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Modelling the One Channel Systems of a Delivery of Goods Provided by Unmanned Aerial Vehicles

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***Abstract*—In this article is revealed the systems of a good delivery witch implement unmanned aerial vehicles during providing the service. the one channel systems of a goods delivery are a goal of this research work. the close analysing of their functional features, the classification, the types and parameters of different systems from this band are presented. in addition, the modelling of the different types of the one channel systems of goods delivery are has done.**

***Keywords*—signal processing, window transformation, multi-window spectrum estimation**

I. Introduction

THERE are the bulk of economic problems that are connected with the work of the systems of the mass service, in which, from one side, many service orders appear to asking for some benefit and, from other side, the providers fulfil their client's wishes[1-3]. The last one needs creation of the appropriate facilities, the tools' supplies and the logistic means. The systems of goods delivery should provide the last one and in such way fulfil the client's needs [1,2,3].

So, the systems of goods delivery (SGD) maintain the process of a goods delivery by transporting the released goods of all types from a seller's site to the destination point, which is chosen by a buyer of those goods. The main tasks of SGD are [4,5,6]:

- found out the quantity of channels for goods delivery;
- found out the rational quantity of transportation platforms;
- provide the calculations of quantity of boarding and landing posts.

There one channel and multichannel SGD4, the difference between which is formed by the number of the transport means, that are involved in the process of goods delivery. The unmanned aerial vehicles (UAV) are the example of those transport tools. As a UAV we understand any aerial vehicle that has no crew's member on the board and comes to fulfill any task which is typical for the manned aerial vehicles [7,8,9].

The UAV are currently in a process of constant technological development that causes the constant expansion of the area of their implementation6,7. SGD can be the one of these areas because UAV's using eliminates some significant disadvantages of the transport facilities8,9. Among the last one are imperfect facilities, an unacceptable quality of communication ways, their overloading, a big distance between the points of goods loading and lending, unpredictable expenditures, etc. [10,11,12].

The goal of this article is analysing SGD that implement UAV during their work. The classification of this one channel SGD is presented and modelling the main parameters of the different one channel SGD is provided [13,14].

II. The System of Goods Delivery Provided by an Unmanned Aerial Vehicle

In the Fig. 1 is shown the structural scheme of SGD provided by UAV.

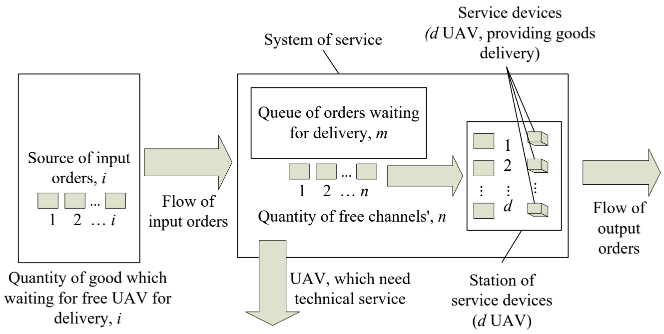

Fig. 1. The structural scheme of SGD provided by UAV

When UAV are used like main components of SGD network, the last one comprise the next linked parts: the source of incoming orders, the service system, service tools and the flow of out coming orders. The source of incoming orders which represents the client's needs for goods is formed by the orders that construct a flow of incoming orders or the quantity of some goods delivery orders. The main parameter of this system's part is the number of goods delivery orders $-i$ [15,16]. The service system is a UAV station where managing a goods delivery from seller to client takes place. The classic scheme of the mass service providing has equal quantity of orders d and free transport channels n. In the case of UAV implementing, the number of free transport channels is unlimited in theory and limited by the quantity of UAV in practice [17,18]. The station of service tools provides fuelling and maintaining service for UAV after the delivery.

The flow of out coming orders is composed by clients, who get the ordered goods after the delivery and previous payment [19,20].

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III. THE FUNCTIONAL PROPERTIES OF THE ONE CHANNEL SYSTEMS OF A GOODS DELIVERY

The SGD divides on one and multichannel systems or those that provide delivery service by the means of one or more UAV accordingly[10]. The article is about the research of one channel SGD on the base of UAV. The main functional properties of these systems are:

- L_s – the mean quantity of orders, that are staying in one channel SGD;
- L_q – the mean quantity of orders that are staying in a queue;
- T_s – the mean duration of order's staying in one channel SGD;
- T_q – the mean duration of order's staying in a queue;
- λ – the intensity of orders' income in one channel system or the mean quantity of orders per a time unit;
- N – the orders quantity in one channel SGD;
- C – the quantity of places in a queue;
- T_0 – the time of one order fulfilment;

$$T_0 = T_p / n, \tag{1}$$

where T_p is the mean time of one trip of a goods delivery; n is the quantity of free UAV; μ is the intensity of service:

$$\mu = 1/T_0; \tag{2}$$

ρ is the total intensity of a channel (the mean quantity of new orders that appears in system during the one order's fulfillment)

$$\rho = \frac{\lambda}{\mu}; \tag{3}$$

q is the relative bypassing ability of one channel SGD (the mean quantity of orders, that coming in and are currently fulfilling)

$$q = 1 - P_{vidm}; \tag{4}$$

P_{vidm} is the service rejection probability

$$P_{vidm} = P_N = \frac{\lambda}{\lambda + \mu}. \tag{5}$$

The functional properties L_s and L_q can be gotten from P_i (when there are i orders in a one channel SGD)[11]. So:

$$L_s = \sum_{i=1}^{\infty} N P_N, \tag{6}$$

$$L_q = \sum_{i=C+1}^{\infty} (N - C) P_N. \tag{7}$$

The dependencies between L_s and T_s, and between L_q and T_q are:

$$L_s = \lambda_{ef} T_s, \tag{8}$$

$$L_q = \lambda_{ef} T_q. \tag{9}$$

The parameter λ_{ef} is the efficient intensity of the orders' income. It is equal to out-coming intensity of order's appearing in case of the situation when all orders can be directed to the system. When some orders are not directed to service by the means of the occupation of newly freed places in a queue, then $\lambda_{ef} < \lambda$.

There is direct dependency between T_s and T_q. In the borders of math standards we can take it dawn like [21,22,23]:

$$T_s = T_q + \frac{1}{\mu}. \tag{10}$$

When we multiply the left and the right parts of this equation by λ, and using the Little's formula[12], the result is:

$$L_s = L_q + \frac{\lambda_{ef}}{\mu}. \tag{11}$$

IV. THE CLASSIFICATION OF THE ONE CHANNEL SYSTEMS OF A GOODS DELIVERY

The classification of the one channel SGD is based on the different features. On the fig. 2 is shown the general scheme of the one channel SGD classification.

As we see on the picture, the next types of the one channel SGD are possible according to the way of a goods delivery and the kind of goods [24,25]:

- the one channel SGD that have a rejection option – when the big quantity of orders comes in a system from the source of orders i (a big intensity λ) and a type of goods lets reject the particular delivery orders;

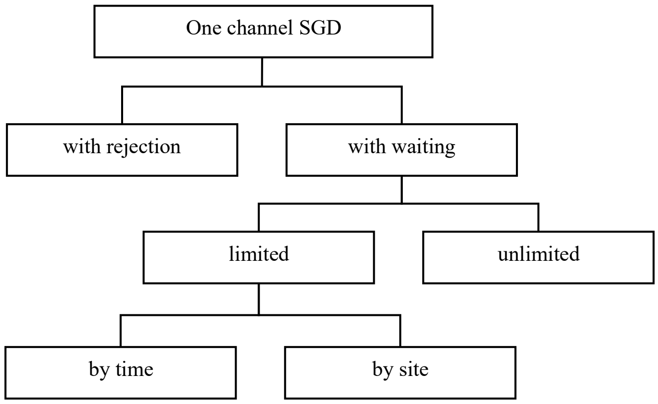

Fig. 2. The classification of one channel SGD

- the one channel SGD that have a time of waiting – when a type of goods do not let reject a delivery order in case of the big quantity of delivery orders comes in system from the source of orders i (intensity λ). This type of SGD is the most approximated to a real work of service stations, because the order's reject is a very unworthy thing from the commercial point of view [26,27];
- the one channel SGD that have an unlimited time of waiting – when for some type of goods (for example, the industrial goods) the time expenditures during the waiting in a queue and the delivery is not the strict condition of the delivery service;
- the one channel SGD that have an limited time of waiting – when for some type of goods (for example, a food) the time expenditures during waiting in a queue and delivery is important. This type of the systems is typical, when the waiting and delivery time influence the final cost of an order;

- the one channel SGD that have a limited time of waiting in particular location – when the storage of delivery goods (goods with a large size) has their limited quantity;
- the one channel SGD that have a limited time of waiting or other crucial parameters – when the minimization of the delivery duration or other important parameters is a very decisive thing. This type of the system is popular when the delivery and waiting parameters significantly influence the final cost of a order[2].

V. The One Channel SGD That Have an Option of a Rejection

Presume that there is a channel reached by an orders' flow of intensity λ. An outcome flow has intensity μ. The graph of this system's states is presented on fig. 3.

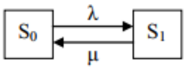

Fig. 3. The graph of states of one channel SGD that has an option of a rejection.

This system can have two states:

- S_0 – a channel is free;
- S_1 – a channel is busy (the order service is happening).

The system's probability:

- P_0 – the probability of the state S_0

$$P_0 = \frac{\mu}{\lambda + \mu}; \qquad (12)$$

- P_1 – the probability of state S_1 [13]

$$P_1 = 1 - P_0. \qquad (13)$$

The one channel SGD that has an option of a rejection is a station of constant service of goods delivery by the means of UAV. The orders that appear during the current delivery fulfilment are automatically ignored. The intensity of an order's flow is $\lambda = 1$ (an order per an hour).

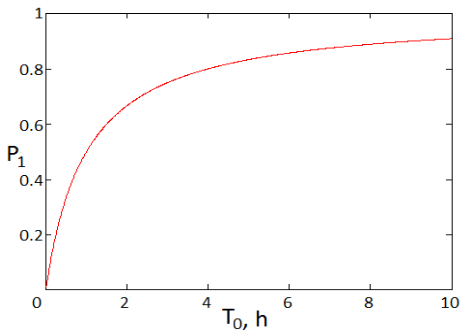

Fig. 4. The dependency between the probability of a channel charge P_1 and the service duration T_0

As the graph shows, when the time of order's service T_0 increases the probability of rejection is also increases because the probability of a channel charge is high $-P_1$. The time of service duration increasing is caused by the enlargement of the distance between a client and a service provider.

VI. The One Channel SGD That Have Waiting Time and a Restricted Queue's Length

The one channel SGD that have waiting time and a restricted queue's length comprise the one channel SGD which service work is narrowed by a time of a order's fulfilment waiting and a place of in-queue location according to the given classification (fig. 2). This is happen because the order's location in a queue (an order number in a list) and a time of order's fulfilment are the crucial parameters of "a queue" issue.

The graph of proposed system is shown on fig. 5.

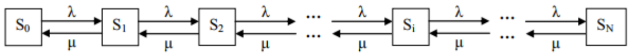

Fig. 5. The graph of system's states in case of a one channel SGD that has a time of waiting and a restricted queue's length

The states of SGD have the next interpretation:

- S_0 – a channel is free;
- S_1 – a channel is busy (a queue is absent);
- S_2 – a channel is busy (there is one order 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).

The system's probability:

- P_0 – the probability of state S_0

$$P_0 = \begin{cases} \dfrac{1-\rho}{1-\rho^{N+1}}, \rho \neq 1, \\ \dfrac{1}{N+1}, \rho = 1; \end{cases} \qquad (14)$$

- P_i – the probability of state S_i

$$P_i = \begin{cases} P_0\rho^i, \rho \neq 1, \ i = 0,1,\ldots \\ \dfrac{1}{N+1}, \rho = 1. \end{cases} \qquad (15)$$

The mean number of in-system orders:

$$L_s = \begin{cases} \dfrac{\rho\left(-(N+1)\rho^N + N\rho^{N+1}\right)}{(1-\rho)(1-\rho^{N+1})}, \rho \neq 1, \\ \dfrac{N}{2}, \rho = 1. \end{cases} \qquad (16)$$

The mean duration of one order's in-systems existence:

$$T_s = \frac{L_s}{\lambda q}. \qquad (17)$$

The upper presented station can be presented like a one channel SGD that has a waiting time option and a limited queue's length and fulfills 50 orders per a time unit by the means of UAV. When this system is busy, a new order cannot be accepted to a service queue and a rejection appears. The time of one order's fulfilment takes $T_0 = 1{,}6$ hour.

In this circumstance the meaning of P_i channel's charge probability can be defined on the base of formulas (14) and (15) and her dependency on the total intensity of a channel load ρ and the number of delivery orders inside SGD i, can be revealed, which is shown on fig. 6.

As the graph shows, when the total intensity of a channel load ρ is less than a one, the probability P_i is maximal. In this case the channel is free and UAV via idle. In situations when the intensity ρ is close or equal to a one, the in-system orders' quantity i approximates to the standard probability's uniform distribution P_i. In the case, when the total intensity ρ is more than a one, than a UAV has not a free time free of service fulfilment.

The mean duration of in-system order's life T_s can be defined on the base of formulas (2), (4), (5), (16) and (17) and their dependency on the total intensity of a channel load ρ can also be revealed, that is depicted on fig. 7.

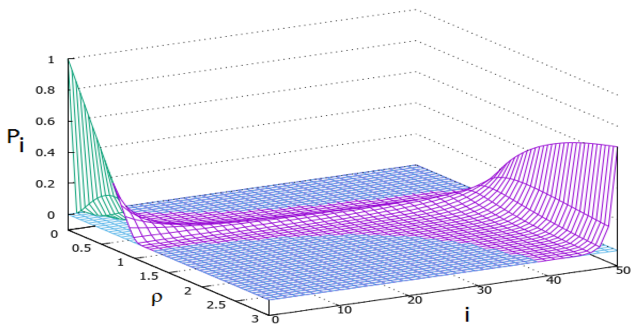

Fig. 6. The dependency between the probability of a channel charge P_i and the total intensity of channel load ρ together with the quantity of delivery orders inside SGD i

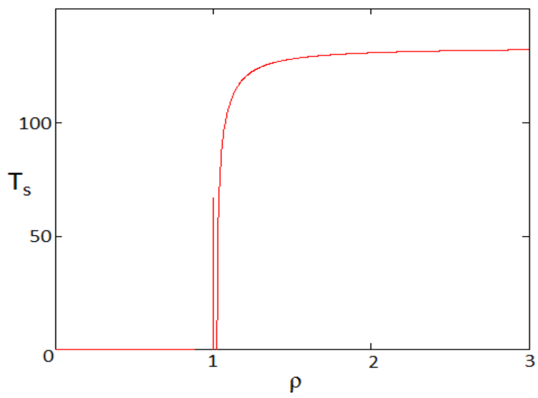

Fig. 7. The dependency between a mean time of in-system order's existence T_s and the total intensity of a channel load ρ

As we can see on the graph, when the total intensity of a channel's load ρ is less than one grade, the mean time of order's in system existents of T_s is equal to zero because a queue is absent. When the intensity ρ is more than one grade the mean time T_s exponentially increases because of the formed queue caused by the pervasive quantity of incoming orders inside the system. After reaching to some level the meaning of time T_s is practically unchangeable. When the total intensity ρ is close to a one, the time of orders in system existence T_s is the time of the fulfilment of the mean number of orders. And this orders' number comprises a half of the all in-system orders [28,29].

VII. The One Channel Systems of a Goods Delivery That Have an Unlimited Time of Waiting

This system states' graph is shown on fig. 8.

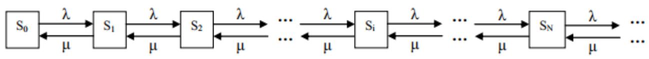

Fig. 8. The states' graph of one channel SGD that has an unlimited time of waiting

The states of this SGD are similar to the previous systems states.

The system's probability:

- P_0 – the probability of the state S_0

$$P_0 = 1 - \rho\,; \tag{18}$$

- P_i – the probability of the state S_i

$$P_i = P_0 \rho^i\,. \tag{19}$$

The mean number of in system orders:

$$L_s = \frac{\rho}{1-\rho}\,. \tag{20}$$

The mean number of orders that are in a queue:

$$L_q = \frac{\rho^2}{1-\rho}\,. \tag{21}$$

The mean time of order's in system existence:

$$T_s = \frac{1}{\mu(1-\rho)}\,. \tag{22}$$

The mean time of an order's in queue existence:

$$T_q = \frac{\rho}{\mu(1-\rho)}\,. \tag{23}$$

This station can also be presented like one channel SGD that has unlimited time of waiting and can fulfill the unlimited quantity of delivery orders by the means of UAV so that the length of a queue is theoretically infinite[14].

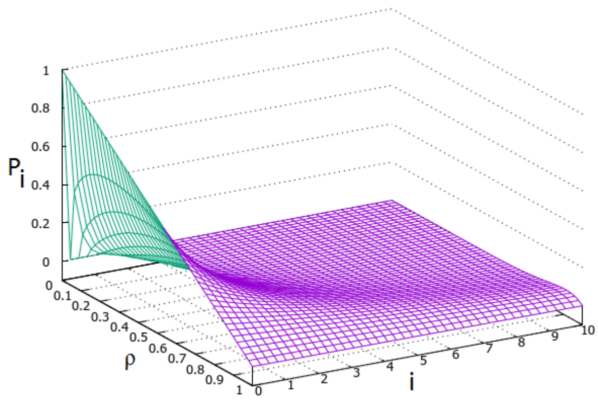

Fig. 9. The dependency between the probability of a channel charge P_i and the total intensity of a channel's load ρ together with the quantity of delivery orders i

In this circumstance the meaning of the probability of a channel charge P_i can be defined by the use of formulas (18) and (19) and the dependence between this probability and the total intensity of a channel's ρ together with the quantity of delivery orders i can be defined, which is shown on fig. 9.

As we can see on the graph, the total intensity of a channel load ρ cannot be more than a one, because it comes from the formula (18), so the probability of a channel charge P_i cannot be less than zero, because this meaning has any physic sense. The less are the total intensity of a channel load ρ and the delivery orders' quantity i, the more is the probability of a channel charge.

The meaning of the mean number of in system orders L_s and in queue orders L_q, can be defined on the base of formulas (20) and (21) and their dependency on the total intensity of a channel load ρ, which is showed on fig. 10.

As the graph shows us, when the total intensity of a channel load ρ increases, the mean numbers of in system orders is L_s and in queue orders L_q also rise. When the intensity ρ approximates to one, the numbers of in system orders L_s and in queue orders L_q approximate to infinity. This causes the overload in the real systems.

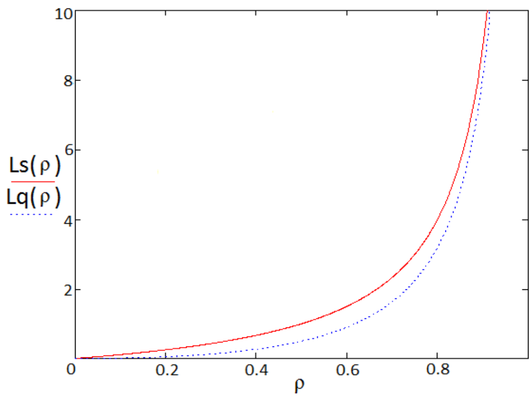

Fig. 10. The dependency between the mean number of delivery in system orders L_s together with in queue delivery orders L_q and the total intensity of a channel load ρ

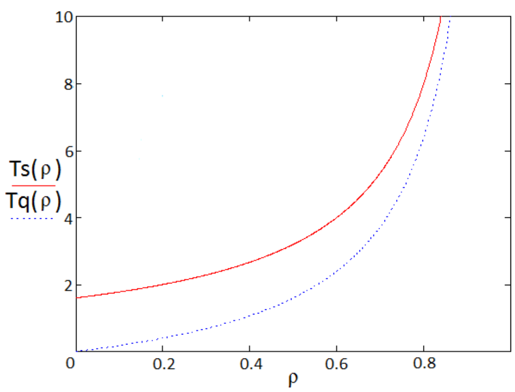

Fig. 11. The dependency between the mean duration of in system T_s together with in queue T_q order's existence and the total intensity of a channel load ρ

The mean duration of in system T_s and in queue T_q order's existence can be defined on the base of formulas (2), (22) and (23) and their dependency on the total intensity of a channel load ρ can also be defined by the means of these formulas, which is showed on fig. 11. As we can see it on the graph, when the total intensity of a channel load ρ increases, the mean duration of in system T_s and in queue T_q order's existence also rise. In close, when the intensity ρ approximates to zero, then the time T_q also approximates to zero, and T_s – approximates to some minimal meaning. When the total intensity ρ approximates to one, then the mean duration of in system T_s and in queue T_q order's existence can approach infinity. In the case of real working systems it can causes the system's overload.

VIII. Conclusion

In this article is taken dawn the analyzing of SGD that widely implementing UAV during their work.

The focal point of this research is the one channel SGD or systems where each goods delivery is provided by the service of one UAV. The specificity of their work is formed by their functional parameters main of which is observed in the article.

On the base of the proposed classification the next types of the one channel SGD are presented – the one that has a cancel option, the one that has waiting time and a limited order's queue and the one that has unlimited time of waiting for order's fulfilment.

The parameters' modelling of each type of SGD is noted. In the case of the one channel SGD with rejection it is clear that increasing of service time consumption is caused by the increasing of distance of goods transportation which also can cause a channel overloading. It is typical for one channel SGD, which have waiting time option and the limited queue length, that when the total intensity of channel loading is less than one point than the probability is the biggest and mean time of goods' in-system staying approximates to zero; when the total intensity of channel loading is close to or equal to a one then the quantity of the goods delivery's orders is very close to the uniform probability distribution and the order's in-system staying time is a time that takes the providing of mean number of orders; when the total intensity of channel loading is more than one point a UAV fulfils constant delivery work and mean time has exponent increase. In the case of one channel SGD that have unlimited waiting time, the less the total intensity of channel loads is, the more probability of channels occupation is and the intensity increasing causes the rising of mean number of orders and the time of order's in-system staying.

During the composing of real SGD the main system's aspect that causes the cost of system's building is the number of the involved UAV. The income from SGD work is grounded on the quantity of fulfilled delivery orders and it can decrease when too much order's cancelling happen or the delivery time's consumption increasing or slowing a queue promotion. So, the number of implemented UAV should be such when the total intensity of channel load approximates to a one. In this case, UAV do not have idle time and it takes not much time of waiting for an order fulfilment.

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