UDC 656.7.086 (45)
DOI: 10.18372/2306-1472.1.13652

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NETWORK ANALYSIS OF COLLABORATIVE DECISION MAKING BY AIR NAVIGATION SYSTEM'S HUMAN-OPERATORS DURING EMERGENCY CASES IN FLIGHT

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Abstract

Purpose: *research of pilot and air traffic controller (ATC) collaborative decision making during emergency case in flight (for example, in case of one engine failure and other engine fires from one side during take-off on multiengine aircraft) for maximum synchronization of operators' technological procedures.* ***Methods:*** *deterministic models of joint decision-making by the air navigation system operators are obtained by network planning methods; their adequacy is confirmed by full-scale modeling on a complex flight simulator. The probabilities of the emergency case development in flight are estimated using the neural network model. For the sequential optimization of the collaborative two-channel network "pilot-air traffic controller" in order to achieve the end-to-end effectiveness of joint solutions, a multi-criteria approach was used: ensuring the minimum time to parry emergency case in flight with maximum safety / maximum consistency over the time of operator actions.* ***Results:*** *synchronized operational procedures of air navigation system operators during emergency cases in flight with the optimal sequence of actions and the minimum time to complete the flight. A conceptual model of the system has been developed for managing and forecasting the development of emergency cases in flight based on deterministic and stochastic models of decision making by the air navigation system human operator, taking into account the influence of factors of a professional and non-professional nature.* ***Discussion:*** *the proposed models will complement the database of flight scenarios development in the decision support system and can be used in the air navigation system operators' joint simulator training process and in the real conditions of aircraft exploitation.*

Keywords: dual channel network; multi-criteria approach; optimal interaction; network graph; synchronization; joint decision-making; decision support system; structured-time table; incident scenario

1. Introduction

Despite the improvements in aircrafts control systems and air traffic control systems, the Human Factor still has a significant impact on flight safety – nearly 80% of aviation events are due to the fault of people [1]. The theory of human factor is gradually developing, tested and institutionalized. The evolution of the aviation system in the direction of a complex socio-technical system with gradual changes and additions to the well-known model of the human factor SHEL (1972) to date is given in [2-7].

The authors distinguish five stages of the evolution of Human Factor models in aviation, related to the emergence of new components of the aviation system and to improve the diagnosis of Air Navigation System's (ANS's) human-operators (H-O) errors:

Stage 1: Professional Skills / Interaction / Errors.

Stage 2: Cooperation in team / Interaction in Team / Error Detection.

Stage 3: Culture / Safety / Errors Prevention.

Stage 4: Safety Management / Safety Balance Models / Minimization of Errors.

Stage 5: Collaborative (Joint) Decision-Making (DM)/Data for DM.

For today, the key to ensuring the safety of flights is the problem of the organization of collaborative decision-making (CDM) by all the operational partners – airports, air traffic control services, airlines and ground operators – on the basis of general information on the flight process and ground handling of the aircraft in the airport [6].

The Global Operating Concept for Air Traffic Management (ATM) [8] provides for the provision of a joint (pilot – air traffic controller (ATC)) DM air traffic control unit based on a dialogue between them and real-time information evaluation at all stages of the flight.

The lives of air passengers in the sky and people on the ground depend on the adequate interaction between the pilot and ATC. According to the statistics of the Aviation Safety Network (ASN) [9], during the second half of the 20th century due to problems in interaction pilot – ATC (language barrier, communicating problems, ATC's interference in the flight crew, wrong ATC instructions/commands, etc.) killed about 2 000 people in aviation accidents.

Coherent, clear interaction between pilot and ATC is most important in emergency cases (EC) in flight, which are characterized by a sharp shortage of time in the DM in conditions of incompleteness and uncertainty of information, as well as significant psychophysiological load on the flight crew (FC). The final decision on the order of the flight in the emergency case is taken by the captain of the aircraft (Capt.), which is fully responsible for the decision.

The ATC is responsible for the correctness and timeliness of the information and advice that given to flight crew, so the ATC in such situations is also given a significant role [10, 11].

The main requirement for the ATC when an emergency case arises is the constant readiness to provide the necessary assistance to the flight crew, depending on the type of situation, taking into account the air situation and meteorological conditions. One of the factors that greatly complicate the interaction between pilot and ATC is the inadequate knowledge of the flight crew procedures performed in emergency case [12].

The technology of flight crew and ATC procedures in the emergency case must be in line with the definition of the algorithm prescribed in the normative and regulatory documents, therefore, for the formalization of the actions of the H-O in EC, it is possible to apply determined models [13, 14]. Since EC is a time-consuming event, when it comes to modeling a collaborative DM pilot and ATC, it is advisable to use network graphs depending on the algorithm of action in EC, which reflects the technological dependence and consistency of operational procedures of operators, ensure their achievement in time, taking into account the cost of resources and the cost of work with the allocation at the same time critical places.

Thus, the problem of optimizing the interaction between pilot and ATC in EC can be solved by the way of development and synchronization (maximal alignment over time) of deterministic models of H-O collaborative DM, which will minimize the critical time needed to solve EC, by definition the optimal sequence of execution of technological procedures.

2. Analysis of the latest research and publications

In 1979, KLM developed the first flight training program for effective methods of interaction and information exchange, known as Cockpit Resource Management (CRM) [15, 16]. Gradually the emphasis was shifted, the decoding of the first letter "C" into the abbreviation changed three times - from Cockpit (cabin) to Crew (crew), and finally - when the concept "crew" consisted of consecutive cabin attendants, ATC's, technical and managerial personnel, and eventually all the airline - "C" became known as Company, and the name of the discipline – "Company resource management". From that time, the awareness of security became a systemic quality, corporate culture [5].

Optimization of the flight crew and ATC interactions as small groups [17, 18] is based on the socionics and sociometrics methods [19, 20].

ATM's global operational concept presents the ICAO vision for an integrated, harmonized and globally interoperable ATM system. Its goal is to move towards the implementation of holistic, cooperative and joint decision-making processes, in which the expectations of the entities of the ATM system will be balanced and aimed at achieving optimal results on the basis of equality and ensuring the access of all participants [8].

The introduction of new technological solutions, in particular, CDM (Collaborative Decision Making), requires the use of a modern information environment based on the concept of system-wide information management (SWIM) and the concept of information on air and traffic flows for the joint use of air Space (FF-ICE - Flight & Flow Information for a Collaborative Environment) [6, 7].

As part of the implementation of the Global Air Navigation Plan [21], ICAO is working on a step-by-step improvement of the civil aviation system, and now the development of "network center systems" (the SWIM concept) has begun, as the current way of data-sharing "point-to-point" has ceased to keep pace with the increase in airspace transport and be effective. SWIM is a kind of internet for aviation: the network is based on providing information when interacting with different aviation systems.

The concept of FF-ICE is limited to the exchange of information about the flight between the subjects of the ATM system [7]. It begins with the timely submission by the user of the airspace of flight information to the ATM system and ends with the archiving of relevant information after the flight. FF-ICE supports all components of the ATM operational concept requiring flight information: Demand and Capacity Balancing (DCB), Conflict Management (CM), Service Delivery Management (SDM), Airspace Organization and Management (AOM), Aerodrome Operations (AO), Traffic Synchronization (TS), Airspace User Operations (AUO), and clarifies the Global ATM operational concept for flight information management. It creates the necessary foundation for the most up-to-date ATM systems and develops a 4D-trajectory management mechanism.

Collaborative decision-making (CDM) involves an uninterrupted process of presenting information and individual DM to different interacting parties, as well as ensuring the synchronization of decisions taken by participants and the exchange of information between them. It is important to ensure the possibility of adopting a joint, integrated solution at an acceptable level of efficiency. One possible approach is the preliminary joint development of procedures to be applied in emergency cases [6]. This requires the creation of a database of models of possible scenarios of the flight situations development, based on models of the joint pilot and ATC DM in emergency cases.

In works [13; 14] is presented using the methods of network planning of the deterministic models of DM by the ANS's H-O (pilot, ATC) in the conditions of normalized algorithms of professional activity with deterministic and probabilistic time for the implementation of technological procedures. The authors outline the critical course and time for the pilot and ATC (separate) operations in emergency cases and the main stages of the DM according to the crew's operating manuals, flight guidance for different types of aircraft, ASSIST guidance (Acknowledge, Separate, Silence, Inform, Support, Time) for "Typical Air Traffic Controller Checklist in Emergency Cases" [22-24], issues related to the synchronization of Pilot Flying (a pilot that performs piloting operations) and Pilot Monitoring (pilot performing communication functions) procedures under cross-monitoring in emergency case [25-26], but a problem of CDM by pilot and ATC in emergency case has not been investigated.

3. Research tasks

The research tasks are:

- conducting a detailed analysis of CDM by pilot and ATC in an emergency case (for example, the failure of one engine and other engine fires on the one side during take-off on a multi-engine aircraft) with network planning methods;
- synchronization of ANS's H-O procedures with an optimal sequence of actions and minimum flight completion time;
- working-out the decision support system (DSS) for ANS's H-O in the emergency cases in flight.

4. The deterministic model of collaborative decision making by Air Navigation System's human-operators during emergency cases in flight

One of the DM methods recommended by aviation guidance in the emergency case is FADEC [27].

Fly the aircraft: Remember the limitations for the aircraft and, if conditions permit, use all available automatic systems, such as autopilot.

Assess the situation (risk & time): Spending more time to assess a situation can lead to a better result. Try to avoid instant / quick decisions if the time is not too limited.

Decide on a workable option and refer to abnormal or emergency checklist: Situation in which the "human resources-equipment-software" system, that is, the natural environment, will have to operate.

Evaluate: Continue to evaluate the situation and actions as the situation develops (feedback lines).

Communicate: Keep in touch with air traffic control authorities to make joint decisions, as well as with other personnel as needed.

The parallel process of simultaneous execution of pilot and ATC technological operations in the emergency case can be represented as a consolidated dual-channel network. For a consistent optimization of such a network in order to achieve the cross-cutting efficacy of joint decisions, it is advisable to use a multi-criteria approach: achieving a minimum time for parity of emergency case with maximum safety / maximum harmonization over the time of H-O actions.

Ways to optimize the network graph for performing procedures by the H-O in the emergency case (by minimizing time with maximum safety) are:

1. Time optimization – by regulating the use of resources minimizing the time of execution of critical paths t_i^k (1):

$$t_i^{k-1} < t_i^k < t_i^{k+1}, \quad (1)$$

where $t_i^{k-1} = max\,min\ t_i^k$ – is a minimum time with maximum safety;

$t_i^{k+1} = min\ max\ t_i^k$ – is a critical time of the maximum (critical) path;

t_i^k – optimal (minimum) time.

2. Changing the topology of the network due to the multi-varied technology implementation procedures.

3. Introduction of parallel execution of procedures with maximum agreement on time (minimum time for two or more charts), that is, obtaining the optimal consolidated time for the execution of procedures t_j^k (2):

$$t_j^{k-1} < t_j^k < t_j^{k+1} \quad , \quad (2)$$

where $t_j^{k-1} = max\,min\ t_j^k$ – is a minimum time with maximum time matching;

$t_j^{k+1} = min\ max\ t_j^k$ – is a critical time of the maximum (critical) path;

t_j^k – optimal (minimum) time.

To investigate the interaction between the flight crew and ATC in the emergency case, consider the incident on November 28, 2010, with the aircraft IL-76TD of the Georgian private airline Sun Ways Airlines, which performed a flight from Karachi to Khartum (Pakistan) with a cargo weighing 31 tons [28]. Immediately after take-off, engine number four failed, then engine number three was on fire. The flame of the engine was noticed from the ground, about which the ATC informed captain. The flight crew tried to make an emergency landing.

At 1:48 local time (UTC + 5), four minutes after the take-off, the aircraft fell to the open ground (6 km from the end of the runway). All flight crew members (seven Ukrainians and Russians) and four men on the ground died. During the accident investigation, it was discovered that at the time of the aircraft fall, two of the four engines did not work.

On the flight simulator KTS-32 (aircraft IL-76TD), the simulation of the flight crew and ATC procedures was carried out in case of one engine failure and other engine fires on the one side during the take-off. Two possible scenarios for the development of events were investigated, when the captain decides to land at the departure airport with direct or reverse heading. Different meteorological conditions were created, the weight of the load and the centering of the aircraft changed, airport charges, and so on.

Based on the results obtained on the simulator KTS-32, a deterministic model of the flight crew and ATC procedures was developed in case of one engine failure and other engine fires on the one side during the take-off. In Table 1 is shown the structure-time table for the execution of flight crew and ATC procedures in case of one engine failure and other engine fires on the one side during the take-off.

The time required to perform procedures aimed at paring emergency case was measured during the Ukraine flight crews and ATC's simulator training, Ukraine Air Force pilots and ATC's simulator training and several foreign airlines flight crews' simulator training.

With network planning, flight crew and ATC procedures were synchronized, resulting in a determined action time by the operators at the stages of parity emergency case, namely:

Stage I – engine failure;

Stage II – another engine fire on one side;

Stage III – approach;

Stage IV – emergency landing.

The obtained data are statistically processed, their statistical characteristics are within the permissible limits: the standard deviation does not exceed 0,5 sec; the coefficient of variation does not exceed 19%. Therefore, the average results can be considered reliable. It was also evaluated the competence of experts who participated in the study, with analysis of their professional activities, open-mindedness, and general erudition; the coefficient of competence is received.

Table 1

The structured-time table for the execution of flight crew and ATC procedures in case of one engine failure and other engine fires on the one side during take-off

Stage	Procedure	Flight crew procedure description	Relies on procedure	Execution time, *t*, sec	Procedure	ATC procedure description	Relies on procedure	Execution time, *t*, sec
I	a_1	Flight engineer (FE) find engine failure	-	2	-	-	-	-
	a_2	FE report Capt. about engine failure	a_1	2				
	a_3	Capt. give FE order to shut down the engine, radio-operator (RO) order to switch off the generator	a_2	4				
	a_4	Capt. give RO order to report ATC about engine failure	a_3	2	b_1	Receive from Capt. report about the engine failure	-	5
	a_5	Capt. give FE order to retract landing gear at height 5m.	a_4	2				
	a_6	Capt. reduce the rate of climb, continue taking off	a_5	4				
II	a_7	Voice annunciator «Fire», red lamp «Fire» on	a_6	2	b_2	Receive from Capt. report about the engine fire	b_1	8
	a_8	FE check engine fire, report Capt.	a_7	3				
	a_9	Capt. give RO order to report ATC about the engine fire	a_8	3				
	a_{10}	Capt. set horizontal flight for increase airspeed	a_9	30				
	a_{11}	At height 120 m. and speed for flaps Capt. give FE order to retract flaps	a_{10}	4	b_3	Inform Capt. about external signs of failures, fixes the time	b_2	10
	a_{12}	At speed for slats Capt. give FE order to retract slats	a_{11}	5	b_4	Check Capt. setting emergency squawk 7700	b_3	5
	a_{13}	FE report Capt. flaps and slats retracted	a_{12}	15	b_5	Report supervisor about emergency case	b_4	5
	a_{14}	Capt. set emergency squawk 7700	a_{13}	4	b_6	Provide clear air space in close proximity to aircraft	b_5	15
	a_{15}	Capt. give FE order to shut down the engine, close fuel valve, switch on fire extinguisher	a_{14}	8	b_7	If necessary set radio silence	b_6	4

Stage	Procedure	Flight crew procedure description	Relies on procedure	Execution time, *t*, sec	Procedure	ATC procedure description	Relies on procedure	Execution time, *t*, sec
	a_{16}	FE check fire, switch on second and third bottle fire extinguisher	a_{15}	30	b_8	Clarifies Capt. further intentions for landing at the departure aerodrome.	b_7	10
	a_{17}	FE report Capt. about fire extinguished or not	a_{16}	2	b_9	Facilitates the decision implementation	b_8	37
					b_{10}	Displays emergency board information	b_9	5
					b_{11}	Ask weather forecast	b_{10}	5
III	a_{18}	Capt. report ATC that they manage to extinguish the fire or not, the decision to land	a_{17}	10	b_{12}	Clarifies whether the engine fire was eliminated	b_{11}	10
					b_{13}	Provides extraordinary landing	b_{12}	4
	a_{19}	Capt. make an approach, give FE order to extend landing gear, flaps, and slats	a_{18}	77	b_{14}	Gives Capt. directions for approach, reports wind direction and speed	b_{13}	8
					b_{15}	Controls the aircraft movement, informs Capt. about the deviation from heading and the glide path	b_{14}	64
	a_{20}	Capt. give FE order to switch on hydraulic pump station on the failed engines	a_{19}	3	b_{16}	Passes the plane to the Tower ATC	b_{15}	4
IV	a_{21}	Capt. proceed landing	a_{20}	30	b_{17}	Clear runway according to local instructions	b_{16}	10
	a_{22}	After stopping on the runway, if fire not extinguished, Capt. turn aircraft direction to the wind	a_{21}	10	b_{18}	By supervisor order set on the readiness of rescue equipment	b_{17}	5

A network diagram (Fig. 1) of flight crew and ATC procedures in the emergency case (one engine failure and another engine fire on one side during take-off) allows to determine the critical time depending on the decision taken by the captain (to make a forced landing at the departure airport with direct or reverse heading), which makes $T_{crit\ dir}$ = 6 min. 02 sec and $T_{crit\ rev}$ = 4 min. 10 sec. Thus, depending on the conditions and circumstances in case of failures quickly perform aircraft landing with a reverse course. So, this is the best variant for completing the flight.

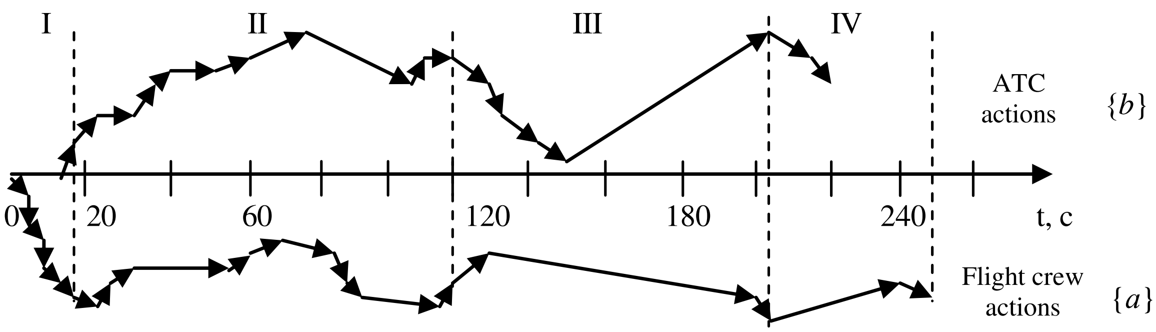


Fig. 1. Network graph of ATC and flight crew procedure in case of one engine failure and other fires from one side during take-off

In this context, the use of flight simulators during ATC professional training is relevant. They will help ATC's to get acquainted with the situation in the flight crew cabin and the parameters of the aircraft's devices during the emergency case. At the same time the ATC:

- will receive the experience of the crew members during the emergency case;
- will pay attention to how the intervention of the dispatcher can disrupt crew members;
- will complete exercises on the use of radio during the emergency case;
- will complete the checklist in the emergency case;
- will participate in captain decision making during the emergency case;
- will observe the features of the go-around procedure.

In the emergency case, ATC is advised to use a checklist that will help to handle incidents in order to establish optimal actions to achieve better cooperation between pilot and ATC. A supervisor who works with ATC, using a checklist, can provide better support as it will more clearly understand the ATC in the EC.

5. Building and development of the decision support system for Air Navigation System's human-operators in the emergency case

The conceptual model of System for control and forecasting the EC development that using DM models on the base of Artificial Intelligence System (AIS) / Decision Support System (DSS) was obtained (Fig. 2), 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 the corporation as well as by interests of a family. At the same time, respondents – ATC pay special attention to the interests of their families, their own economic status and professional promotion [13, 29].

Deterministic and stochastic models for ANS's H-O (pilot, ATC) 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 EC.

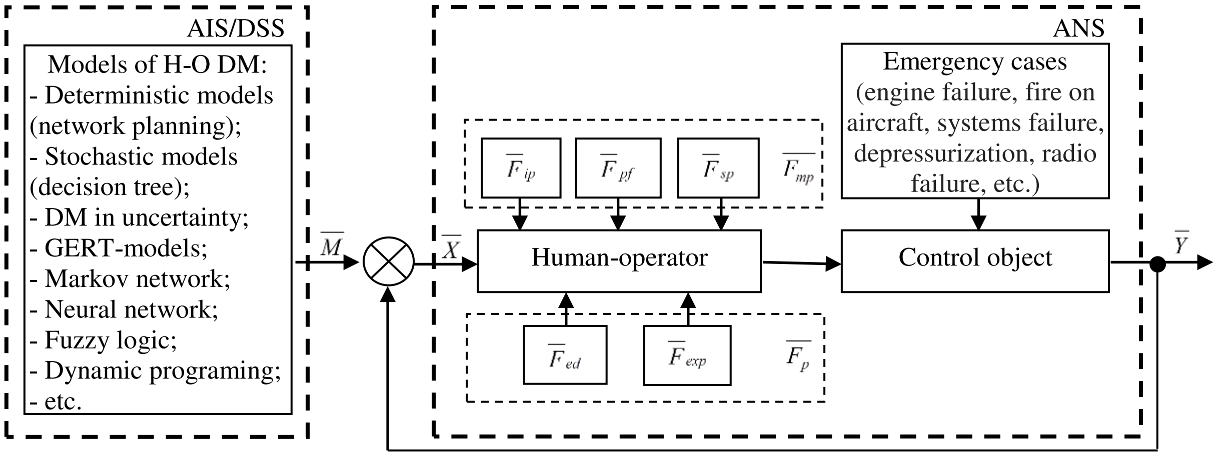
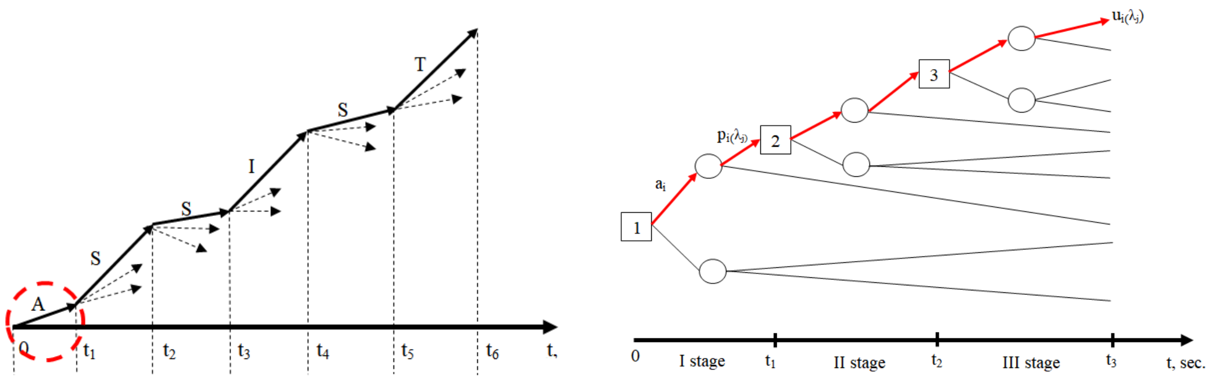


Fig. 2. The conceptual model of System for control and forecasting the EC development

Deterministic and stochastic models for ATC are presented in Fig. 3, 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; *{λ}* – is the set of the factors influencing DM.

With using neural network models, the values of probabilities (p_n) [13; 30], expected outcomes (r_k) and additional inputs – factors (ξ_k) (Fig. 4) of EC development were received.



a) b)

Fig. 3. Models of ANS's H-O DM: a) deterministic model; b) stochastic model

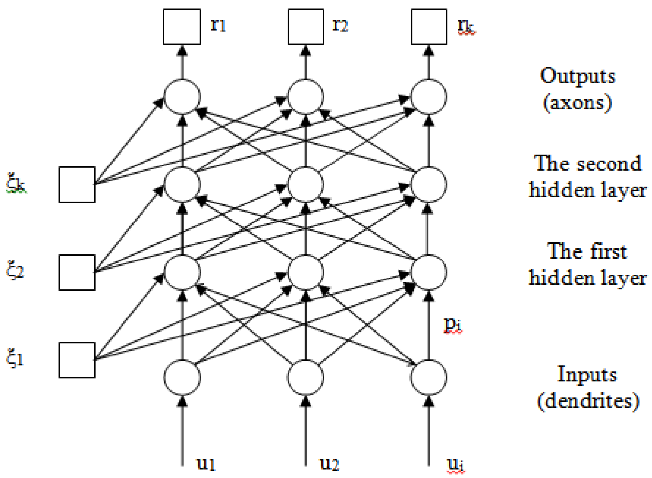


Fig. 4. The neural network model of EC development with additional inputs of influencing DM factors

The network has additional inputs, called the Bias (offset) that takes into account additional restrictions on calculating parameters (3):

$$\sum_{i=1}^{n} p_i u_i - \xi_k \ge 0 \quad (3)$$

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 2).

Table 2

The matrix of Bias identification

Alternative decisions	Factors that influencing on the ANS's H-O DM					
	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 the neural network are (4):

$$\overline{R} = f(\overline{net} - \overline{\xi}), \quad (4)$$

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 (5):

$$A_{opt} = min\,max\{R\} = = min\,max\left\{ t_i (\sum_{i=1}^{n} p_i u_i - \xi_k) \right\}. \quad (5)$$

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 [13]. 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 EC 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 the 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 [13; 14]. Thus according to results of stochastic network analysis of the flight situation development from normal to catastrophic the following values obtained: the 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 [13; 14].

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 [13; 14]. The expected risk in the process of DM of H-O is equal (6):

$$R_{DM} = \begin{cases} R_A = min\{R_{ij}\} \\ R_B = \{\gamma, \rho\} \\ R_{AB} = \{X(x_1, x_2, x_3), \gamma, \rho\} \end{cases}, \quad (6)$$

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 behavior;

ρ – is a system of an individual's preferences in a concrete situation of the choice;

R_{AB} – is a mixed choice made by the 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 [13; 14].

The methodology of research and training in ANS as STS has developed [31]. 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.

Research has shown that the choice of the optimal variant of the forced flight completion in emergencies requires 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.; DSS for flight dispatcher for support of the DM regarding aircraft landing in emergencies to choice alternative landing aerodrome; 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. [13; 31]. 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 the calculation of the DM process by H-O (pilots, ATC, UAV's operators) under risk are presented in Fig. 5 [32]. With using this program operator can obtain an optimal solution for such problem as landing in bad weather condition, EC in flights, etc.

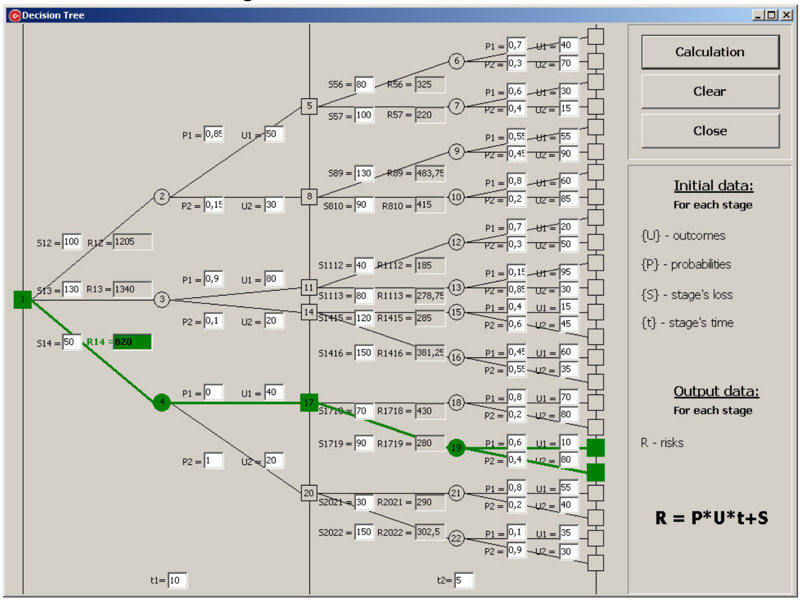


Fig. 5. The result of the calculation of ANS's H-O DM process under risk

6. Conclusions

With the help of network planning the procedures of ATC and flight crew in case of one engine failure and other fires from one side during take-off with the optimal sequence of actions and the minimum completion time of the flight, which is 4 min. 10 sec with forced landing with a reverse heading, were synchronized. The deterministic models of the collaborative decision making by pilot and ATC for performing operational procedures by the H-O in the EC were obtained.

The conceptual model of System for control and forecasting the EC development that taking into account the influence on DM process by ANS's 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) was presented. Deterministic and stochastic models for ANS's H-O (pilot, ATC) were obtained in accordance with the flight manual of aircraft or the adopted technologies of ATC work ASSIST. With using the neural network model, the values of probabilities of EC development were received. The optimal solution was found by the criterion of expected risk minimization.

The direction of further research is the development of deterministic and non-deterministic network models of collaborative decision-making by ANS's H-O with probabilistic time for the implementation of technological procedures and identification of appropriate risks.

The developed deterministic models will allow supplementing the database of flight scenarios development in the decision support system of the pilot / ATC in the emergency case for optimization of collaborative decision making and can be used in the future both in the ANS's H-O training process and in real conditions. The operation of the aircraft is based on the use of SWIM and FF-ICE concepts.

Designing and calculating scenarios of the development of flight situations, forecasting possible actions of H-O in EC will allow preventing the negative development of the emergency situation toward the catastrophic in a timely manner.

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Мережевий аналіз спільного прийняття рішень операторами аеронавігаційної системи в особливих випадках в польоті

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Мета: *дослідження консолідованого прийняття рішень пілотом та авіадиспетчером у разі виникнення особливого випадку в польоті (на прикладі відмови одного двигуна та пожежі іншого з однієї сторони під час зльоту на багатомоторному повітряному кораблі) для максимальної синхронізації технологічних процедур операторів.* ***Методи:*** *детерміновані моделі спільного прийняття рішень операторами аеронавігаційної системи отримані методами мережевого планування, їх адекватність підтверджена натурним моделюванням на комплексному авіаційному тренажері. Ймовірність розвитку особливого випадку в польоті оцінені за допомогою нейромережевої моделі. Для послідовної оптимізації консолідованої двоканальної мережі «пілот-авіадиспетчер» з метою досягнення наскрізної ефективності спільних рішень використаний мультикритеріальній підхід: досягнення мінімального часу на парирування особливого випадку в польоті при максимальній безпеці/максимальному узгодженні за часом дій операторів.* ***Результати:*** *синхронізовані операційні процедури операторів аеронавігаційної системи в особливих випадках в польоті з оптимальною послідовністю дій і мінімальним часом завершення польоту. Розроблена концептуальна модель системи для управління та прогнозування розвитку особливих випадків в польоті на основі детермінованих та стохастичних моделей прийняття рішень людиною-оператором аеронавігаційної системи,враховуючи вплив факторів професійного та непрофесійного характеру.* ***Обговорення:*** *запропоновані моделі доповнять базу даних розвитку сценаріїв польотних ситуацій в системі підтримки прийняття рішень і можуть бути використані в процесі спільної тренажерної підготовки операторів аеронавігаційної системи і в реальних умовах експлуатації повітряного корабля.*

Ключові слова: двоканальна мережа; мультикритеріальний підхід; оптимальна взаємодія; мережевий графік; синхронізація; спільне прийняття рішень; система підготовки прийняття рішення; структурно-часова таблиця; сценарій розвитку події

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Сетевой анализ совместного принятия решений операторами аэронавигационной системы в особых случаях в полете

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Цель: *исследование консолидированного принятия решений пилотом и авиадиспетчером при возникновении особого случая в полете (на примере отказа одного двигателя и пожара другого с одной стороны во время взлета на многомоторном воздушном корабле) для максимальной синхронизации технологических процедур операторов.* ***Методы:*** *детерминированные модели* *совместного принятия решений операторами аэронавигационной системы получены методами сетевого планирования, их адекватность подтверждена натурным моделированием на комплексном авиационном тренажере. Вероятности развития особого случая в полете оценены с помощью нейросетевой модели. Для последовательной оптимизации консолидированной двухканальной сети «пилот-авиадиспетчер» с целью достижения сквозной эффективности совместных решений использован мультикритериальный подход: обеспечение минимального времени на парирование особого случая в полете при максимальной безопасности/максимальной согласованности по времени действий операторов.* ***Результаты:*** *синхронизированы операционные процедуры операторов аэронавигационной системы в особых случаях в полете с оптимальной последовательностью действий и минимальным временем завершения полета. Разработана концептуальная модель системы для управления и прогнозирования развития особых случаев в полете на основе детерминированных и стохастических моделей принятия решений человеком-оператором аэронавигационной системы, учитывающая влияние факторов профессионального и непрофессионального характера.* ***Обсуждение:*** *предложенные модели позволят дополнить базу данных развития сценариев полетных ситуаций в системе поддержки принятия решений и могут быть использованы в процессе совместной тренажерной подготовки операторов аэронавигационной системы и в реальных условиях эксплуатации воздушного корабля.*

Ключевые слова: двухканальная сеть; мультикритериальный подход; оптимальное взаимодействие; сетевой график; синхронизация; совместное принятие решения; система поддержки принятия решений; структурно-временная таблица; сценарий развития события

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