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# SIMULATION OF SPATIAL DATA STREAMS TO TEST FLIGHT DISPATCHING ALGORITHMS FOR UNMANNED AERIAL VEHICLES

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**Abstract**

Recently, there has been a rapid growth and expansion of the scope of application of unmanned aerial vehicles (UAVs). However, the increase in the number of UAVs and the expansion of their scope of application also causes an increase in the number of incidents involving UAVs. Thus, an increase in the number of UAVs simultaneously in airspace requires the development and testing of systems designed to monitor compliance with the rules and restrictions associated with aircraft flights. The rapid growth in the number of UAVs will necessarily lead to the fact that such dispatch systems will have to ensure the safe operation of a large number (thousands and even tens of thousands) of UAVs. Currently, the operability and efficiency of such systems is being tested on real scenarios with the participation of real UAVs. This type of testing is expensive, limited, difficult to scale, and poorly reproducible. This article proposes an alternative approach to testing the dispatch systems of the UAV – debugging and testing on prepared synthetic datasets.

It is proposed to form these sets using the simulation of spatial data streams for debugging of flight dispatching algorithms for unmanned aerial vehicles. The authors have developed and implemented a solution for preparing such synthetic datasets.

## 1 Introduction

In recent time, the scope of application of unmanned aerial vehicles (UAVs) is rapidly increasing and expanding. They are already widely used in search and rescue operations, firefighting, law enforcement activities, management of emergency response operations and mitigation of natural disaster consequences. There are also new application areas of UAVs, such as precision agriculture [1, 2] and infrastructure monitoring [3].

On the other hand, the increased number of UAVs and their expanded application cause the increased number of incidents involving UAVs. For example, the source [4] says that UAV flights in the immediate vicinity of the airport entail serious disruptions in its normal operation, increasing the accident risk for manned aircraft.

UAV flights over densely populated urban areas can put the population on the ground at risk, so a certain set of rules is required to regulate such flights. Moreover, UAV flights must be performed subject to certain restrictions. For example, the flight should not be allowed over certain spatial zones, such as areas of nuclear power plants or military installations.

Thus, the need to develop and test the systems designed to monitor compliance with the rules and restrictions related to aircraft operations increases with the number of UAVs which are simultaneously in the airspace. Such systems should provide both monitoring of individual UAV flights and control of compliance with the flight regime by large Unmanned Aircraft Systems (UAS). The rapid growth in the number of UAVs will lead to the need for such dispatching systems to ensure the safe operation of a large number (thousands and even tens of thousands) of UAVs.

Currently, the operability and efficiency of such systems is being tested on real scenarios with the participation of real UAVs. This kind of testing is expensive, limited, difficult to scale and poorly reproducible. According to the authors of this article, testing of UAV dispatching systems should be conducted on specially prepared data sets. Such data can be obtained by simulating the flow of spatial data on the unmanned aircraft locations.

Dispatch systems of UAVs must process data on the location of a large number of UAVs and UASs in the air in real time and identify complex events based on this processing. In order to debug the algorithms of such data processing, the data sets with various preset parameters are needed, which, additionally, should predictably change to accomplish the tasks being solved at this stage of debugging. These are, for example, the intensity of data flows, their number, the frequency of monitored complex events occurrence, etc. The problem is that such datasets are rather challenging (and sometimes even impossible) to obtain using real UAVs.

The authors suggest to solve this problem by using simulation modeling of spatial and temporal data flows about the location of unmanned aircraft. The authors propose a solution that consists in creating synthetic datasets with pre-defined parameters.

Various options for modeling various aspects related to aircraft flights have already been considered in publications [5–10]. The source [5] describes the flight simulation of a multi-rotor unmanned aerial vehicle in the MatLab / Simulink software package. According to the authors of the publication, the simulation results were used to test the flight modes of a real multirotor unmanned aerial vehicle. The authors proposed the method for simulation of helicopter flight in the “vortex ring” mode [6]. They used artificial neural networks to simulate the loading characteristics of the main rotor at a dangerous descent of a helicopter. The work [7] is a review and comparative analysis of various flight dynamics modeling tools that allow formation of dynamic properties and the movement patterns of various aircraft. The researchers describe the simulation of the spatial maneuvers made by an aircraft [8]. As the authors point out in [8], the results of such modeling can significantly reduce the time and financial costs of determining the aircraft maneuverability characteristics. The results of modeling a flight control system for a single UAV of quadcopter type in the Simulink/MATLAB environment are available [9]. The aim of this simulation was to reproduce the flight dynamics of a real UAV to evaluate the quadcopter control system. The work [10] also described the simulation results of the flight control system of a single quadcopterr UAV, but already in the SiminTech dynamic simulation environment. The obtained simulation results, as noted by the authors of [10], allow the reproduction of flight dynamics of a real physical object and assessment of the UAV control system.

To summarize the statements above, a survey of the scientific publications specified herein shows that the application of the simulation method of various data flows on the aircraft movement to study various aspects of their behavior is not completely new or original. Whereas this method was previously applied for modeling and investigating only the individual behavior pattern of the aircraft, the new approach proposed by the authors assumes the simulation modeling of spatial data for a behavior pattern of a large number of unmanned aerial vehicles in airspace over a certain area.

## 2 Methods and materials

To assess the feasibility of the described approach, the authors of this article have developed a program called “UAV Flight Simulator”, which creates a synthetic set of simulated spatial data entering the dispatching system. It is presumed that this dispatch system controls a certain observation area – an airspace over the polygon on the sphere.

The data entering the dispatching system are tuples with the following scheme: the time of position data receiving; UAV location data; UAV identifier.

The location data of each UAV is received at a certain frequency defined by the program settings.

Each simulated UAV belongs to a certain class. The following parameters for each class are set:

- frequency of sending UAV data about its location;
- minimum permissible UAV flight speed;
- maximum permissible UAV flight speed;
- minimum permissible UAV flight height;
- maximum permissible UAV flight height;
- maximum permissible UAV acceleration;
- maximum admissible value of the negative acceleration modulus;
- maximum UAV pitch angle;
- maximum permissible angle of change in the UAV flight course.

It is believed that each UAV can perform the following maneuvers (within the range of its class characteristics):

- flight speed increase;
- flight speed decrease;
- course changing;
- pitch angle changing.

The program-based model assumes that the simulated UAV can enter the airspace controlled by the dispatch system from any direction. The maneuvers performed by each simulated UAV are determined using a software random generator, taking into account the constraints set for this class of UAVs.

## 3 Discussion

In the process of data preparation for debugging scheduling algorithms, some problems were identified. For load testing of the dispatching system, in some cases, it is necessary that the number of UAVs in the observation area do not go beyond a certain range during the testing. In the initially implemented model, the number of UAVs in the observation area decreased over time, since after reaching a predefined number, the generation of new UAVs stopped, though their flight outside the observation area continued.

The graphs of the number of UAVs in the observation area are presented in Figures 1, 2, 3, 4, 5, and 6. The time is shown horizontally, the number of created UAVs is shown vertically.

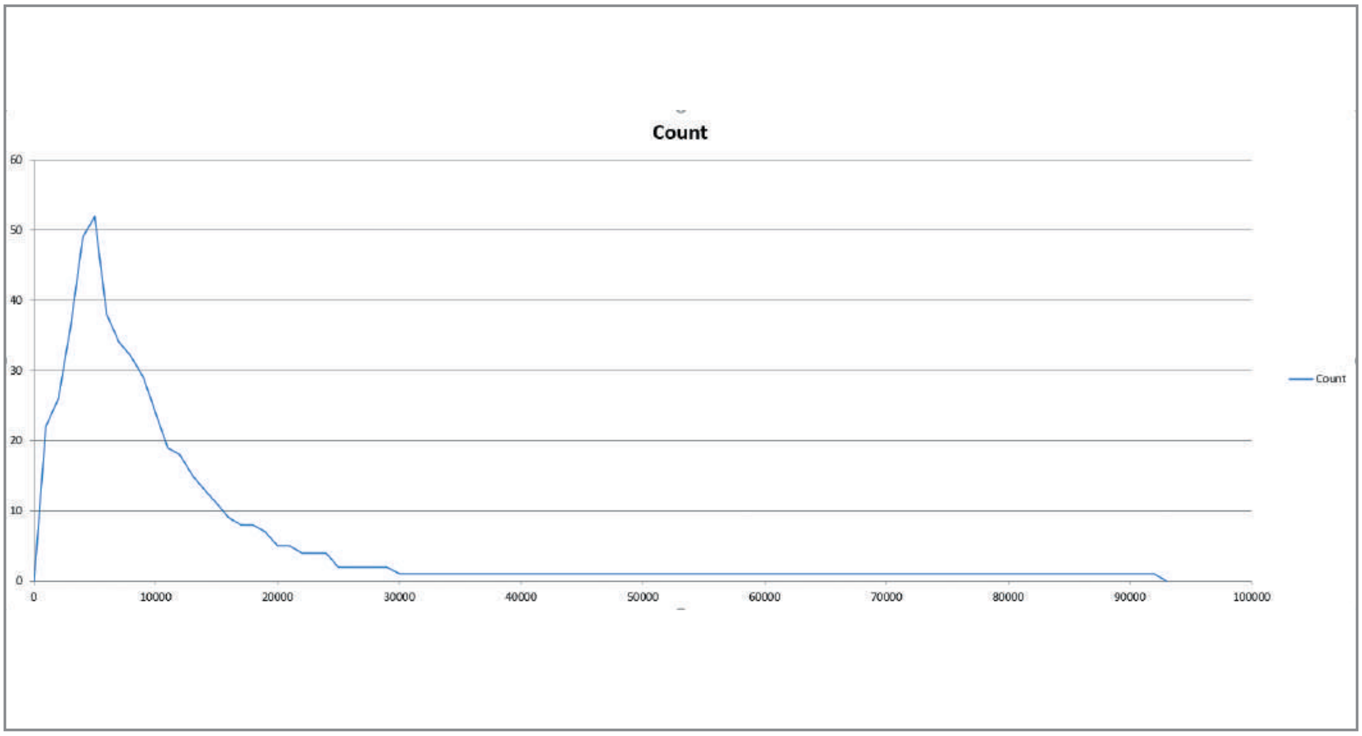


**Fig. 1.** UAVs amount: 100; side of the surveillance area: 1 km; time-dependent data: 0 ms – 100,000 ms; counts – every 1,000 ms.

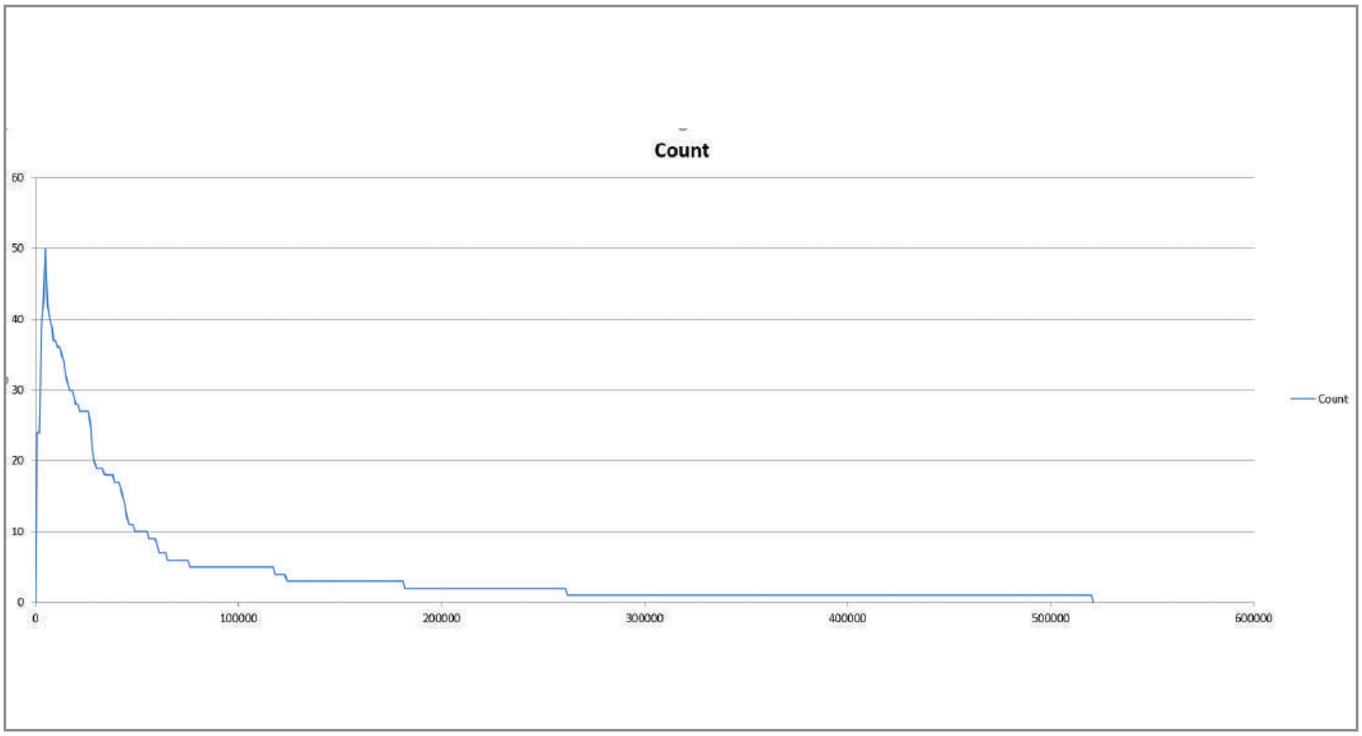


**Fig. 2.** UAV quantity: 100; side of the surveillance area: 5 km; time-dependent data: 0 ms – 600,000 ms; counts – every 1,000 ms.

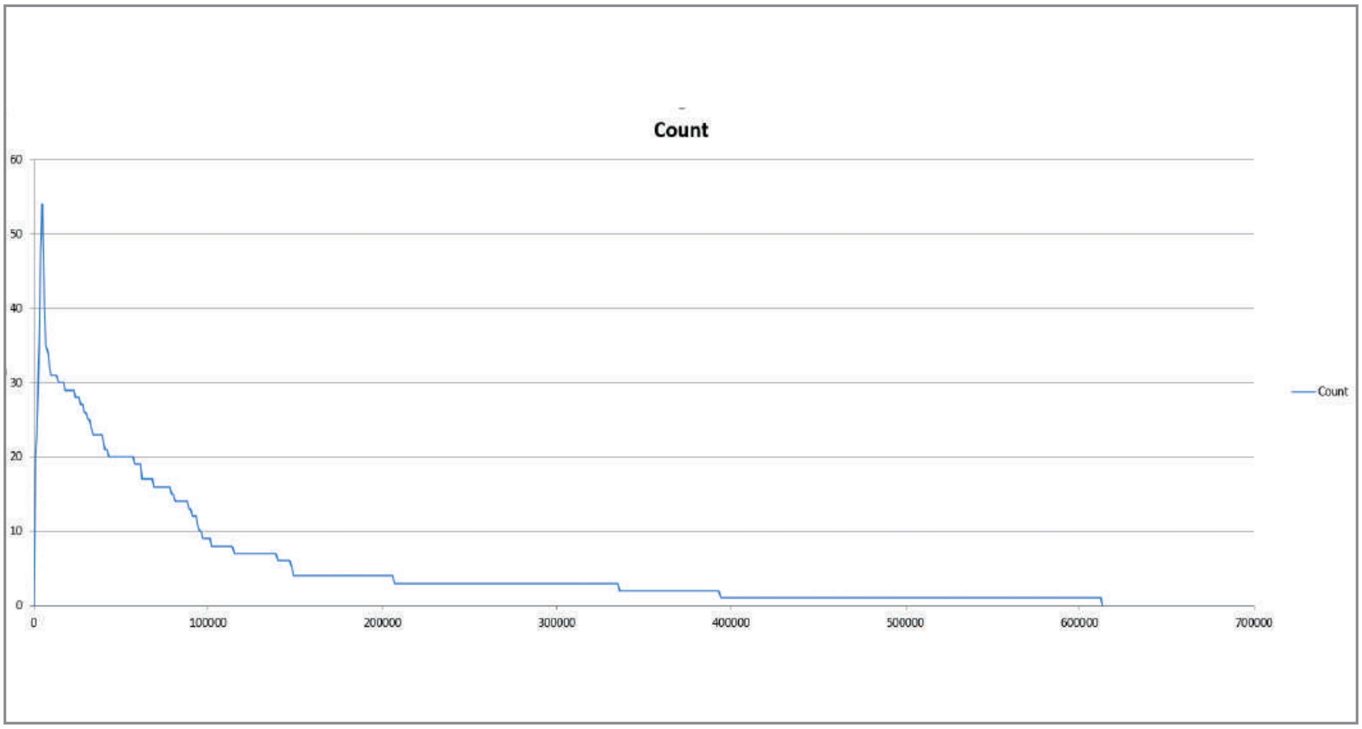


**Fig. 3.** UAV quantity: 100; side of the surveillance area: 10 km; time-dependent data: 0 ms – 700,000 ms; counts – every 1,000 ms.

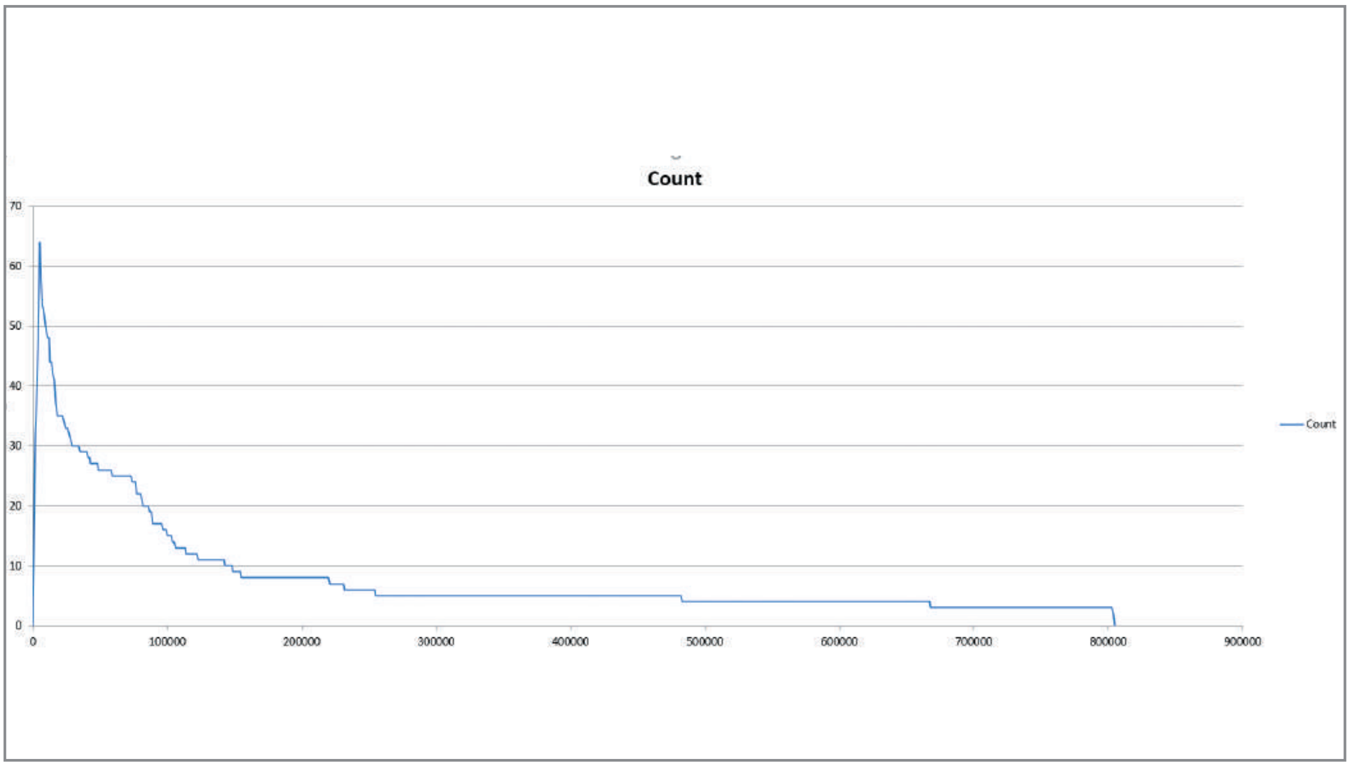


**Fig. 4.** UAV quantity: 100; side of the surveillance area: 25 km; time-dependent data: 0 ms – 900,000 ms; counts – every 1,000 ms.

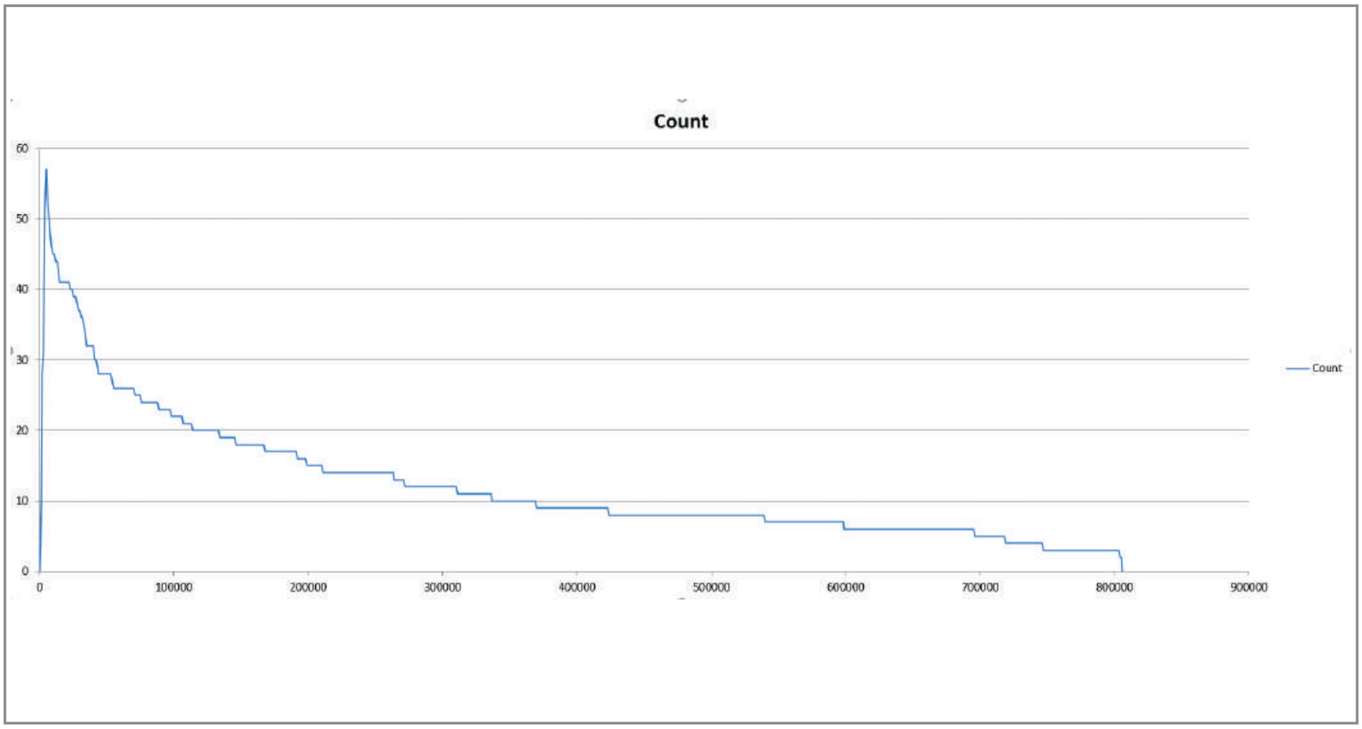


**Fig 5.** UAV quantity: 100; side of the surveillance area: 50 km; time-dependent data: 0 ms – 900,000 ms; counts – every 1,000 ms.

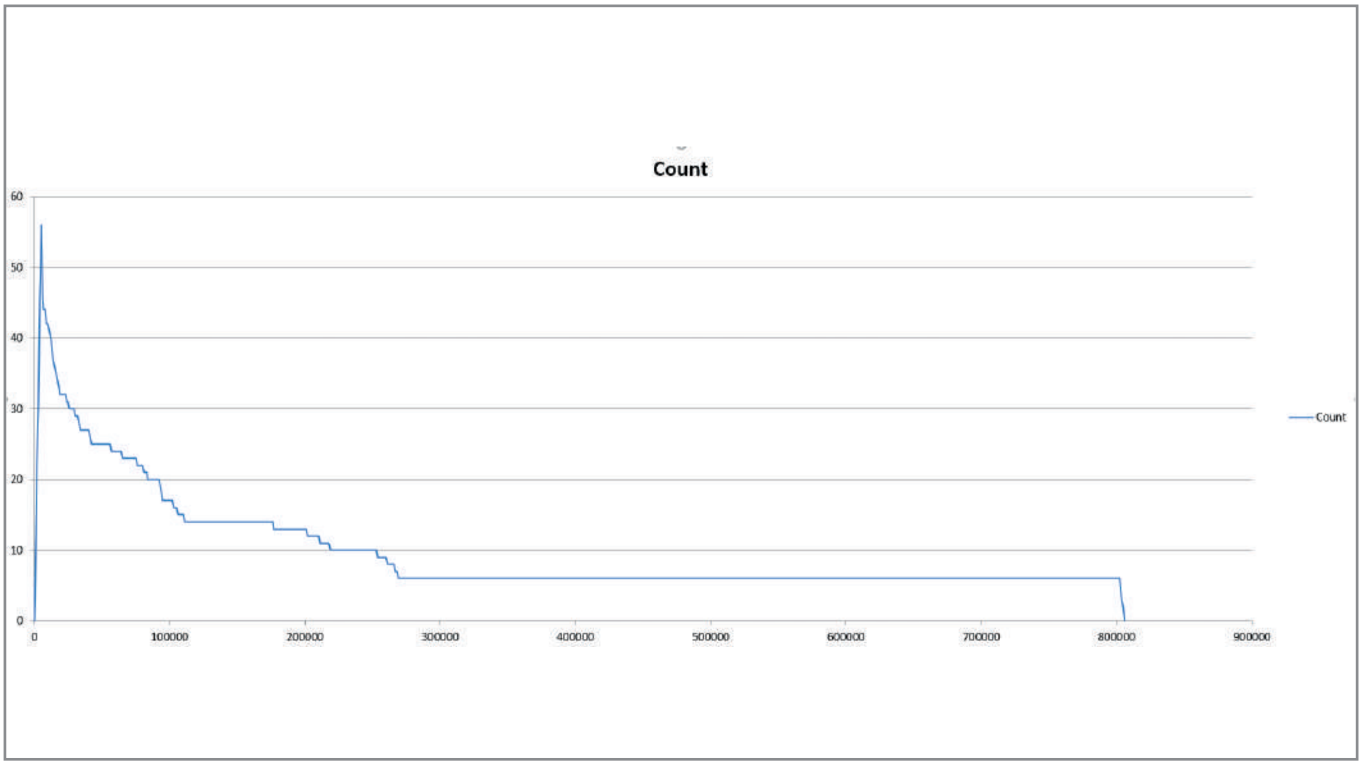


**Fig. 6.** UAV quantity: 100; side of the surveillance area: 100 km; time-dependent data: 0 ms – 900,000 ms; counts – every 1,000 ms.

To solve this problem, it is necessary to implement a tool that will allow adding new simulated UAVs at the right time.

The time point for adding new simulated UAVs can be determined statistically, since the maneuvers performed by each simulated UAV are determined using a software random generator, considering the constraints set for this class of UAVs. However, this approach is resource-intense, since all possible combinations of input parameters require a large number of program launches.

The authors' approach to solve this problem presupposes the presence of an operator – a person who launches the program. After the program completion, operator is offered to view the schedule of the UAV number. These examples are shown in Fig. 1–6. After reviewing the schedule, the operator independently decides when to add new simulated UAV, and relaunches the UAV Flight Simulator program, indicating the moment of adding new simulated UAV. In Fig. 7 we see the results of UAV addition at different time points: 0 ms (default), 5,000 ms and 10,000 ms.

## 4 Conclusion

Thus, we can conclude that the proposed approach to debugging the scheduling algorithms for unmanned aircraft using prepared synthetic datasets obtained using simulation of spatio-temporal data flows on the location of unmanned aircraft is inexpensive, makes it easy to scale and easily reproduced. The authors have developed and implemented a solution for preparing such synthetic datasets. The article describes some of the problems associated with the implementation of this solution and the design solutions adopted.

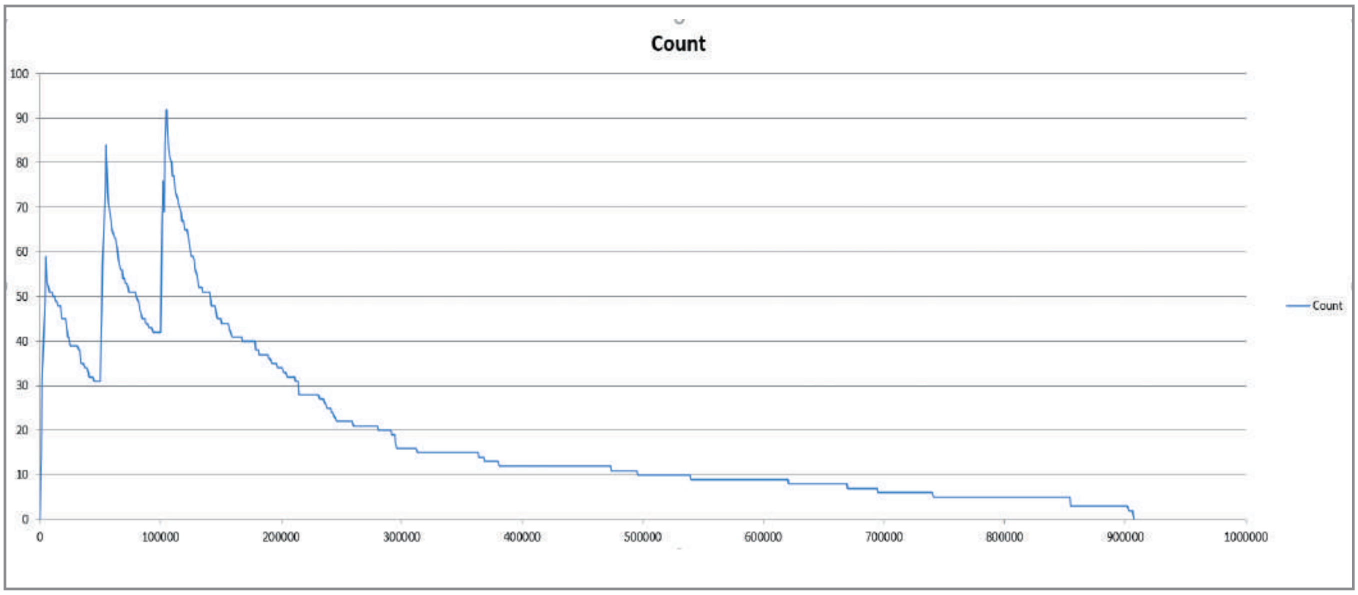


**Fig. 7.** The graph of the total UAV number within the entire work session with the program

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