Collaborative decision-making during pre-simulation training: Optimal approach and radar vectoring procedures

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Abstract

Experts' forecasts show a significant increase in global demand for highly qualified aviation professionals, including pilots and air traffic controllers, by 2030. Joint simulation training of aviation specialists is a critical stage of professional education and plays a significant role in further ensuring flight safety. At the briefing stage, the instructor checks the readiness of trainees for practical activities, including collaborative decision-making (CDM) between the aircraft crew and air traffic controller in complicated, complex, emergency situations. GPS signals are currently subject to instability. In the case of interference with GPS navigation equipment onboard an aircraft flying according to the rules of Area Navigation (RNAV), the pilot and air traffic controller must be able to collaborate effectively in the radar vectoring procedure. 28.3% of GPS problems are related to the descent and landing stages. The authors proposed to use as the elements of testing at the stage of pre-simulation training the collaborative performance of the training tasks "Choosing the optimal landing aerodrome" and "Vectoring". Based on the expert judgment method, models of individual and CDM in choosing the optimal landing aerodrome are developed. By the network planning method, the synchronized vectoring operations of the pilot and air traffic controller in complicated situation "Unable required position" are worked out. The significance of trainees' actions for the training task "Vectoring" is obtained by fuzzy logic methods. A comparison of the comprehensive assessment of trainees' performance in the training task "Vectoring" by additive and multiplicative aggregation is considered. The expert system for multiplicative assessment of the results of pre-simulation training will allow for making an objective conclusion about the mastery of the necessary knowledge, skills, and abilities by trainees and the acquisition of professional practice-oriented competencies in CDM.

Keywords

air traffic controller, decision-making matrix, emergency, expert judgment method, fuzzy logic, landing aerodrome, network planning, pilot, training task, vectoring

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1. Introduction

1.1. Introduction to the problem

According to experts, the number of passengers and cargo transported by air will double by 2035 [1]. The forecasts of the International Air Transport Association (IATA) and the International Civil Aviation Organization (ICAO) show that in the next 20 years, the demand for air transport will grow by an average of 4.3% per year [1, 2]. The aviation industry is developing dynamically, opening up new, attractive prospects for professional development, and is confidently emerging from the crisis. New aviation companies are being established, creating new jobs that will require qualified aviation professionals. Already in 2019, the aviation industry provided a total of 65.5 million jobs worldwide, and despite the challenges faced by the aviation market, it is predicted that this statistic will increase from year to year [3].

Taking into account the forecast values, the aviation transport system in the coming years will need many highly educated specialists: pilots, air traffic controllers (ATCOs), and engineers. Table 1 presents the results of research by the ICAO, which compares the average number of specialists around the world who will need to be trained annually with the training capabilities of existing institutions [4]. This indicates an existing shortage of specialists, namely 160 000 pilots, 40 000 ATCOs, and 360 000 engineers.

Table 1
ICAO comparative analysis of the number of specialists who need to be trained annually with the training capabilities of existing institutions [4]

Type of specialists	Actual number of specialists in 2010	Number of specialists needed by 2030	Need for annual training	Training system capabilities	Annual deficit of specialists
Pilots	463 386	980 799	52 506	44 360	8 146
ATCOs	67 024	139 796	8 718	6 740	1 978
Engineers	580 926	1 164 969	70 331	52 260	18 071

A comparable situation with staff is observed in the European region [5]. According to forecasts, by 2036, the aviation segment will need [6]:

- 620 000 new pilots (67 pilots per day for aircraft with more than 100 seats).
- 125 000 ATCOs (13 new ATCOs every day).

Simulator training is a set of forms and methods of education that allow trainees to develop practical skills using the theoretical knowledge of several academic disciplines by performing complex tasks and exercises under the guidance of an instructor [7]. The purpose of the training is to improve the work of aviation specialists and develop practical skills in standard and non-standard situations. The quality and quantity of exercises, and objective assessment of exercises affect the effectiveness of simulator training.

To optimize the effectiveness of the training following EUROCONTROL recommendations, theoretical and practical training are combined from the very beginning of the training using a pre-training system [7]. The training process starts with the acquisition of skills on simulators (SA – skill acquisition), then the performance of individual tasks (PTP – part-task practice) is practiced and continues with simulator training. Guided SA (G-SA) is currently relevant – the acquisition of skills accompanied by interactive assessment, commenting, and control over the trainees' actions. Guided practice of partial task completion (G-PTP) is the practical implementation of specific tasks, accompanied by comments, display of results, assessment of the trainees' actions, and the possibility of feedback [7].

Effective use of simulators makes it possible: 1) to provide a gradation "from simple to complex" of professional competence formation in safe conditions, especially when practicing unpredictable and emergency flight conditions; 2) to optimize training resources (involving instructors who are not actively involved in training); 3) to repeat training exercises several times; 4) to develop skills and improve decision-making abilities in conditions of uncertainty and time pressure (development of professional confidence). Significant changes in the aviation system are "passed" through their modeling on simulator equipment. Based on the correct strategy for using simulators, in which a significant role is assigned to the instructor of practical training, it is possible to design a systematic approach to the development of a set of professional competencies required by the employer.

1.2. Motivation

Joint simulation training of aviation specialists is a critical stage of professional education and plays a significant role in further ensuring flight safety. At the briefing stage, the instructor checks the readiness of trainees for practical activities, including collaborative decision-making (CDM) between the pilot and ATCO in complicated, complex, emergency situations. However, there are currently no objective methods for assessing the interaction between operators at all stages of the flight. This fact motivates to develop the expert system for multiplicative assessment of aviation specialists' (pilot and ATCO) CDM during pre-simulation training.

1.3. Contribution

This research contributes to the enhancement of the measurement of the aviation specialists' interaction in complicated, complex, emergency situations based on the expert system for multiplicative assessment of the results of pre-simulation training. It will allow making an objective conclusion about the mastery of the necessary knowledge, skills, and abilities by trainees and the acquisition of professional practice-oriented competencies in CDM in emergencies.

1.4. The organization of the paper

The paper consists of six sections. The first section includes an introduction, it concentrates on the analysis of related works and problem statements. The second section considers the development of the models of individual and CDM by the pilot and ATCO when performing the training task "Vectoring". The third section discusses the expert system for quantitative assessment of CDM by the pilot and ATCO during pre-simulation training. The fourth part is results and discussions. The fifth section is the conclusion. The sixth section describes the future research directions.

1.5. Formulation of the problem

The ever-increasing volume of air traffic places new demands on airspace capacity [2]. The concept of Performance-Based Navigation (PBN) is being implemented to ensure the efficiency of airspace use by providing direct routes, track accuracy, and high accuracy of navigation systems [8]. Two main types of navigation procedures exist within PBN: Area Navigation (RNAV) and Required Navigation Performance (RNP) [9, 10]. In this context, RNAV refers to a particular navigation specification with a given lateral accuracy that must be maintained for 95% of the flight time. RNP includes onboard Receiver Autonomous Integrity Monitoring (RAIM) – a technology for the assessment of the Global Positioning System (GPS) signals' integrity. A satellite may be transmitting slightly incorrect information, resulting in erroneous navigation data, but the GPS receiver cannot detect this using standard methods. RAIM uses redundant signals to obtain and compare multiple GPS coordinates, and a statistical function determines whether the error can be attributed to any of the signals. However, despite the use of modern satellite navigation equipment, the current problem is the instability of GPS signals, especially near war zones, which negatively affects the correctness and accuracy of aircraft positioning (complicated flight situation). For 46 hours, 873 aircraft in the Baltic region had problems with GPS signals and related equipment, according to a Swedish OSINT analyst. [11]. In the case of 43 aircraft, GPS navigation was unavailable for more than two hours. Der Spiegel journalist notes that the massive loss of signal in the Baltic Sea region may be the result of Russia's "hybrid war" [11]. In such cases, the pilot can request help from the ATCO to receive instructions on the correct flight course – a common task that is solved by the radar vectoring procedure [12, 13].

According to the CDM concept [14], the effective interaction of aviation specialists is a precondition for ensuring safety at all stages of an aircraft flight in standard and non-standard situations. Aviation specialists must closely follow the regulatory documents that have been reviewed in the course of their professional training and activities. At the same time, the content of professional training documents and guidance documents often differs, making it difficult to develop a single algorithm for joint actions, especially in emergencies. Joint pre-simulation and simulation training of aviation specialists (pilots and ATCOs) is used to prevent conflicts between decisions and actions of CDM participants in real flight conditions [15].

Publication [16] discusses integrated models for training aviation specialists (pilots and controllers), [17] – a game-based approach to implementing CDM at a leading European airport, and [18] – partnership programs between aviation educational institutions and airlines. The authors have presented new approaches to the improving of aviation specialists' professional activity (intelligent decision support system [19, 20, 21]) and practical training (artificial neural network for pre-simulation training [22], machine learning [23], intelligent integrated training system "CDM – Education" [24]) in emergencies using CDM.

Methods of CDM, proposed by the authors [19–24]:

- Method for integrating decision-making models in certainty, risk, and uncertainty (deterministic and stochastic models).
- Method of subjective-objective CDM based on individual and collaborative decision-making models.
- Method for managing the development of the situation by using the integration of decision-making models (non-stochastic, stochastic, and deterministic models) and CDM models (individual and collaborative decision-making models).
- Method of CDM modeling based on the priority of the factors influencing decision-making.
- Method of CDM modeling based on the priority of the Hurvitz criteria.
- Method of Collaborative Decision-Making in education "CDM-E".
- Method of CDM in an emergency with a multi-step (multi-stage) decision-making process.

However, no objective methods for assessing the interaction between operators at all stages of flight in complicated, complex, emergency situations have yet been proposed. Therefore, an urgent problem is the development of the expert system for multiplicative assessment of aviation specialists' (pilot and ATCO) CDM during pre-simulation training.

The purpose of the work is to solve the following problems:

- Development of the models of individual and collaborative decision-making by the pilot and ATCO when performing training tasks based on the expert judgment method.
- Calculating the significance of trainees' actions for the training task "Vectoring" by fuzzy logic methods.
- Comparison of the comprehensive assessment of trainees' performance in the training task "Vectoring" by additive and multiplicative aggregation.

2. Models of individual and collaborative decision-making by the pilot and air traffic controller when performing training tasks

According to [25], in the vast majority of reports from the aircraft, regarding problems with obtaining navigation information, the crews required radar guidance (vectoring) from ATC. In its turn, European Union Aviation Safety Agency (EASA) explicitly recommends that in case of problems with receiving GPS signals, pilots should be prepared to request and receive guidance (vectoring) from the ATCO as long as necessary [26]. Based on IATA data [27], 28.3% of the problems in obtaining navigation information from GPS are related to the descent and landing stages.

Input data based on real situation for training task:

1. Aircraft Boeing 737-8MAX.
2. Flight from Istanbul Sabiha Gökçen LTFJ (departure aerodrome) to Rize-Artvin LTFO (arrival aerodrome). Alternate aerodrome in bad weather conditions (BWC) Trabzon LTCG.
3. Runway in use at destination Rize-Artvin LTFO RW24 due to strong wind.
4. Suspected arrival route ZUBRE 1K following approach RNP Z RW24 (conventional arrival ZUBRE 1B following approach VOR Z or NDB Z RW 24).
5. Weather:

- Wind 230/16 VRB 210V260.
- Visibility 10 km.
- Clouds BKN 2800' SCT 1000'.
- Temperature 15, dew point 11.
- Pressure QNH 1021.
- No significant changes (with the subsequent deterioration of weather conditions).

6. There are three operators in the CDM: pilot (O_1), ATCO (O_2), and expert/Artificial Intelligence (AI) (O_3).
7. Factors are taken into account by all operators while decision-making:

- $\{a_j\}$ – factors influencing decision-making by operator O_1 (pilot).
- $\{b_j\}$ – factors influencing decision-making by operator O_2 (ATCO).
- $\{c_j\}$ – factors influencing decision-making by operator O_3 (expert/AI).

The common objective factors for all operators (a_j, b_j, c_j):

- a_1, b_1, c_1 – the weather conditions.
- a_2, b_2, c_2 – the distance to the applicable aerodromes/the quantity of fuel onboard.
- a_3, b_3, c_3 – the tactical and technical characteristics of the runways.
- a_4, b_4, c_4 – the flight and technical characteristics of the aircraft.
- a_5, b_5, c_5 – the approach systems and navigation aids at the applicable aerodromes.
- a_6, b_6, c_6 – Threat and Error Management (TEM).

The usual situation during the flight over Turkey territory is unstable GPS signal due to military conflicts in Ukraine and Syria.

Trainees are performing two tasks during pre-simulation training (Figure 1):

- Task 1: Decision-making in uncertainty – choosing the optimal landing aerodrome in BWC.
- Task 2: Decision-making in certainty – vectoring.

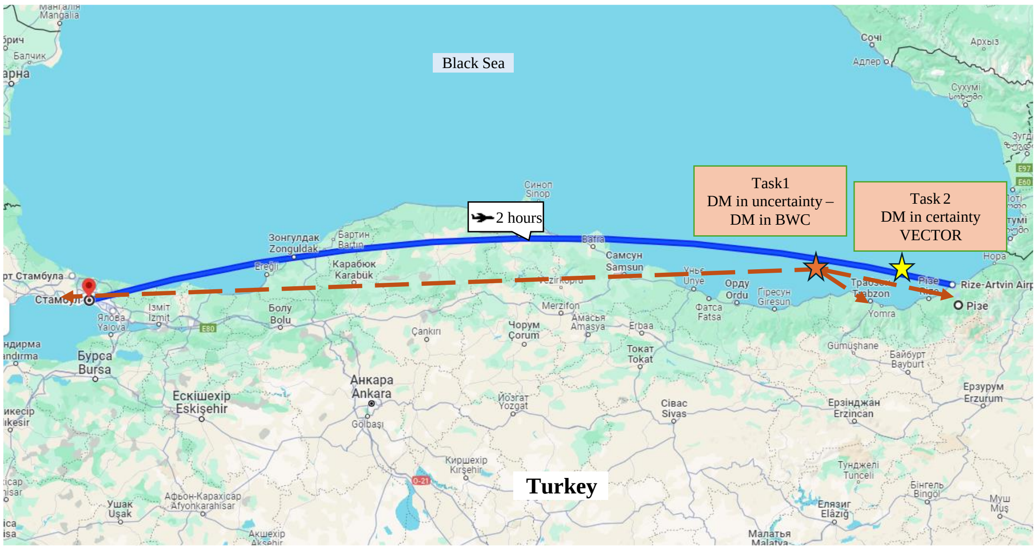

Figure 1: The tasks that trainees are performing during pre-simulation training.

2.1. Task 1: Decision-making in uncertainty – choosing the optimal landing aerodrome

For rational CDM, all operators (pilot (O_1), ATCO (O_2), and expert/Artificial Intelligence (AI) (O_3)) are analyzing and considering the current flight situation. The operators are composing the decision-making matrices, where alternative solutions are the departure aerodrome Istanbul Sabiha Gökçen LTFJ, arrival aerodrome Rize-Artvin LTFO, and alternate aerodrome Trabzon LTCG. All operators are taking into account the identical factors in the present situation, but with varying advantages for themselves.

The decision-making matrices for operators in BWC are in Tables 2–4. Optimal solutions are based on the Wald (W), Laplace (L), Hurwitz (H), and Savage (S) criteria.

Table 2
The decision-making matrix for operator O_1 (pilot)

Alternative decisions		Factors						Solutions			
$\{A\}$		a_1	a_2	a_3	a_4	a_5	a_6	W	L	H, α=0.5	S
Departure aerodrome	Istanbul (A_1)	8	2	9	9	9	8	2	7.5	8.3	7
Arrival aerodrome	Rize (A_2)	5	9	8	9	7	8	5	7.7	8.6	4
Alternate aerodrome	Trabzon (A_3)	6	7	7	9	5	7	5	6.8	8.6	4
	MAX							5	7.7	8.6	4

The optimal landing aerodrome follows the pilot's decision based on the Wald (W) criterion – Rize (A_2) and Trabzon (A_3), Laplace (L) criterion – Rize (A_2), Hurwitz (H)

criterion – Rize (A_2) and Trabzon (A_3), Savage (S) criterion – Rize (A_2) and Trabzon (A_3). The optimal landing aerodrome follows the ATCO's decision based on the Wald (W) criterion – Rize (A_2) and Trabzon (A_3), Laplace (L) criterion – Rize (A_2), Hurwitz (H) criterion – Rize (A_2), Savage (S) criterion – Trabzon (A_3). The optimal landing aerodrome follows the expert/AI's decision by all criteria – Rize (A_2).

Table 3
The decision-making matrix for operator O_2 (ATCO)

Alternative decisions		Factors						Solutions			
{A}		b_1	b_2	b_3	b_4	b_5	b_6	W	L	H, α=0.5	S
Departure aerodrome	Istanbul (A_1)	8	2	9	8	9	8	2	7.3	5.5	7
Arrival aerodrome	Rize (A_2)	5	9	8	8	7	8	5	7.5	7.0	4
Alternate aerodrome	Trabzon (A_3)	6	7	7	8	5	7	5	6.7	6.5	3
	MAX							5	7.5	7.0	3

Table 4
The decision-making matrix for operator O_3 (expert/AI)

Alternative decisions		Factors						Solutions			
{A}		c_1	c_2	c_3	c_4	c_5	c_6	W	L	H, α=0.5	S
Departure aerodrome	Istanbul (A_1)	7	2	10	10	9	8	2	7.7	6.0	8
Arrival aerodrome	Rize (A_2)	6	9	8	10	7	8	6	8.0	8.0	4
Alternate aerodrome	Trabzon (A_3)	6	7	8	10	5	7	5	7.2	7.5	5
	MAX							6	8.0	8.0	4

A matrix of collective decision-making is built to determine the consistency of operators (Table 4). It contains identical objective factors for operators (pilot (O_1), ATCO (O_2), expert/AI (O_3)), and the solutions of the operators from individual matrices. The CDM matrix uses the opinions of operators (subjective factors). The optimal CDM for operators in complicated situation "Unable required position" based on the Wald (W), Laplace (L), and Hurwitz (H) criteria is presented in Table 5. The optimal CDM is determined by objective and subjective factors that influence the decisions of all operators (pilot, ATCO, expert/AI) by Wald (W) criterion – Rize (A_2) and Trabzon (A_3), Laplace (L) and Hurwitz (H) criteria – Rize (A_2). The optimal landing aerodrome by all criteria – Rize (A_2).

Table 5
The CDM matrix for all operators (pilot, ATCO, expert/AI)

Alternative decisions $\{A\}$	Operators/Solutions											
	O_1	O_2	O_3	W	O_1	O_2	O_3	L	O_1	O_2	O_3	H, $\beta = 0.5$
A_1^*	2	2	2	2	7.5	7.3	7.7	7.3	8.3	5.5	6.0	5.5
A_2^*	5	5	6	5	7.7	7.5	8.0	7.5	8.6	7.0	8.0	7.0
A_3^*	5	5	5	5	6.8	6.7	7.2	6.7	8.6	6.5	7.5	6.5

2.2. Task 2: Decision-making in certainty – vectoring

By the method of subjective-objective CDM based on individual and CDM models the optimal landing aerodrome is defined – Rize (A_2). During arrival, it was the message "Unable required position" (complicated situation), which meant that it was impossible to perform the RNAV approach. The crew requested VECTORS to VOR ART to perform a conventional VOR approach from the right seat according to MEL 34-51-01 – VOR1 UNSERVICEABLE. Due to the unstable GPS signal for proceeding to the landing aerodrome, it is necessary to use the radar vectoring procedure [28]. Simplified analysis of the pilot and ATCO technological operations during the vectoring is presented in Table 6.

Table 6
Structure-time table of the pilot (p_i) and ATCO (c_j) technological operations during the vectoring – an example

Pilot's operations, p_i	The sequence of the technological operations	Previous operations	ATCO's operations, c_j	The sequence of the technological operations	Previous operations
p_1	The message "Unable required position"	-	c_1	Acceptation and confirmation of the information, reporting to the supervisor	p_1
p_2	The decision about landing aerodrome	p_1	c_2	Meteorological and technical information about landing aerodrome	p_2, c_1
p_3	Following the ATCO's instructions	p_2	c_3	Vector instructions: heading, altitude, and speed restrictions	p_2, c_2
p_4	Landing	p_3	c_4	The final approach and landing clearance	p_3, c_3

According to Table 5, the network graphs of the synchronized technological operations of the pilot and ATCO during the vectoring are built (Figure 2).

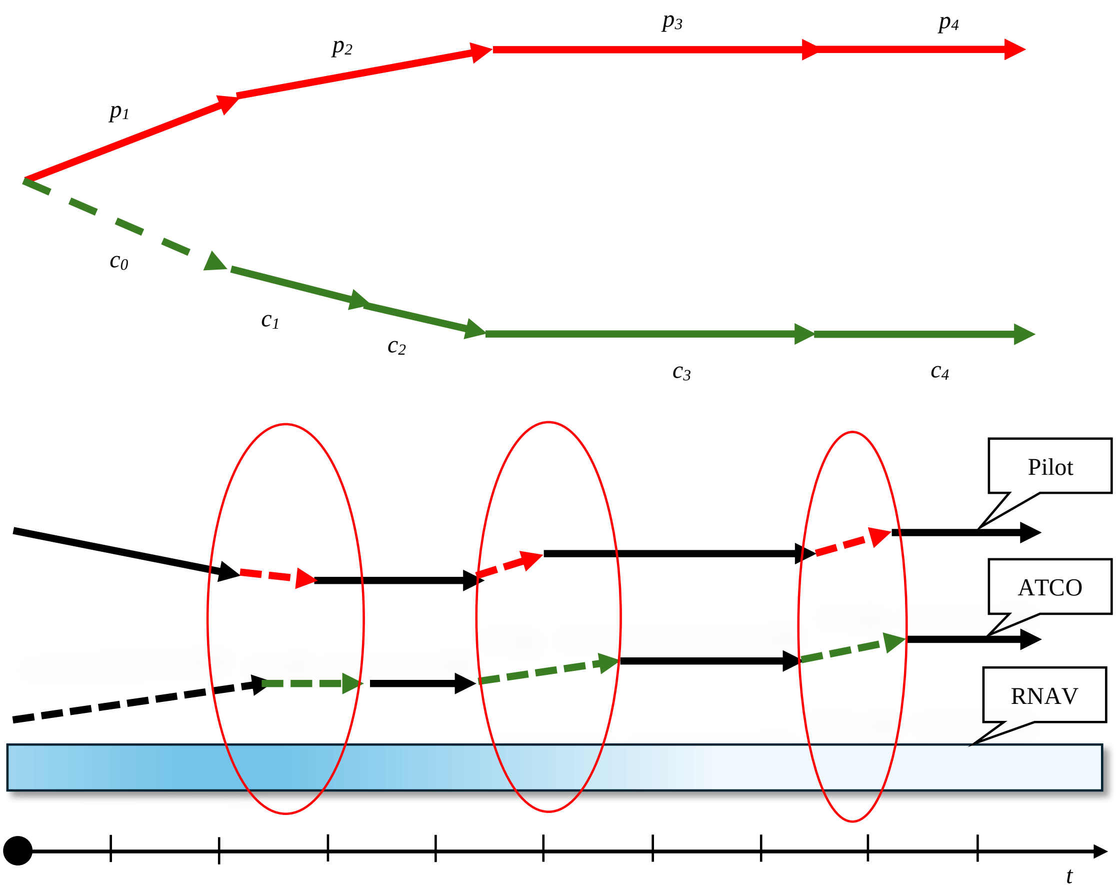

Figure 2: The network graphs of the technological operations of the pilot (p_i) and ATCO (c_j) during the vectoring.

Each time the ATCO performs radar guidance by vectors, he must assume responsibility for all navigation parameters: heading, altitude, and speed (rate of climb/descent) until the final approach track is intercepted.

The ATCO must not risk the safety of the aircraft when using the radar vectoring procedure. He must not gamble with the risk of losing echeloning. ATCO must ensure that the appropriate distance is maintained each time a flight clearance is granted.

3. Expert system for quantitative assessment of collaborative decision-making by pilot and air traffic controller during pre-simulation training

Quantitative assessment of the CDM by pilot and ATCO during pre-simulation training was carried out with the help of an expert system (Figure 3).

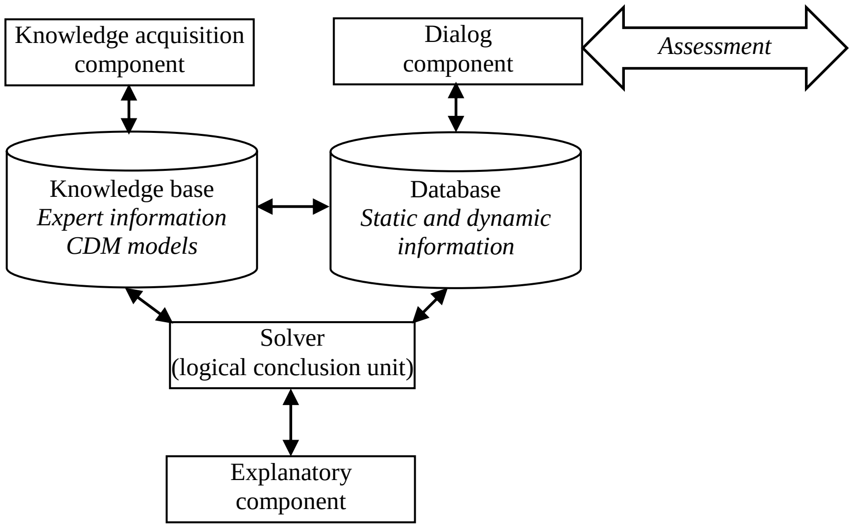

Figure 3: The scheme of an expert system for quantitative assessment of the CDM by pilot and ATCO during pre-simulation training.

The database contains information on the flight plan of the aircraft and its changes; tactical and technical characteristics of the aircraft; geographical, technical, and meteorological information on the air traffic control area and aerodromes.

The knowledge base contains expert data obtained based on an expert survey of aviation specialists (values of the parameters of the CDM models) and rules for using this data (CDM models). The solver (logical inference unit) generates scenarios of training tasks based on the initial data from the database and knowledge from the knowledge base.

The trainee assessment is performed based on determining the discrepancy between the standard and actual actions of the trainee.

The significance of trainees' actions for the radar vectoring procedure (setting (ATCO) and holding (pilot) of navigation parameters: heading, altitude, and speed (rate of climb/descent)) is obtained by fuzzy logic methods [29] (Figure 4). The use of membership functions in the context of fuzzy information allows for formalizing qualitative characteristics.

According to Figure 4, the quantitative indicators of the level of significance of trainees' actions for the radar vectoring procedure (setting (ATCO) and holding (pilot) of navigation parameters: heading, altitude, and speed (rate of climb/descent)) are:

- Heading – 70 units.
- Altitude – 40 units.
- Speed (rate of climb/descent) – 10 units.

Assessment of the CDM by the pilot and ATCO during pre-simulation training is a rather complex and responsible task. For pre-simulation training assessment, the artificial neural networks are used [22, 30].

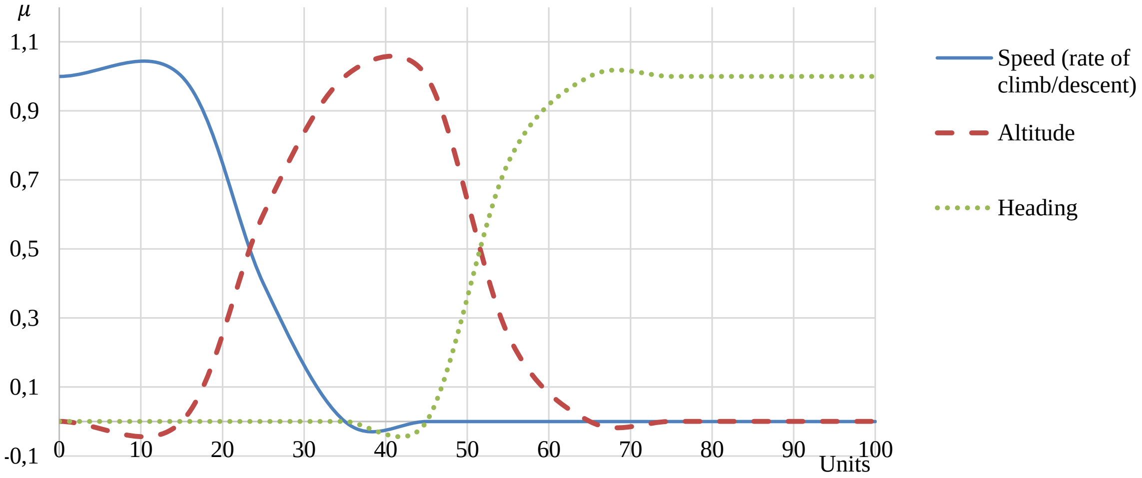

Figure 4: The membership functions μ for determining the significance of trainees' actions for the radar vectoring procedure.

Additive or multiplicative aggregation of the results of pre-simulation training task performance for comprehensive assessment of the CDM by the pilot and ATCO is proposed. The results of the assessment of the radar vectoring procedure (setting (ATCO) and holding (pilot) of navigation parameters: heading, altitude, and speed (rate of climb/descent)) by additive and multiplicative aggregation are shown in Table 7: R – rank; R_{av} – average rank; w – weight coefficient; A, B – marks of the trainees; W_{ad} – additive assessment; W_m – multiplicative assessment.

Two trainees took part in the experiment: trainee A who did not miss classes and trainee B who missed classes. Let's compare the results of trainee B's comprehensive assessments obtained by additive and multiplicative aggregation (he received a mark of 0 – completely unable to set/hold the altitude) during pre-simulation training. Comprehensive assessment of trainee B's performance in the training task "Vectoring", obtained based on the additive aggregation:

$$W_{ad} = \sum_{i=0}^{n} w_i f_i = 0.49 \cdot 5 + 0.32 \cdot 0 + 0.19 \cdot 4 = 2.23.$$

Table 7

An example of a comprehensive assessment of the radar vectoring procedure: additive and multiplicative aggregation

Navigation parameters	Assessment of the trainees						Additive aggregation		Multiplicative aggregation	
	R	R_{av}	C	w	A	B	$W_{ad}(A)$	$W_{ad}(B)$	$W_m(A)$	$W_m(B)$
Heading, f_1	1	1.21	0.93	0.49	5	5	2.45	2.45	2.20	2.20
Altitude, f_2	2	2.16	0.61	0.32	4	0	1.28	0.00	1.56	0.00
Speed (rate), f_3	3	2.89	0.37	0.19	4	4	0.76	0.76	1.30	1.30
Sum/ Aggregation	–	–	1.91	1.00	13	7	4.49	3.21	4.46	0.00

Comprehensive assessment of trainee B's performance in the training task "Vectoring", obtained based on the multiplicative aggregation:

$$W_m = \prod_{i=1}^{n} f_i^{w_i} = 5^{0.49} \cdot 0^{0.32} \cdot 4^{0.19} = 0.$$

During pre-simulation training of the pilot and ATCO, the multiplicative aggregation of practical results should be used, as it does not provide for mutual compensation due to positive (higher) results in other elements of the assessment, as is the case with additive aggregation.

4. Results and discussions

The illustrative example for pre-simulation training of the pilot and ATCO about flight Boeing 737-8MAX from departure aerodrome Istanbul Sabiha Gökçen (A_1) to arrival aerodrome Rize-Artvin (A_2) with alternate aerodrome Trabzon (A_3) is considered.

Trainees are performing two tasks during pre-simulation training:

- Task 1: Decision-making in uncertainty – choosing the optimal landing aerodrome in BWC.
- Task 2: Decision-making in certainty – vectoring.

The decision-making matrices for choosing the optimal landing aerodrome in BWC by the pilot, ATCO, and expert/AI with the help of the expert judgment method are built. Six common objective factors are taken into account by all operators while decision-making: the weather conditions; the distance to the applicable aerodromes/the quantity of fuel onboard; the flight and technical characteristics of the aircraft; the approach systems and navigation aids at the applicable aerodromes; the tactical and technical characteristics of the runways; Threat and Error Management (TEM). Optimal solutions are based on the Wald, Laplace, Hurwitz, and Savage criteria. By the subjective-objective CDM method, using individual and collaborative decision-making models, the optimal landing aerodrome Rize (A_2) is determined.

During arrival, it was the message "Unable required position" (complicated situation), which meant that it was impossible to perform the RNAV approach. Due to the unstable GPS signal for proceeding to the landing aerodrome, it is necessary to use the radar vectoring procedure. Structure-time table and network graphs of the synchronized technological operations of the pilot and ATCO during the vectoring are presented.

The scheme of the expert system for quantitative assessment of the CDM by the pilot and ATCO during pre-simulation training is designed. The trainee assessment is performed based on determining the discrepancy between the standard and actual actions of the trainee. The significance of trainees' actions for the radar vectoring procedure (setting (ATCO) and holding (pilot) of navigation parameters: heading, altitude, and speed (rate of climb/descent)) is obtained by fuzzy logic methods. The quantitative indicators are:

- Heading – 70 units.
- Altitude – 40 units.
- Speed (rate of climb/descent) – 10 units.

An experiment was conducted with two trainees: trainee A who did not miss classes and trainee B who missed classes. The results of trainee comprehensive assessments during pre-simulation training obtained by additive and multiplicative aggregation are compared. The multiplicative aggregation of practical results more preferable because it does not provide for mutual compensation due to positive (higher) results in other elements of the assessment, as is the case with additive aggregation.

5. Conclusions

Joint simulation training of aviation specialists is a critical stage of professional education and plays a significant role in further ensuring flight safety. At the briefing stage, the instructor checks the readiness of trainees for practical activities, including CDM between the aircraft crew and ATCO in complicated, complex, emergency situations. GPS signals are currently subject to instability. In the case of interference with GPS navigation equipment onboard an aircraft flying according to the RNAV rules, the pilot and ATCO must be able to collaborate effectively in the radar vectoring procedure. 28.3% of the problems in obtaining navigation information from GPS are related to the descent and landing stages. The authors proposed to use as the elements of testing at the stage of pre-simulation training the collaborative performance of the training tasks "Choosing the optimal landing aerodrome" and "Vectoring".

Based on the expert judgment method, models of individual and CDM on choosing the optimal landing aerodrome in BWC by the pilot, ATCO, and expert/AI are developed. The optimal solutions are calculated using the Wald, Laplace, Hurwitz, and Savage criteria (training task 1). By the network planning method based on structure-time table and network graphs, the synchronized vectoring operations of the pilot and ATCO in complicated situation "Unable required position" are worked out (training task 2).

The significance of trainees' actions when performing the training task "Vectoring" (setting (ATCO) and holding (pilot) of navigation parameters: heading, altitude, and speed (rate of climb/descent)) for quantitative assessment in the expert system is obtained by fuzzy logic methods.

A comparison of the comprehensive assessment of trainees' performance in the training task "Vectoring" by additive and multiplicative aggregation is considered, and the expediency of using multiplicative aggregation of practical results is proved.

The expert system for multiplicative assessment of the results of pre-simulation training will allow for making an objective conclusion about the mastery of the necessary knowledge, skills, and abilities by trainees and the acquisition of professional practice-oriented competencies in CDM.

6. Future scope

Further researches are aimed at developing an Intelligent System for Collaborative Decision-Making while Training (IS CDM-T) for joint education of aviation specialists (pilots, operators of drones, flight dispatchers, ATCOs, handling agents, maintenance personnel, etc.) using big data analysis and machine learning. To control AI solutions, aviation professionals need to use hybrid intelligent systems that integrate human and machine capabilities.

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