we equate the value of the drone fleet prevented damage to zero ($D_c = 0$) than the model (1) can be modified into the model of unrecoverable drone fleet (4):

$$G = \int_0^{D_p} f(D) dD. \quad (4)$$

Consider the opportunity to evaluate the drone fleet survivability based on the model (3). Assume the following limitations and assumptions for the drone fleet.

- The recoverable drone fleet consists of n drones and each of the drones has stability q .
- Both the drone fleet residual damage D_r and the drone fleet prevented damage D_c have a normal distribution and there is no correlation between them.
- Resources of drones recovery is characterized by restoration rate μ , drones per hour (dr/h).
- The drone fleet is able to perform the required task, if during time τ drone fleet has n_r drones and by the end of performing the required task the number of the redundant drones is $k_r n_r$, where k_r is the drone fleet redundancy coefficient.

Let introduce the following parameters needed for evaluating the drone fleet survivability:

- n is the number of the drones; n_r is the number of the drones needed for performing the required tasks;
- k_r is the drone fleet redundancy coefficient;
- q is the drone stability; μ is the drone fleet restoration rate, dr/h ;
- $\Delta\mu$ is the limit deviation from the norms of the drone fleet recovery, %;
- Δd is the error limit in evaluating the value of the drone fleet damage, %;
- K_A is the drone fleet operational availability coefficient showing what part of the drone is not under maintenance (repair) and can be used for performing the required tasks;
- p is the probability of the drone failure-free operation;
- τ is time needed for performing the required tasks by the drone fleet.

The algorithm of evaluating the drone fleet survivability rate includes the following steps.

1. Calculation of the mathematical expectation of the drone fleet damage

$$D_i = n_i(1 - q_i). \quad (5)$$

2. Calculation of the limit deviation in evaluating the drone fleet damage

$$\Delta D_p = \frac{\Delta d}{100} D. \quad (6)$$

3. Calculation of the mathematical expectation of the residual fleet damage

$$D_r = D - D_c = D - \mu\tau. \quad (7)$$

4. Calculation of the permissible drone fleet damage

$$D_p = K_A n - n_r - n_r(1 + k_r)(1 - p) - k_r n_r. \quad (8)$$

5. Calculation of the dispersion of the residual drone fleet damage

$$\delta_{D_r} = \sqrt{\left(\frac{\Delta D}{3}\right)^2 + \left(\frac{\Delta\mu}{100} \mu \frac{\tau}{3}\right)^2}. \quad (9)$$

6. Calculation of the drone fleet survivability rate

$$G = F\left(\frac{D_p - D_r}{\delta_{D_r}}\right) + F\left(\frac{D_r}{\delta_{D_r}}\right), \quad (10)$$

where both $F\left(\frac{D_p - D_r}{\delta_{D_r}}\right)$ and $F\left(\frac{D_r}{\delta_{D_r}}\right)$ are Laplace functions.

RESULTS

Using the proposed algorithm of evaluating the drone fleet survivability rate, some dependencies were obtained (see Fig. 1 for the input data presented in Table 1 and Fig.2 for the input data presented in Table 2).

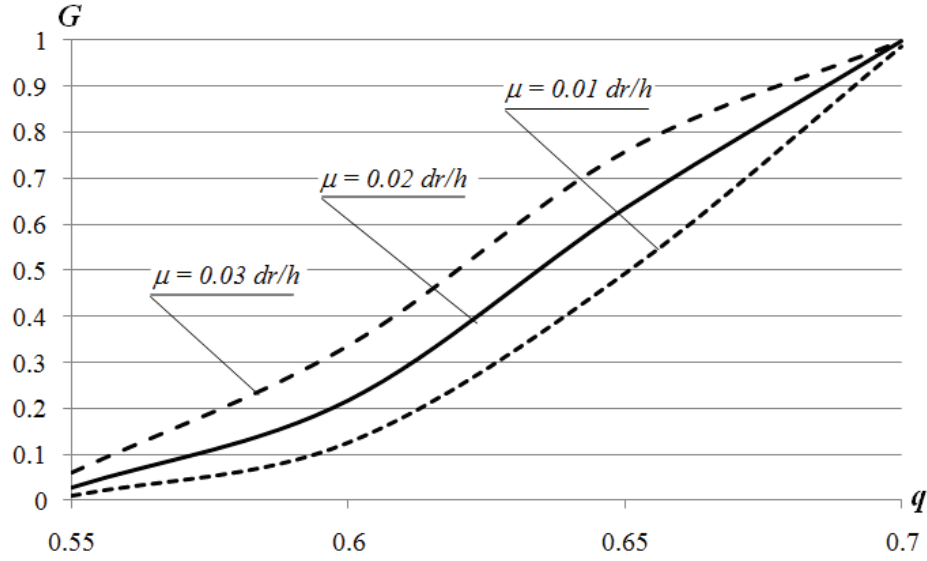


FIGURE 1. Dependencies of the drone fleet survivability rate on the drone stability

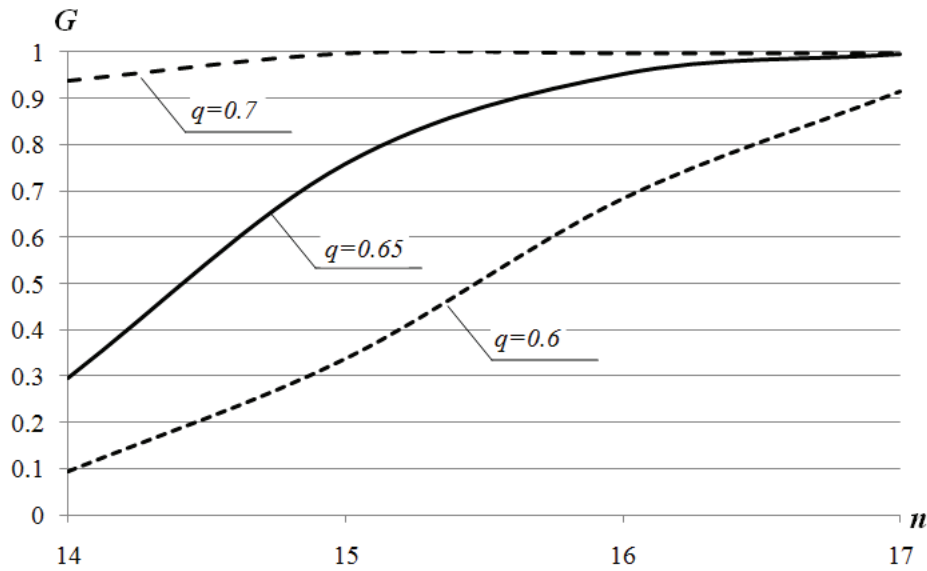


FIGURE 2. Dependencies of the drone fleet survivability rate on the number of the drones

TABLE 1. The input data used for building the dependencies shown in Fig. 1

| n | n_r | k_r | $\Delta\mu$ | Δd | K_A | p | τ |
|-----|-------|-------|-------------|------------|-------|-----|--------|
| 15 | 5 | 0.2 | 20 | 40 | 0.8 | 0.8 | 24 |

TABLE 2. The input data used for building the dependencies shown in Fig. 2

| μ | n_r | k_r | $\Delta\mu$ | Δd | K_A | P | τ |
|-------|-------|-------|-------------|------------|-------|-----|--------|
| 0.03 | 5 | 0.2 | 20 | 40 | 0.8 | 0.8 | 24 |

We can make the following conclusions based on the analysis of the proposed dependencies:

1. To improve the drone fleet survivability, we should increase the value one of the following parameters: drone fleet restoration rate, the drone stability, the number of the drones.
2. For the input data presented in Table 1 the maximum value of drone fleet survivability rate is achieved when $\mu = 0.3$ and $q = 0.7$ (Fig. 1).
3. For the input data presented in Table 2 the maximum value of drone fleet survivability rate is achieved when $n = 17$ and $q = 0.7$ (Fig. 2).
4. Increasing the value of the drone fleet restoration rate from 0.1 to 0.3 (Fig. 1) makes it possible to increase the value of drone fleet survivability rate: 5.9 times when $q = 0.55$, 2.7 times when $q = 0.6$, 1.5 times when $q = 0.65$ and 1.01 times when $q = 0.7$.
5. Increasing the value of the number of the drones from 14 to 17 (Fig. 2) makes it possible to increase the value of drone fleet survivability rate: 9.9 times when $q = 0.55$, 3.7 times when $q = 0.6$, 1.5 times when $q = 0.65$ and 1.1 times when $q = 0.7$.

CONCLUSIONS

An approach and the algorithm to the drone fleet survivability assessment based on a stochastic continues-time model have been proposed. According to the algorithm, the following parameters should be calculated: the mathematical expectation of the drone fleet damage, the limit deviation in evaluating the drone fleet damage, the mathematical expectation of the residual fleet damage, the permissible drone fleet damage, the dispersion of the residual drone fleet damage, the drone fleet survivability rate. Using the algorithm makes it possible to determine the ways for improving the recoverable drone fleet survivability, taking into account amazing factors of an accident. To improve the drone fleet survivability, we should increase the value one of the following parameters: drone fleet restoration rate, the drone stability, the number of the drones.

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