AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

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# METHODOLOGY OF RESEARCH AND TRAINING IN AIR NAVIGATION SOCIO-TECHNICAL SYSTEM

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## Abstract

***Purpose****: on the basis of professional and non-professional factors formalization, designing of models of decision making by Air Navigation System's human-operator and flight situation development to work-out the methodology of research and training in Air Navigation Socio-technical System.* ***Methods****: systemic analysis, reflexive theory, network planning, decision tree, Markov network, GERT network, neural network, expert method.* ***Results****: the Air Navigation System has been presented as a complex Socio-technical System. The influence of the professional factors (knowledge, skills, abilities, experience) as well as the factors of non-professional nature (individual-psychological, psycho-physiological and socio-psychological) on the decision making by Air Navigation System's human-operator has been defined. Graphical-analytical, deterministic, stochastic, reflexive, neural network models of decision making by Air Navigation System's human-operator and flight situation development have been obtained. The program complex "Prompt" which operative and timely selection of the optimal flight completion strategy in the unusual situations required an aircraft forced landing has been created. Methodology of research and training in Air Navigation Socio-technical System has been developed.* ***Discussion****: the result of the evaluation of non-professional factors is determination the socio-psychological impact on human-operator's decision making by identifying the preferences, diagnostics the individual-psychological qualities of human-operator in the development of flight situation, monitoring of the human-operator's psycho-physiological indicators (emotional state). The proposed models will allow timely diagnosing and predicting the possible actions of human-operator in the expected and unexpected conditions of aircraft operation. The algorithms and methodology for analysis of situation development under influence of decision making by human-operator can be used in other technogenous production.*

**Keywords**: Air Navigation System; decision making; Decision Support System; flight emergency; formalization; human factor; modeling; Socio-technical System.

## 1. Introduction

Air Navigation System (ANS) in conformity to the principles of functioning may be referred to Socio-Technical systems (STS) within which close co-operation between human and technological components occurs [1]. The distinguishing feature of the STS is availability of the hazardous kinds of activity as well as usage of the high-level technologies in production. Since operations in STS generally involve high-risk / high-hazard activities, the consequences of safety breakdowns are often catastrophic in terms of loss of life and property [1]. The more a human-operator (H-O) is trying to control a production process being aided by high level technologies, especially in case of distant operation, the more non-transparent becomes the result of the operation of a system, which is accompanied by a high degree risk of causing catastrophic outcomes [2 – 3]. Most investigations were conducted with a view to provision of safety in nuclear power production [4 – 5], [22]. In the ANS provision of safety is rather actually with the aim of prevention threats on the operational level, for example in the event of technical equipment damage or maintenance personnel faults [3]. The provision of flight safety in the ANS by means of high level technological processes depends primarily on reliability of H-O as well as his timely professional decisions. Currently, one of the main strategic problems of mankind on the path to sustainable development is the safety and stability of technogeneous production [5]. As noted technogeneous production is a complex system that contains interrelated technical, economic and social objects. It has a multilevel hierarchical structure and a high level of risk [6 – 7]. Recent results show that there are frequent and common emergency such as disaster, accidents, crashes in hydraulic engineering, chemical and military industries, gas and oil pipelines, nuclear power plants and transport [4 – 7].

## 2. Analysis of latest research and publications

Statistical data show that human errors account for up 80% of all causes of aviation accidents [8 – 9]. The existing approaches to checking separate aspects (psycho-physiological, behavioural, ergonomic, professional, etc.) do not consider the functional state of H-O in the conditions of the dynamic change of external and internal factors [3]. Representation of the ANS in the form of a STS first makes possible to take into account the influence of social, cultural environment of people who decision making (DM). Culture surrounds people and affects their values, convictions and behaviour, which they share along with other members of different social groups. Culture serves to bind us together as members of groups and to provide clues as to how to behave in both normal and unusual situations. The psychologist Hofstede suggests that culture is a “collective programming of the mind” [2]. Thus fatal mistakes can be committed by normal, healthy, highly motivated and well equipped personnel [1, 3, 8, 10]. Scientists have used lately the term “departure of conscience” when they analyzed the causes of aviation events conditioned by the insufficient development of the appropriate cultural values in a person that makes decisions [8]. Aviation systems with its complex interrelation between a man and technologies have been evolved towards complex STS.

Nowadays ICAO addressed awareness of cultural interfaces and the impact of cross-cultural factors on aviation safety in circular Human Factors Digest [2]. The circular presents the safety case for cultural interfaces in aviation safety with reference to three established conceptual safety models: the SCHELL model, Reason’s model of latent conditions, and the Threat and Error Management (TEM) model. The evolutions of Human factor's models are presented (from 1972 to present time) in Table 1. There are 4 stages of the evolution of the Human factor's models associated with the appearance of new system components and the diagnosis of operator errors:

1. Professional skills / Interaction / Errors.
2. Cooperation in team / Error detection.
3. Culture / Safety / Error prevention.
4. Safety Management / Minimization of errors.

Therefore, components such as culture and the influence of society are important for the safety in aviation (for example SCHELL model). One of the possible approaches to the solution of these problems is formalization and mathematical presentation of the ANS operators’ activities in the form of a complex STS on the base of the systemic analysis. It’s necessary timely to diagnose the individual properties of the operator and forecasting of emergency situations. Taking into account in the act of DM by a H-O within ANS, besides the separate professional factors (knowledge, habits, skills, experience) also the factors of non-professional nature (individual-psychological, psycho-physiological and socio-psychological) enables to predict the H-O’s actions on the basis of modelling the “large-scale” outcomes of individual actions with the aid of the reflexive theory [11].

*Table 1*

**Evolution of Human factor's models**

| Years | Model | Content of model | Content of stage of evolution human factor's model | Number of stage |
|---|---|---|---|---|
| 1972 | SHEL | Software (procedures) - Hardware (machines) - Environment - Liveware | Professional skills<br>Interaction<br>Errors | I |
| 1990 | Reason's "Swiss Cheese Model" | Active errors - Latent errors - Windows of opportunity - Causation chain | | |
| 1993 | SHELL | Software (procedures) - Hardware (machines) - Environment - Liveware - Liveware (humans) | | |
| 1999 | CRM | Crew - Resource - Management | Cooperation in team<br>Error detection | II |
| 2000 | TEM | Threat and Error - Management | | |
| 2000 | MRM | Maintenance - Resource - Management | | |
| 2004 | SHELL-T (SHELL-Team) | Software (procedures) - Hardware (machines) - Environment – Liveware - Liveware (humans) - Team | | |
| 2004 | SCHELL model and CRM | Software (procedures) – Culture - Hardware (machines) - Environment - Liveware - Liveware (humans) | Culture<br>Safety<br>Error prevention | III |
| 2004 | LOSA | Line - Operation - Safety - Audit | | |
| 2009 | HEAD | Human - Environment - Analysis - Design | | |
| 2010 | HFACS | Human Factors - Accident - Classification - System | | |
| 2013 | SMS | Safety Management System | Safety management<br>Minimization of errors | IV |

## 3. Research tasks

The research tasks are:

– decomposition of the DM process by ANS's H-O, systemic analysis and formalization of the factors which affect the DM within ANS treated as complex STS;

– diagnostics the individual properties of the operator and forecasting of emergency situations;

– designing the models of DM by ANS's H-O and flight situation development;

– creating of a computer program for Decision Support Systems (DSS) of H-O in unusual situations;

– development the methodology of research and education of ANS as STS;

– preparation of the individual tasks for the scientific work of aviation students in education after Master class of DM in ANS.

## 4. Monitoring and Diagnostics of the Individual Properties of the Human-Operator during the Professional Activity

Analysis of influence of the factors of professional and non-professional activities on the DM in ANS as STS has been made (Fig. 1) [12].

The ambient conditions determine the reaction of H-O and this reaction changes the environmental conditions accordingly. One of the possible approaches to the solution of these problems is formalization and mathematical presentation of the ANS operators' activities in the form of a complex STS on the base of the systemic analysis. For example, modelling of H-O DM in the unexpected conditions of flight (difficult flight situation, hearing channel of identification informational by H-O, route stage of flight) functional $\overline{Y}$ (Fig. 2). The distinctions between "professional" and "non-professional" factors, features of factors are indicated in books and articles [12 – 13]. On the basis of the methods for analysis of DM by the H-O ANS using graph, stochastic, GERT, Markov network, reflexive theory the methodology for analysis of flight situation development under influence of DM by H-O ANS in FE has been developed. The proposed models will allow timely diagnosing and predicting the possible actions of H-O in the expected and unexpected conditions of operation of the aircraft (AC). The practical value of the research carried out is to develop a method for conducting a prolonged socio-psychological correction of the H-O ANS in the process of training and professional activity, as well as the application for investigators of the approach to the evaluation of the activity of H-O during the investigation of the aviation accidents.

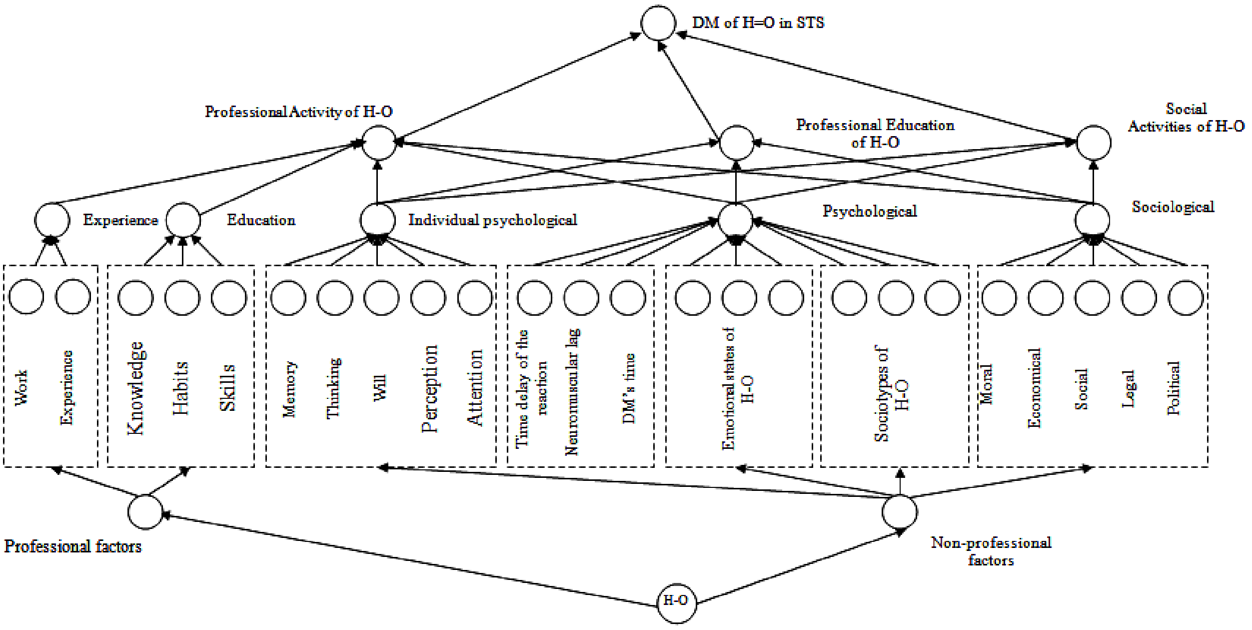


Fig. 1. Factors impact in ANS as STS.

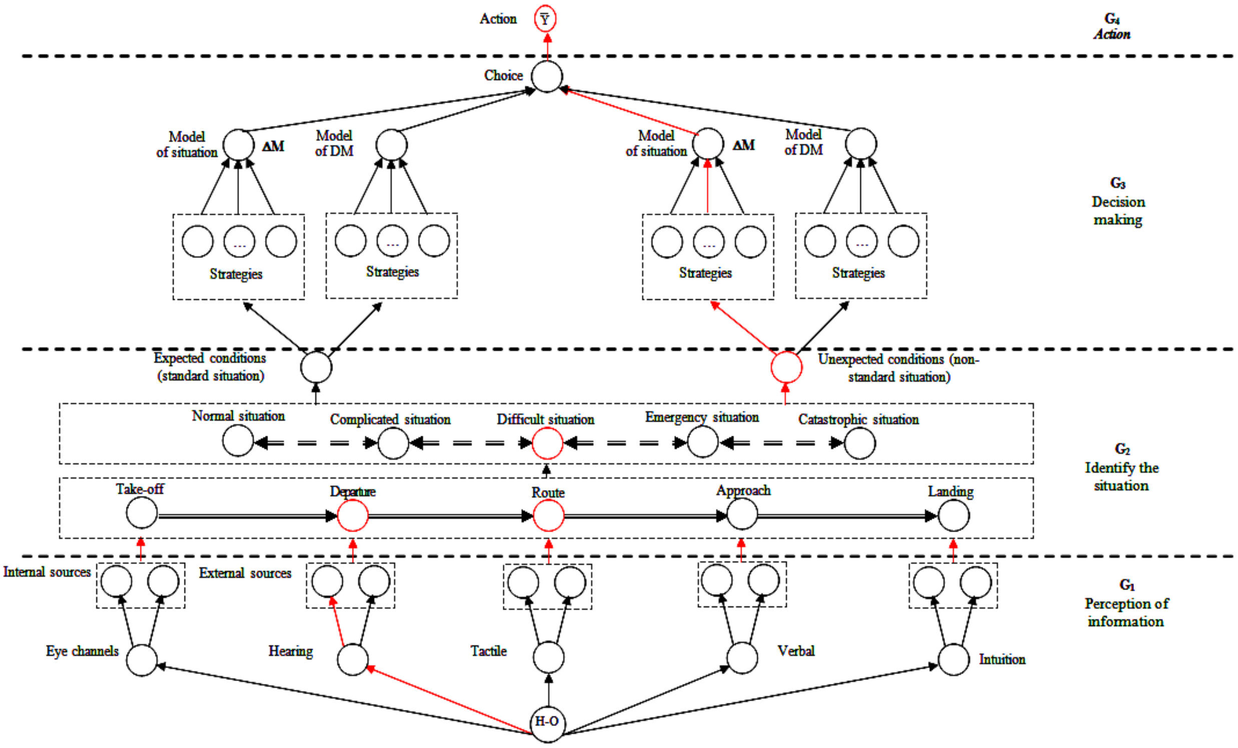


Fig. 2. Graf of DM by H-O.

In order to take into account the complex of the factors that influences on H-O of the ANS as STS in the expected and unexpected conditions of operation of an AC a reflexive model of bipolar choice of H-O has been worked-out (Fig. 3). In the informational processor of the reflexive intuitive selection of H-O is selected in the directions of positive pole *A*, negative pole *B*; mixed selection *AB* according of reflexive theory [11]. The choice of H-O ANS is described by the function (1):

$$X = f\,(x_1, x_2, x_3\,), \qquad (1)$$

where $X$ – is probability, that H-O is ready to choose a positive pole A in the reality; $x_1$ – is a pressure of the environment on H-O toward positive alternative at the moment of the choice, $x_1 \in [0,\ 1]$; $x_2$ – is a pressure of the previous experience of H-O toward positive alternative at the moment of the choice, $x_2 \in [0,\ 1]$; $x_3$ – is a pressure of the intention of H-O toward positive alternative in moment of the choice, $x_3 \in [0,\ 1]$.

Verified the reflexion theory, i.e. unexpected emergency situations H-O performs automatic selection influenced by previous experience ($x_1$) and environment ($x_2$). In expected emergency situations the choice of H-O has influenced by the intention ($x_3$) of the H-O.

The alternative solution $B$ – is the choice of H-O, which is determined by H-O preferences system under which any form of arrangement of $F$-set is understood, i.e., removing the uncertainty of choice of some element $f^* \in F$ on the basis of selection rule $K$. A selection of a rule $K$ shows the concept of a rational behaviour of individual $\gamma$ and his preferences system $\rho$ in a particular situation of choice $\{\gamma, \rho\} \to K$. The ANS's H-O preferences system are influenced by professional $\overline{F}_p$ and non-professional $\overline{F}_{np}$ factors (2-3):

$$\overline{F}_p = \{\overline{F}_{ed}, \overline{F}_{\exp}\}; \qquad (2)$$

$$\overline{F}_{np} = \{\overline{F}_{ip}, \overline{F}_{pf}, \overline{F}_{sp}\}, \qquad (3)$$

where $\overline{F}_{ed}$ – are knowledge, skills and abilities, acquired H-O during training; $\overline{F}_{\exp}$ – are knowledge, skills and abilities, acquired H-O during professional activity; $\overline{F}_{ip} = \{f_{ipt}, f_{ipa}, f_{ipp}, f_{ipth}, f_{ipi}, f_{ipn}, f_{ipw}, f_{iph}, f_{\exp}\}$ – is set of H-O individual-psychological factors (temperament, attention, perception, thinking, imagination, nature, intention, health, experience); $\overline{F}_{pf}$ – is set of H-O psycho-physiological factors (features of the nervous system, emotional types, sociotypes); $\overline{F}_{sp} = \{f_{spm}, f_{spe}, f_{sps}, f_{spp}, f_{spl}\}$ – is set of H-O socio-psychological factors (moral, economic, social, political, legal factors).

For example, with using expert method have been obtained the preferences system of the pilot on the set of individual-psychological factors $\overline{F}_{ip}$, which reflect the objective characteristic of DM and thinking psychology of H-O [12 – 13]: he is guided by action, in cases of normal and catastrophic situations (4-5):

$$\begin{aligned}&(f_{iph}, f_{\exp}) \succ f_{ipa} \succ f_{ipw} \succ f_{ipt} \succ \\ &\succ f_{ipi} \succ f_{ipp} \succ f_{ipth} \succ f_{ipn}\end{aligned}, \qquad (4)$$

$$\begin{aligned}&(f_{iph}, f_{\exp}) \succ (f_{ipt}, f_{ipp}) \succ f_{ipa} \succ \\ &\succ f_{ipw} \succ f_{ipth} \succ f_{ipi} \succ f_{ipn}\end{aligned}, \qquad (5)$$

where $f_{iph}$ – is health; $f_{ipexp}$ – is experience; $f_{ipa}$ – is attention; $f_{ipw}$ – is intention; $f_{ipt}$ – is temperament; $f_{ipi}$ – is imagination; $f_{ipp}$ – is perception; $f_{ipth}$ – is thinking; $f_{ipn}$ – is nature.

In both cases, the most significant factors are the health and experience. During a flight situation development towards catastrophe such factors such as temperament and ability to perceive information are getting much more significant role. Other individual-psychological factors remain unchanged.

The preferences models for military pilots and navigators allowed to obtain the priorities of socio-psychological factors $\overline{F}_{sp}$ (6):

$$f_{sps} \succ f_{spe} \succ f_{spl} \succ f_{spp} \succ f_{spm}\,, \qquad (6)$$

where $f_{sps}$ – are social factors; $f_{spe}$ – are economics factors; $f_{spl}$ – are legal factors; $f_{spp}$ – are political factors; $f_{spm}$ – are moral factors.

In Fig. 4 presents the priority of economics and social factors in result of influence of socio-psychological factors on the professional activities of military pilots and navigators.

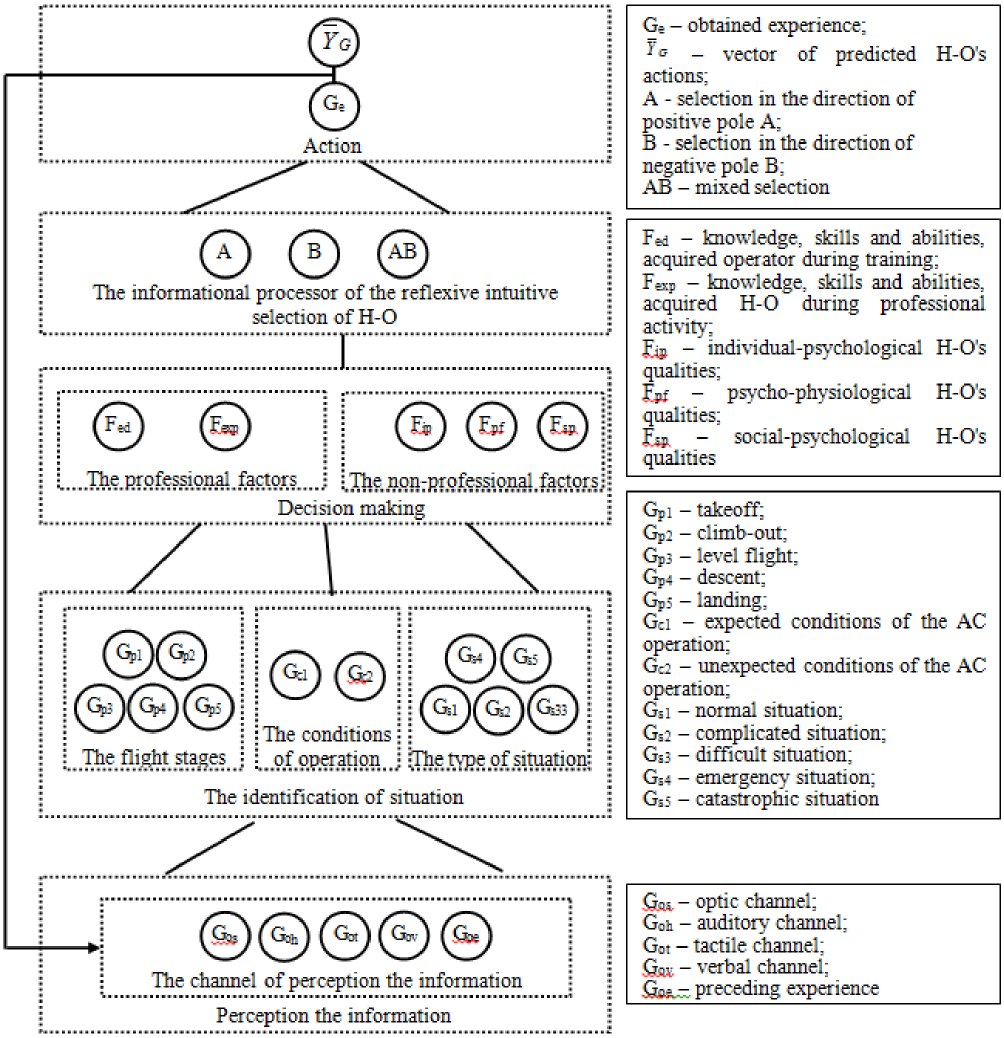


Fig. 3. The model of DM by H-O ANS

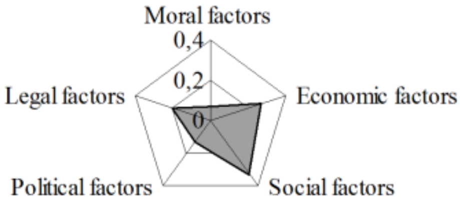


Fig. 4. The influence of socio-psychological factors on the professional activities of military pilots and navigators.

The previous studies the factors that affect the DM by ANS's H-O have been determined, namely: level of knowledge, skills, abilities, preceding experience as well as the factors of non-professional nature. The analysis of social-physiological factors conducted by the authors allowed to make a conclusion that the activities of pilots are influenced by the own image, the image of corporation as well as by interests of a family. At the same time respondents – air traffic controllers pay special attention to interests of their families, their own economic status and professional promotion.

The nature of the operator's work depends on the dynamic properties of the control object. Researches in worldwide practice to determine changes in the emotional state of H-O are mostly held by direct measurements of physiological characteristics, such as heart rate, blood pressure, tremors of hands, perspiration, changes in iris, etc., which are applying the appropriate medical equipment, sensors [14]. Such studies of the H-O physical condition have practical value, but it is difficult to obtain measurements of actual emotional state H-O during execution of professional duties, particularly in aviation accident. It is required to obtain the real characteristics of the emotional state of H-O without interference in ergonomic conditions of operator activity.

It is proposed to evaluate move of assessment of the pilot is piloting parameters (deviation ailerons, rudder direction, etc.) and negotiations on the flight deck, i.e. communications between the pilot and controller because its more available for investigation are piloting parameters. The pace and range of motion of the pilot during controlling the air vehicle that changes with increasing emotional stress is an indicator of emotional state [8, 12]. Identification of the current emotional state of the operator is based on analysis of variance obtained from spontaneous, emotional or sensible (phase portraits) types of activity H-O for using dispersion analysis and determine of stability for using Nyquist criterion (Fig. 5).

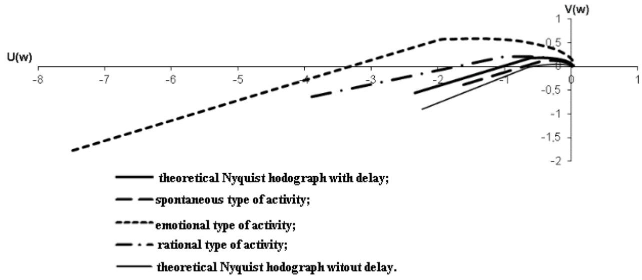


Fig. 5. Nyquist hodograph to diagnose the emotional state of H-O and definition of ANS stability during deformation emotional experience.

Monitoring of H-O current emotional state and diagnostics of emotional experience deformation in the form of transition to dangerous types of H-O activity (reasonable or emotional) in extreme situations and determining the functional stability of H-O will allow time to prevent the development of flight situation.

## 5. Models of Decision Making by Human-Operator in Air Navigation System as a Socio-Technical System

The structural analysis of flight emergencies (FE) development and DM by aircraft (AC) crew and air traffic controller (ATC) in FE enabled to obtain such results [12 – 13, 15 – 16]: graphical-analytical models of FE development and DM by a H-O (controller, pilot) in FE; deterministic models; stochastic models type decision trees, Markov chains and GERT network (Graphical Evaluation and Review Technique); reflexive models of bipolar choice in FE under the influence of external environment, previous experience and intentional choice by H-O.

Network analysis of DM by H-O in FE under certainty with using the network planning methods gave a chance to obtain [15 – 16]: structural-time table of the actions taken by H-O (controller, pilot) in FE; network graph of taking the actions by a H-O (controller, pilot) in the FE; critical time of taking the actions by a H-O (controller, pilot) in the FE. Logic determined models for a H-O (controller) are presented in Fig. 6, which were obtained in accordance with the adopted technologies of ATC's work ASSIST (Acknowledge, Separate, Silence, Inform, Support, Time).

The critical time for performing the operations by an ATC in the FE namely: engine failure on take-off, AC depressurization, hydraulic system faults, failure of the electric power supply system, etc. as well as the critical time of the AC crew actions in case of an engine failure on take-off and approach to land in the adverse meteorological conditions has been obtained [12].

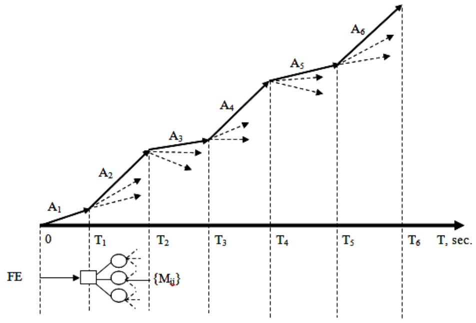


Fig. 6. The network graph of carrying out the actions by an ATC in the ANS.

Models of DM by H-O in FE in risk have been obtained with using decision tree. The expected risks $R_A$, $R_B$ of making a decision in the ANS under the influence of the external environment $x_1$, the previous H-O's experience $x_2$ and the intentional choice of H-O $x_3$ have been obtained. The expected risk in the process of DM of a H-O is equal (7):

$$R_{DM} = \begin{cases} R_A = min\{R_{ij}\} \\ R_B = \{\gamma, \rho\} \\ R_{AB} = \{X(x_1, x_2, x_3), \gamma, \rho\} \end{cases}, \tag{7}$$

where $R_A$ – is an expected risk of the DM for a H-O with taking into account the criterion of the expected value minimization; $R_B$ – is an expected risk of the DM for a H-O with taking into account his model of preferences; $R_{ij}$ – is an expected risk for making $A_{ij}$-decision; $\gamma$ – is a concept of a rational individual's behaviour; $\rho$ – is a system of individual's preferences in a concrete situation of the choice; $R_{AB}$ – is a mixed choice made by a H-O.

For example, let's analyse catastrophic situation development under hazardous weather conditions using decision tree, Markov network and stochastic network GERT [17 – 20] (Fig. 7).

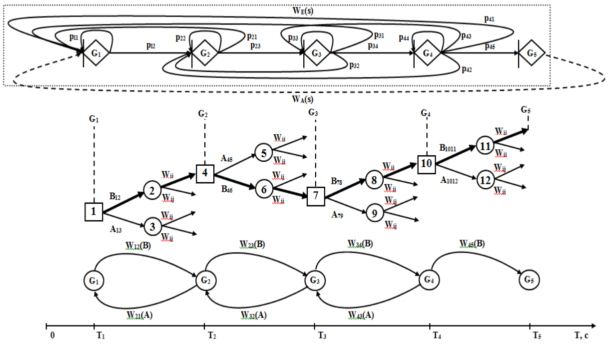


Fig. 7. One of the scenarios of flight situation development: *A, B* – is the selection in the direction of positive or negative pole respectively; $G_1$, $G_2$, $G_3$, $G_4$, $G_5$ – are normal, complicated, difficult, emergency, catastrophic situations respectively.

According to data of the National Transportation Safety Board (NTSB) [21], during the last 10 years 21,3% aviation accidents happened due to weather conditions, of which 39,1% – in adverse weather conditions. The major cause of aviation accidents in adverse weather conditions (68%) considered improper and untimely DM by AC crew.

The example of the computation of the expected risks in the course of the transition between flight situations is presented in Fig. 8. The selection in the direction of the negative pole in compliance with the $S_{1\text{-}2\text{-}3\text{-}4B}$ scenario leads to the maximum expected risk $R$=1028 conventional units (c.u.). The choice in the direction of the positive pole when the FE occurs at the first stage of DM by H-O ANS (for example, a flight to alternative aerodrome in the difficult meteorological conditions) has a risk which is 60,5 times lesser: $R$=17.

Based on the W-functions of positive and negative H-O choice the Markov network of flight situations development from normal to catastrophic has been constructed (Fig. 9).

In stochastic networks of the flight situation development of GERT type the tops are represented by stages of the situation (normal, complicated, difficult, emergency or catastrophic), and the arcs are represented by a process of transition between stages of the situation. The algorithm of stochastic network analysis has been developed. Thus according to results of stochastic network analysis of the flight situation development from normal to catastrophic the following values have been obtained: mathematical expectation of flight situation development time $t_{ij}$; variance of flight situation development time $t_{ij}$; probability of flight situation development $p_{ij}$.

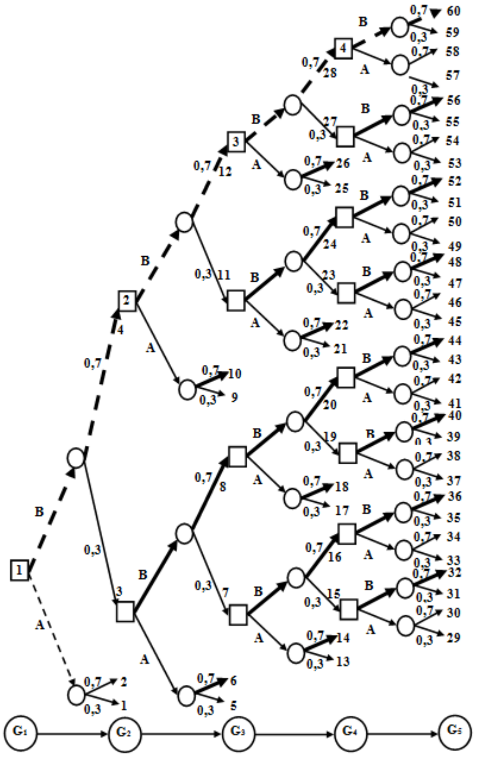


Fig. 8. The example of the computation of one of the scenarios of flight situation development: *A, B* – is the selection in the direction of positive or negative pole respectively; $G_1$, $G_2$, $G_3$, $G_4$, $G_5$ – are normal, complicated, difficult, emergency, catastrophic situations respectively.

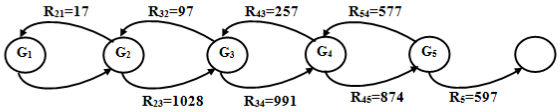


Fig. 9. Markov chains of the development of flight situation: $G_1$ ,$G_2$, $G_3$, $G_4$ ,$G_5$ – are normal, complicated, difficult, emergency, catastrophic situations respectively; $R_{ij}$ – is the value of risk during transition between flight situations

The developed neural network model of evaluating the efficiency of the potential alternative of flight completion on the basis of the two-layer perceptron (Fig. 10) differs from the used ones because it enables to define with a high degree of precision the amount of the possible loss due to the complex taking into account of the influences of various separate factors differing from the point of view of their significance which characterize the potential place for making a forced landing. The entry parameters of the model in the form of the artificial neural network are factors which characterize the potential alternative of the flight completion.

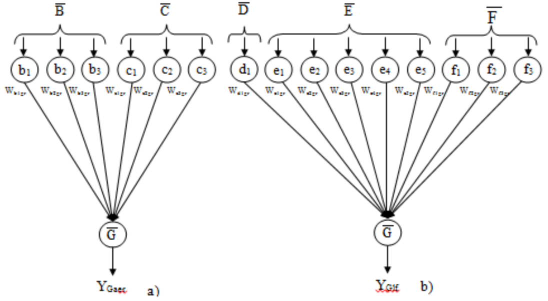
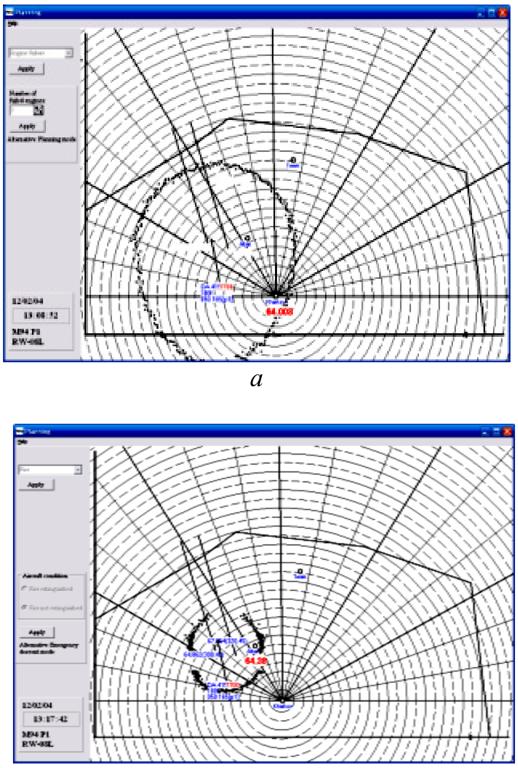


Fig. 10. Neural network model: *a* – the potential alternative of the flight completion is an aerodrome; *b* – the potential alternative of the flight completion is a landing field

Decision Support System of ATC in the emergency situations has been developed [12]. For the informational support of an ANS to enable it to make operative and timely decision concerning the selection of the optimum flight completion strategy in unusual situations which require a forced landing the specialized program complex “Prompt” has been created. With the aid of the program “Prompt” the subsystems of forming the strategies of actions, predicting the development of a situation, defining the characteristics of the alternative variants of the flight completion, evaluation of the efficiency of the potential alternatives and building the optimum decision were realized. The program “Prompt” enables to handle two non-standard situations – an engine failure and fire on board an aircraft. When the recommendation concerning the necessity to accomplish a forced landing is obtained, the field of approachability for the aircraft is built on the monitor, also values of the potential loss required for selection of a definite flight completion alternative as well as the coordinates of the potential landing sites (azimuth, range) are presented on the monitor. The program envisages the formation of the field of approachability for two extreme cases – the regime of planning and regime of an immediate descent (Fig. 11).

The program complex “Prompt” allows: to give the recommendations concerning the possibility of the further flight continuation or the necessity to accomplish a forced landing of the aircraft with the aid of the interface suitable for the user; to define the field of approachability of the aircraft in case when the necessity to make a forced landing arises; to form the evaluation of the alternative variants of the flight completion and define the optimum variant using the potential-loss minimization criterion.


*a*

*b*

Fig. 11. The field of approachability and defined potential loss for a few variants of the flight completion: *a* – in case of the complete failure of the aircraft engines; *b* – in case of the fire on board the aircraft which was not extinguished

## 6. Methodology of Research and Training in Air Navigation Socio-technical System

Methodology of research and training in ANS as STS has been developed:

1. Human factor problem. Analysis of complex control systems as STS (Aviation systems, Chemical production, Energy, Military industry, etc.).

1.1. Individual-psychological factors / comparative analysis of different age and social groups.

1.2. Socio-psychological factors / comparative analysis of different age and social groups (countries, regions, cities, etc.).

1.3. Monitoring of psycho-physiological factors (ordinary, extraordinary, emergency situations, ect).

2. Diagnostics, monitoring of the factors (professional and non-professional) that influence on DM by the H-O in STS.

2.1. Diagnostics, monitoring of the professional factors.

2.2. Diagnostics, monitoring of the non-professional factors.

2.3. Diagnostics of individual-psychological factors / comparative analysis of different age and social groups.

2.4. Diagnostics of socio-psychological factors / comparative analysis of different age and social groups (countries, regions, regions, cities, etc.).

2.5. Monitoring of psycho-physiological factors (ordinary, extraordinary, emergency situations, ergonomic correction of results, ect.).

2.6. Comparative analysis of different age, social groups, countries, etc.

3. Complex accounting of the factors affecting the H-O DM in the STS.

3.1. Methods of aggregation of the factors that influence on DM in the STS (additive, multiplicative aggregation, etc.).

3.2. The method of generalization of heterogeneous factors, with the help of which the influence of individual-psychological, socio-psychological and psycho-physiological factors in the STS determines.

3.3. Reflexive bipolar choice in the positive / negative pole. Reflexive information processor for diagnostics and predicting the development of situations, etc.

4. Models of DM in STS and forecasting the development of the situation for different spheres of industry as STS.

4.1. Deterministic models of DM in STS.

4.2. Stochastic models of DM in STS by an H-O in extreme situations (under conditions of stochastic reflexive bipolar choice).

4.3. Neural network, Markov chains, GERT-models of DM in STS by an H-O in extreme situations.

4.4. Models of diagnostics of the emotional state of H-O in extreme situations.

4.5. Master Class of DM, etc.

5. Algorithm for diagnostics the pilot's emotional state by the parameters of piloting (movement of the ailerons, etc.) in extreme situations. Algorithm for diagnostics the H-O's emotional state in extreme situations.

5.1. Stability of STS during deformations of the emotional state by H-O.

5.2. Methods of stability correction of STS.

5.3. Methodology for modeling the development of an emergency situation, taking into account the impact of individual and social factors on DM, etc.

6. Applied tasks of the DM in STS by an H-O (Aviation systems, Chemical production, Energy, military industry, etc.).

6.1. Prerequisites for a catastrophic situation, etc.

6.2. Preventing catastrophic situation, etc.

6.3. Accident investigation problems, etc.

7. Development on-line systems.

7.1. On-line system of DM study.

7.2. On-line diagnostics of the factors of non-professional activities on the DM by H-O.

7.3. On-line diagnostics of the emotional state of H-O.

7.4. On-line professional diagnostics for using DM with socionics.

7.5. On-line business planning, etc.

Let’s consider the individual works of aviation students in education (course “Basic of DM in ANS” in National Aviation University, Kyiv) after Master class of DM in ANS. Plan of research FE “Aircraft Decompression”:

– technology of H-O (ATC) actions in FE “Aircraft Decompression”;

– decomposition of technology on the operational procedure;

– block-scheme of algorithm of the operational procedure of the ATC in FE “Aircraft Decompression”;

– structural-timing table of the operational procedure of the ATC in FE “Aircraft Decompression”;

– network graph of taking the actions by a H-O ATC in the FE “Aircraft Decompression”;

– DM under risk and calculation of the optimal solution using the criterion of Expected value;

– DM under uncertainty and calculation of the optimal solution with using Wald and Laplace criteria.

For example, there is individual work of students “DM in emergency situation “Aircraft Decompression”.

*Decision making under certainty.*

Algorithm of H-O DM under certainty in the emergency situation “Aircraft Decompression”:

1. To choose the emergency situation from the ASSIST list.

2. Technology of human operator (ATC) actions in emergency situation.

3. Decomposition of technology on the operational procedures: $A_{\mathrm{i}}$, $i = \overline{1,n}$ .

4. Definition of time $t_{\mathrm{i}}$, $i = \overline{1,n}$ with help of the method of experts' estimations.

4.1. Determine the experts' group opinion (sample average, arithmetical mean) $t_{grj} = t_{middle}$.

Determine the coordination of experts' opinion for $t_{\mathrm{i}}$, $i = \overline{1,n}$ :

– dispersion for each factor – $D_j$;

– square average deviation – $\sigma_{\mathrm{j}}$;

– coefficient of the variation for each $t_{\mathrm{i}} - v_{j,}$.

5. To build the algorithm block-scheme.

6. To build the structural-timing table.

7. To build the network graph of taking the actions by a H-O (ATC) in the emergency situation.

8. Determine the critical time and the critical path of complex work $T_{cr.}$

Results of individual work are presented in Table 2 and in Fig. 12-13.

From the graph has been defined the critical way: $W_{cr} = A1 - A2 - A6 - A7 - A8 - A9$ and the critical time for operations execution: $T_{cr}$ = 72 seconds (Table 2).

*Table 2*

**Structural-timing table of ATC actions**

| № | Designation of actions, $A_{\mathrm{i}}$ | Content of ATC actions | Based on actions | Time of actions $t_{\mathrm{i}}$, sec |
|---|---|---|---|---|
| 1 | *A1* | AC Decompression | x | 25 sec-1 min |
| 2 | *A2* | Confirm request for immediate descend and decompression | *A1* | 8 |
| 3 | *A3* | Divert AC from previous route | *A1, A2* | 10 |
| 4 | *A4* | Clear airspace beneath the AC | *A2, A3* | 5 |
| 5 | *A5* | Ask for the crews' intentions | *A1* | 25 |
| 6 | *A6* | Silence mode | *A1, A2* | 5 |
| 7 | *A7* | Inform Emergency services and all concerned ATC units about emergency | *A1, A5, A6* | 15 |
| 8 | *A8* | Provide priority landing on the nearest airport | *A1, A5, A7* | 5 |
| 9 | *A9* | Give all necessary advice (heading, weather, frequency, etc.) | *A8* | 8 |

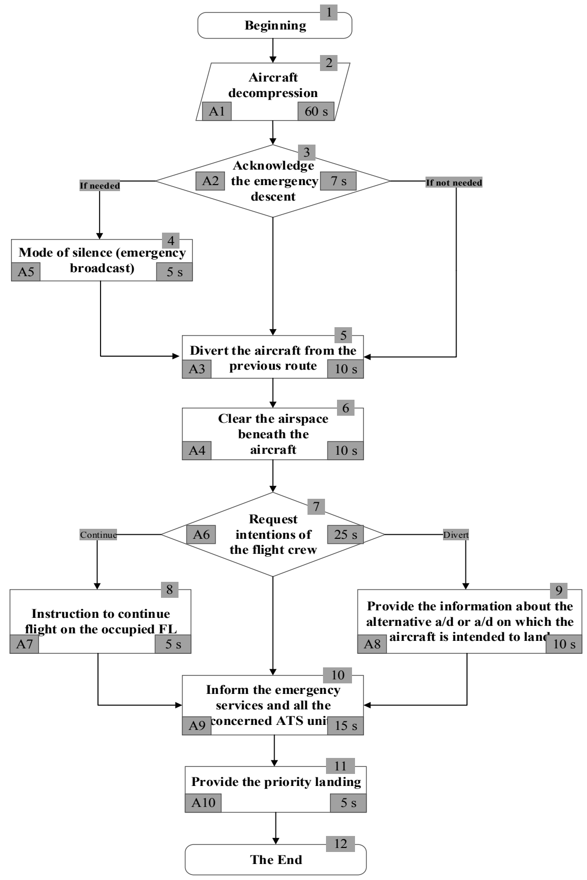


Fig. 12. Block-scheme carrying out the actions by an ATC in FE "AC Decompression"

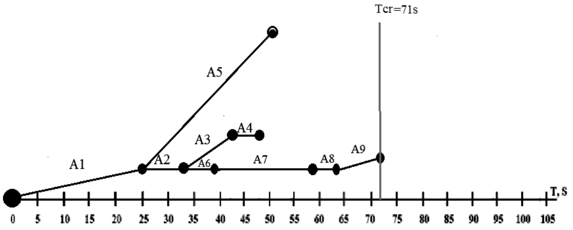


Fig. 13. The network graph of carrying out the actions by an ATC in FE "AC Decompression"

*Decision making under risk.*

Using case: AC BAE 146-300 flied from Dnipropetrovs'k to Minsk. At the quarter of its route pressurization problem was happened. AC characteristics require minimal landing distance 1380 m. Poltava, Kirovograd and Boryspil are the nearest aerodromes. Poltava has paved runway of 3000 m length, Kirovograd – soft-field runway of 1301 m length, Boryspil – two paved runways of 4000 m and 3500 m length correspondingly. Boryspil is alternative aerodrome for flight from Dnipropetrovs'k to Minsk. Pilot is informed about thunderstorm activity near Kyiv ACC. Which of this scenario should pilot take under conditions of risk: continue flight to destination of make a diversion?

This problem we will solve with the help of decision tree. At first, the structural analysis of the situation was performed. We defined the stages of solution (square nodes): emergency descent of AC, choosing of intentions by pilot; choosing of aerodrome for emergency landing; choosing of the nearest aerodrome; choosing between alternative or departure aerodrome for emergency landing.

At the second step we defined of alternatives at each stage. On decision tree we have the following alternatives (Fig. 14).

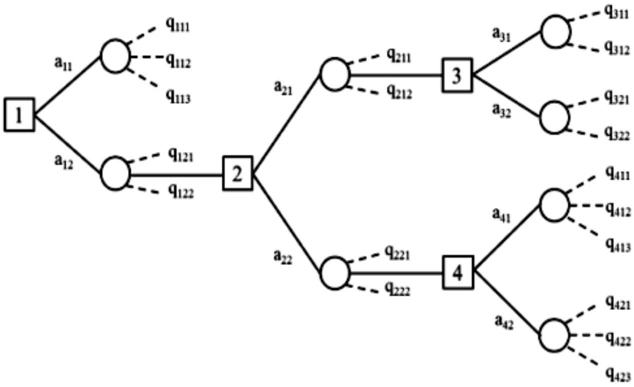


Fig. 14. Decision tree of the ATC actions in case of AC Decompression

According to the calculations, the optimal solution is $a_{12}$, $a_{21}$ and $a_{31}$. So, in the conclusion we may say that in case of pressurization problems the pilot should make a forced landing at the nearest aerodrome Poltava.

*Decision making under uncertainty.*

Decision making under uncertainty, as under risk, involves alternative actions whose payoffs depend on the (random) states of nature. In decision making under uncertainty, the decision maker has no knowledge regarding any of the states of nature outcomes, and/or it is costly to obtain the needed information. In such cases, the DM depends merely on the decision maker's personality type. On approach of aircraft to Boryspil aerodrome decompression happened. We have to make a choice of the optimum landing aerodrome with classical theory of decision criteria: Wald and Laplace. Alternate aerodrome is an aerodrome to which an aircraft may proceed when it becomes either impossible or inadvisable to precede to or to land at the aerodrome of intended landing. Alternate aerodromes include the following: Boryspil, Zhuliany, Gostomel, Antonov. In Table 3 represented decision matrix with sets of alternative actions $A = \{A_1, A_2, \dots A_i, \dots, A_m\}$ and factors $\lambda = \{\lambda_1, \lambda_2, \dots \lambda_j, \dots, \lambda_n\}$ that influence on the decision effects:

$A_1$ – landing at Boryspil aerodrome;
$A_2$ – landing at Zhuliany aerodrome;
$A_3$ – landing at Gostomel aerodrome;
$A_4$ – landing at Antonov aerodrome;
$\lambda_1$ – availability of fuel on board;
$\lambda_2$ – remoteness;
$\lambda_3$ – tactic-technical characteristics of runway;
$\lambda_4$ – weather conditions;
$\lambda_5$ – lighting system approach;
$\lambda_6$ – landing system approach;
$\lambda_7$ – navigation aids approach;
$\lambda_8$ – conditions of apron, taxiways, ect.

*Table 3*

**Decision matrix**

| Alternative actions | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\lambda_4$ | $\lambda_5$ | $\lambda_6$ | $\lambda_7$ | $\lambda_8$ | Wald | Lap-lace |
|---|---|---|---|---|---|---|---|---|---|---|
| Boryspil | 9 | 8 | 5 | 3 | 7 | 8 | 5 | 4 | 3 | 6,1 |
| Zhuliany | 10 | 7 | 7 | 5 | 8 | 7 | 6 | 3 | 3 | 6,6 |
| Gostomel | 7 | 5 | 6 | 7 | 5 | 6 | 3 | 8 | 3 | 5,9 |
| Antonov | 6 | 6 | 8 | 8 | 4 | 7 | 4 | 5 | 4 | 6 |

As we can see, if this flight is regular it is better to land at Zhuliany aerodrome for the most optimal solution regarding to Laplace criterion. But regarding Wald criterion it is better to land at Antonov aerodrome if this flight is performed for the first time.

On the basis of the individual works students taking part in conferences and reporting about results of scientific work.

## 7. Conclusions

The ANS has been presented as a complex Socio-Technical System. The influence on the DM by H-O of the ANS of the professional factors (knowledge, skills, abilities, experience) as well as the factors of non-professional nature (individual-psychological, psycho-physiological and socio-psychological) has been defined.

The result of the evaluation of non-professional factors is determination the socio-psychological impact on DM of H-O by identifying the preferences, diagnostics the individual-psychological qualities of H-O ANS in the development of flight situation, monitoring of the psycho-physiological factors (emotional state) H-O ANS for timely diagnostics transition to a potentially dangerous mental activity and determine the stability of ANS in the performance of professional actives.

The network analysis of the actions of an AC crew and ATC in the FE has been made with the aid of the network planning methods; also the logic determined models of DM by H-O ANS in FE have been developed. The numerical indices of an expected risk in the stochastic models of DM by H-O ANS under risk and uncertainty have been defined. The scenarios of developing a flight situation in case of selecting either the positive or negative pole under the pressure of the external environment, the preceding experience of a human-operator and the intentional selection (intention) in accordance with the reflexive theory have been obtained. The neural network model on the basis of the two-layer perceptron realized in it enables to define with a high degree of precision in the regime of real time the quantity of the possible loss due to the complex consideration of the various factors of different significance which characterize the potential place for accomplishing a forced landing.

To ensure the informational support of an operator of the ANS with the purpose of assisting him in taking the operative and timely decision concerning the selection of the optimal flight completion strategy in the unusual situations which require a forced landing of an aircraft the program complex “Prompt” has been worked-out.

The methodology of research and education of ANS as STS has been developed. The scientific work of aviation students in education after Master class of DM in ANS has been presented.

It is our belief, that the methods of analysis of DM by ANS’s H-O can be used in fields other than aviation. The algorithms and methodology for analysis of situation development under influence of DM by H-O can be useful in any technogenous production. In future we are planning consider other different complex STS, such as hydraulic engineering, chemical and military industries, gas and oil pipelines, nuclear power plants and transport etc. It is necessary to analyse the all factors influencing the DM of operators in these systems in order to predict the development of the technogenic catastrophe and prevent it.

## References

[1] International Civil Aviation Organization. (2002) *Human Factors Guidelines for Safety Audits Manual.* 1st ed. Doc. ICAO 9806-AN/763. Canada, Montreal, ICAO Publ., 138 p.

[2] International Civil Aviation Organization. (2004) *Cross-Cultural Factors in Aviation Safety: Human Factors Digest № 16*. Circ. ICAO 302-AN/175. Canada, Montreal, ICAO Publ., 39 p.

[3] International Civil Aviation Organization. (2013) *Safety Management Manual (SMM).* 3rd ed. Doc. ICAO 9859-AN 474. Canada, Montreal, ICAO Publ., 251 p.

[4] Bertsch V., Treitz M., Geldermann J., Rentz O. (2007) Sensitivity Analyses in Multi-Attribute Decision Support for Off-Site Nuclear Emergency and Recovery Management. *International Journal of Energy Sector Management*, vol. 1 (4), pp. 342-365.

[5] Flueler T. (2006) *Decision Making for Complex Socio-technical Systems: Robustness from Lessons Learned in Long-Term Radioactive Waste Governance (Environment & Policy)*. USA, Springer Publ., 386 p.

[6] Keating C., Fernandez A., Jacobs D. Kauffmann A. (2001) Methodology for Analysis of Complex Sociotechnical Processes. *Business Process Management Journal*, vol. 7, iss. 1, pp. 33–50.

[7] Baxter G., Sommerville I. (2011) Socio-Technical Systems: From Design Methods to Systems Engineering. *Interacting with Computers*, no. 23 (1), pp. 4-17.

[8] Leychenko S., Malishevski A., Mikhalic N. (2006) *Chelovecheskii faktor v aviatsii.* Monografiya v dvukh knigakh. Kniga pervaya [Human Factors in Aviation: monograph in two books. Book 1st.]. Kirovograd, YMEKS Publ., 512 p. (In Russian)

[9] Kulik N., Kharchenko V., Lutskii M. (2008) *Entsiklopediya bezopasnosti aviatsii* [Encyclopedia of Aviation Safety]. Kyiv, Technology Publ., 1000 p. (In Russian)

[10] Makarov R., Nidzii N., Shishkin G. (2000) *Psikhologicheskie osnovy didaktiki letnogo obucheniya* [Psychological Foundations of Didactics in Flight Education]. Moscow, Mapchak Publ., 534 p. (In Russian)

[11] Lefebvre B. (2008) Intentsional'no-refleksivnaya model' agenta [Intentional-Reflective Model of the Agent]. *Refleksivnye protsessy i upravlenie,* vol. 1, pp. 69–78. (In Russian)

[12] Kharchenko V., Shmelova T., Sikirda, Y. (2012) *Pryynyattya rishen' operatorom aeronavihatsiynoyi systemy.* Monohrafiya [Decision-Making of Operator in Air Navigation System. Monograph]. Kirovograd, KFA of NAU Publ., 292 p. (In Ukrainian)

[13] Kharchenko V., Shmelova T., Sikirda Y. (2016) *Pryynyattya rishen' v sotsiotekhnichnykh*

*systemakh.* Monohrafiya [Decision-Making in Socio-Technical Systems. Monograph]. Kyiv, NAU Publ., 308 p. (In Ukrainian)

[14] Holovakha R.V. (2004) *Biotekhnichna systema dlya kontrolyu psykhofiziolohichnoho stanu operatora.* Diss. kand. tekhn. nauk [Biotechnical System for Monitoring the Psychophysiological State of the Operator. Cand. eng. sci. diss.]. Kharkiv, 154 p.

[15] Rizun N., Shmelova T. (2016) Decision-Making Models of the Human-Operator as an Element of the Socio-Technical Systems. Chapter 9. *Strategic Imperatives and Core Competencies in the Era of Robotics and Artificial Intelligence.* USA, Pennsylvania, International Publisher of Progressive Information Science and Technology Research, pp. 167-204. doi: 10.4018/978-1-5225-1656-9.ch009

[16] Shmelova T. Sikirda Yu., Rizun N., Salem A., Kovalyov Yu. (2018) *Socio-Technical Decision Support in Air Navigation Systems : Emerging Research and Opportunities.* Manuscript. USA, Hershey, IGI Global Publ. 305 p. doi: 10.4018/978-1-5225-3108-1

[17] Hamdy A. Taha (2011) *Operations Research. An Introduction.* 9th ed. Pearson Prentice Hall Publ., 838 p.

[18] Neumann K. (1990) Stochastic Project Networks. Temporal Analysis, Scheduling and Cost Minimization. *Lecture Notes in Economics and Mathematical Systems*, vol. 344, USA, Springer-Verlag Publ., 237 p.

[19] Saaty T. (2010) *Jelementy teorii massovogo obsluzhivanija i ee prilozhenija.* 3e izdanie [Elements of the Mass Service Theory and Its Applications. 3rd ed.]. Moscow, LIBROKOM Publ., 510 p. (In Russian)

[20] Shakya S., Santana R. (2012) *Markov Networks in Evolutionary Computation (Adaptation, Learning and Optimization).* USA, Springer Publ., 225 p. doi: 10.1007/978-3-642-28900-2_6

[21] Aviation Accident Statistics. (2018) *National Transportation Safety Board.* Available at: www.ntsb.gov/aviation/aviation.htm (accessed 08.02.2018)

[22] Pawęska M., Tubis A. (2012) The Research of the Quality of Passenger Transport Services on a Selected Regional Route. *Logistics and Transport*, no. 2(15), p.p. 91-98.

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**Методологія досліджень та навчання в аеронавігаційній соціотехнічній системі**

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**Мета**: на основі формалізації професійних і непрофесійних факторів, конструювання моделей прийняття рішень людиною-оператором аеронавігаційної системи та розвитку польотної ситуації розробити методологію досліджень та навчання в аеронавігаційній соціотехнічній системі. **Методи**: системний аналіз, рефлексивна теорія, мережеве планування, дерево рішень, мережа Маркова, мережа GERT, нейронна мережа, експертний метод. **Результати**: аеронавігаційна система представлена як складна соціотехнічна система. Визначено вплив професійних факторів (знань, навичок, вмінь, досвіду), а також факторів непрофесійного характеру (індивідуально-психологічних, психофізіологічних та соціально-психологічних) на прийняття рішень людиною-оператором аеронавігаційної системи. Отримано графічно-аналітичні, детерміновані, стохастичні, рефлекторні, нейромережеві моделі прийняття рішень людиною-оператором аеронавігаційної системи, та розвитку ситуаціях, які потребують польотної ситуації. Створено програмний комплекс "Підказка", який оперативно та своєчасно підбирає оптимальну стратегію завершення польоту в позаштатних виконання вимушеної посадки повітряного корабля. Розроблено методологію досліджень та навчання в аеронавігаційній соціотехнічній системі. **Обговорення**: результатом оцінки непрофесійних факторів є визначення соціально-психологічного впливу на прийняття рішень людиною-оператором шляхом виявлення переваг, діагностика індивідуально-психологічних якостей людини-оператора при розвитку польотної ситуації, моніторинг психофізіологічних показників людини-оператора (емоційного стану). Запропоновані моделі дозволять своєчасно діагностувати та прогнозувати можливі дії людини-оператора в очікуваних та неочікуваних умовах експлуатації повітряного корабля. Алгоритми та методологія аналізу розвитку ситуації під впливом прийняття рішень людиною-оператором можуть використовуватись в інших техногенних виробництвах.

**Ключові слова**: аеронавігаційна система; людський фактор; моделювання; особливий випадок у польоті; прийняття рішень; система підтримки прийняття рішень; соціотехнічна система; формалізація.

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**Методология исследований и обучения в аэронавигационной социотехнической системе**

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**Цель:** на основе формализации профессиональных и непрофессиональных факторов, конструирования моделей принятия решений человеком-оператором аэронавигационной системы и развития полетной ситуации разработать методологию исследований и обучения в аэронавигационной социотехнической системе. **Методы**: системный анализ, рефлексивная теория, сетевое планирование, дерево решений, сеть Маркова, сеть GERT, нейронная сеть, экспертный метод. Результаты: аэронавигационная система представлена как сложная социотехническая система. Определено влияние профессиональных факторов (знаний, навыков, умений, опыта), а также факторов непрофессионального характера (индивидуально-психологических, психофизиологических и социально-психологических) на принятие решений человеком-оператором аэронавигационной системы. Получены графоаналитические, детерминированные, стохастические, рефлексивные, нейросетевые модели принятия решений человеком-оператором аэронавигационной системы и развития полетной ситуации. Создан программный комплекс "Подсказка", который оперативно и своевременно подбирает оптимальную стратегию завершения полета во внештатных ситуациях, требующих выполнения вынужденной посадки воздушного корабля. Разработана методология исследований и обучения в аэронавигационной социотехнической системе. **Обсуждение**: результатом оценки непрофессиональных факторов является определение социально-психологического влияния на принятие решений человеком-оператором путем выявления предпочтений, диагностика индивидуально-психологических качеств человека-оператора при развитии полетной ситуации, мониторинг психофизиологических показателей человека-оператора (эмоционального состояния). Предложенные модели позволят своевременно диагностировать и прогнозировать возможные действия человека-оператора в ожидаемых и неожидаемых условиях эксплуатации воздушного корабля. Алгоритмы и методология анализа развития ситуации под влиянием принятия решений человеком-оператором могут использоваться в других техногенных производствах.

**Ключевые слова**: аэронавигационная система; моделирование; особый случай в полете; принятие решений; система поддержки принятия решений; социотехническая система; формализация; человеческий фактор.

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