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REVEALING THE REGULARITIES RELATED TO THE PROFESSIONAL ACTIVITIES OF THE AIR TRAFFIC CONTROLLER OF AIRPORT TRAFFIC CONTROL TOWER

The object of research is the professional activity of an air traffic controller of the airport traffic control tower (henceforth Tower controller). The subject of research is the regularities revealing in this specialist activity in the performance of its work responsibility for the trainee reference model formation in the intelligent training system «ATC of Tower». One of the most problematic areas is the lack of training systems that would allow for independent training of these aviation specialists, whose knowledge assessment would be automatic and objective.

The study used methods of analysis, combined timing, synthesis, statistical analysis and probabilistic modelling. The approach to data collection and analysis proposed as part of study made it possible to obtain an information flows circulation model at the Tower controller workplace and formalize the time characteristics of technological operations performed by it during the aircraft landing procedure. This is fundamentally important for the development of the trainee reference model of the intellectual training system, as well as for the implementation of the training mode and automatic objective assessment of the student's knowledge and skills.

The approbation obtained results of this approach of data collection and analysis make it possible to consider it an effective tool for obtaining objective information about the subject area of the Tower controller's professional activity, which is a complex continuous-discrete stochastic dynamic control system with a mixed structure. In contrast to the formation of reference models existing approaches, the approach to collecting and analysing data proposed in the work makes it possible to develop a trainee reference model that more fully describes the Tower controller's activities. Also, the proposed model reflects the order of actions, and when interacting with the trainee current model, it allows to implement objective (without an instructor) automatic assessment.

Keywords: *information flows circulation model, time characteristics of technological operations, Tower controller.*

1. Introduction

Almost all spheres of human activity are whatever the case related to information technologies, and the level of their development often determines the success of the tasks that must be solved. With regard to the subject area related to the professional training of air traffic controllers, the current «degree of maturity» of methods and means of information technology allows to shift the emphasis to the independent work of the subject of training in this area.

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

At the Information Technologies Department of the Flight Academy of the National Aviation University (Ukraine), research is being carried out in order to improve the quality of air traffic control by operators of navigation services and traffic control systems. And in work [1] the method of the same name is presented, the reflection of which is the intelligent training system «ATC of Tower» being developed, the specification of which puts forward the following requirements:

1. The ability to work in the modes of demonstration, training, control, in which it is assumed, respectively:

– demonstration of the stages of the decision-making process when issuing permits for take-off and landing;

– display of special prompts that help the student in making the necessary decisions;

– dialogue between a student and a system that provides an opportunity to introduce independently made decisions;

– assessment of the student's actions, from the point of view of quantitative and qualitative parameters of the solution formed by it.

2. Presence of the monitor of meteorological data, changing during the operation of the system, as much as possible similar to the weather display of aerodrome metrological automated system – AMAS-1.

3. Availability of the aerodrome model, which reproduces the movement of aircraft along the aerodrome movement area.

2. The object of research and its technological audit

The air traffic controller's activity has all the features of an operator's activity, the main part of which is described by an algorithm of its behaviour and consists of technological operations [2] under certain conditions. The ultimate goal of the activity is to obtain a beneficial effect. This goal is achieved in stages, through the solution of individual problems, so it is possible to speak not only about the algorithm for solving a separate problem, but also about the algorithm of the operator's activity as a whole [3]. It should also be noted that flight safety is ensured not only by the correctness of the algorithm of actions, but also by efficiency and timeliness. Therefore, to formalize the model of behaviour of an air traffic controller, it is necessary to use a linguistic algebraic system, which makes it possible to implement both a description of correct activity and an assessment of its behaviour from the side of quantitative indicators.

In the presented work, *the object of research* is the air traffic controller of the airport traffic control tower (hereafter Tower controller) professional activity. The research subject is the revealing the regularities of this specialist activity in the performance of its work responsibility in order to form a trainee reference model of the intelligent training system «ATC of Tower». The reference model in the process of system functioning closely interacts with the trainee current model. Based on this information, the system forms an individual trajectory for the trainee.

The reference model is based on:
– the list (set) of technological operations (TO), the correctness of the implementation of which should be subject to control in terms of qualitative and quantitative characteristics. An extended list of TOs, obtained at the stage of knowledge elicitation about the subject area using the combined method of timing [4];
– the procedure of performing TOs depending on the situation, namely air and ground picture (situation), aircraft performance characteristics, weather conditions, etc. [5];
– an information flows circulation model, developed on the basis of an analysis of the Tower controller workplace, for which regularities in the circulation of information have been identified;
– reference values of the time that is spent on performing each of the TOs. The basis for these values is the regularities discovered among the TOs time characteristics of the Tower controller's activity, which provide the possibility of an objective automatic assessment of the trainee operator's activity.

3. The aim and objectives of research

The aim of research is to develop trainee reference model for the implementation of training and knowledge assessment modes in the intelligent training system «ATC of Tower». To achieve it, relying on the work on the formation of the list of technological operations and the pro-

cedure of their performing, done at the previous stages of the study, it is necessary to solve the following tasks:

1. Reveal the regularities of information flows circulation and form a model of the circulation of these flows at the Tower controller workplace.

2. Analyse the distribution laws of technological operations execution time (time characteristics), and to identify regularities in the time characteristics of delays in responses (pauses) between operators of air traffic services at the aerodrome.

4. Research of existing solutions to the problem

4.1. Methods and means analysis of automated knowledge control of a human operator. The issues of the assessment automation of the air traffic controller's activities were considered in the works [6, 7], where a generalized structural construction of the simulator is presented, taking into account the most significant tasks that must be implemented for training, monitoring and evaluating the actions of operators. According to the proposed structure, the simulator can be represented as a system consisting of an operator, an operator's automated workstation, a simulator, equipment for monitoring and evaluating the actions of trainees, an instructor, and connections between them.

If to compare this structure with other traditional training complexes that are used to train air traffic controllers, it is possible to conclude that components such as an operator's workstation and a simulator have been added to the structure. The instructor in this system acts as the administrator of the simulator training, as well as the object of feedback for the debriefing.

In the process of assessment, console operations are recorded, logical, operational and time deviations of the operator's actions are determined (exceeding the time for performing operations, prolonged inactivity), i. e. operational control is carried out. As a result, all deviations of the operator's actions are compared with those actions that are regulated in the dynamic objects control system. At the same time, violations of the algorithms of actions, unfulfilled mandatory or unacceptable actions are detected. Based on the results of monitoring the execution of individual operations and stages of the problem being solved, a training strategy is formed and a training forecast is calculated, which makes it possible to implement an individual approach to training operators of automated training systems [6]. But in this structure, there is an instructor who brings an element of subjectivity to the training process and the system is not mobile.

The issues of improving the quality of training air traffic controllers through the implementation of an individual training approach using procedural simulators were also considered in works [8, 9], where the principles of developing independent automated means of registration, analysis and evaluation of actions were studied. The basis for the implementation of an individual approach is the cyclical scheme of the information flow model, which consists of the following main tasks [10]:

1. Formation of input data – a set of technological operations, the practicing of which is necessary, as well as their volume and complexity.

2. Generation of exercises – the exercise consists of flight plans and event activation blocks, which are being practiced.

3. Practicing exercises on the simulator.

4. Comparison of the actual actions of the controller with the reference and fixing mistakes – a four-stage assessment of the actions of the one who is undergoing training, namely:

1) registration of the air traffic controller's actions;

2) recognition of actions;

3) identification of mistakes;

4) assessment of actions using a frame model for representing knowledge about typical technological units and their structure.

5. Final assessment of student actions – automated assessment acts as a decision support system for the instructor. The instructor independently evaluates the candidate based on the assessment.

6. Trend analysis – carried out in two stages, namely:

1) data pre-processing – a selection of data on a specific TO for a certain period is carried out;

2) application of a predictive model based on neural networks and the windowing method.

7. Review training history.

Considering the above, the implementation of an individual training approach to air traffic controllers on procedural simulators is possible due to the use of an instructor/expert decision support system, which automates the assessment of specific technological operations, and, as a result, the formation of a training forecast.

The method of improving the aircraft management of operators of the navigation service systems and traffic control in [1] involves the use of the intelligent training system «ATC of Tower». This system consists of the following subsystems:

1. A server that includes a knowledge base and a database.

2. Computer of the trainee, consisting of:

– subsystems «exercise generator»;

– subsystems «knowledge assessment of the trainee»;

– interface;

– demonstration subsystem.

The training and control processes are carried out on the basis of updating the sets of configuration fuzzy products in the accounts of the trainee (success records), if such are already in the database. If there is no such data in the database o of the trainee, a basic exercise is generated to determine its level of knowledge and skills. Verification in the system is carried out by entering a username and password. Fuzzy products are managed by obtaining data from the knowledge base. The knowledge base includes: a trainee reference model (reference data of the operator's activity) fuzzy sets of meteorological conditions, as well as the of the runway condition and aircraft stages.

Analysis of methods and means of knowledge automated control of a human operator has shown that the assessment of practical skills of operators in general is carried out by comparing its actions with reference models or data.

4.2. Analysis of methods for the formation of the subject reference models in the man-plus-machine system. The use of reference models at the moment is mainly considered in the development of intelligent systems of general didactic teaching and represent a set of reference values, the so-called reference sets [11], to determine the competence of the student. In works [11, 12], it is proposed to extract reference sets from the state educational standard on higher education. Reference models, formed for automated training systems for operators [13, 14], basically have the form of a set/list of algorithms for actions

in specific normal and emergency situations described in the production documentation.

In [15], a project was considered to improve operator training programs by assessing human performance in comparison with the optimal operator model described using the optimal control theory. The authors propose to design an idealized power system with a control system using the following procedure:

1. Design a simple power system operator workstation based on a real-time simulator, supports the identification of simple operator tasks.

2. Design a system for monitoring human-computer interaction and implement it into a developed workstation.

3. Compare the performance of the real operator and the optimal model, evaluate its performance, and as a result, consider this optimal model as a reference model for the operator.

In [16], the reference model of the system is built, as in the previous case, on the knowledge gained from an expert in the process of interacting with system, thereby forming and sorting out a set of solutions.

The method of modelling the operator's activity and evaluating its effectiveness indicators under the conditions of the action of destabilizing factors: hardware failures, software failures, operational changes of the system goal, modification of environmental conditions was proposed in [17]. The modelling scheme described in this work is based on the functional-structural theory of describing systems «man-machine-environment», supplemented by elements of the queuing theory. The general view of the model is presented by the algebraic method in the form of a finite sequence, consisting of: performance indicators of the operator, the original algorithm of the operator's actions under normal operating conditions of the system, a set of ergonomic factors.

The human operator model proposed in [18] was developed to analyse the aircraft crew's actions during an approach. It contains subsystems for monitoring actions, processing information, making decisions (choosing a procedure) and performing actions.

The actions monitoring subsystem takes into account the sensory limitations of the operator.

The information processing subsystem is the so-called «information processor», consists of two submodels, «evaluator» and «detector of discrete events». The evaluator is a Kalman filter that changes over time. The purpose and task of the «detector of discrete events» is to establish a set of rules that will describe elementary actions in a certain sequence on the initial data of any problem that needs to be solved.

The making decisions and performing actions subsystem includes a number of procedures or tasks that can be executed at any time. These procedures can be quite general, such as «fly the aircraft» or «control the approach», or they can be quite specific, such as performing a specific checklist or requesting a specific flap setting for the aircraft.

As can be seen from the analysis, for the implementation of training modes and automated control in training systems, it is necessary to implement the so-called trainee reference model. This will make it possible to carry out an objective assessment based on the qualitative and quantitative indicators of its operator activities, as well as to implement an individual training approach.

The application of the above approaches to knowledge extraction and, as a consequence, the formation of reference

models is partially acceptable. And also fully implemented only for well-documented and structured subject areas that do not belong to complex continuous-discrete stochastic dynamical systems with a mixed structure. When using the optimal control theory, the functional-structural description of systems is made using mathematical models, which is a rather complex and uninformative approach to represent the decision-making process in the air traffic services system.

5. Methods of research

Regularities of information flows obtained by the data mining method of the documentation regulating the Tower controller's professional activity, the analysis of its workplace, as well as the use of the combined method of timing. The synthesis method was used in the development of the information flows circulation model at the Tower controller workplace, when servicing an arriving aircraft. When revealing the regularities of time characteristics of technological operations, the methods of statistical analysis and probabilistic modelling were used.

6. Research results

6.1. Information flows circulation model: identification of afferent and efferent operators. In the process of work, the Tower controller performs the functions of a «human operator» – it receives and transmits information to ensure safe air traffic control (ATC) through the use of data transmission channels.

Reproduction and display of information occurs visually, using displays and indicators, and/or acoustically, using electrodynamic loudspeakers (speakers) [19]. Thus, it is possible to talk about information flows, where communication channels are regularities of circulation of this information. *Information flows (IP)* is the physical movement of information from one employee of an enterprise to another or from one department to another [20].

As a result of the Tower controller workplace analysis, all acoustic (A) and visual (V) IPs passing through it, as well as the means ensuring their receipt/transmission, were determined. Each information flow is assigned its own code, which corresponds to a sequence number (Table 1).

Based on the Tower controller work instruction, analysis of its workplace, as well as the combined method of timing its professional activities [4], the *information flows circulation model at the Tower controller workplace* when servicing the arriving aircraft is proposed (Fig. 1).

This model depicts the flows of information that the Tower controller operates when performing a specific TO. The documentation regulating the professional activity of an air traffic controller is not defined as an information flow during direct ATC, since it is assumed that it has been studied in full before the controller takes over duty.

Table 1

List of information flows at the Tower controller workplace

| No.	Information flow	IP type	Means for displaying/reproducing information
1	Radar information	V	Radar monitor (additional information equipment)
2	Planning information	V	Planning information monitor
3	Meteorological information	A/V	Weather display of the AMAS AVIA-2
4	Information about the aircraft position according to the direction finder	V	Indicator (pointer) of an automatic radio direction finder
5	Runway occupancy information	V	Light board «Runway occupied»
6	Visual inspection of the airfield	V	Human visual apparatus
7	Current time information	V	Coordinated Universal Time Clock
8	Communication with the aircraft crew	A	Receiver and transmitter means of radio communication
9	Listening to adjacent control units	A	Radio communication receiver
10	Approach controller	A/V	Loudspeaker
11	Central aerodrome dispatcher	A/V	Loudspeaker/ Telephone
12	Briefing-Office dispatcher	A/V	Loudspeaker/ Telephone
13	Controller (aero navigator) of the military sector	A/V	Telephone /Loudspeaker
14	Flight Information Service controller	A/V	Telephone /Loudspeaker
15	Meteorological observation point (Meteo-Main)	A/V	Loudspeaker/ Telephone
16	Duty forecaster (Forecaster)	A/V	Loudspeaker/ Telephone
17	Weather Locator Operator	A/V	Loudspeaker/ Telephone
18	Shift engineering service of Tower	A/V	Loudspeaker/ Telephone
19	Airport search and rescue brigade	A/V	Loudspeaker/ Telephone
20	Militarized airport security	A/V	Loudspeaker/ Telephone
21	Automobile transport of airport services	A	Radio set (internal airport radio communication)
22	Supervisor	A	Direction voice messages
23	Information about the operability of the main landing system and the instrument landing system (ILS)	A/V	Display panel
24	Information about the aerodrome lighting system	V	Display panel
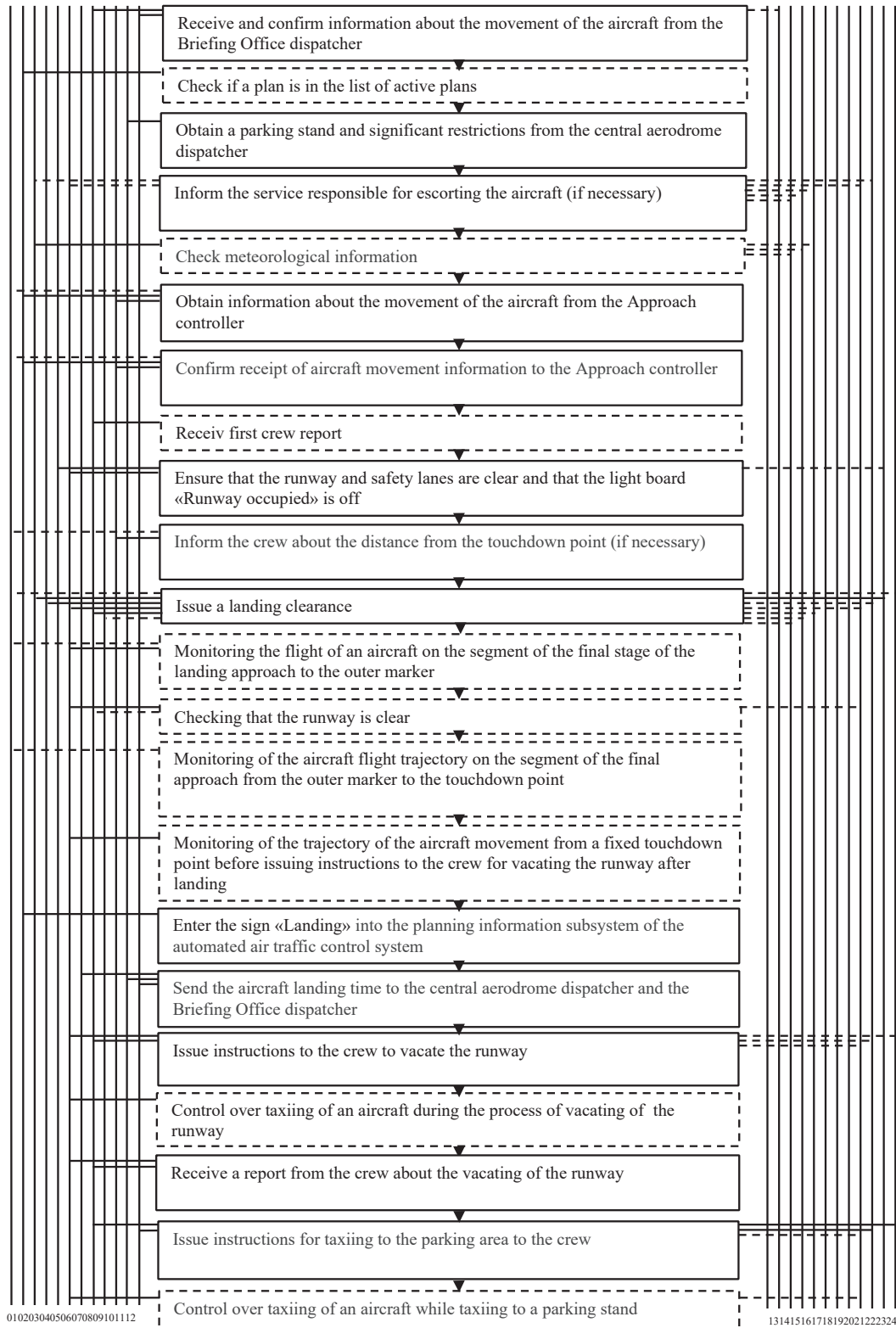
Fig. 1. Information flows circulation model at the Tower controller workplace

The information flows circulation model at the Tower controller workplace contains the following elements:

1. Technological operations (blocks). The continuous line denotes TO, which have the character of efferent actions (pressing buttons, entering data, etc.), and the dashed line – afferent (receiving and transmitting commands, etc.).

2. Information flows are presented in the form of vertical lines, numbered according to Table 1.

3. Communication channels are horizontal lines connecting TOs and identifying information flows in the form of regularities. Communication channels marked with solid lines are permanent (deterministic) – the controller, performing TOs, uses this information each time.

Dashed lines indicate communication channels that are not permanent, which means the following:

– in the absence of information in the flow on this channel, the time of maintenance execution remains unchanged, as well as its implementation as a whole;

– in the presence of information in the flow on this channel, which is mandatory (information about the ornithological situation, information about the air situation), the following maintenance parameters may change:

1) time performance parameters (an increase in the amount of information transmitted in a message), which determines their probabilistic component;

2) the frequency of execution/repetition (for example, when changing the runway visual range parameters, their value is promptly transmitted to the aircraft crew and such changes during landing approach can occur up to 5 times).

Insomuch as the sources of information flows are technical equipment, weather conditions, people-operators, they are characterized by failures, rapid variability, and errors, due to the stochasticity, dynamism and complexity of the air traffic control system.

The obtained information flows circulation model at the Tower controller workplace has been piloted [21] and allows one to determine the type of data and the means that display it, which is necessary for the air traffic controller to make decisions, as well as afferent and efferent operators. This allows to describe the heterogeneity of the elements that are involved in the performance of each TO, and the influence of these elements on the corresponding time characteristics.

6.2. Evaluation of time parameters of Tower controller technological operations. In many respects, the adequacy of a real system model, is considered, is determined by the choice of statistical distribution laws that describe the parameters of this system. Therefore, it is extremely important to set the laws of distribution of random variables, consistent with empirical data, when modelling [22]. In general, by the nature of the estimates of works used, there are deterministic and probabilistic (stochastic) estimates and the corresponding models.

Deterministic models are those in which there are no random changes: external influences, internal parameters and the variables themselves. In these models, the behaviour of an object is determined by specific values of the initial conditions and input variables [23]. They are characterized by a certain structure and a well-defined (deterministic) evaluation of the work according to the selected criterion. One such criterion may be time, which allows an estimate of the duration of the work. Such a model can also display a probabilistic system, then it is a certain simplification of it [24].

A probabilistic model is an economic and mathematical model in which the parameters, conditions of functioning and characteristics of the state of a modelled object, represented by random variables and associated with stochastic (that is, random, irregular) dependencies, or the initial information is also represented by random variables. So, the characteristics of the state in the model are determined not unambiguously, but through the distribution laws of their probabilities. When constructing a probabilistic model, the methods of correlation and regression analyses and other statistical methods are used [24]. These models are based on the use of large series of tests with random parameters, and the accuracy of the results obtained depends on the number of experiments performed [25].

In the presence of uncertainty, probabilistic estimates of work are used. The previously mentioned subject area of the Tower controller's professional activity is an open complex continuous-discrete stochastic dynamic control system with a mixed structure [26]. This fact presupposes the presence in the system of elements characterized by both deterministic and probabilistic time characteristics.

Evaluation of the time characteristics of the Tower controller TOs in the process of servicing arriving aircraft is one of the important steps in building a reference model of the intelligent training system «ATC of Tower». To obtain a more detailed description of the human operator's activity and obtain time characteristics for each of its technological operations, a combined method of timing (timekeeping) was used [4] using two different approaches, which are called, according to the classification presented in [27]:

– timing using control and recording equipment (voice recorder or tape recorder method);

– timing by the method of direct observation with video recording of the working process or self-observation (paper method).

In the first case, timing made it possible to determine the types and duration of actions (operations), the duration of pauses between individual operations, but at the same time, only afferent operators were determined. In the second case with timing with the method of direct observation, both afferent and efferent operators were obtained, but the time indicators (characteristics) of operations were less accurate than in the first case. Thus, 63 hours and 40 minutes of tape (Dictaphone) recordings for the period April-September 2015 were collected and transcribed.

Each technological operation obtained as a result of the timing is assigned a code consisting of a letter (L – landing) and a number (Table 2).

By the descriptive statistics method, the main statistical characteristics of the execution time of TOs were obtained, which was identified on the basis of transcribing the timing data of the Tower controller's activity (Table 3).

This method of analysis allowed to determine the first group of technological operations, which can be attributed to deterministic TOs, the execution of which takes 1 second:

– First communication with the Briefing Office dispatcher – call (L1);

– First communication with the Briefing Office dispatcher – answer (L2);

– Confirmation of information about a departure from another aerodrome (L4);

– First communication with the central aerodrome dispatcher – call (L5);

– First communication with the central aerodrome dispatcher – answer (L6);

– First communication with the Approach controller – call (L11);

– First communication with the Approach controller – answer (L12);

– Reporting to services/request about readiness of services to record updated information about landed aircraft (L24);

– Confirmation of the readiness of services to accept updated information about landed aircraft (L25).

The aforementioned technological operations are coordination functions with the airport services for establishing the first communication (first call), as well as checking the readiness to record updated information.

Descriptive statistics also made it possible to conclude that the execution time of a certain part (second group) of technological operations has a normal distribution, which is determined depending on the fulfilment of certain criteria. One of these criteria is the coincidence of the arithmetic mean, thickest value and median. Another criterion is the analysis of indicators of skewness and kurtosis.

Skewness is a measure of the symmetry (noncentrality) of the distribution curve relative to the mean. The skewness shows in which direction most of the distribution values are shifted relative to the mean. A zero-skewness value means that the distribution is symmetric about the mean, positive skewness indicates a shift in the distribution towards smaller values, and negative skewness – towards larger values. In most cases, a distribution with skewness is taken as normal, which ranges from −1 to +1. In studies that do not require high accuracy of results, a distribution with an asymmetry, which does not exceed 2 in absolute value, is considered normal [28].

Kurtosis is a measure of the «smoothness» («peakedness» or «flat-toppedness») of the distribution. If the kurtosis value is close to 0, this means that the shape of the distribution is close to normal. Positive kurtosis indicates «flat-toppedness» of the distribution, in which the maximum probability is less noticeable than in the normal one. A kurtosis value greater than 5.0 indicates that there are more values at the edges of the distribution than around the mean. Negative kurtosis, on the contrary, characterizes the «peakedness» of the distribution, the graph of which is more elongated along the vertical axis than the graph of the normal distribution.

Table 2

Coding of revealed technological operations (TO)

TO code	Technological operation name
L1	First communication with the Briefing Office dispatcher – call
L2	First communication with the Briefing Office dispatcher – answer
L3	Receiving information about a departure from another aerodrome
L4	Confirmation of information about a departure from another aerodrome
L5	First communication with the central aerodrome dispatcher – call
L6	First communication with the central aerodrome dispatcher – answer
L7	Parking request for arriving aircraft
L8	Receiving the information about the parking stand for the arriving aircraft
L9	Confirmation of the parking information
L10	Aircraft flight time from another aerodrome
L11	First communication with the Approach controller – call
L12	First communication with the Approach controller – answer
L13	Obtaining information about the approaching aircraft
L14	Confirmation of information about the approaching aircraft
L15	Aircraft handover from the Approach controller
L16	Receiving first crew report
L17	Issuance of a landing clearance
L18	Confirmation of landing clearance from the crew
L19	Monitoring of the aircraft flight trajectory on the segment of the final approach
L20	Receiving a crew report after landing
L21	Issuance of runway vacating instructions
L22	Reception of crew confirmation of runway vacating instructions
L23	Aircraft taxiing controlling during runway vacating
L24	Reporting to services/request from readiness services to record updated information about landed aircraft
L25	Confirmation of the readiness of services to accept updated information about landed aircraft
L26	Issuance of updated information about the landed aircraft
L27	Confirmation of updated information about landed aircraft by services
L28	Receiving crew report about runway vacating
L29	Issuance of taxiing instructions
L30	Receiving confirmation of taxiing instruction
L31	Aircraft taxiing controlling in the process of taxiing to the parking stand
L32	Receiving the report from the crew «On stand. Out»
L33	End of communication confirmation

Note: the determination of time characteristics of technological operations (marked with a grey background), relative to deterministic or probabilistic estimates, is inappropriate, since the time of their execution proportionally depends on the performance characteristics of a particular aircraft type, that is, on the input parameters of the system

Table 3

Descriptive statistics of time characteristics of technological operations (TO)

TO code	Average	Standard error	Median	Thickest value	Standard deviate	Sample variance	Kurtosis	Skewness	Class	Least value	Maxima	Total	Count	Level of reliability (95.0 %)
L1	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L2	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L3	3.00	0.27	3.00	4.00	1.49	2.21	−1.42	−0.07	4.00	1.00	5.00	90.00	30.00	0.55
L4	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L5	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L6	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L7	3.30	0.39	3.00	2.00	2.12	4.49	0.18	0.93	8.00	1.00	9.00	99.00	30.00	0.79
L8	2.00	0.17	2.00	1.00	1.29	1.66	1.34	1.43	5.00	1.00	6.00	120.00	60.00	0.33
L9	1.53	0.20	1.00	1.00	1.11	1.22	9.19	2.86	5.00	1.00	6.00	46.00	30.00	0.41
L10	–	–	–	–	–	–	–	–	–	–	–	–	–	–
L11	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L12	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L13	3.33	0.25	3.00	2.00	1.95	3.82	11.04	2.80	12.00	1.00	13.00	200.00	60.00	0.50
L14	1.70	0.13	1.00	1.00	1.03	1.06	2.52	1.70	4.00	1.00	5.00	102.00	60.00	0.27
L15	–	–	–	–	–	–	–	–	–	–	–	–	–	–
L16	5.95	0.25	5.00	5.00	1.92	3.68	1.63	1.09	9.00	3.00	12.00	357.00	60.00	0.70
L17	10.03	0.69	9.50	8.00	3.77	14.24	3.86	1.55	18.00	5.00	23.00	301.00	30.00	1.41
L18	3.72	0.17	3.50	3.00	1.33	1.77	3.22	1.31	7.00	2.00	9.00	223.00	60.00	0.34
L19	–	–	–	–	–	–	–	–	–	–	–	–	–	–
L20	2.80	0.33	2.00	1.00	1.83	3.34	1.48	1.30	7.00	1.00	8.00	84.00	30.00	0.68
L21	4.47	0.26	4.50	5.00	1.41	1.98	−0.41	0.03	5.00	2.00	7.00	134.00	30.00	0.53
L22	3.17	0.21	3.00	2.00	1.15	1.32	−1.33	0.39	3.00	2.00	5.00	95.00	30.00	0.43
L23	–	–	–	–	–	–	–	–	–	–	–	–	–	–
L24	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L25	1.00	0.00	1.00	1.00	0.00	0.00	–	–	0.00	1.00	1.00	30.00	30.00	0.00
L26	3.85	0.12	4.00	4.00	0.94	0.88	−0.06	0.31	4.00	2.00	6.00	231.00	60.00	0.25
L27	2.25	0.18	2.00	1.00	1.37	1.89	−0.16	0.95	5.00	1.00	6.00	135.00	60.00	0.35
L28	2.00	0.11	2.00	2.00	0.59	0.34	0.23	0.00	2.00	1.00	3.00	60.00	30.00	0.22
L29	5.47	0.29	5.00	5.00	2.23	4.96	3.85	1.59	12.00	2.00	14.00	328.00	60.00	0.92
L30	3.40	0.32	3.50	4.00	1.73	3.01	−0.89	0.22	6.00	1.00	7.00	102.00	30.00	0.65
L31	–	–	–	–	–	–	–	–	–	–	–	–	–	–
L32	4.57	0.38	4.00	4.00	2.08	4.32	0.29	0.63	9.00	1.00	10.00	137.00	30.00	0.78
L33	2.63	0.27	2.00	2.00	1.47	2.17	1.87	1.31	6.00	1.00	7.00	79.00	30.00	0.55

Note: the determination of time characteristics of technological operations (marked with a grey background), relative to deterministic or probabilistic estimates, is inappropriate, since the time of their execution proportionally depends on the performance characteristics of a particular aircraft type, that is, on the input parameters of the system

Based on the foregoing, the following TO can be attributed to operations with a normal distribution law:

1) issuance of runway vacating instructions (L21);

2) issuance of updated information about the landed aircraft (L26);

3) receiving crew report about runway vacating (L28).

And finally, the third group of technological operations is operations that were not included in the first and second groups. To determine the distribution law of the time of their execution, the consistency of the hypothesis about the correspondence of empirical distributions to theoretical distribution laws was tested. The consistency was determined by the method of fitting distributions using the STATISTICA software package, using the Distribution Fitting toolkit. software package module provides an assessment of the analysis from the side of goodness-of-fit criteria, which make it possible to refute or confirm the correctness of the hypothesis about the nature of the distribution in the empirical series and to give an answer whether it is possible to accept the model expressed by the theoretical distribution law for a given empirical distribution [29].

Fig. 2 shows a model of the distribution of time characteristics of technological operation L17, which corresponds to the lognormal distribution. Chi-square test for goodness of fit = 0.08179 and a probability value $p = 0.77489$ indicate that the data are in good agreement with the distribution hypothesis.

The distribution of the technological operations execution time having a low level of reliability is approximated by the most suitable distribution laws. It is made taking into account the fact that the system that is being modelled is supposed to be used for educational purposes. And the emphasis of the is focused on the decision-making process, as well as working out particular tasks. In the future, when assessing the skills and abilities of the trainee, it is advisable to use the interval of the minimum (least value) and maximum (maxima) values of empirical studies as reference values, since any value of this segment is practically justified (there is timing data of existing specialists with different work experience).

The type of operations described above, with low level of reliability, is the technological operation L16, which has a probability distribution, approximated by a lognormal distribution (Fig. 3).
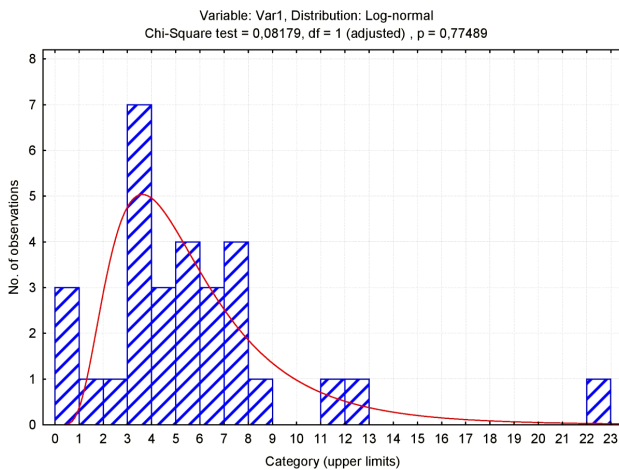

Variable: Var1, Distribution: Log-normal
Chi-Square test = 0,08179, df = 1 (adjusted), p = 0,77489

Fig. 2. Lognormal distribution of the execution time of technological operation L17

Variable: Var1, Distribution: Log-normal
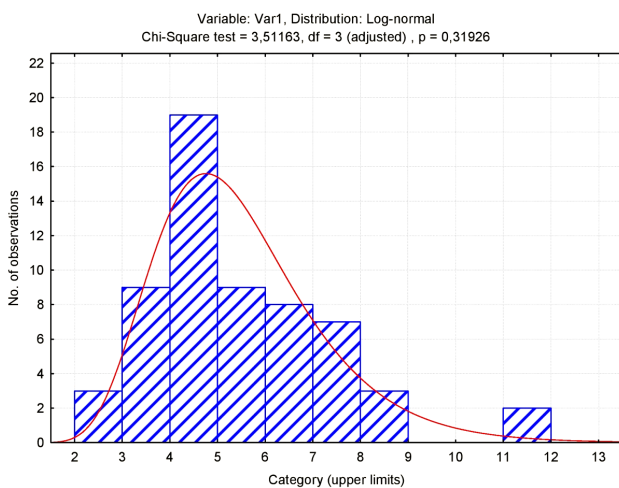Chi-Square test = 3,51163, df = 3 (adjusted), p = 0,31926

Fig. 3. Lognormal distribution of the execution time of technological operation L16

Further, each technological operation was found that was not included in the first group of technological operations with a deterministic execution time and in the second group with the operation execution time, which obey the normal distribution, passed the step of fitting the distribution. As a result, a list of distribution laws for the time characteristics of technological operations was obtained, which were summarized in a general Table 4.

Table 4

Time distribution laws of technological operations (TO) characteristics

TO code	Distribution law	Chi-square test	Probability, p
L3	Uniform	0.66667	0.71653
L7	Exponential	1.30895	0.51971
L8	Exponential	1.05429	0.59029
L9	Chi-square (approximation)	1.09260	0.29590
L10	Aircraft flight time from another aerodrome	–	–
L13	Lognormal (approximation)	0.95109	0.32944
L14	Exponential	1.27000	0.52994
L15	Aircraft handover from the Approach controller	–	–
L16	Lognormal (approximation)	3.51163	0.31926
L17	Lognormal	0.08179	0.77489
L18	Gamma (approximation)	2.82255	0.24383
L19	Monitoring of the aircraft flight trajectory on the segment of the final approach	–	–
L20	Chi-square	0.43701	0.80372
L21	Normal	0.04077	0.83997
L22	Chi-square	0.26304	0.60804
L 23	Aircraft taxiing controlling during runway vacating	–	–
L 27	Exponential (approximation)	4.32450	0.11507
L 29	Lognormal (approximation)	3.15842	0.36784
L 30	Chi-square	1.94782	0.58331
L 31	Aircraft taxiing controlling in the process of taxiing to the parking stand	–	–
L 32	Lognormal	0.33772	0.56115
L 33	Lognormal	0.08338	0.77276

Note: the determination of time characteristics of technological operations (marked with a grey background), relative to deterministic or probabilistic estimates, is inappropriate, since the time of their execution proportionally depends on the performance characteristics of a particular aircraft type, that is, on the input parameters of the system

Technological operation L15 (Aircraft handover from the Approach controller) represents the time spent by the crew to change the frequency of one control sector (in this case, the Approach controller) to another (Tower controller) and prepare the aircraft for the final stage of the approach. For the Tower controller, this time is characterized by the interval from the moment the entry point into the glidepath (Final Approach Point) and the first radiotelephone communication with the Tower controller or the distance from the Final Approach Point (in most cases it is equal to a distance of 20 km) to the touchdown point on the runway (Fig. 4).
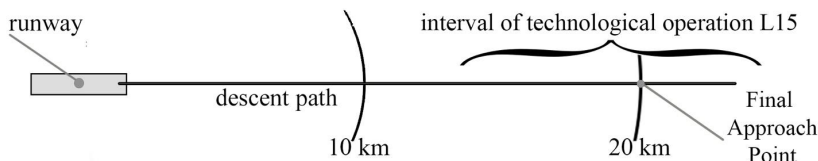
Fig. 4. Interval of technological operation L15

To determine this parameter, data were collected and analysed describing the distance of the aircraft from the touchdown point at the time of the first communication with the Tower air traffic controller. Distance was measured in kilometres. The results of the analysis of the obtained sample using descriptive statistics are presented below:
– average = 17.76125;
– standard error = 0.261830785;
– median = 17.8;
– thickest value = 18;
– standard deviate = 2.341885735;
– sample variance = 5.484428797;
– kurtosis = 0.177667906;
– skewness = 0.289138532;
– class = 11.5;
– least value = 12.8;
– maxima = 24.3;
– count = 80.

Thus, the distance at which the aircraft crew first communicates with the Tower controller can be described by the normal distribution law with an average value of 17.76125 km.

The method of timing (timekeeping) using control and recording equipment also made it possible to determine the response delay time during the communication of the Tower controller with the aircraft crew and other services. The response delay is the time between the issuance of the «request» and the response between the communicants. Descriptive statistics of response delay data (in seconds) are presented in Table 5.

Checking the consistency of the response delay time data to the theoretical distribution laws showed that the interaction between communicants can be described by Chi-square or exponential distribution laws depending on the communicants. The results are presented in Table 6.

Table 5

Response delay time during communication between the Tower controller with the crew of the aircraft (AC) and with other communicants

Components of descriptive statistics	Communicant						
	AC crew	Central aerodrome dispatcher	Briefing Office dispatcher	Approach controller	Surface transport	Meteorological service	Shift engineer
Average	1.44	1.37	1.43	1.18	1.32	1.47	1.38
Standard error	0.09	0.09	0.10	0.05	0.06	0.10	0.13
Median	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Thickest value	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Standard deviate	0.89	0.90	0.97	0.52	0.63	0.78	0.92
Sample variance	0.79	0.80	0.93	0.27	0.40	0.61	0.85
Kurtosis	8.19	13.27	7.22	6.99	3.81	5.80	12.40
Skewness	2.67	3.33	2.67	2.86	2.05	2.12	3.20
Class	5.00	5.00	5.00	2.00	3.00	4.00	5.00
Least value	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maxima	6.00	6.00	6.00	3.00	4.00	5.00	6.00
Count	100.0	100.0	100.0	100.0	100.0	62.0	50.0

Table 6

The list of distribution laws of the response delay time during the communication of the Tower controller with other communicants

Communicant	Distribution law	Chi-square test	Probability, p	Distribution histogram function
Aircraft crew	Exponential	0.00353	0.95259	$Y = 100 \cdot \text{Expon}(x; 1.269)$
Central aerodrome dispatcher	Chi-square	0.02030	0.88670	$Y = 100 \cdot \text{Chi2}(x; 0.6747)$
Briefing Office dispatcher	Chi-square	0.15369	0.69503	$Y = 100 \cdot \text{Chi2}(x; 0.699)$
Approach controller	Chi-square	0.22389	0.63610	$Y = 100 \cdot \text{Chi2}(x; 0.403)$
Surface transport	Exponential	0.26621	0.60589	$Y = 100 \cdot \text{Expon}(x; 1.383)$
Meteorological service	Exponential	0.30076	0.58341	$Y = 60 \cdot \text{Expon}(x; 1.101)$
Shift engineer	Chi-square	0.79686	0.37204	$Y = 50 \cdot \text{Chi2}(x; 0.704)$

As can be seen from Fig. 5, the model of the distribution of the response delay time during radio communication between the air traffic controller and the aircraft crew corresponds to an exponential distribution.
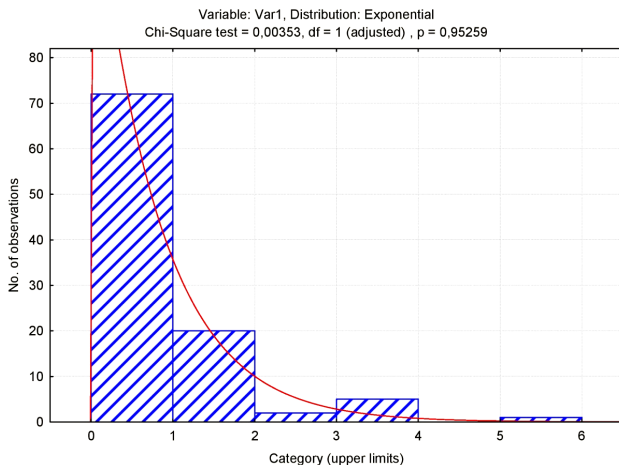

Fig. 5. Exponential distribution of the response delay time when working with the aircraft crew

Pearson's consistency criteria Chi-square=0.00353 and a probability value greater than 95 %. This indicates that the data are in good agreement with the distribution hypothesis.

7. SWOT analysis of research results

Strengths. The strengths of this research are that the resulting data array, consisting of a list of technological operations, the procedure of their execution, an information flows circulation model and regularities in the studied subject area, allow to form a trainee reference model of intellectual training system. As a result, it allows to implement the modes of training and objective automated control of knowledge, assessing the actions of the trainee from the point of view of quantitative and qualitative parameters of the solution formed by it.

Weaknesses. The weaknesses of this research are the data obtained as a result of the study, which are implemented in the trainee reference model, very narrowly specialized. But this does not exclude the possibility of using the proposed method of forming a reference model for other areas of activity that have complex continuously discrete stochastic dynamical systems with a mixed structure.

Opportunities. The information flows circulation model obtained in the course of the study and the regularities of information circulation in it can be used as a basis for further research and the formation of the ergonomics of the operator's workplace of the Tower controller. The procedure of performing technological operations, depending on the situation, allows to form a model of errors and, as a result, to implement alternative individual trajectory of the trainee current model to create an adaptive component of an intelligent training system. The regularities of the time characteristics of technological operations of the Tower controller can be used to calculate the acceptance rate of both aerodrome facilities and the aerodrome «in general».

Threats. The «ATC of Tower» Intelligent Training System, which includes reference and current trainee models, aims to complement the existing air traffic controller training system by introducing self-directed training, rather than replacing it.

8. Conclusions

1. The regularities of information flows circulation at the workplace of the Tower controller and regularities of its activities in the navigation service and traffic control system at the approach stage are revealed. The resulting the information flows circulation model at the Tower controller workplace makes it possible to determine the types of data and means of their display, which are necessary for the air traffic controller to make a decision, as well as afferent and efferent operators. This makes it possible to describe the heterogeneity of the elements involved in the performance of each technological operation, and the influence of these elements on their time characteristics.

2. The analysis of the distribution laws of the technological operations execution time (time characteristics) shows that it is conditionally possible to distinguish three groups of technological operations, which:

1) can be described by average values of time;

2) can be described using the normal distribution law;

3) can be described by other (uniform, exponential, Chi-square, lognormal, gamma) distribution laws.

Also, regularities of time characteristics of response delays (pauses) between communicants of air traffic services at the aerodrome were identified.

The data obtained at this stage makes it possible to carry out simulation modeling of the trainee reference model, taking into account the exchange of information in the air traffic control system, the time characteristics of technological operations. And, as a result, to implement modes of training and automated objective control of knowledge in an intelligent training system.

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