Collective Models of the Aviation Human-Operators in Emergency for Intelligent Decision Support System

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Abstract

The steps to create the Intelligent Decision Support System for the Air Navigation System's human-operators in an emergency are presented. A scheme of the intelligent control module of the Intelligent Decision Support System for the Air Navigation System's human-operators in an emergency, which is based on Hybrid Intelligence, is worked-out. The static, dynamic, and expert input data required by Intelligent Decision Support System for the Air Navigation System's human-operators in an emergency are determined. An Artificial Neural Network model for collaborative decision-making by the Air Navigation System's human-operators in an emergency is designed.

The order of the collaborative decision-making by the varied aviation collaborators for selecting the most appropriate landing airdrome in an emergency during the aircraft flight in the integrated airspace is developed. The examples of the individual and collective models of decision-making by the pilot, air traffic controller, and Unmanned Aerial Vehicle operator in the emergency "Engine failure during takeoff due to bird strike" in the conditions of segregated airspace based on the methods of decision-making under uncertainty are presented.

Keywords

Artificial intelligence, collaborators, decision-making, hybrid intelligence, intelligent control, natural intelligence, neural network, uncertainty

1. Introduction

Aircraft and trains are considered the safest means of transportation. By looking at the statistics of accidents on different modes of transport, we can see that it is much easier to get into an accident on a bus than to become a victim of an accident in the air. Most of the crashes are due to an oversight by the authorities (terrorist attack) or a mistake by the pilot and technical services [1].

Every day, about 10 thousand flights rise into the sky (3.65 million per year). Of the total annual air passenger traffic, about 1000 people are dying on average per year. The mortality rate over the past 50 years has decreased from a probability of 1:264 thousand to 1:127.5 million. During the entire existence of aviation (100 years), about 150 thousand people died [2].

Most crashes occur in the USA, Russia, and Canada (over 1300 as of 2018) due to an increase in passenger traffic (data before the COVID coronavirus pandemic). Currently, the optimistic dynamics of recovery: air traffic in 2021 reached almost 70% of the forecast year 2019 [2; 3]. Let's analyze the reasons for aviation accidents [2–8].

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Over the past 10 years, the first positions remain with the countries: Russia, the USA, Ukraine, Congo, and Germany. At the same time, the USA remains the leader in the number of victims. This is due to the increased freight and passenger traffic. A large number of accidents of private aircraft and helicopters, as well as small aeronautics, are recorded daily. Over the past 5 years, there have been no major air crashes in the USA. After the September 2001 terrorist attacks on two Boeings, the aircraft fell, but with the number of passengers not exceeding 50 people. A huge number of accidents are recorded in the military sphere on training missions or in the course of performing combat missions [4].

The greatest number of tragedies was recorded in the 70s of the XX century. Among them, a collision of two aircraft on 03/28/1977 near the island of Tenerife stands out, in which 583 people died.

In terms of the number of victims in the course of air accidents, a different picture emerges. The top three are the USA, Russia, and Colombia. Brazil, France, India, Indonesia, Canada, Great Britain, and Mexico continue the list. Some of the largest accidents are the crash of an Airbus A320 in the Java Sea (Indonesia) due to a thunderstorm, an Airbus A321 in the Sinai Peninsula (Egypt) as a result of a terrorist attack, and an Airbus A320 due to the suicide of a German pilot, as a result of which the aircraft crashed into the ridge of the Provencal Alps (France) [2].

Among the reasons for aviation accidents, in most cases, human factors are cited (more than 70%): the inexperience of the pilots or the inability to correct the situation. The second most common reason for accidents is technical malfunctions (18%). Common ones include gear failure, electronics and sensors failure, or engine failure (fire). The third in the list of reasons is the external environment (14%) [5–7].

In the PlaneCrashInfo database [8] the reasons for aviation accidents are divided into five groups: pilot errors, technical malfunctions, meteorological conditions, diversions, and other reasons. The examples of the reasons for aviation accidents are given in Table 1. The diagram of the distribution of the reasons for aviation accidents is presented in Figure 1.

Table 1
The reasons for aviation accidents

Pilot errors (49%)	Technical malfunctions (23%)	Meteorological conditions (10%)	Diversions (8%)	Other reasons (10%)
Violation of procedures VFR flight in IFR conditions Collision with the ground Hard landing Landing below the minimum Loss of orientation Premature descent Excessive landing speed Landing over the runway Fuel shortage Navigation errors Use of an incorrect runway for takeoff/landing Collisions in the air caused by a novice pilot	Engine failure Equipment failure Structural damage Design defects	Turbulence Mountain wave Poor visibility Heavy rain Strong wind Icing Thunderstorm Lightning strike Cumulonimbus clouds	Aircraft hijacking Wrecked aircraft Explosive device onboard Suicide of the pilot	Air traffic controller errors Ground service errors Overloading the aircraft Improper loading of the aircraft Collisions with birds Low fuel quality Incapacity of the pilot Obstacle on the runway Collision in the air caused by other aircraft Fire/smoke in flight (flight deck, cabin, cargo compartment) Maintenance errors

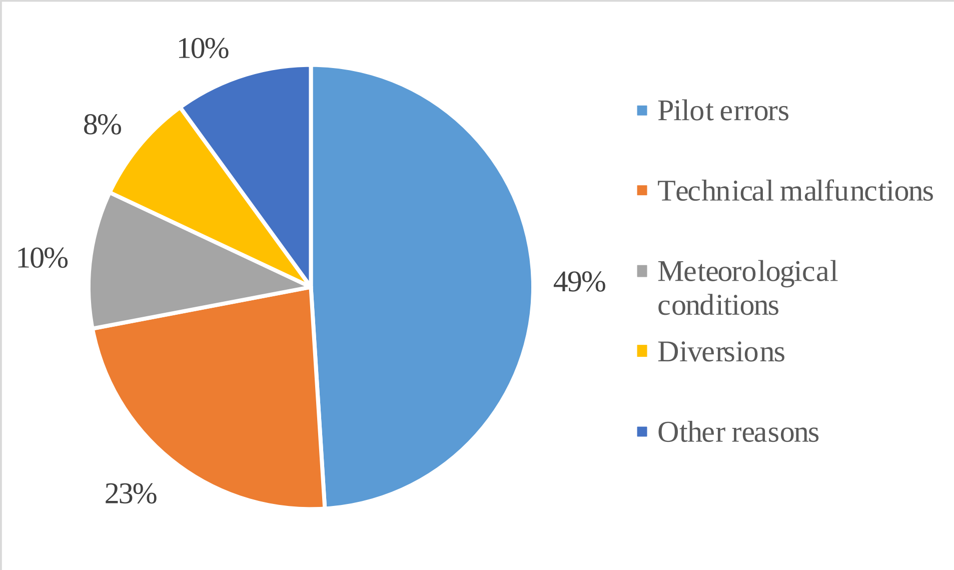

Figure 1: The diagram of the distribution of the reasons for aviation accidents

As can be seen from Figure 1, most aviation accidents happen because the human factors. To improve flight safety, it is necessary to create systems to support the human-operators of the Air Navigation System (ANS), especially for optimal decision-making in non-standard situations.

2. Analysis of the latest research and publications

In accordance with the requirements of the regulations of the International Civil Aviation Organization [9–14], a prerequisite for flight safety, especially in an emergency, is the effective interaction of all ANS human-operators. It is provided by organizing the collaborative decision-making (CDM) process for continuous presentation of information and individual decision-making by interacting participants, as well as providing consistency of actions and interchange of information between participators [15] based on the concepts of System Wide Information Management (SWIM) and Flight & Flow Information for a Collaborative Environment (FF-ICE) [16; 17].

As shown by the authors [18], CDM in an emergency requires the ANS human-operators to process large volumes of various data. To fully take into account all factors that affect the process of CDM in an emergency, an adaptive Intelligent System for Supporting Collaborative Decision Making (ISSCDM) is designed [19]. It embraces static, dynamic, and expert data on the status of the control subject – ANS human-operators (features of the pilot, remote pilot, air traffic controller, ground operator, flight dispatcher, engineer, etc.), control object (aircraft), and the ambient (features of the air situation, air traffic control zones, and airdromes).

ISSCDM exploits the models of CDM that are built using the objective-subjective method [20]. In addition, it is suggested to use Artificial Neural Networks (ANN) with Machine Learning (ML) and Big Data (BD) analyzing tools to solve similar tasks [21].

However, at present, there is a problem of control Artificial Intelligence (AI) solutions by human-operator, which necessitated the introduction of Hybrid Intelligence (HI) systems that use both human and machine competence [22].

The purpose of the article is working-out the collective models of the ANS human-operators in emergency for the Intelligent Decision Support System, which is based on Hybrid (Combined) Intelligence, that is, cooperation of Natural and Artificial Intelligence.

3. Scheme of the intelligent control module of the Intelligent Decision Support System for the Air Navigation System's human-operators in emergency

The effectiveness of ANS human-operators' decisions depends on the rational use of intelligent automation at all stages of aircraft flight in the form of the Intelligent Decision Support Systems (IDSS), flexible Cyberphysical Systems with Hybrid Intelligence, etc. [19-22]. Control of intellectualization processes and the development of appropriate intelligent systems depends on the availability of initial data on the quality of functioning of objects and subjects of ANS. The steps to create the IDSS for the ANS human-operators in an emergency are presented in Table 2.

Table 2
The steps to create the IDSS for the ANS human-operators in an emergency

Step	System	Models	Input data	Output data
I	Expert System – a demo version of the Intelligent System	Expert estimates, statistics	Expert estimates	Expert estimates, statistics
II	Decision Support Systems	Individual and collaborative decision-making models	Expert estimates, statistics	Expert estimates, statistics, optimal solutions (individual and collaborative decision-making)
III	Artificial Intelligence Systems (without training)	Artificial Neural Network of decision making	Expert estimates, statistics, optimal solutions	The results of Artificial Neural Network solutions, Big Data
IV	Artificial Intelligence Systems with Machine Learning	Artificial Neural Network Machine Learning	Expert estimates, statistics, optimal solutions, Big Data	Big Data, decision-making, and forecasting of the situation
V	Artificial intelligence Systems with self-learning (Deep Learning)	Deep Learning Artificial Neural Network	Big Data	Big Data, situation identification, decision-making, and forecasting of the situation
VI	Intelligent systems, flexible Cyberphysical Systems with hybrid intelligence	Models of decision-making by the subjects of the situation (natural and artificial intelligence)	Expert estimates, statistics, optimal solutions, Big Data, Analytical Data	Optimal/rational data, situation development control, data of decision-making by Artificial and Natural Intelligence

A scheme of the intelligent control module of IDSS for the ANS human-operators in an emergency, which is based on hybrid (combined) intelligence, is worked-out (Figure 2).

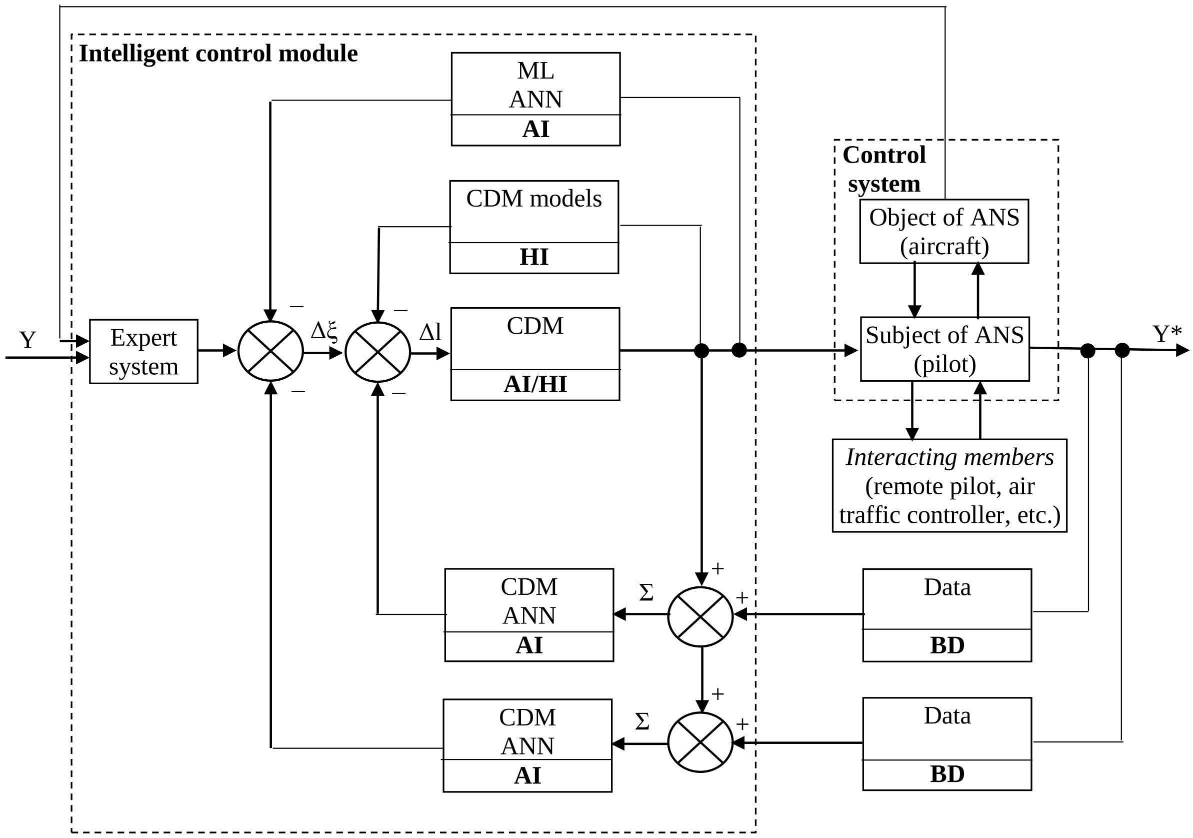

Figure 2: A scheme of the intelligent control module of IDSS for the ANS human-operators in an emergency: AI – Artificial Intelligence; ANN – Artificial Neural Network; ANS – Air Navigation System; BD – Big Data; CDM – Collaborative Decision-Making; HI – Hybrid Intelligence; ML – Machine Learning

So, the intelligent control module of IDSS allows the ANS human-operators to control decision-making by the AI in an emergency.

4. Input data of the Intelligent Decision Support System for the Air Navigation System's human-operators in an emergency

The input data required for the formation of decisions by the IDSS are divided into three groups: static, dynamic, and expert:

1. Static data on aircraft, control zones/airdromes, and ANS human-operators:

- Flight plan (planned data on the aircraft: aircraft identification index; flight rules and type of flight; aircraft type and turbulence category; aircraft equipment; airdrome of departure; estimated departure time; aircraft minima; cruising speed; flight level; flight route; airdrome of arrival and arrival time; reserved airdromes; fuel reserve; the total quantity of people onboard; rescue equipment, etc.);
- Flight Operations Manual (flight-technical characteristics of the aircraft: aerodynamic quality; normal and maximum takeoff mass of aircraft; quantity and type of engines; maximum and cruising horizontal speed; vertical speed; flight distance; practical flight ceiling; required runway length; quantity of crew members, etc.);
- Aeronautical Information Publication (AIP) (scheme of flight routes and location of navigation aids; boarders of control reception-transfer; air navigation and airport charges; coordinates of airdromes; the height of airdromes; minimum of airdromes; schemes of approach to landing at airdromes; quantity and type of runways at airdromes; length of the runway; landing angle of the runway; the slope of the runway; lighting, air navigation, and rescue equipment of the

airdromes; availability of engineering, handling, customs, migration, and border control services at the airdromes, etc.);

- Diplomas of education, certificates of advanced training and internships, employment records, professional and psychological testing, interviews, questionnaires of human-operators (level of education; experience of work in the specialty; class of specialist; flight crew minima; experience of actions in an emergency; individual-psychological, psychophysiological, and socio-psychological features).

2. Dynamic data on aircraft, control zones/airdromes, and ANS human-operators:

- Radar surveillance, radio communication (aircraft monitoring data: flight situation type; aircraft state; aircraft height; coordinates of the aircraft; aircraft flight course; actual landing mass of the aircraft);
- Radar surveillance, radio communication, NOtice To Air Missions (NOTAM) (air situation; Unmanned Aerial Vehicles (UAV) flights; prohibitions/restrictions on the airspace use; meteorological conditions on the route and at the airdromes; state of the runway; state of lighting and navigation equipment; readiness of emergency services at the airdromes);
- Flight plan (composition of aircraft crew; composition of the controller team).

3. Expert data:

- Aviation experts (the results of the aviation experts' estimation (the values of the parameters of decision-making models) and the rules for using this data).

Therefore, it is necessary to create two types of databases. The first type of database is a stationary source of data (planned information on the flight, technical features of the aircraft; characteristics of the control zones/airdromes) – they are created before the start of the IDSS; the second group – is a dynamic source of data (monitoring data on aircraft; technical information on the control zones/airdromes; meteorological information on the control zones/airdromes) – databases, which are quickly built by the system when processing dynamic information. Expert data are stored in the knowledge base. Models – the scenarios of individual and collective decision-making by ANS human-operators in the emergency – are in the database of models. The content of data and knowledge bases is adjusted based on factual information.

The variety of data types for making decisions in an emergency requires a new approach to measuring potential subsequences. Machine Learning and, when enough data accumulates, Deep Learning, based on ANN, are proposed. The ANN benefits are training ability on the examples, real-time operation, determinism, and robustness [19], which determines the choice of the ANN for CDM by ANS operators in an emergency.

The structure of the intelligent data processing for CDM by ANS operators in an emergency is given in Figure 3.

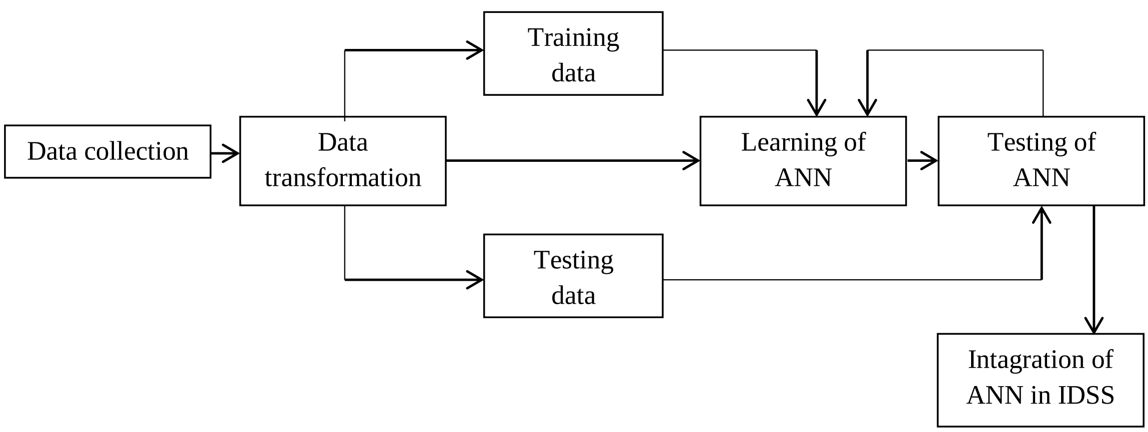

Figure 3: The structure of the intelligent data processing for CDM by the ANS human-operators in an emergency based on ANN

In the case of Machine Learning, normalization is a procedure for pre-processing input data (training, testing, and validation samples, as well as real data), in which the values of the characteristics in the input vector are reduced to a certain range, for example, [0 … 1] or [-1 … 1] [21]. The expert estimates are received based on the Expert Judgment Method (EJM) [23].

5. Artificial Neural Network for the collaborative decision-making by the Air Navigation System's human-operators in an emergency

For CDM by the ANS human-operators in an emergency, a multilayer recurrent ANN with biases is developed (Figure 4). It can approximate any functional dependence due to the hidden neuron layers and is capable of learning. The dynamism of recurrent ANN is a very important property for a complex socio-technical ANS, as feedback changes the inputs of neurons, which leads to changes in the state of ANN.

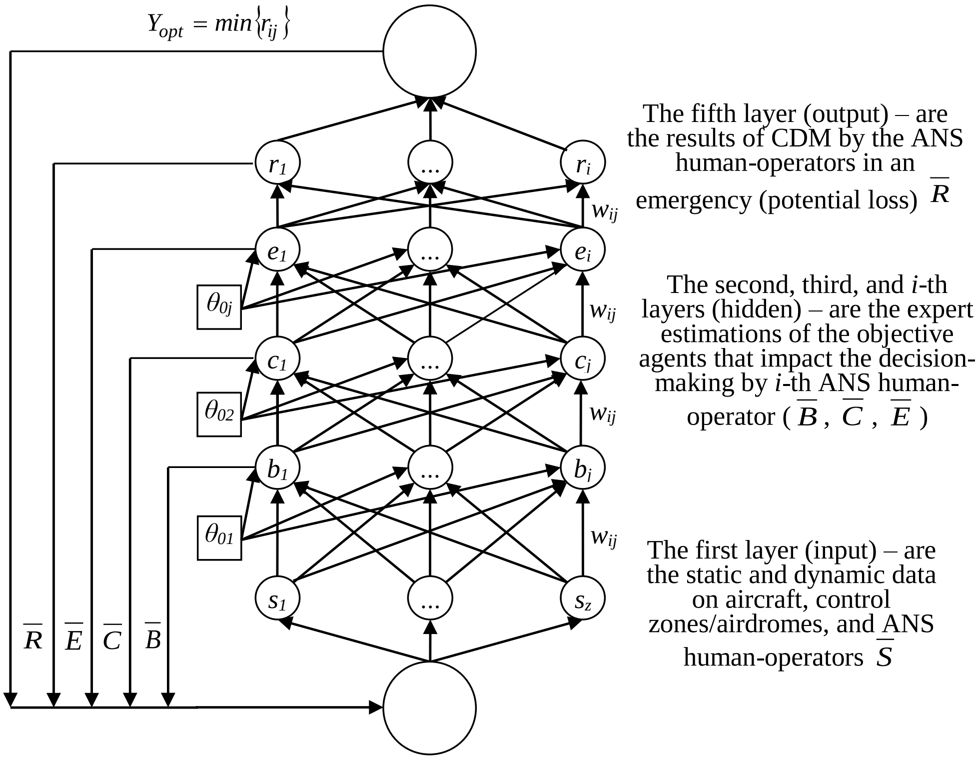

Figure 4: ANN model for CDM by the ANS human-operators in an emergency

Consider the ANN model, presented in Figure 4.

The first layer (input) – are the static and dynamic data on aircraft, control zones and airdromes, ANS human-operators ($\overline{S}$).

The second, third, and *i*-th layers (hidden) – are the expert estimations of the objective agents that impact the decision-making by *i*-th ANS human-operator ($\overline{B}$, $\overline{C}$, $\overline{E}$). Additional input Bias $\overline{\theta}$ characterizes the impact of subjective agents on decision-making.

The fifth layer (output) – are the results of CDM by the ANS human-operators in the emergency (potential loss) $\overline{R}$.

Output vectors of the second, third, fourth (hidden) layers (1):

$$\overline{B},\overline{C},\overline{E} = f(\overline{net} - \overline{\theta}) = f(\overline{W}\{\overline{S},\overline{B},\overline{C}\} - \overline{\theta}), \quad (1)$$

where $\overline{W}$ – are the weight coefficients $\overline{W} = \{w_{ij}\}$;

$\overline{\theta}$ – are the biases of objective agents' estimations due to the impact of subjective agents.

The output vector of the fifth (output) layer (2):

$$\overline{R} = f(\overline{W},\overline{E}). \quad (2)$$

Output signals of vectors of neuron layers (3):

$$\overline{B},\overline{C},\overline{E},\overline{R}=\begin{cases}1;\ if\ \ f(\overline{W}\{\overline{S},\overline{B},\overline{C}\}-\overline{\theta}),f(\overline{W},\overline{E})>0\\0;\ if\ \ f(\overline{W}\{\overline{S},\overline{B},\overline{C}\}-\overline{\theta}),f(\overline{W},\overline{E})\le 0\end{cases}, \quad (3)$$

where f – is a nonlinear activation function.

The output vector (result) depends on the objective and subjective agents. The optimal option of CDM by the ANS human-operators in the emergency is selected based on minimizing potential costs (4):

$$Y_{opt}=min\{r_{ij}\}. \quad (4)$$

Input, intermediate, and output components of ANN are set according to statistics and expert evaluations by aviation experts.

6. Collective decision-making models of the Air Navigation System's human-operators in an emergency

The order of the CDM by the varied aviation collaborators for selecting the most appropriate landing airdrome in an emergency during the aircraft flight in the integrated airspace:

1. Researching the flight route. Working-out the individual decision-making matrices (DMM) with the possible decisions $\{PD\}$ – are the applicable landing airdromes; agents that impact decision-making $\{\xi\}$ – are the conditions of natural agents in an emergency; results $\{r\}$ – are the anticipated outputs of the selection of applicable landing airdromes caused by agents impacting decision-making.
2. Possible decisions $\{PD\}$ – is a set of all applicable airdromes $\{PD\}$ = $\{ADep$ U $AArr$ U $\{AApp\}\}$ = $\{PD_1, PD_2, \ldots, PD_i, \ldots, PD_n\}$, where $ADep = PD_1$ – is an airdrome of departure and its features; $AArr = PD_2$ – is an airdrome of arrival and its features; $AApp = PD_n$ – are the other applicable airdromes in accordance with the flight route and their features.
3. Agents impacting the decision-making for the human-operators $\{\xi\} = \{\xi_1, \xi_2 \ldots, \xi_j, \ldots, \xi_m\}$, where ξ_m – are the equal or various agents.
4. Results $\{r\}$ – is a set of the anticipated outputs caused by the selection of the applicable landing airdromes in emergency $\{r\} = \{r_{11}, r_{12}, \ldots, r_{ij}, \ldots, r_{mn}$ ($i = 1, \ldots, m$; $j = 1, \ldots, n$). The anticipated outputs R_{ij} are calculated based on the EJM [23] according to the data from the normative documents and surveys of H_i human-operators: H_1 – pilot; H_2 – controller; H_3 – engineer; H_i – other aviation collaborators.
5. Working-out the individual DMM for each human-operator. DMM for the first human-operator (H_1 –pilot) is in Table 3.

Table 3
DMM in emergency for human-operator H_1

The matrix 1	{PD}	Agents that impact decision-making by human-operator H_1 – pilot					
		ξ_1	ξ_2	…	ξ_j	…	ξ_n
Possible decisions	PD_1	r_{11}	r_{12}	…	r_{1j}	…	r_{1n}
	PD_2	r_{21}	r_{22}	…	r_{2j}	…	r_{2n}
	…	…	…	…	…	…	….
	PD_i	r_{i1}	r_{i2}	…	r_{ij}	…	r_{in}
	…	…	…	…	…	…	…
	PD_m	r_{m1}	r_{m2}	…	r_{mj}	…	r_{mn}

In the same way, DMM for the second human-operator (H_2 – controller), the third human-operator (H_3 – engineer), and other human-operators, who are interacting in an emergency, are working-out.

6. Researching of decision-making conditions in an emergency (type of flight). Selection of the methods of the decision-making under uncertainty based on the flight safety priority:

- the criterion of Wald (maxmin/minmax) – for the first-time flight (5):

$$PD^* = \max_{PD_i}\left\{\min_{\xi_j} r_{ij}(PD_i, \xi_j)\right\}, \tag{5}$$

where PD_i – is a possible decision from the set *{PD}*;

ξ_j – is an agent from the set *{ξ};*

- the criterion of Laplace – for the regular flight (6):

$$PD^* = \max_{PD_i}\left\{\frac{1}{n}\sum_{j=1}^{n} r_{ij}(PD_i, \xi_j)\right\}; \tag{6}$$

where n – is a number of the impacting agents;

- the criterion of Hurwicz – is exploiting the coefficient of optimism-pessimism α (7):

$$PD^* = \max_{PD_i}\left\{\alpha \max_{\xi_j} r_{ij}(PD_i, \xi_j) + (1-\alpha)\min_{\xi_j} u_{ij}(PD_i, \xi_j)\right\}, \tag{7}$$

where α – is a coefficient of optimism-pessimism, $0 \le \alpha \le 1$, 0 – is a peak of pessimism and 1 – is a peak of optimism.

7. Searching the optimal decisions for each human-operator with the help of the criteria of Wald, Laplace, Hurwicz:

- $PD_1^* = PD_j(H_1)$ – are the decisions of pilot – $\{D_{H1}\}$;
- $PD_2^* = PD_j(H_2)$ – are the decisions of controller – $\{D_{H2}\}$;
- $PD_3^* = PD_j(H_3)$ – are the decisions of engineer $\{D_{H3}\}$.

8. Formation of the collective DMM (Table 4), where:

- *{PD}* – are the possible decisions*;*
- *{r}* – are the results of the optimal decisions of the human-operators by the chosen criteria/flight conditions from the individual DMM $PD_j(H_1)$; $PD_j(H_2)$; $PD_j(H_3)$ (H_1 – pilot; H_2 – controller; H_3 – engineer).

Table 4

The collective DMM in emergency

The collective matrix	*{PD}*	Outputs of optimal decisions by all human-operators					
		$PD_j(H_1)$	$PD_j(H_2)$	$PD_j(H_3)$	$PD_j(H_j)$	**…**	$PD_n(H_n)$
Possible decisions	PD_1	r^*_{11}	r^*_{12}	r^*_{13}		…	r^*_{1n}
	PD_2	r^*_{21}	r^*_{22}	r^*_{23}		…	r^*_{2n}
	…	…	…	…	….	…	….
	PD_i	r^*_{i1}	r^*_{i2}	r^*_{i3}	r^*_{ij}	…	r^*_{in}
	…	…	…	…	….	…	…
	PD_m	r^*_{m1}	r^*_{m2}	r^*_{m3}		…	r^*_{mn}

9. Searching the optimal decisions for all human-operators with the help of the criteria of Wald, Laplace, Hurwicz based on flight safety maximization and loss minimization:

- for the criterion of Wald (8):

$$PD^* = \max_{i}\left\{\min_{l} D^l_{Hij}\right\}, \tag{8}$$

where $D^l_{Hij} = \min_{j}\left\{r^l_{Hij}\right\}$ – are the optimal decisions by the human-operators from the individual DMM with minimum loss;

- for the criterion of Laplace (9):

$$PD^* = \max_i \left\{ \frac{\sum_{l=1}^{L} D^l_{Hij}}{l} \right\}; \quad (9)$$

where $D^l_{Hij} = \min_j \left\{ \frac{\sum_{j=1}^{n} r^l_{Hij}}{n} \right\}$ – are the optimal decisions by the human-operators from the individual DMM with minimum loss;

- for the criterion of Hurwicz (10):

$$PD^* = \max_i \left\{ \beta \max_l D^l_{Hij} + (1-\beta) \min_l D^l_{Hij} \right\}; \quad (10)$$

where $D^l_{Hij} = \alpha \max_j r^l_{ij} + (1-\alpha) \min_j r^l_{ij}$ – are the optimal decisions by the human-operators from the individual DMM, $0 \le \alpha \le 1$; $0 \le \beta \le 1$.

According to the actual situation, a particular criterion is selected. It is important to meet the condition for working-out individual DMM: the sameness of the agents that impact decision-making in the individual DMM (b_j, c_j, e_j).

7. The illustrative example of the collaborative decision-making by the Air Navigation System's human-operators in the emergency "Engine failure during takeoff due to bird strike"

According to the International Civil Aviation Organization, there are 5500 bird strikes with aircraft every year [2; 8]. Most accidents happen during takeoff or landing. 75% of accidents in the air occur at an altitude of up to 300 meters, 20% – at an altitude of 300 to 1500 meters, and only 5% – above 1500 meters. In addition, birds do not always collide with the cockpit, and this happens only in 12% of cases, in 45% of cases they get into the engine. Of course, during the development of the engine, the designers took into account the possibility of a collision, but the fact is that even the best engines stop in this case. The most famous feathered story happened in 2009 in North America. A US Airways aircraft took off from New York's LaGuardia Airport and collided with a flock of birds. As a result, both engines stalled. Pilot Chesley Sullenberger instantly made the only right decision and landed on the water of the Hudson River. The landing was brilliant – all 155 people on board survived.

Theoretically, the engines were supposed to withstand a collision with a bird weighing up to 2 kg, so a pair of crows, a seagull, or even a chicken did not pose a threat. But according to one version, the aircraft collided with a flock of wild geese, each of which weighs about 4 kg. The calculations are as follows: if the aircraft at a speed of 320 km/h collides with a seagull, then the impact force will be about 3200 kg per square centimeter. And if the same bird and an aircraft collide 2 km higher at a speed of 690 km/h, the impact will be 3 times more powerful than a 30 mm projectile shot [24].

It is very dangerous when a bird hits the fairing. Such a case occurred in 2004 when a passenger jet made an emergency landing in Mumbai. When they got off the aircraft, the passengers saw a one and a half meter dent under the cockpit and cracks all over the "nose".

Speaking of modern technology, if the bird gets into the engine, then our chances are 50/50. If the bird is small, then there is nothing to be afraid of, but if it is large, then the compressor may stall. It occurs when the flow of air through the engine is disrupted – this can result in the blades breaking away from the compressors, a fire, or an engine explosion. The other, a turboprop, is strong enough to withstand a bird strike, but a small one. It's still possible for the engine to fail. Although the bird does not clog the engine, the blades can bend or come off due to it, and the engine will stop working.

Despite all that, the designers have foreseen everything possible, and if one engine stops working, the aircraft will be able to fly to the nearest landing site using the remaining engines. The probability of failure of all engines at once is almost zero. In addition, all airports use a system to scare away feathered guests: bioacoustic installations that reproduce sounds that birds are afraid of, harmless but very noisy pyrotechnics, and the most "mods" release falcons and hawks. During takeoff and landing, the aircraft releases and turns on the headlights to scare away birds.

There is presented an example of CDM by the ANS human-operators in the emergency "Engine failure during takeoff due to bird strike" in the conditions of segregated airspace when the aircraft flight performs in the segregated airspace in parallel with UAV flights. Decision-making in this situation requires close interaction between the aircraft crew, air traffic controller's unit, and engineering service.

Initial data:

1. Aircraft: Antonov An-148-100A, medium-range aircraft (maximum landing mass 38550 kg).
2. Flight route (Figures 5–6): airdrome Kharkiv (UKHH) (A_1) – airdrome Lviv (UKLL) (A_2).

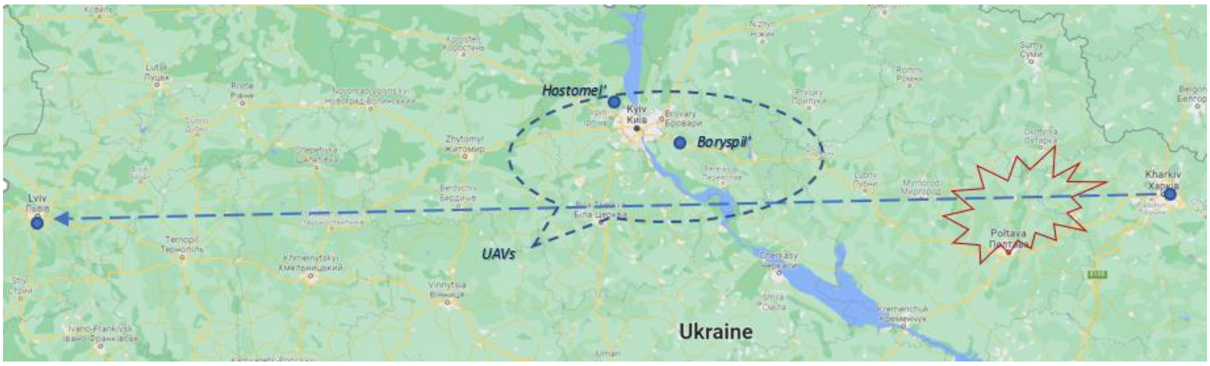

Figure 5: The flight route Kharkiv (UKHH) (A_1)–Lviv (UKLL) (A_2) on the geographical map

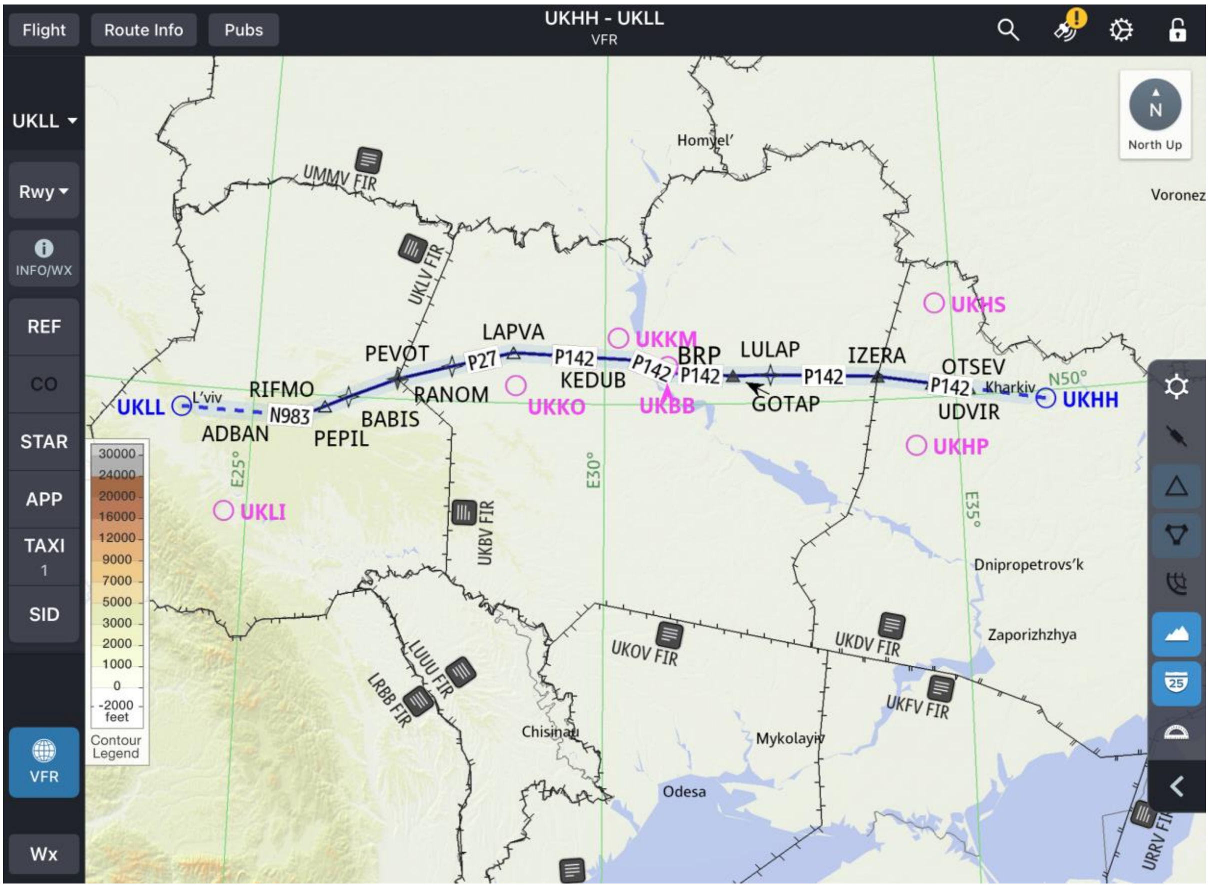

Figure 6: The flight route Lviv (A_1)–Kharkiv (A_2) on the navigation map

3. Reserved (alternate) airdromes:
   Boryspil (A_{r1});
   Hostomel (A_{r2}).
4. Low visibility takeoff (runway visual range 400 m). During takeoff, the bird hit the engine and damaged it. Commander decided to continue climbing flight level 200 which was slightly less than the maximum level with one engine inoperative and proceed to arrival airdrome Lviv. Distance to the destination was less than an hour with one engine inoperative.
5. While climbing, the weather conditions at the reserved airdrome Boryspil deteriorated.
6. An-148-100A is performing the flight in the segregated airspace; there are UAV group flights along the route.
7. Agents that impact decision-making by the human-operators:
   $\{b\}$ – the agents that are analyzed by the human-operator H_1 (pilot);
   $\{c\}$ – the agents that are analyzed by the human-operator H_2 (controller);
   $\{e\}$ – the agents that are analyzed by the human-operator H_3 (engineer).

For the effective CDM, all human-operators has analyzed the actual situation. There are three human-operators in the CDM process: pilot (H_1), controller (H_2), and engineer (H_3).

Each human-operator has formed DMM, where the possible decisions are the applicable airdromes for the route "Kharkiv–Lviv", and each human-operator has considered the identical agents in the actual situation, but with varied benefits. When selecting the optimal airdrome, human-operators (H_1, H_2, H_3) are guided by the same agents (b_j, c_j, e_j) [18]:

b_1, c_1, e_1 – the weather conditions at the applicable airdromes;
b_2, c_2, e_2 – the distance to the applicable airdromes;
b_3, c_3, e_3 – the technical characteristics of the runways;
b_4, c_4, e_4 – the quantity of fuel onboard;
b_5, c_5, e_5 – the available navigation aids;
b_6, c_6, e_6 – the sustainability of radio communication;
b_7, c_7, e_7 – other agents (intensity of the air traffic, logistics, commercial questions, etc.).

These agents are objective. DMM for human-operators in the emergency "Engine failure during takeoff due to bird strike" are in Tables 4-6.

Anticipated outputs considered by the pilot (operator H_1) are represented in Table 5.

Table 5
Individual DMM in emergency for human-operator H_1 (pilot)

The matrix 1		Agents impact decision-making by human-operator H_1 – pilot							Decisions		
Possible decisions $\{PD\}$		b_1	b_2	b_3	b_4	b_5	b_6	b_7	W	L	H, α=0.7
Departure airdrome	Kharkiv (A_1)	3	7	8	7	7	7	4	3	6.14	6.5
Arrival airdrome	Lviv (A_2)	9	4	8	6	9	8	9	**4**	**7.57**	**7.5**
Reserved airdromes	Boryspil (A_{r1})	5	5	9	8	9	9	3	3	6.86	7.2
	Hostomel (A_{r2})	5	5	7	7	9	7	3	3	6.14	7.2

The optimal airdrome for an emergency landing on the route "Kharkiv–Lviv" according to the pilot's decision (red color in DMM) by the criteria of Wald, Laplace, and Hurwitz is Lviv (A_2).

Anticipated outputs considered by the controller (operator H_2) are represented in Table 6.

Table 6
Individual DMM in emergency for human-operator H_2 (controller)

The matrix 2	Agents impact decision-making by	Decisions

human-operator H_2 – controller											
Possible decisions {*PD*}		c_1	c_2	c_3	c_4	c_5	c_6	c_7	*W*	*L*	*H, α=0.5*
Departure airdrome	Kharkiv *(A_1)*	2	7	8	7	7	7	4	2	6.00	5.0
Arrival airdrome	Lviv *(A_2)*	9	4	8	6	9	8	9	**4**	**7.57**	**6.5**
Reserved airdromes	Boryspil *(A_{r1})*	5	6	9	8	9	9	2	2	6.86	5.5
	Hostomel *(A_{r2})*	5	6	7	7	9	7	2	2	6.14	5.5

The optimal airdrome for an emergency landing on the route "Kharkiv–Lviv" according to the controller's decision (red color in DMM) by the criteria of Wald, Laplace, and Hurwitz is Lviv (A_2).

The matrix of the anticipated outputs of decision-making by the engineer is represented in Table 7.

Table 7

Individual DMM in emergency for human-operator H_3 (engineer)

The matrix 3		Agents impact decision-making by human-operator H_3 – engineer							Decisions		
Possible decisions {*PD*}		e_1	e_2	e_3	e_4	e_5	e_6	e_7	*W*	*L*	*H, α=0.3*
Departure airdrome	Kharkiv *(A_1)*	3	7	8	7	7	7	4	3	6.14	4.5
Arrival airdrome	Lviv *(A_2)*	9	4	8	9	9	8	9	**4**	**8.00**	**5.5**
Reserved airdromes	Boryspil *(A_{r1})*	5	5	9	8	9	9	3	3	6.86	4.8
	Hostomel *(A_{r2})*	5	5	7	9	9	7	3	3	6.43	4.8

The optimal airdrome for an emergency landing on the route "Kharkiv–Lviv" according to the engineer's decision (red color in DMM) by the criteria of Wald, Laplace, and Hurwitz is Lviv (A_2).

To determine the consistency of human-operators, collective DMMs were formed, in which the agents in the individual DMM for the operators (pilot (H_1), controller (H_2), and engineer (H_3)) are identical, the decisions of the human-operators are taken from the matrices, represented in Tables 4-6. In the collective matrices, the subjective agents – opinions of the human-operators are consumed.

The optimal collective decisions by the criterion of Wald are presented in Table 8. In this case, the optimal airdrome for landing is determined by the objective agents (weather conditions at the applicable airdromes, distance to the applicable airdromes, technical characteristics of the runways, a quantity of fuel onboard, available navigation aids, sustainability of radio communication, etc.) and subjective agents (the features of the pilot, controller, engineer).

Table 8

Collective DMM in emergency for all operators

Applicable airdromes	O_1	O_2	O_3	*W*	O_1	O_2	O_3	*L*	O_1	O_2	O_3	*H, β=0.5*
Kharkiv *(A_1)*	3	2	3	2	6,14	6,00	6,14	6,10	6,5	5	4,5	5,5
Lviv *(A_2)*	4	4	4	4	**7,57**	7,57	8,00	**7,71**	7,5	6,5	5,5	**6,5**
Boryspil *(A_{r1})*	3	2	3	2	6,86	6,86	6,86	6,86	7,2	5,5	4,8	6
Hostomel *(A_{r2})*	3	2	3	2	6,14	6,14	6,43	6,24	7,2	5,5	4,8	6

The optimal airdrome for landing in the emergency "Engine failure during takeoff due to bird strike", determined based on the objective and subjective agents, is the arrival airdrome Lviv (A_2)

according to the criterion of Wald, Laplace, and Hurwitz. The accounts demonstrated a balance between the flight safety and the value of the flight (maximization of flight safety and minimization of loss).

8. Results and discussion

The optimal airdrome for landing in the emergency "Engine failure during takeoff due to bird strike" during the aircraft flight on the route Kharkiv–Lviv in the integrated airspace according to the criterion of Wald (for the first-time flight), Laplace (for the regular flight), and Hurwitz (with the coefficient of optimism-pessimism) is the arrival airdrome Lviv.

This decision is made based on both the objective agents (weather conditions at the applicable airdromes, distance to the applicable airdromes, technical characteristics of the runways, a quantity of fuel onboard, available navigation aids, sustainability of radio communication, etc.) and subjective agents (the features of the pilot, controller, engineer).

The accounts demonstrated a balance between the flight safety and the value of the flight (maximization of flight safety and minimization of loss).

9. Conclusion

The steps to create the IDSS for the ANS human-operators in an emergency are presented. A scheme of the intelligent control module of IDSS for the ANS human-operators in an emergency, which is based on the HI, is worked-out. The static, dynamic, and expert input data required by Intelligent Decision Support System for the ANS human-operators in an emergency are determined. ANN model for CDM by the ANS human-operators in the emergency is designed.

The order of the CDM by the varied aviation collaborators for selecting the most appropriate landing airdrome in an emergency during the aircraft flight in the integrated airspace is developed. The examples of the individual and collective models of decision-making by the pilot, air traffic controller, and engineer in the emergency "Engine failure during takeoff due to bird strike" in the conditions of segregated airspace based on the methods of decision-making under uncertainty are presented.

The direction of further research is the development of the individual and collective decision-making models by all aviation collaborators in emergencies to use as a part of IDSS for the cooperation of human and artificial intelligence. Next research is needed to develop a methodology for effective interaction between artificial intelligence systems and ANS subjects (pilot, remote pilot, air traffic controller, ground operator, flight dispatcher, engineer, etc.).

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