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# The Method of Time Distribution for Environment Monitoring Using Unmanned Aerial Vehicles According to an Inverse Priority

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**ABSTRACT**

This paper presents a time-saving method for monitoring the ecology of a dispersed territory using the delivery of measurement units provided by unmanned aerial vehicles with measurement sensors according to a reverse priority algorithm. It is achievable because of the decreasing mean waiting time of the order inside a queue during low-priority order servicing. The experimental research that confirms the efficiency of the proposed method in the case of delivery distributed measurement systems for low-priority measurement is carried out. The experimental research of the proposed method in the case of one-channel and many-channel SMD that can have an option of order rejection or an in-queue waiting option is conducted in WeBots. The probability distributions in the case of this system applying are compared with similar probability distributions in the case of systems of direct priority applying. Comparison and analysis enable us to conclude that the probability distribution in the case of SMD with a direct priority of delivery tends to decrease and approximates zero. This is related to the fact that means at the end of the queue to be handled have a lower priority, as these means of measurement take longer to handle the order than those at the head of the queue. Thus, the means of a low priority will be serviced in the last charge and there is a constant possibility that in some cases such orders will be rejected. The proposed method enables moderate this situation by using increasing the possibility of servicing the low-priority orders. The method can increase the efficiency of environmental monitoring and pollution emission control.

**Keywords**: UAV, distributed measurement, system of mass service, environment monitoring, pollution monitoring.

## INTRODUCTION

An ecology monitoring as a part of an economical life and as a management function means to form a unitary system of delivery measurement tools and services. Such a challenge as environmental pollution must be met with a quick reaction to dynamic changes in the situation. Rapid response and prevention of aggravation are essential for environmental safety and human health, and important for real-time monitoring of the environment of a dispersed territory (Blackstock et al., 2017).

Using unmanned aerial vehicles (UAV) for environmental monitoring, especially pollution control is an efficient solution because of its independence from an inappropriate state of transport service, poor quality of roads, overloaded transport routes, and other negative factors (Yang et al., 2014; Zhu et al., 2015). There are special mathematical models of systems for means delivery (SMD) for environment monitoring (Knysh et al., 2018a). Combining SMD and UAV has potential but is not efficient enough because such a combination cannot provide a maximal theoretical speed of means of distributed measured system delivery servicing in practice (Viunenko and Voronets, 2008). This challenge can be solved by the means of UAV traffic control improvements, such as a time distribution for orders servicing according to a priority or limiting the average time of waiting in a queue during the delivery of a measuring unit (UAV).

In the previous work (Knysh et al., 2018b), a method of time distribution for order servicing provided by UAVs according to a direct priority was proposed. The specificity of this method is grounded on an assumption that the UAV at the end of a queue (having a low priority) requires significantly more time for servicing than the UAV situated at the head of a queue (having a high priority). Therefore, the means of a low priority tend to be serviced in the last turn, and in this case, there is a possibility that such orders cannot be serviced at all. The goal of this work is the development of a method that allows decreasing the time of orders servicing for UAVs are applied for UAVs of low priority.

To reach this goal, the next main steps should be fulfilled:

- Define the parameters of SMD that can influence the meantime of waiting in a queue.
- On the basis of a math model that reflects the dependency of SMD parameters in the meantime of waiting in a queue in the case of a direct priority application (Knysh et al., 2018b) develop a mathematical model for the inverse priority application.
- On the basis of this math, the model develops a method that allows decreasing the time of means delivery and uses the principle of a low priority.
- Perform numerical experimental research and prove the adequacy of results of math modeling.

## THE PARAMETERS OF THE SYSTEM OF MEANS DELIVERY

SMD is divided into one-channel and many-channel systems of delivery and in this case, the delivery of measuring devices (sensors) is provided, in proportion, by one or more UAVs (Dogan, 2003). The mean time of the order waiting in a queue of means delivery depends on the next parameters of such systems:

- $\lambda$ – the intensity of the order's income or the mean quantity of orders per time unit;
- $N$ – the order's quantity inside SMD;
- $C$ – the number of places in SMD;
- $n$ – the quantity of idle unmanned aerial vehicles;
- $\mu$ – the total service intensity;
- $\rho$ – the total intensity of a channel's load (the mean quantity of orders that come in the system during servicing of one order).

## THE METHOD OF A TIME DISTRIBUTION

This work has proposed the method that enables saving the time of delivery provided by a UAV according to inverse priority by the means of decreasing the meantime of waiting inside the orders' queue during the delivery of a means' unit with low priority depending on the parameters of SMD. Let us observe the SMD that uses UAV for delivery providing and implements a service time quantum according to an inverse proportion. The efficiency of such a system is higher because the system can handle orders that are normally handled by other types of systems in the last round, and in many cases, such handling does not occur at all (Knysh et al., 2018b). Such efficiency is provided by quantizing of service's time according to an inverse priority. In this case, the priority of the queue's member's servicing is changed to the opposite meaning, so the meantime of waiting in a queue is decreased and the probability of the system's states is changed. Quantizing solves the task of the system's optimization, so the meantime of waiting in a queue tends to decrease. Using a camera with machine learning can significantly increase the efficiency of UAVs. Such methods with image processing are used in different branches (Romanyuk et al. 2015) and they can be easily transferred to ecology monitoring.

During the work of SMD that implements service time quantizing and uses the principle of inverse priority, a measurement unit is endowed with a portion of the service time that depends on the number of a priority. The greater the number of priorities, the more time is needed for orders' servicing or the longer the distance between a measured means' base(station) and a point of territory for environment parameters measurement. The total service intensity according to an inverse priority is proportional to the meantime of waiting in a queue μ = $t$.

$$\begin{cases} \frac{d}{dt} P_0 = -n\lambda P_0 + \mu^2 P_1, \\ \frac{d}{dt} P_1 = -(n-1)\lambda P_1 + \mu^2 P_2 + n\lambda P_0 - \mu^2 P_1, \\ \frac{d}{dt} P_2 = -(n-2)\lambda P_2 + \mu^2 P_z + (n-1)\lambda P_1 - \mu^2 P_2, \\ \dots, \\ \frac{d}{dt} P_n = -\lambda P_{n-1} - \mu^2 P_n, \\ \sum_{j=0}^{n} P_{n-j} = 1. \end{cases} \quad (1)$$

In the static state all derivatives are equal to zero, $j = 0, \dots, n$, so solving of the equation's is:

$$\begin{cases} P_1 = \frac{n\lambda P_0}{\mu^2}, \\ P_2 = \frac{(n-1)\lambda P_1}{\mu^2} = \frac{(n-1)\lambda^2 P_0}{\mu^4}, \\ \dots, \\ P_{n-j} = \frac{(2n-j-1)\cdot\ldots\cdot(n-2)(n-1)n\lambda^{n-j} P_1}{\mu^{2(n-j)}} = \frac{n!\lambda^{n-j} P_0}{j!\mu^{2(n-j)}}, \\ \sum_{j=0}^{n} P_{n-j} = 1 = P_0 \sum_{j=0}^{n} \frac{n!\lambda^{n-j}}{j!\mu^{2(n-j)}}. \end{cases} \quad (2)$$

Using the math model of a direct priority method of time distribution for the SMD that uses UAV (Knysh et al., 2018b) let us describe a work of SMD, that is based on quantizing the service time according to inverse priority (Bekon & Kharrys, 2004), by the next set of the equation:

$$P_0 = \frac{1}{\sum_{j=0}^{n} \frac{n!\lambda^{n-j}}{j!t^{2(n-j)}}}. \quad (3)$$

Thus, the probability that the UAV (a channel) is busy.

$$P = 1 - P_0 \quad (4)$$

Hence, the solution of the equation's set (2) with $\mu = t$ lets in the case of the orders of a low priority service a transition from the minimization of UAV's stopping to the minimization of the meantime of waiting in a orders' queue, which is proved by the formula (4). It enabled to decrease the time of means delivery carried out by UAV in the case of low priority and in such a way it forms the basis of the proposed method.

## THE NUMERICAL EXPERIMENTAL RESEARCH ON THE BASIS OF THE PROPOSED METHOD

Let us assume that there is an SMD provided by a UAV that has $\lambda = 6$ income orders for measurement servicing and the mean service's intensity (a system's load) is $\rho = 0,65$. The system has $N = 3$ channels that can have a "free" or "busy" state. Inside the system, there are $\mu = 9.23$ orders simultaneously that are waiting for servicing. In the case of such intensity, the system on average serves the orders more quickly than it appears inside the system so that the system is considered stable and not overloaded. Let us consider the case of a one-channel SMD which uses one UAV and two ways of delivery servicing:

- with rejections, when an order for delivery in the case when the quantity of income orders is more than the queue's size or the quantity of the channels $N$ obtains a service's rejection (the second call for servicing is still possible);
- with waiting in a queue (in this case one UAV services $N$ channels by turn).
- In the case of a one-channel SMD that provides a rejection option (Fig. 1) there are two system states:
- $S_0$ – a channel is free and the UAV is ready to service a delivery order;
- $S_1$ – a channel is still busy, UAV is already servicing an order and is not ready to service a new order.

In the case of the service time distribution method using a direct priority (Knysh et al., 2018b) the system's probabilities are:

- $P_{0m}$ – the probability of state $S_0$

$$P_{0m} = \frac{\mu^2}{\lambda^2 + \mu^2}; \quad (5)$$

- $P_{1m}$ – the probability of state $S_1$

$$P_{1m} = 1 - P_{0m} \quad (6)$$

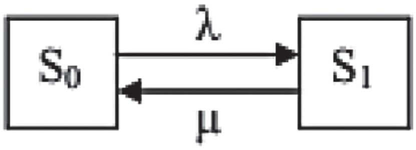


**Fig. 1.** The graph of one-channel SMD states in the case of a rejection option

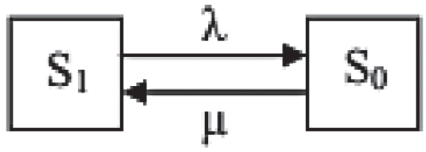


**Fig. 2.** The graph of the one-channel SMD state in the case of a system of a rejection option and an inverse priority

Let us use the proposed method of time distribution in the case of measuring the means of delivery provided by UAV according to an inverse priority. Thus, a one-channel SMD that has a rejection option will assume the next shape (Fig. 2.)

In its way, the probabilities $P_{0m}$ (7) and $P_{1m}$ (8) will achieve the states $P_{1z}$ and $P_{0z}$, in proportion

$$P_{1z} = \frac{\mu^2}{\lambda^2 + \mu^2}; \tag{7}$$

$$P_{0z} = 1 - P_{1z}. \tag{8}$$

The probabilities' distribution for a one-channel SMD of a direct priority of delivery $P_m$ and an inverse priority of delivery $P_z$ is shown in Figure 3.

One can see that the probability distribution $P_m$ for one-channel SMD of a direct priority of a delivery that has a rejection choice tends to decrease. This happening is caused by the next specificity of a system's work: the means in a queue's end are labeled as a low-priority order because the time needed for its servicing is significantly greater than the time needed for means servicing ahead of a queue. Thus, the means with a low priority will be serviced in the last turn. The proposed method enables this case to be moderated by the means of increasing the probability of service access for the orders of a low priority that is shown in the appropriate probabilities' distribution $P_z$. In the case of a one-channel SMD that has a rejection option (Fig. 4) there are the next possible states:

- $S_0$ – a channel is free;
- $S_1$ – a channel is busy (there is no queue);
- $S_2$ – a channel is busy (only one order is in a queue);
- $S_i$ – a channel is busy (there are $i$ - 1 orders in a queue);
- $S_N$ – a channel is busy (there are $N$ - 1 orders in a queue).

In the case of the proposed time distribution method, used for providing the measurement means delivery by the means of UAV according to a direct priority (Knysh et al., 2018b), the system's probabilities are:

$$P_{0m} = \frac{1 - \rho_m}{1 - \rho_m^{N+1}}, \tag{9}$$

$$P_{im} = P_{0m} \rho_m^{\,i}. \tag{10}$$

where: $\rho_m = \rho^2$ – the total intensity of a channel's load for the proposed methods.

Let us use the proposed method of a service time distribution for delivery by the means of

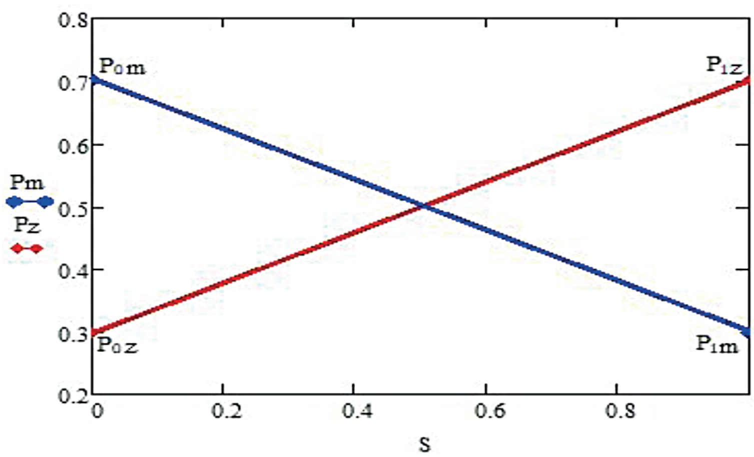


**Fig. 3.** The probabilities' distribution for a one-channel SMD of a direct priority $P_m$ and an inverse $P_z$ priority of delivery

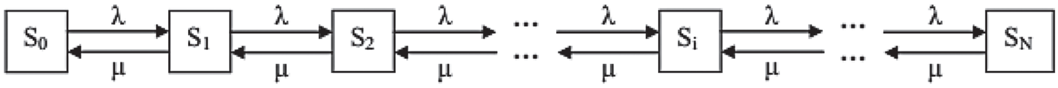


**Fig. 4.** The graph of the state of a one-channel SMD that has a choice of waiting

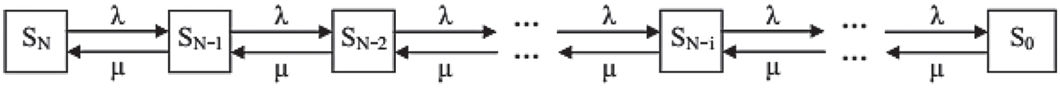


**Fig. 5.** The graph of a state of a one-channel SMD of an inverse priority that has a choice of waiting

UAV according to an inverse priority. Thus, a one-channel SMD that proposes a choice of waiting will achieve the concept presented in Figure 5.

The probabilities $P_{0m}$ (11) and $P_{im}$ (12) will assume the form $P_{Nz}$ and $P_{(N-i)z}$, in proportion:

$$P_{Nz} = \frac{1-\rho_m}{1-\rho_m^{N+1}}; \tag{11}$$

$$P_{(N-i)z} = P_{Nz}\rho_m^{\ i} \tag{12}$$

The probability distributions for a one-channel SMD of a direct priority $P_m$ and an inverse priority $P_z$ of a delivery that provides customers with a choice of waiting are shown in the graph in Figure 6.

As it comes from the graph, the probability distribution $P_m$ for a one-channel SMD of a direct priority of a delivery that provides customers with a choice of waiting tends to decrease. This happens due to the similar specificity of a system's work: the means from a queue's end are considered to have a low priority because it needs significantly more time for servicing than the analogical one from a queue's head. Therefore, the measuring means of a low priority are serviced in the last turn and there is a constant possibility that in some cases those orders do not receive an appropriate service at all. The proposed method enables us to improve this portion of a system's work and increase the probability of low-priority order servicing, which is shown by the probability distribution $P_z$.

In the case of a many-channel SMD which implements some quantity of UAV to fulfill its work and uses two modes of order servicing:

1) With a rejection option – when the large quantity of delivery orders comes into a system from a source of calling *i* (the case of huge intensity $\lambda$) and the type of UAV let reject the fulfillment of some delivery orders;
2) With waiting time – when a large quantity of delivery orders comes in a system from a source of calling *i* (an intensity is $\lambda$) and the type of measuring means do not let reject the call for a delivery servicing.

In the case of a many-channel SMD with a rejection option (Fig. 7), that has *N* channels for order servicing, the orders' flow of intensity $\lambda$,

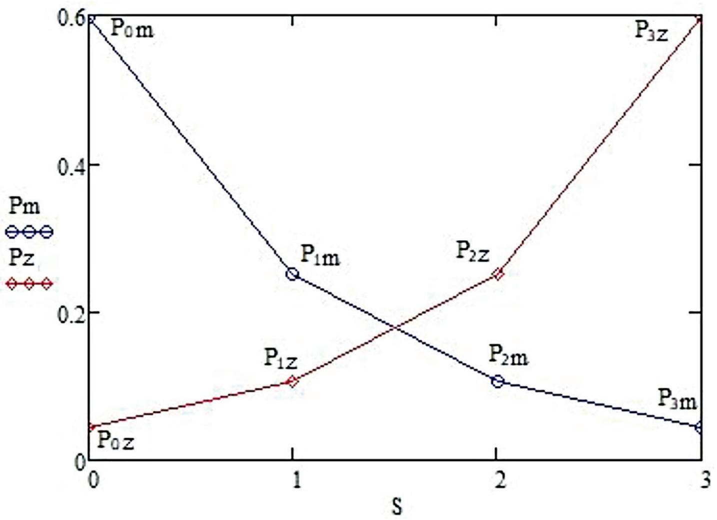


**Fig. 6.** The probabilities' distributions for a one-channel SMD of a direct priority $P_m$ and an inverse priority $P_z$ of a delivery that provides customers with a choice of waiting

and the intensity of servicing $\mu$, the possible states have such interpretation:

- $S_0$ – all channels are free;
- $S_1$ – one channel is busy, and the other $N$ - 1 channels are free;
- $S_2$ – two channels are busy, and the other $N$ - 2 channels are free;
- $S_i$ – $i$ channels are busy, and the other $N$ - $i$ channels are free;
- $S_N$ – all channels are busy, and the order gets a service rejection.

In the case of the method of servicing time distribution implemented according to a direct priority (Knysh et al., 2018b), the system's probabilities are :

$$P_{0m} = \frac{1}{\sum_{i=0}^{N} \frac{\rho_m^{2i}}{i!}}; \qquad (13)$$

$$P_{im} = \frac{\rho_m^{2i}}{i!} P_{0m}. \qquad (14)$$

Let us implement the proposed method of servicing the time distribution of an inverse priority to the system of the delivery of a by the means of a UAV. In such a case, the multi-channel SMD with an option of rejection assumes the shape that is presented in Figure 8.

In its turn, $P_{0m}$ (13) and $P_{im}$ (14) get the shape of $P_{Nz}$ and $P_{(N-i)z}$, in proportion

$$P_{Nz} = \frac{1}{\sum_{i=0}^{N} \frac{\rho_m^{2i}}{i!}}; \qquad (15)$$

$$P_{(N-i)z} = \frac{\rho_m^{2i}}{i!} P_{Nz} \qquad (16)$$

The probability distribution of a multi-channel SMD of a direct $P_m$ and an inverse $P_z$ priority of delivery, that has an option of rejection, is shown in Figure 9.

As one can see in the graph, the probability distribution $P_m$ of a multi-channel SMD of a direct priority that has an option of a service's rejection tends to decrease and approximates zero. This is connected with the fact that the measurement UAV at the end of an orders queue has a low priority because the time of its servicing is significantly greater than the servicing time of orders that are in the head of a queue. That happens because the means

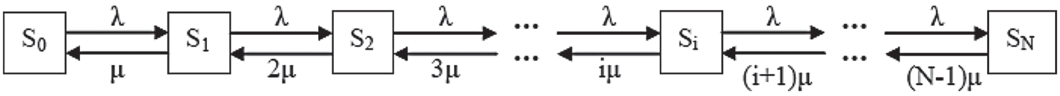


**Fig. 7.** The graph of states of a many-channel SMD with an option of rejection

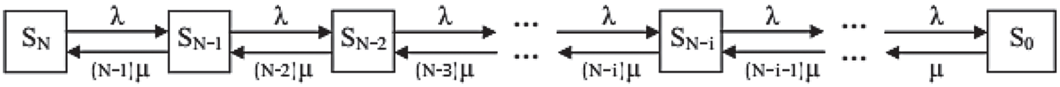


**Fig. 8.** The graph of states of a many-channel SMD of an inverse priority and an option of rejection

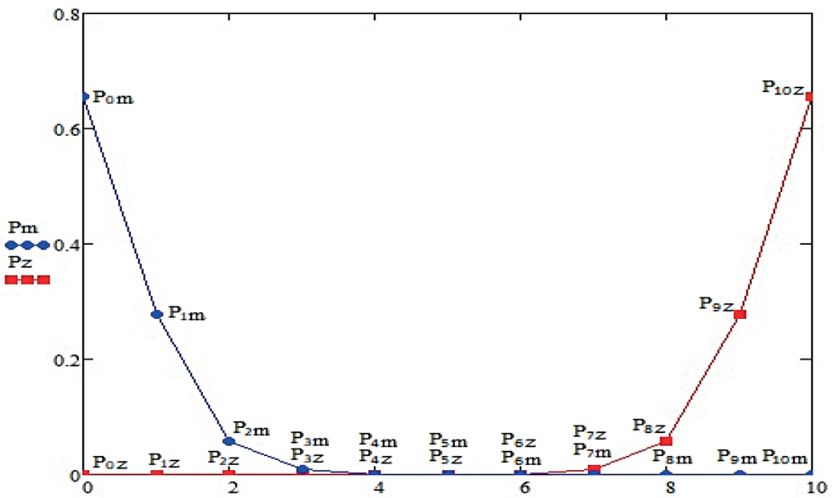


**Fig. 9.** The probabilities' distribution of a multi-channel SMD of a direct $P_m$ and an inverse $P_s$ priority of delivery that has an option of service rejection

at the end of a queue obtain a low priority so the system's time, which is spent on their servicing, is significantly greater than in the case of servicing the orders from the head of a queue. Thus, the UAV of a low priority will be serviced in the last turn and there is a high probability of complete rejection of a service's work for such a type of order. The proposed method can decrease the number of rejections by the means of increasing the probability of low-priority order servicing, which is shown by the probabilities' distribution $P_z$.

In the case of a multi-channel SMD that has a waiting time mode and a limited length of a queue (Fig. 10), the calculations are carried out when $C = 2$. Then the possible system states are:

- $S_0$ – all channels are free;
- $S_1$ – one channel is busy, and the other $C$ - 1 channels are free;
- $S_2$ – two channels are busy, and the other $C$ - 2 channels are free;
- $S_C$ – $C$ channels are busy (the all possible), and there is no queue;
- $S_C$ – $C$ channels are busy, one order is in a system's queue;
- $S_N$ – all $C$ channels are busy, $N$ - $C$ orders are in a queue.

Let us use the proposed method of a service time distribution in case of a delivery provided by the means of a UAV that is based on an inverse priority. In this way, a multi-channel SMD that has a waiting time option gets a concept presented in Figure 11.

$$P_{Nz} = \begin{cases} \left( \sum_{i=0}^{C-1} \frac{\rho_m^{2i}}{i!} + \frac{\rho_m^{2C}\left(1 - \left(\frac{\rho_m^2}{C}\right)^{N-C+1}\right)}{C!\left(1 - \frac{\rho_m^2}{C}\right)} \right)^{-1}, & \frac{\rho_m^2}{C} \neq 1, \\ \left( \sum_{i=0}^{C-1} \frac{\rho_m^{2i}}{i!} + \frac{\rho_m^{2C}}{C!}\left(N - C + 1\right) \right)^{-1}, & \frac{\rho_m^2}{C} = 1; \end{cases} \quad (17)$$

Using the case of the method of service time distribution according to a direct priority (Knysh et al., 2018b), the system's probabilities for inverse priority $P_{0m}$ (17) and $P_{im}$ (18) achieve the states $P_{Nz}$ and $P_{(N-i)z}$, in proportion:

$$P_{(N-i)z} = \begin{cases} \frac{\rho_m^{2i}}{i!} P_N, & 0 \le i \le C, \\ \frac{\rho_m^{2i}}{C! C^{i-C}} P_N, & C \le i \le N. \end{cases} \quad (18)$$

The probability distribution in the case of a many-channel SMD that has a waiting time option and is based on a direct $P_m$ and an inverse $P_z$ priority of a delivery schematically is shown in Figure 12.

As it comes from the picture, the probability distribution $P_m$ in the case of a multi-channel SMD that has a waiting time option and is based on a direct $P_m$ and inverse $P_z$ priority of delivery tends to decrease. It can be connected with the fact that the means, that are at the end of a orders queue, are defined as a low-priority subject of delivery because the time granted for their delivery is significantly longer than for the ones from a queue head. In this way, the UAV of a low priority will be serviced in the last turn and there is a constant probability that servicing of such measurement UAV will not happen at all. The proposed method enables us to moderate this work situation of environment parameters by the means of increasing the probability of a low-priority orders' servicing that is underlined by the appropriate distribution of probabilities $P_z$. This method can decrease the time of distributed measurement of territory using a UAV as a measurement unit. The WeBots program environment was used for experimental imitation simulation of the proposed method. Mavic 2 Pro was selected for the UAV model. An example of realization is shown in Figure 13. The experimental results of efficiency have no significant difference from theoretical ones.

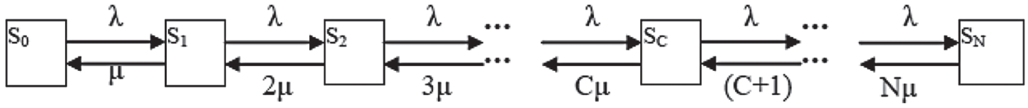


**Fig. 10.** The graph of states of multi-channel SMD that has a waiting time

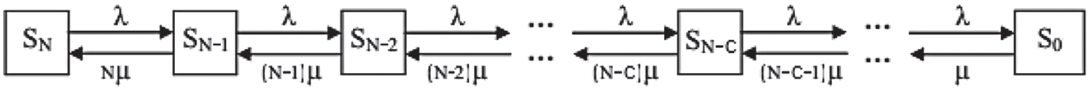


**Fig. 11.** The graph of the state of multi- channel SMD that has a waiting time option and an inverse priority as its basic principle

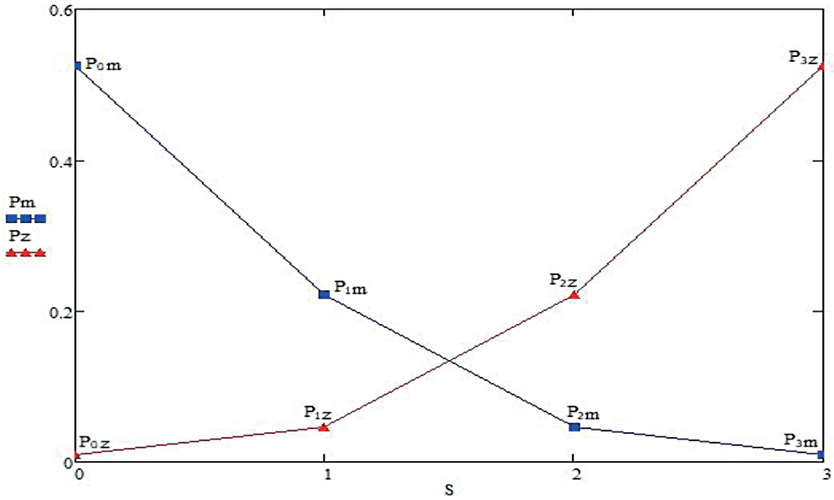


**Fig. 12.** The probability distribution in the case of a multi-channel SMD that has a waiting time option and is based on a direct $P_m$ and inverse $P_z$ priority of delivery

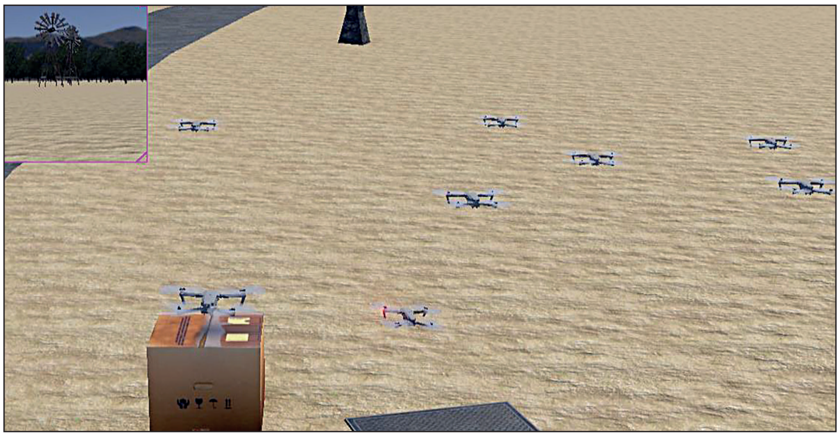

**Fig. 13.** Simulation experiment in WeBots for Mavic 2 Pro UAVs

## CONCLUSIONS

In this study, a method has been developed to reduce the delivery time of measurement means delivered by unmanned aerial vehicles according to reverse priority. This can be achieved by reducing the average waiting time in the service queue during the delivery of a low-priority measure unit according to SMD parameters.

The experimental research of the proposed method in the case of one-channel and many-channel SMD that can have an option of order rejection or an in-queue waiting option is conducted in the WeBots program. The probability distributions in the case of this system applying are compared with similar probability distributions in the case of systems of direct priority applying (Knysh et al., 2018b).

Comparisons and analyses enable concluding that the probability distribution in the case of SMD with a direct priority of delivery tends to decrease and approximates zero. This is connected with the fact that measuring UAVs situated at the end of a service queue are attributed with a lower priority because those means need more time for order servicing than means situated next to the head of a queue. As a result, low priority means will be handled last and there is a permanent possibility that in some cases such orders will be rejected. The proposed method mitigates this situation by taking advantage of the increased capacity to handle low-priority orders.

When working with SMDs that use UAVs as a means of transport, it is worthwhile to use direct and reverse priority methods for delivery of means of measurement. (Knysh et al., 2018b). In this case, a minimal load on a system's work and an opportunity to service almost all the orders are obtained. Moreover, income orders will not be rejected and will spend less time in a queue. In practice, this leads to an increase in incomes, and for some types of measuring means, this system's specificity is crucial when measuring on the distributed territory a time of delivery influences the data quality and adequate of dynamically changing situation. In real life, this method can be used for ecology problem monitoring, like air or water pollution, to control complicated dynamic changes in the weather.

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