TECHNOLOGY, CREATIVITY, IMPLEMENTATION

REAVILING THE DISTRIBUTION REGULARITIES OF THE PROCEDURE EXECUTION TIME OF THE ALGORITHM OF TOWER CONTROLLER`S ACTIONS USING GERT NETWORKS

Liudmyla Dzhuma
Ph.D., Associate Professor, Assistant Professor at the Department of Information Technology,
Flight Academy of the National Aviation University, Ukraine
e-mail: ldzhuma@gmail.com, orcid.org/0000-0002-7043-3544

Oleksii Lavrynenko
Air traffic controller Kyivcentraero Regional Branch of UkSATSE, Ukraine
e-mail: lavrykkot@gmail.com, orcid.org/0000-0001-8783-3731

Summary

The article discusses issues related to the calculation of the parameters distribution of the procedure execution time of the algorithm of the Tower controller`s actions when servicing the aircraft performing the approach (hereinafter simply the ALGORITHM), using the Graphical Evaluation and Review Technique (GERT network). ALGORITHM is an integral part of the trainee reference (or model-following) model in the intelligent training system "ATC of Tower", which is being developed by the Department of the Information Technologies of the Flight Academy of the National Aviation University. The reference model is formed on the basis of a list (set) of extremely detailed technological operations, the order of performing these operations upon a specific situation, a model of information flows circulation at the specialist's workplace, reference values, and time spent probabilistic models on performing technological operations. The reference model in the process of system functioning closely interacts with the trainee current model, thereby ensuring the fixation of his mistakes. On the basis of his mistakes, the intelligent system forms an individual training trajectory for the trainee and provides an opportunity for an objective automatic assessment of his operation activities. The use of the GERT network in calculating the ALGORITHM time distribution parameters allows obtaining the expected mean time value and the root-mean-square (standard) deviation, but in some cases, it does not allow calculating the execution time of its individual parts, for which the time is directly proportional to the performance characteristics of an aircraft.

Keywords: intelligent training system, trainee reference model, technological operations, approach, aircraft, transfer function, average expected time.

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1. Introduction

Today, the "degree of maturity" of the methods and means of information technology allows us to shift the emphasis on the independent work of the subject of training in almost any area, and the professional training of air traffic controllers is no exception.

The relevance of the direction is provided by the possibility of forming an individual trajectory of the trainee training based on the mistakes made by him at the previous stages, and the implementation of the objective control of knowledge.

At the Department of the Information Technologies of the Flight Academy of the National Aviation University, research is being carried out to improve the quality of the air traffic control by the operators of the navigation service systems and traffic control, and the work *(Piliponok, 2017)* presents the method of the same name, implemented in the intelligent training system "ATC of Tower". The specification of this system provides the modes of demonstration, training and control.

The reference model embedded in the system makes it possible to implement training and knowledge control modes. This model in the process of system functioning closely interacts with the trainee current model. On the basis of this information, the system forms an individual trajectory of the professional training for the trainee.

The reference model is based on:

1. The list of technological operations (TOs), the correctness of which must be controlled in terms of qualitative and quantitative indicators. An extended list of TOs was obtained at the stage of extracting knowledge about the subject area using the combined method of timing *(Dzhuma, et al, 2015).*
2. The procedure of performing TOs, depending on the situation, which is determined by the air and ground traffic situation, aircraft performance characteristics, weather conditions, etc.
3. A model of information flow circulation, developed on the basis of an analysis of the workplace of an air traffic controller of the airport traffic control tower (henceforth Tower controller), for which information circulation patterns have been identified *(Dzhuma, et al, 2016).*
4. The reference values of the time that is spent on performing each of the TOs. The basis for these values are the regularities we discovered among the temporal indicators of technological operations of the Tower controller’s activity, which provide the possibility of an objective automatic assessment of the operator's activity of the subject of training.

Determination of the order of performing TOs (ALGORITHM), as well as obtaining the parameters of the execution time distribution of its procedures, are integral parts of the problem being solved. The procedure of performing TOs can be obtained as a result of the analysis of the Tower controller’s professional activity, the patterns identified in it, as well as on the basis of the developed model of information flows circulation at the Tower controller’s work place.

Obtaining the parameters of the distribution of the execution time of the ALGORITHM procedures becomes possible through the use of GERT network, which allows one to describe complex systems consisting of the independently operating and interacting subsystems, and describe not only the averaged values of the system parameters, but provide complete information, which is the distribution function of these parameters as random variables.

2. Construction of an algorithm for the Tower controller’s actions when a landing aircraft performing approach

As noted earlier, the work of an air traffic controller officer (ATCO) should be regarded as an operator's activity. The basis of this judgment is the analysis of the tasks of control, management, transmission or transformation of information solved by a specialist, interaction with technical devices and the external environment using a variety of special means of displaying information and controls *(Strelkov, 2001).*

The logical organization of the human operator's activity, consisting of a set of actions and operational units of information, is usually called the algorithm of the human operator's activity *(Dushkov, et al, 2005).* A distinction should be made between prescribed and implemented algorithms. When designing a human-machine system, one should strive for bringing the prescribed and implemented algorithms as close as possible. Difficulties in achieving complete identity of both types of algorithms are due, firstly, to insufficient knowledge of the internal organization of the operator's actions, which complicates their identification, and secondly, to the fact that a person, within certain limits, can change the way of achieving the goal, depending on various conditions. In this case G.V. Sukhodolsky *(Suhodolskij, 1994).* proposes to distinguish between reliable (hard) and probabilistic (stochastic, flexible) algorithms.

In the first case, we are talking about an unambiguous sequence in which actions follow each other with a probability equal to 1 (one). In the second case, an ambiguous sequence is assumed in which the transition from action to action is carried out with a probability $0 < p < 1$ *(Dushkov, et al, 2005).*

To represent the Tower controller activities, which services aircraft arriving at the aerodrome area in order to land, on the basis of the results of the study, an algorithm of his actions was formed. We have chosen a graphical way of the algorithm representing as the most visual. In a graphical representation, the algorithm is depicted as a sequence of interconnected functional blocks (in our case, technological operations), each of which corresponds to the execution of one or more actions. The algorithm also indicates the probabilities of transition from one functional block to another or their repeated execution if the probability of triggering is not equal to 1.

This algorithm is conventionally divided into the following procedures:

1. Procedure "1-1" – transmission by the Briefing Office dispatcher of the information about the aircraft departure from another aerodrome. The transmitted information includes flight numbers (aircraft call sign) and universal time coordinated of departure from another aerodrome.

2. Procedure "2-2" – the Approach controller sends information about the incoming aircraft. At this stage, information about the intended type of approach and additional information, if any, is transmitted.

3. Procedure "3-3" – the final stage of the aircraft approach. The duration of this stage depends directly on the aircraft performance characteristics: the flight speed at the descent stage, or, in other words, the time the aircraft remains on the final approach track from the moment of first communication contact with Tower controller until the moment of braking after landing. At this stage, the controller makes a decision on issuing a landing clearance in accordance with the air situation at the aerodrome (available aircraft for departure, work on the runway) and its area (aircraft making go-around procedure).

4. Procedure "4-4" – vacating the runway after landing and taxiing the aircraft to its parking position. The procedure when the controller issues instructions for the aircraft to vacate the runway, as well as instructions for taxiing to the parking area.

5. Procedure "5-5" – transmission of information to the Briefing Office dispatcher about the actual time (UTC) of aircraft landing. A feature of this procedure is that a possible start of its execution is the beginning of the previous procedure "4-4", in other words, these procedures can be performed in parallel. The end of the procedure is limited up to a regulated time after landing, during which a landing telegram must be sent to the authorities concerned. According to the Ukrainian legislation and European standards, this time should not exceed 5 minutes after aircraft landing at the destination airport.

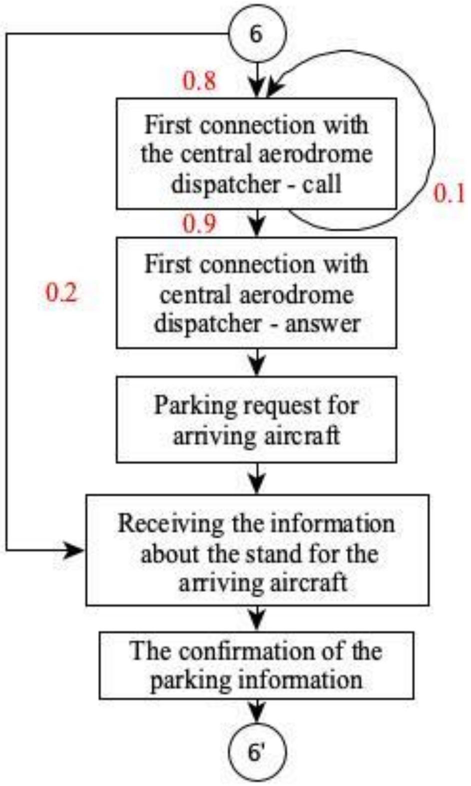


Fig. 1. Algorithm for performing the procedure "6-6"

5. Procedure "6-6" – request/receipt of information from the central airdrome dispatcher about the parking stand for the arriving aircraft. Depending on the air traffic management automated system used at a specific workplace or air traffic service unit, information about aircraft parking stand is transmitted either by communication channels and this algorithm is performed, or by displaying the parking number in the aircraft formular.

The procedure begins from the moment of getting the information about the aircraft departure from another aerodrome and ends at the stage of issuing taxi- instructions. In other words, this procedure is a parallel process for procedures "2-2", "3-3" and part of the procedure "4-4". The algorithm for this procedure is shown in Figure 1.

The general algorithm will be considered as procedural component of the trainee reference model, which will allow us to evaluate the skills and actions of the operator in terms of qualitative parameters. Also, on the basis of the obtained general algorithm, further work on the creation of a mistakes model is possible in accordance with the structure of the trainee model described in this work *(Klyukin, 2012)*. The mistakes of the trainee are analysed within this model, ensuring the automation of assessment, and as a result, alternative trajectories of training the trainee current model are determined, which makes it possible to introduce an adaptive component into the intelligent learning system.

3. Calculation of the distribution parameters of the execution time for the algorithm procedures using GERT networks

When designing systems, it is important to know not just the average values of the system parameters, but to have more complete information, which is the distribution function of these parameters as random variables.

Methods such as Markov random field make it possible to easily estimate the mathematical mean value and dispersion of the number of times a process is in the states of a non-returnable set, but the distribution functions of these quantities are quite difficult to calculate, and in Petri nets, to obtain numerical results, simulation modeling is required, which allows by repeated repetition of numerical experiments evaluate all necessary statistics, including distribution functions, mathematical mean value and dispersion *(Dorrer, 2016)*.

GERT networks are referred to as network models (N-schemes). They allow us to describe complex systems consisting of independently working and interacting subsystems.

Some sources *(Dorrer, 2016)* say that the formalisms of GERT networks resemble the description of Colored Petri nets, while other sources *(Zyryanov, et al, 2012)* say that these networks are a variant of semi-Markov random field (models), but the random variables in them are characterized not only by dispersion, but also by the distribution law.

The structure of the GERT network can be described in the form of a graph

$$G=(N,A),$$

where N is the set of network nodes, $N=\{n_1,\ldots,n_n\}$, n is the number of nodes; A is the set of oriented arcs, $A=\{a_{ij},i,j\in(1,\ldots,n)\}$. The arc a_{ij} connects two nodes (n_i and n_j) and is directed from n_i to n_j sources *(Zyryanov, et al, 2012).*

A directed edge (arc) is associated with which node i leaves and which node j enters, and is denoted as an arc $\langle i,j\rangle$. The arc $\langle i,j\rangle$ in the framework of GERT networks is considered as "work on the arc" and has the weight of some additive parameter (for example, the work execution time). For a GERT network, the weight of the arc $\langle i,j\rangle$ is the vector $\left[p_{ij},F_{ij}\right]$, where p_{ij} is the conditional probability of the execution of the arc i,j under the condition of activation of the node i and F_{ij} is the conditional distribution function of the execution time of the arc i,j, under the condition that $\langle i,j\rangle$ is satisfied. In this case, the arc $\langle i,j\rangle$, for which $F_{ij}=0$, is called an "idle" arc or an arc on which no work is performed.

The nodes of the GERT network are interpreted as states of the system, and arcs as transitions from one state to another. Such transitions are associated with the execution of generalized operations characterized by the distribution density and the probability of execution *(Dorrer, 2016; Filips, et al, 1984; Zyryanov, et al, 2012).*

Each node on the network has an input and output activation function. The input function defines the condition under which the node can be activated. The output function defines a set of conditions associated with the result of activating a node.

Types of input functions:

- AND-function – a node is activated if all arcs inputted in it are executed;
- IOR-function – the node is activated if any arc or several arcs inputted in it are executed;
- EOR-function – a node is activated if any arc inputed in it is executed, provided that at a given time only one arc inputted in this node can be executed.

Types of output functions (Fig. 2): deterministic function (DT) – all arcs leaving the node are executed if the node is activated; stochastic function (ST) – only one arc outgoing from a node is executed with a given probability if the node is activated.

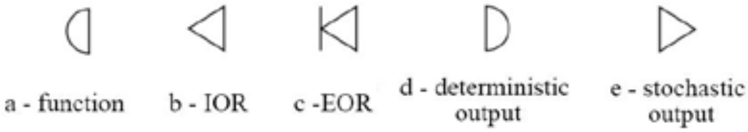


Fig. 2. Input and output functions of GERT network nodes

By combining all the input and output functions, we get six different types of nodes (Fig. 3):

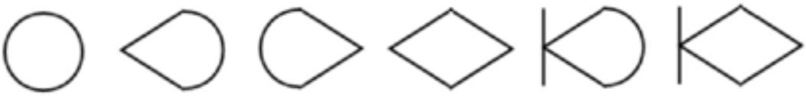
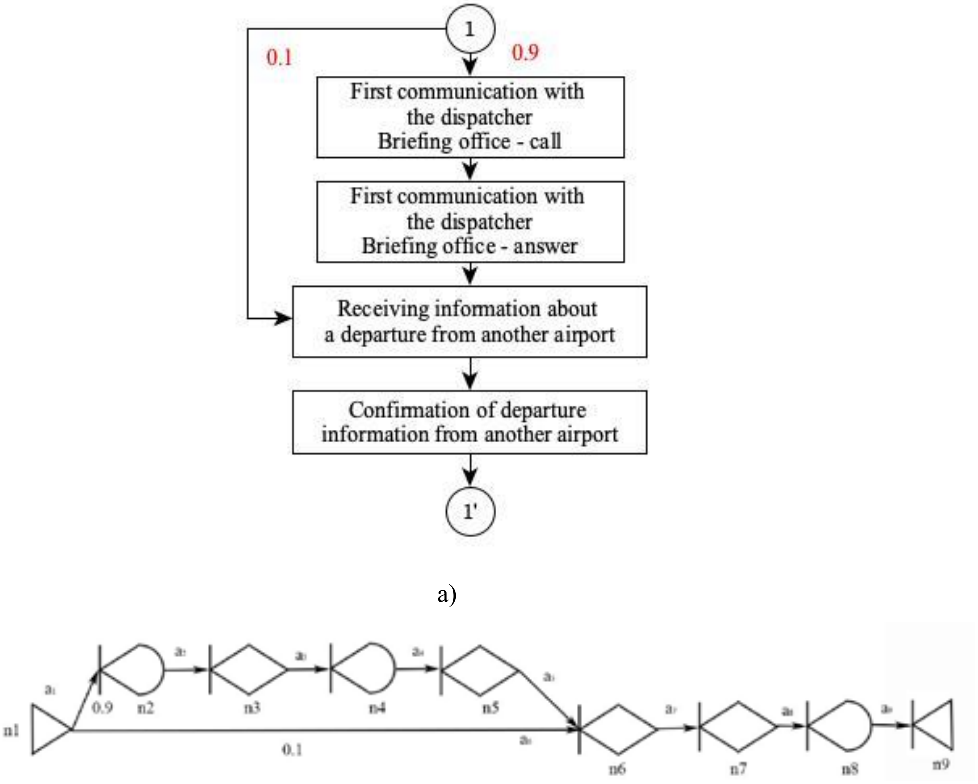


Fig. 3. Types of nodes in the GERT network

A node with an input AND function and a stochastic output function is called a STEOR node. Activation of a node means that the system has passed into a certain state and determines a lot of further work (operations). One or several works (operations) begin their execution immediately after the activation of the node that is their beginning. A node is activated if its input function is executed. After executing the output function of the activated node, it becomes inactive.

The results of the functioning of the graph G can be presented in the form of a set of parameters of the network being executed: the probability of the network runoff activation, the runoff distribution function, etc.

Thus, a GERT network is a network in which each node belongs to one of six types of nodes, for each arc $\langle i, j \rangle$, where a weight of the form $\left[p_{ij}, F_{ij} \right]$ with the above value is defined and the initial distribution of network sources is given *(Pritsker, 1996a; Pritsker, 1996b)*. The initial task for calculating the parameters of the mean time, (root-mean-square) standard deviation from the mean and the probability of an event is to represent the process in the form of a GERT network. Figure 4 shows the procedure "1-1" for transmitting information about a departing aircraft from another aerodrome from the Briefing Office dispatcher in the form of an algorithm (a) and a GERT network (b), taking into account stochastic and deterministic outcomes of individual technological operations.



a)

b)

Fig. 4. Model of the transmitting information process about the departing aircraft from the Briefing Office dispatcher a) in the form of an algorithm b) in the form of a GERT network

The process model in the form of a GERT network (Fig. 4b) includes 9 nodes $N=\{n_1,\dots,n_9\}$ and a set A containing seven arcs on which the following operations are performed:

a_1 – initial state;
a_2 – first communication with the Briefing office dispatcher – call;
a_3 _time of delay in response with the Briefing Office dispatcher;
a_4 – first communication with the Briefing office dispatcher – answer;
a_5 – time of delay in response with the Briefing Office dispatcher;
a_6 – initial state;
a_7 – receiving information about a departure from another aerodrome;
a_8 – time of delay in response with the Briefing Office dispatcher;
a_9 – confirmation of information about a departure from another aerodrome.

Each arc $a \in A$ of the GERT network is characterized by the probability of execution of this arc p_a, as well as the distribution of the probabilities of the parameter value transmitted over the network.

Figure 4 shows the probabilities of triggering transitions that are not equal to 1, that is, this is an arc a_1 with a probability of 0.9 and a_6 with a probability of 0.1. Let y be a random variable characterizing the process on the arc a (in our case, it describes the execution time of the operation) with the conditional distribution density $f_a(y)$.

Thus, the full characteristic of the arc a is the vector $[p_a, f_a(y)]$. Along with the distributions $f(y)$, we will consider the functions $M_y(s)$ generated by them, which are called generating functions and are calculated as (*Pritsker, 1996a; Pritsker, 1996b)*:

For a random variable with continuous distribution $f(y)$

$$M_y(s)=\int e^{ys} f(y)dy, \tag{1}$$

where s is a mean parameter, and the integral is taken over the entire domain of definition of the random variable y.

For a random variable with discrete distribution $f(y)$

$$M_y(s)=\sum e^{ys} f(y), \tag{2}$$

where summation is performed over all values of y. It is assumed that the integral in formula (1) and the sum in expression (2) are finite.

The use of generating functions makes it possible to evaluate the probabilistic characteristics of complex systems described by GERT networks in a simpler manner than when working directly with distributions of random variables. In this case, an important property of the generating function of a random variable is the ability to calculate the initial moments of the distribution $f(y)$. It is known that the k-th initial moment of a random variable y with a continuous distribution density function $f(y)$ is the integral

$$v_k=\int y^k f(y)dy, k=0,1. \tag{3}$$

In particular, $v_0=1, v_1=m(y)$ is the mathematical mean value of a random variable y; the second moment v_2 allows us to determine the dispersion of the random variable: $\sigma^2(y)=v_2-m^2(y)$.

The use of generating functions makes it possible to represent the characteristic of the arc $a \in A$ in the form of a vector $[p_a, M_a(s)]$., and the product of these components

$$W_a(s)=p_a M_a(s) \tag{4}$$

is called the *transfer function* of the arc $a \in A$ or its *W*-function (*Pritsker, 1996a; Pritsker, 1996b*).

The meaning of the transfer function is as follows. If the signal y acts at the input node n_i of some arc a_{ij}, then the signal $x = W_{ij}(s)y$ will arrive at the output node of this arc n_j. Also, the use of *W*-functions allows you to calculate the probabilistic characteristics of a system containing many arcs.

In figure 4b, two series-connected arcs a_7 and a_8 are shown, on which independent random variables y_7 and y_8 are given with their own distributions $f_7(y_7)$ and $f_8(y_8)$.

As a result of executing these arcs, we get a random variable $z = y_7 + y_8$ with a distribution function equal to the product of functions: $f(z) = f_7(y_7) f_8(y_8)$. Then, in accordance with formula (3), we obtain an expression for the generating function of the quantity z:

$$M_z(s) = M_{y_6+y_7} = \int\int e^{s(y_6+y_7)} f_6(y_6) f_7(y_7) = \int e^{sy_6} f_6(y_6) dy_6 \int e^{sy_7} f_7(y_7) dy_7 = M_6(s) M_7$$

Let us now turn to the *W*-functions. For each arc, the functions $W_7 = p_7 M_7(s)$, $W_8 = p_8 M_8(s)$ are known. The probabilities of completing arcs p_1 and p_2 are independent, therefore, the probabilities of completing both arcs is equal to their product: $z = p_7 p_8$. Thus, we obtain those arcs a_7 and a_8 are equivalent to one arc a_{78} (Fig. 5) with the transfer function

$$W_{78} = p_{78} M_{78}(s) = p_7 p_8 M_7(s) M_8(s) = W_7(s) \cdot W_8(s) \qquad (5)$$

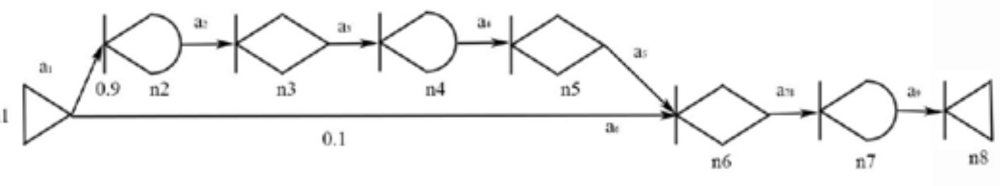


Fig. 5. Model of the transmitting information process about a departed aircraft from the Briefing Office dispatcher with an equivalent one arc a_{78}

Considering the section of the GERT network from arc a_1 to arc a_5, two operations have a deterministic value (the operation time is 1 second), and three operations are given by independent random variables, with the following distributions:

a_1 is normal distribution law;

a_3 *and* a_5 are described by the chi-square distribution.

Therefore, the expression for the generating function of the quantity can be considered as the sum of independent random and deterministic quantities $z = y_1 + y_3 + y_5$ with the distribution function equal to the product of functions: $f(z) = f_1(y_1) f_3(y_3) f_5(y_5)$ and deterministic quantities.

$$\begin{aligned} M_{z_1}(s) = M_{y_1+y_3+y_5} &= \int\int\int e^{s(y_1+y_3+y_5)} f_1(y_1) f_3(y_3) f_5(y_5) + y_2 + y_4 = \\ &= \int e^{sy_1} f_1(y_1) dy_1 \int e^{sy_3} f_3(y_3) dy_3 \int e^{sy_5} f_5(y_5) dy_5 + y_2 + y_4 = \\ &= M_1(s) M_3(s) M_5(s) + y_2 + y_4 \end{aligned}$$

The probability of fulfillment for all arcs of the network section from a_1 to a_5 is equal to 1, therefore, the probability of fulfillment of the section of arcs is equal to their product:

$p_{z_1} = 1$. Thus, we obtain those arcs $a_1 a_2 a_3 a_4 a_5$ are equivalent to one arc a_{15} (Fig. 6) with a transfer function

$$M_{15} = p_{15} M_{15}(s) = p_{15} M_1(s) M_2(s) M_3(s) M_4(s) M_5(s) = \\ = W_1(s) \cdot W_2(s) \cdot W_3(s) \cdot W_4(s) \cdot W_5(s). \quad (6)$$

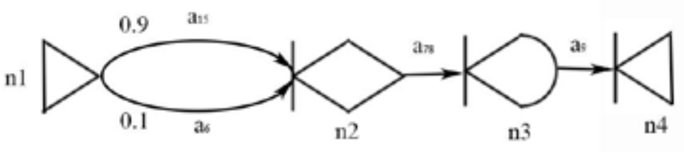


Fig. 6. Model of the transmitting information process about the departed aircraft from the Briefing Office dispatcher with equivalent arcs a_{15} and a_{78}

The resulting network has two parallel branches a_{15} and a_6, each of which is determined by its own *W*-function $W_{15} = p_{15} M_{15}(s)$ and $W_6 = p_6 M_6(s)$, and the output side of node n_1 is stochastic. This means that only one outgoing arc can be executed at a time, so the final *W*-function is the sum of the *W*-functions of the individual branches:

$$W_{12} = p_{12} M_{12}(s) = p_{15} M_{15}(s) + p_6 M_6(s) = W_{15}(s) + W_6(s). \quad (7)$$

This result is generalized to any number of parallel arcs, provided that all of them are EXCLUSIVE-OR.

The characteristics of the processes performed on arcs (in seconds) are given in table 1.

Table 1

Characteristics of processes performed on arcs

Arc name	**Probability of execution**	**Distribution type**	**Distribution parameters**	**Generating function** *Mij* (*s*)
a_1	0.9	Exponential	$a = 1.5$	(1 – *s* / $^{a)}$-1
a_2	1	Constant	$a = 1$	exp (*s*)
a_3	1	Chi square	k=1	(1-2*s*)$^{-k/2}$
a_4	1	Constant	$a = 1$	exp (*s*)
a_5	1	Chi square	k=1	(1-2*s*)$^{-k/2}$
a_6	0.1	Exponential	$a = 1.5$	(1 – *s* / *a*)$^{-1}$
a_7	1	Uniform	[1…6]	(exp (*s*) – exp (1*s*)) / 5*s*
a_8	1	Chi square	k=1	(1-2*s*)$^{-k/2}$
a_9	1	Constant	$a = 1$	exp (*s*)

Let us write out expressions for transfer functions $W_{ij}(s) = p_{ij} M_{ij}(s)$:

$$W_1(s) = 0.9(1 - s/1.5)^{-1},$$

$$W_2(s) = \exp(s),$$

$$W_3 = (1 - 2s)^{-1/2},$$

$$W_4(s) = \exp(s),$$

$$W_5 = (1-2s)^{-1/2},$$

$$W_6(s) = 0.1(1-s/1.5)^{-1/2}$$

$$W_7(s) = (\exp(s)-(1s))/5s,$$

$$W_8 = (1-2s)^{-1/2}$$

$$W_9(s) = \exp(s).$$

We use formulas (5) and (6) to obtain the transfer function of the GERT network (shown in Figure 6) from node n_1 to node n_4 along arc a_{15}:

$$W_{19} = W_{15}(s)\cdot W_{78}(s)\cdot W_9(s).$$

Substituting the expressions for the transfer functions of all arcs into the formula and doing some transformations, we get

$$W_{19} = 0.9\left(1-\frac{s}{1.5}\right)^{-1}(2\exp(s))\left(2(1-2s)^{-\frac{1}{2}}\right)\frac{\exp(s)-\exp(1s)}{5s(1-2s)^{-\frac{1}{2}}\exp(s)}.$$

In order to determine the generating function of the considered system, we use the formula

$$M(s) = \frac{W(s)_{19}}{W(0)_{19}},$$

which follows from the relations $W_{19}(s) = p_{19}\,M_{19}(s)19, W_{19}(0) = p_{19}$, because $M_{19}(0) = 1$.

Let us now proceed to calculating the moments of distributions at the output of the system, along the arc a_1. Calculating the derivative $dM_{19}(s)/ds$ at $s = 0$, we obtain an estimate of the first moment – the mathematical mean value:

$$v_1(y_9) = m(y_9) = \left.\frac{dM_{19}(s)}{ds}\right|_{s=0} = 8{,}34\,sec.$$

Further, finding the second derivative $d^2M_{19}(s)/ds^2$ at $s = 0$, we obtain the second moment of the distribution of the function y_9:

$$v_2(y_9) = m(y_9) = \left.\frac{d^2M_{19}(s)}{ds^2}\right|_{s=0} = 77{,}106\,sec^2.$$

Whence it follows that

$$\sigma^2(y_9) = v_2(y_9) - m^2(y_9) = 77{,}106 - 8{,}34^2 = 7{,}546\,sec^2,$$

$$\sigma(y_9) = 2{,}747\,sec.$$

Thus, in this system, the average expected time for transmitting information about an aircraft departure from another aerodrome from the Briefing Office dispatcher with the initial communication is 8.34 sec., and the root-mean-square (standard deviation) from the average is 2.747 sec.

Consider now a chain of nodes from n_1 to n_4. This chain differs from the previously considered only in the first link – a_6 instead of a_{15}. Making calculations similar to those given above, we get

$$W_{69}(s) = W_6(s)\cdot W_{78}(s)\cdot W_9(s) = \frac{0.1\left(1-\dfrac{s}{1.5}\right)^{-\frac{1}{2}}\left(\exp(s)-\exp(1s)\right)}{5s(1-2s)^{-\frac{1}{2}}\exp(s)},$$

whence

$$M(s) = \frac{W(s)_{69}}{W(0)_{69}},$$

Having calculated the first and second moments of the random variable y_9, of the section of the chain a_{69},we obtain

$$v_1(y_9) = m(y_9) = \left.\frac{dM_{69}(s)}{ds}\right|_{s=0} = 6,03\,sec.$$

$$v_2(y_9) = m(y_9) = \left.\frac{d^2M_{69}(s)}{ds^2}\right|_{s=0} = 26,06\,sec^2.$$

$$\sigma^2(y_9) = v_2(y_9) - m^2(y_9) = 26,06 - 5,03^2 = 0,7569\,sec^2,$$

$$\sigma(y_9) = 0,87\,sec.$$

So, the average time of transmission of information about an aircraft departure from another aerodrome from the Briefing Office dispatcher without initial communication is 5.03 sec., and the root-mean-square (standard deviation) from the average is 0.87 sec.

The capabilities of GERT networks make it possible to carry out similar calculations for the *“2-2” procedure* – transmission by the Approach controller of information about the incoming aircraft. A graphical representation of the GERT network of this process is shown in Figure 7.

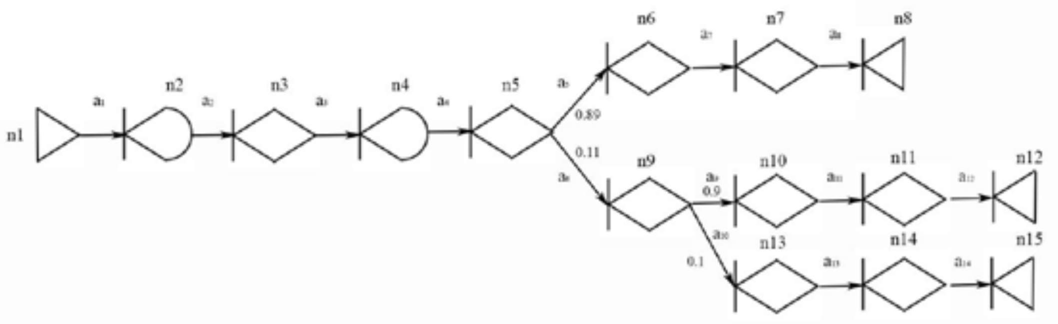


Fig. 7. Process model transmission by the Approach controller of information about the incoming aircraft in the GERT network form

The model for this process in the GERT network form (Fig. 7) contains 15 nodes, that is, $N = \{n_1, \ldots, n_{15}\}$ and a set A containing fourteen arcs on which the following operations are performed:

a_1 – first communication with the Approach controller – call;
a_2 – time of delay in response with the Approach controller;
a_3 – first communication with the Approach controller – answer;
a_4 – time of delay in response with the Approach controller;

a_5 – obtaining information about the approaching aircraft (using the instrumental approach system (ILS) with the probability $p = 0.89$);

a_6 – selection of an alternative approach method (probability of actuation $p = 0.11$);

a_7 – time of delay in response with the Approach controller;

a_8 – confirmation of information about the incoming aircraft;

a_9 – obtaining information about the approaching aircraft (using a visual approach with a probability $p = 0.9$);

a_{10} – obtaining information about the incoming aircraft (using the method of NDB (non-directional beacon) approach with the probability $p = 0.1$);

a_{11} – time of delay in response with the Approach controller;

a_{12} – confirmation of information about the incoming aircraft;

a_{13} – time of delay in response with the Approach controller;

a_{14} – confirmation of information about the incoming aircraft.

Since the time characteristics for all types of approach, as well as the response delay time with the Approach controller correspond to the same distribution laws and have the same parameters, the average expected time – for the Approach controller to transmit information about the approaching aircraft will be the same and will be 8.729 sec., And the root-mean-square (standard deviation) deviation from the mean will be 2.817 sec.

The probability of each outcome of an approach method selection. For the ILS system is 0.80/(0.85 + 0.05) = 0.89, for a visual approach – 0.09/(0.85 + 0.05) = 0.1, and for a NDB approach the probability of an outcome is 0.009/(0.85 + 0.05) = 0.01.

For procedure "5-5" – transmission of information to the Briefing Office dispatcher about the actual landing time of the aircraft and procedure "6-6" –request/receipt of information from the central airdrome dispatcher about the parking stand for the arriving aircraft, a characteristic feature is the presence of a cyclic operation of the transition. The triggering of this cyclic transition is due to the possible Tower controller workload in performing other operations, as well as a technical factor (problems with communication of a loudspeaker device). Graphical models of GERT networks of these stages are presented in Figures 8 and 9. The cyclic transition, or the so-called loop, of the first model is designated by arc a_5, where the signal from the output of node n_3 is fed to the input of the previous node n_2, for the second model, the loop is formed by transition a_3, connecting nodes n_3 and n_2.

Let's consider an anti-parallel connection, taking as an example a section of the GERT network corresponding to the procedure "5-5" (Fig. 10). Signal y arrives at the input of node n_3 it is added to the feedback signal v, and the sum of these signals u passes through arc a_3, as a result of which the output signal x is formed at the output of node n_3. But this signal along the arc a_5 with the transfer function $W_5(s)$ returns to the input of node n_2, turning into v.

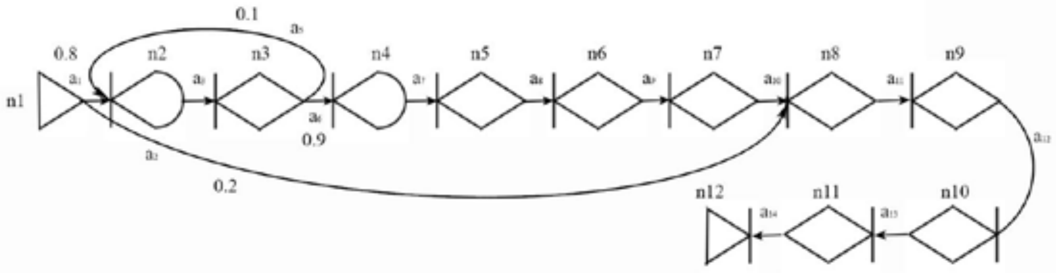


Fig. 8. Model of the process of transmitting information to the Briefing Office dispatcher about the actual landing time of the aircraft in the GERT network form

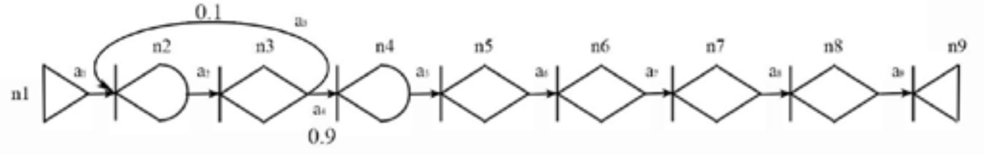


Fig. 9. A model of the process of requesting/receiving information from the central airdrome dispatcher about parking stand for an arriving aircraft in the GERT network form

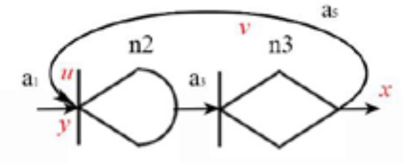


Fig. 10. Anti-parallel connection of arcs of the GERT network

Taking into account the property of the transfer functions, we obtain the following relations between the signals:

$$u = y + v,\ v = W_5(s)x,\ x = W_3(s)u,$$

whence, excluding the variables u and v, we have

$$x = \frac{W_3(s)}{1 - W_3(s)W_5(s)},$$

i.e. the transfer function for this anti-parallel connection is

$$W_{b.c} = \frac{x}{y} = \frac{W_3(s)}{1 - W_3(s)W_5(s)}. \tag{8}$$

Thus, when calculating the time distribution parameters when using the transfer function for loop (8), the average expected time for the process of transmitting information to the Briefing Office dispatcher about the actual aircraft landing time is 7.848 sec., the root-mean-square (standard deviation) from the average will be 3.066 sec. For the process of requesting/receiving information from the central airdrome dispatcher about the parking stand for the arriving aircraft, the average expected time is 9.04 sec., the standard (root-mean-square) deviation from the average will be 4.87 sec.

Since in some cases the disadvantage of GERT networks is the complexity of analytical calculations to determine the moments of the distribution function of the output quantity and the presence of subsystem blocks in the procedures "3-3" and "4-4" (the final stage of the aircraft approach and vacating of the runway after landing and taxiing of the aircraft to its parking stand respectively) the execution time of which is directly proportional to the flight performance specific aircraft, the calculation of distribution parameters becomes possible only with simulation.

4. Conclusions

The result of the scientific work is the algorithm of the Tower controller`s action when servicing the aircraft performing the approach with the calculated distribution parameters of the procedure execution time. ALGORITHM is conventionally divided into six procedures to simplify work with it. The resulting ALGORITHM is a procedural component of the trainee reference model, designed to assess the skills and actions of the student in terms of qualitative parameters.

Also, this ALGORITHM allows us to develop a mistakes model, and as a result, to implement alternative training trajectories for the trainee current model in the context of creating an adaptive component of the intellectual training system.

GERT networks, thanks to their specifications, allow describing complex systems consisting of independently operating and interacting subsystems, as well as calculating the distribution parameters of the execution time of procedures.

On the basis of the developed models of GERT networks for the ALGORITHM procedures, the values of the average expected execution time for each specific procedure and the root-mean-square deviation (standard deviation) from the mean, necessary for further work with the simulation model, were obtained.

It was also revealed that the determination of the distribution parameters of the procedures execution time using GERT networks in the presence of blocks with computational-dependent components in the ALGORITHM (a block with the calculation of aircraft performance parameters), which also cannot be described by deterministic indicators or probability distributions, is not advisable. For this type of procedure, simulation is the most appropriate method for identifying parameters.

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