Deterministic and Stochastic Models of Decision Making in Air Navigation Socio-Technical System

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Abstract. The conceptual model of System for control and forecasting the emergency situations development that taking into account the influence on decision making by Air Navigation Socio-Technical System human-operator of professional and non-professional factors has obtained. Optimization models of decision making such as deterministic model, stochastic model (under risk and uncertainty), neural network models have presented. Behavioral models appropriate using in Decision Support Systems for timely predicting of human-operator actions in the emergencies.

Keywords: **d**ecision making, deterministic and stochastic models, human-operator, neural network, professional and non-professional factors.

1 Introduction

At present, one of the main strategic problems of humanity on the path to sustainable development is the safety and reliability of technogenous production, which is a complex system of interconnected technical, economic and social objects; has a multilevel hierarchical structure and characterized by a high risk [1]. Emergencies, catastrophes, accidents in hydraulic engineering, chemical and military industries, gas and oil pipelines, nuclear power plants, as well as in transport are frequent and commonplace Air Navigation System (ANS), in which there is a close interaction between man and technological components, also evolved towards integrated Socio-Technical Systems (STS) [1, 2]. Socio-technical systems, as a rule, have two common features: the presence of hazardous activities and the use of high technology.

It is believed that aviation is the safest type of mass transportation and one of the safest socio-technical production systems in the history of humanity. For a century, aviation has gone a long way in the field of safety of flights from an unstable system to the first "ultra-safe" system in the history of transport, that is, a system in which the number of catastrophic failures in the field of safety is less than one million production cycles [3].

Over the year 2017, the Aviation Safety Network [4] has recorded a total of 10 fatal aircraft accidents, resulting in 44 occupant fatalities and 35 persons on the ground. This makes 2017 the safest year ever, both by the number of fatal accidents as well as in terms of fatalities. In 2016 Aviation Safety Network has recorded 16 accidents and 303 lives lost. Five accidents involved cargo flights, five were passenger flights. Given the expected worldwide air traffic of about 36,8 million flights, the accident rate is one fatal passenger flight accident per 7,36 million flights. Since 1997, the average number of aircraft accidents has shown a steady and persistent decline due to the continuing flight safety-driven efforts by international aviation organisations.

Elimination of accidents remains the key point for all kinds of aviation activity. But it is impossible for aviation systems to be completely free of hazardous factors and associated with them risks. Neither human activity nor human designed systems are completely free of operational errors and its consequences [3, 5]. Flight safety is a dynamical parameter of aviation system. Thus, risk factors should continuously mitigate. It is important to note that the adoption of indicators for the effectiveness of safety of flights is often influenced by internal and international standards, as well as cultural features [6]. When the risk factors and operational errors are reasonably monitored, flight safety can be managed [3].

Statistics over the past decades indicate the dominant role of the human factor in the total number of aviation accidents, which is about 80% [5, 7]. Therefore, researches of the human factor effect on flight safety remain relevant.

The circular of ICAO presents the safety cases for cultural interfaces in aviation safety with reference to established main conceptual safety models: SHEL model, Reason’s model of latent conditions, Threat and Error Management (TEM) model and other human factor's models [1, 3]. There are four stages of the evolution of the human factor's models (from 1972 to present time) [8, 9] associated with the appearance of new system components and the diagnosis of human-operator (H-O) errors:

1. Professional skills of H-O / Interaction of H-Os / Definitional of H-O’s errors.
2. Cooperation in team / Interaction of H-Os in team / Error detection.
3. Influence of Culture / Safety / Error prevention.
4. Safety Management / Safety balance models / Minimization of errors.

The component *Culture* means the ongoing interaction of a group of people with their environment. Culture develops and changes due to technological, physical, and social changes in the environment. When pursuing safety in these systems, it is narrow and restrictive to look for explanations for accidents or safety deficiencies exclusively in technical terms or purely from the perspective of the behavioral sciences. It is necessary to systematically analyze and classify all the factors in the ANS as STS that have an impact on the H-O in the performance of professional activities guided by the requirements of ICAO documents in accordance with the steps below:

1. Analysis of ANS as STS: diagnostics, monitoring of the all factors (*professional* and *non-professional (*individual-psychological, socio-psychological and psychophysiological factors) that influence on decision making (DM) by the H-O in STS.
2. Determining the professional type of the operators namely energy consumption for the choice of profession and the compatibility of operators in the group.

3. Complex accounting of the all factors affecting the operator's DM in the STS.

4. Modelling of DM in STS using deterministic and stochastic models of DM in STS by an H-O in emergence situations (ES) (under conditions of stochastic reflexive bipolar choice too); neural network, Markov, GERT (Graphical Evaluation and Review Technique)-models of DM in STS; models of diagnosis of the emotional state of H-O in ES, etc.

5. Forecasting the emergency. Preventing the catastrophic situations.

Therefore, taking into account the influence on DM process by ANS H-O the professional factors (knowledge, habits, skills, experience) as well as the factors of non-professional nature (individual-psychological, psycho-physiological and socio-psychological) [10–12] will allow to predict the H-O's actions on the basis of the reflexive theory [13].

The purposes of the work are: formalization of the influence of the professional and non-professional factors on the H-O DM within ANS as STS; development of models of H-O DM in Air Navigation Socio-Technical System (ANSTS); working-out computer programs for Decision Support Systems (DSS) of H-O in ES.

2 Optimization Models of Decision Making by Human-Operator in Air Navigation Socio-Technical System

Decomposition of the DM process by H-O ANS and the systemic analysis of influence of the factors of professional and non-professional activities on the DM in ANSTS were done [10, 11]. In order to take into account the complex of the factors that influencing on H-O of the ANSTS in the expected and unexpected conditions of an aircraft operation a reflexive model of bipolar choice of H-O was worked-out [8].

The conceptual model of System for control and forecasting the ES development that using DM models on the base of Artificial Intelligence System (AIS) / Decision Support System (DSS) was obtained (Fig. 1), where $\overline{F}_p = \{\overline{F}_{ed}, \overline{F}_{exp}\}$ – are the professional factors; $\overline{F}_{np} = \{\overline{F}_{ip}, \overline{F}_{pf}, \overline{F}_{sp}\}$ – are the non-professional factors; $\overline{F}_{ed}$ – are the knowledge, skills and abilities, acquired H-O during training; $\overline{F}_{exp}$ – are the 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 a set of H-O individual-psychological factors (temperament, attention, perception, thinking, imagination, nature, intention, health, experience); $\overline{F}_{pf}$ – is a 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 a set of H-O socio-psychological factors (moral, economic, social, political, legal factors).

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 (ATC) pay special attention to interests of their families, their own economic status and professional promotion [11, 12].

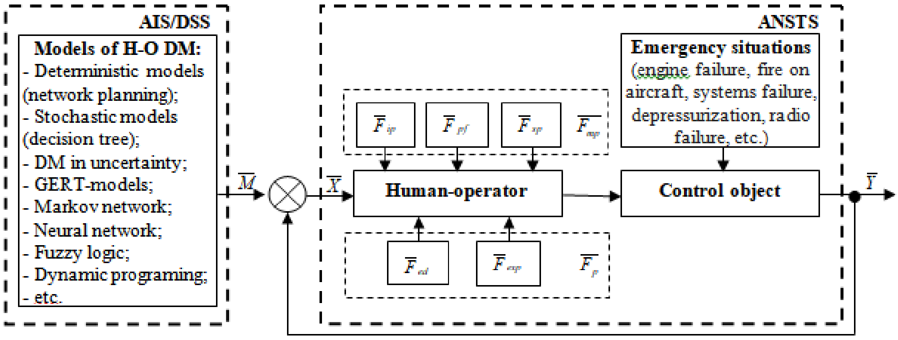
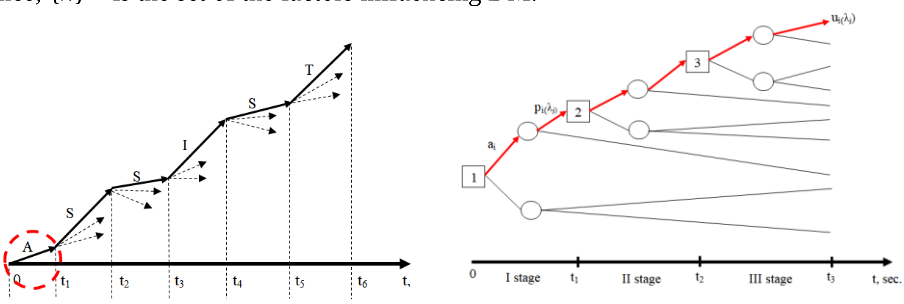


Fig. 1. System for control and forecasting the ES development

Deterministic and stochastic models for ANS H-O (pilot, controller) were obtained in accordance with the flight manual of aircraft or the adopted technologies of controller's work ASSIST (Acknowledge, Separate, Silence, Inform, Support, Time) in ES. Deterministic and stochastic models for ATC are presented in Fig. 2, where $\{A\}$ – is the set of the operations which are carried out by the controller in accordance with ASSIST; $\{T\}$ – is the time of decision making; $\{P\}$ – is the set of the probabilities of *j*-factor influence during *i*-alternative solution choice; $\{U\}$ – is the set of the losses associated with choosing *i*-alternative solution during *j*-factor influence; $\{R\}$ – is the set of the risks associated with choosing *i*-alternative solution during *j*-factor influence; $\{\lambda\}$ – is the set of the factors influencing DM.



a) *b)*

Fig. 2. Models of DM in ANSTS: a) deterministic model; b) stochastic model

With using neural network models, the values of probabilities (p_n) [11], expected outcomes (r_k) and additional inputs - factors (ξ_k) (Fig. 3) of ES development were received.

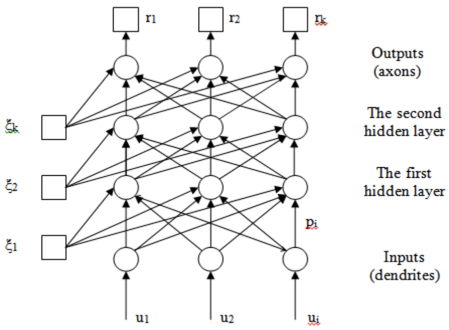


Fig. 3. Neural network model of ES development with additional inputs of influencing DM factors.

The network has additional inputs, called the Bias (offset) that takes into account additional restrictions on calculating parameters (2):

$$\sum_{i=1}^{n} p_i u_i - \xi_k \geq 0. \qquad (2)$$

where p_i – are the weight coefficients; u_i – are the neural network inputs; ξ_k – is a Bias (shift) under influencing factors of uncertainty (Table 1).

Table 1. Matrix of Bias identification

Alternative decisions	**Factors that influencing on the decision making**					
	λ_1	λ_2	…	λ_j	…	λ_m
A_1	ξ_{11}	ξ_{12}	…	ξ_{1j}	…	ξ_{1m}
A_2	ξ_{21}	ξ_{22}	…	ξ_{2j}	…	ξ_{2m}
…	…	…	…	…	…	…
A_i	ξ_{i1}	ξ_{i2}	…	ξ_{ij}	…	ξ_{im}
…	…	…	…	…	…	…
A_n	ξ_{n1}	ξ_{n2}	…	ξ_{nj}	…	ξ_{nm}

The outcomes of neural network are (3):

$$\overline{R} = f(\overline{net} - \overline{\xi}), \qquad (3)$$

where f – is a non-linear function (active function) that takes into account the time of decision making t_i; $\overline{net}$ – is a weighted sum of inputs.

The optimal solution is found by the criterion of an expected value with the Savage criterion (4):

$$A_{opt} = min\,max\{R\} = min\,max\left\{t_i(\sum_{i=1}^{n} p_i u_i - \xi_k)\right\}. \quad (4)$$

The critical time of the flight crew actions in case of an engine failure on take-off and approach to land in the bad weather conditions was obtained [10]. The selection in the direction of the negative pole leads to the maximum expected risk R=1028. The choice in the direction of the positive pole when the ES occurs at the first stage of DM by H-O ANS (for example, a flight to alternative aerodrome) has a risk which is 60,5 times lesser: R=17.

In stochastic network 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 was developed [10, 11]. Thus according to results of stochastic network analysis of the flight situation development from normal to catastrophic the following values obtained: mathematical expectation of flight situation development time t_{ij} – $M[t_{ij}]$; the variance of flight situation development time t_{ij} – $\delta^2[t_{ij}]$; the probability of flight situation development p_{ij} – p_{ij}, p_{ji}, p_{ii}. Based on the *W*-functions of positive and negative of H-O choice the Markov's network of flight situations' development from normal to catastrophic was constructed [8].

In addition, with using reflexive model the risks R_A, R_B of DM 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 obtained [8]. The expected risk in the process of DM of H-O is equal (5):

$$R_{DM} = \begin{cases} R_A = min\{R_{ij}\} \\ R_B = \{\gamma, \rho\} \\ R_{AB} = \{X(x_1, x_2, x_3), \gamma, \rho\} \end{cases}, \quad (5)$$

where R_A – is an expected risk of the DM for H-O with taking into account the criterion of the expected value minimization; R_B – is an expected risk of the DM for H-O with taking into account his model of preferences; R_{ij} – is an expected risk for making A_{ij}-decision; γ – is a concept of a rational individual's behaviour; ρ – 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, if the pilot, the ATC and the society have a choice in the direction of the *negative pole B*, the preferences model can form the plane of the disaster *K* [8].

Methodology of research and training in ANS as STS has developed [14]. Let's consider the individual works of aviation students and post-graduate students in education (course "Basic of DM in ANS" in National Aviation University, Kyiv) after Master class of DM in ANS [15].

Research has shown that the choice of the optimal variant of the forced flight completion in emergencies requires from the operator to analyze the significant amount of diverse information. The following conceptual models of DSS in ANS have obtained, such as DSS for ATC in emergencies, for example "Aircraft Decompression", "Low oil pressure", "Engine failure", etc. [10, 11, 15]; DSS for flight dispatcher for support of the DM regarding aircraft landing in emergencies to choice alternative landing aerodrome [10, 11]; DSS for operator of Unmanned Aerial Vehicles (UAV) in emergencies situation, for example in losing of communication with UAV and choosing optimal landing place, etc. [16]. DSS contain common sets of components, such as data related components, algorithm related components, user interface and display related components. The user interface and the result of calculation of DM process by H-O (pilots, ATC, UAV's operators) under risk are presented in Fig. 4 [17]. With using this program operator can obtain optimal solution for such problem as landing in bad weather condition, ES in flights, etc.

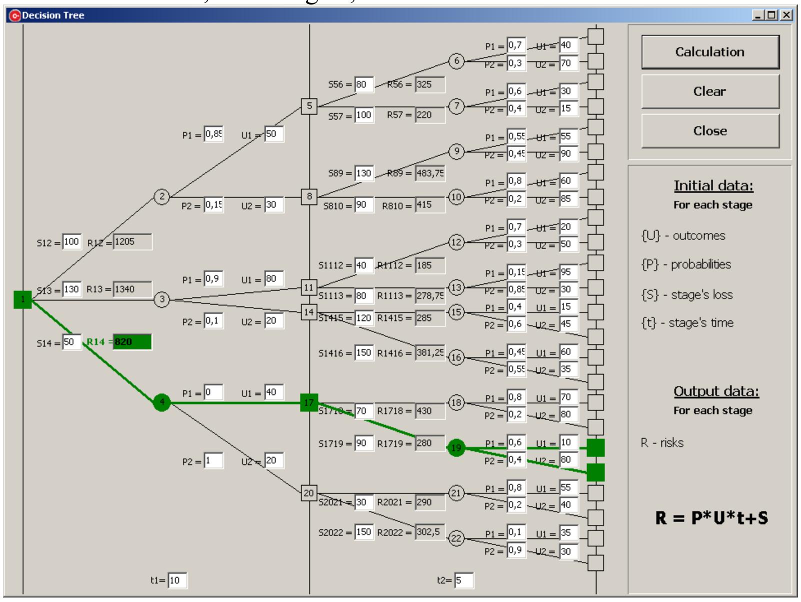


Fig. 4. The result of calculation of H-O DM process under risk.

3 Conclusion

The conceptual model of System for control and forecasting the ES development that taking into account the influence on DM process by ANS H-O of the professional factors (knowledge, habits, skills, experience) as well as the factors of non-professional nature (individual-psychological, psycho-physiological and socio-psychological) has presented. Deterministic and stochastic models for ANS H-O (pilot, controller) have obtained in accordance with the flight manual of aircraft or the adopted technologies of ATC work ASSIST. With using neural network model, the values of probabilities of ES development have received. The optimal solution has found by the criterion of an expected risk minimization.

Further research should be directed to solution of the complex practical tasks of improving the operator's actions in different cases of emergencies, to creation the software for these problems. Models of ES development and of DM by UAV's in ES will allow predicting the H-O's actions with the aid of the informational-analytic and diagnostics complex for research H-O behavior in extreme situation.

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