Data pre-processing for optimization of collaborative decision-making by aviation specialists during the practical training considering the factor's priority

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Abstract

This paper presents a novel aspect of the practical training for aviation specialists utilizing collaborative decision-making (CDM) methods, required particularly in emergencies. Although components and procedures in the air navigation system have improved, human factors still have a major influence on flight safety: 80 percent of accidents are caused by human mistakes, and 42 percent of mistakes are caused by incorrect decision-making. Thus, reducing the impact of human factors on flight safety remains a pressing issue. CDM is a procedure for involving individual and collective data by diverse interacting aviation personnel in professional decisions. Collective practical training of aviation specialists is a major phase of professional education and performs a considerable role in further assuring flight safety. The purpose of this publication is improvement the collective practical training of aviation specialists based on a comparison of the pre-processing results obtained by the CDM during the joint performance of practical tasks in the emergency situations of "Engine failure" (the most frequent) and "Cargo failure" (the most danger) considering objective and subjective factors' priority. Based on the Expert Judgment Method and the Wald, Laplace, Hurwitz, and Savage criteria in uncertainty conditions, models of individual and collective decision-making when selecting the optimal aerodrome for forced landing taking into account the objective and subjective factors are developed. Data pre-processing for planning and modeling situations in Intelligent (Hybrid) Integrated Training System "CDM - Education" (CDM-E) based on Machine Learning and Big Data analyzing tools will allow optimizing the CDM of aviation specialists (manned and unmanned aircraft pilots, air traffic controllers, flight dispatchers, air traffic safety electronics personnel, maintenance staff, ground services personnel, etc.) in emergencies considering the objective and subjective factors' priority.

Keywords

air traffic controller, air traffic safety electronics personnel, cargo fire, decision-making matrix, emergency, engine failure, expert judgment method, optimal landing aerodrome, pilot, training task

1. Introduction

According to global statistics, 2023 was the safest year in the history of commercial aviation, surpassing 2014, which was previously considered the leader in this indicator. At the same time, by the annual safety report of the International Air Transport Association (IATA), in 2023, a record low accident rate was recorded – 0.03 cases per million flights [1]. To get into an aircraft accident, a person would have to travel by passenger commercial air transport every day for 103 239 years.

Based on the data received by the National Transport Investigation Bureau (NTIB), in 2023, during the operation of Ukrainian commercial civil aircraft in passenger and cargo transportation,

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aviation works, training flights, and the operation of general aviation, 61 events occurred, compared to 57 events registered in 2022 [2]:

- one accident (during commercial transportation in Mali),
- 48 incidents,
- seven damages to the aircraft on the ground (DAG),
- five extraordinary events.

In 2023, the factors that led to aviation incidents and accidents involving Ukrainian civil aircraft were distributed as follows (Figure 1): 8 (16%) – human factors (5 (10%) aircraft crews and 3 (6%) maintenance personnel); 23 (47%) – technical factors (failures of systems and components for technical reasons); 17 (35%) – external environment (including ornithology); 1 (2%) – unspecified factors. In 2023, no flights of foreign civilian aircraft were carried out on the territory of Ukraine.

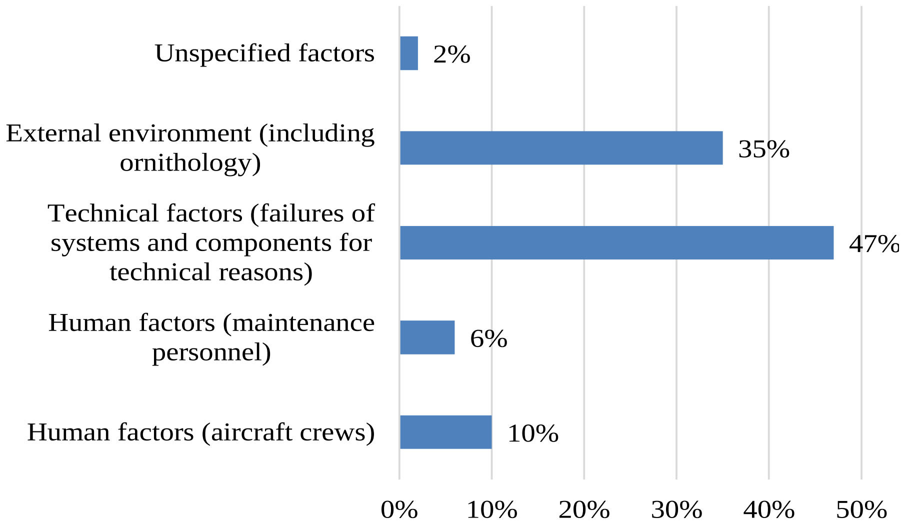

Figure 1: Distribution of aviation incidents and accidents with Ukrainian civil aircraft by factors in 2023.

In 2023, the level of flight safety of Ukrainian companies remained approximately at the level of 2022. Compared to the previous year:

1. During passenger and cargo transportation on scheduled and non-scheduled routes:

- no catastrophes in 2023, 2 catastrophes in 2022,
- one accident occurred in 2023, no accidents in 2022,
- no serious incidents occurred in 2023, while in 2022 there was one,
- the number of incidents is 48, while in 2022 there were 54,
- seven DAGs took place in 2023, while in 2022 there were no DAGs,
- five extreme events occurred in 2023, there were no extreme events in 2022.

2. No information was received by the NTIB in 2023 on catastrophes, accidents, serious incidents, incidents, DAGs, and extreme events that occurred during aviation works (including training flights), as well as during the operation of general aviation, as in 2022. This is primarily due to the introduction of a special martial law regime in Ukraine and the closure of the airspace for civil aircraft flights, and secondly to a decrease in the total amount of flight hours and the reluctance of aviation entities to inform the NTIB of such events.

In 2023, the total flight time of certified companies amounted to 80378 flight hours, which is slightly more than in 2022 (80317 hours). This was due to an increase in commercial transportation, thanks to which transport companies flew 76999 hours (in 2022: 76688 hours). In turn, the flight time for aviation works and training flights decreased and amounted to 3379 hours (in 2022, the flight time was 3629 hours).

Taking into account all the data obtained, when operating aircraft of certified companies and training organizations, the overall accident rate for high-level events (catastrophes, accidents, serious incidents) decreased (improved) by three times compared to 2022, and amounts to 1.2 events per 100 000 flight hours.

Despite the fact that 2023 was a year without aviation accidents with human casualties, the crash of a Mi-8-MTV helicopter at Gao aerodrome (Republic of Mali) resulted in serious injuries to the passengers of the aircraft. The circumstances of the events investigated by the NTIB indicate that flight safety problems persist at critical stages of flight, especially during landing. Factors contributing to these events include trivial reasons, such as the flight crew's failure to comply with standard operating procedures (SOPs), adverse weather conditions, and inadequate flight data monitoring (analysis) and government oversight programs.

Although components and procedures in the air navigation system have improved [3–6], human factors still have a major influence on flight safety: 80 percent of accidents are caused by human mistakes, and 42 percent of mistakes are caused by incorrect decision-making [7–10]. At the same time, humans are the main link in the aviation system. Thus, reducing the impact of human factors on flight safety remains a pressing issue.

2. A state-of-the-art literature review

According to the concept of collaborative decision-making (CDM) of the International Civil Aviation Organization (ICAO) [11], efficient cooperation among aviation professionals is a precondition for providing safety at any stage of an aircraft flight in both normal and abnormal situations. Aviation personnel must strictly adhere to the normative documents that have been considered in the process of their professional education and work. Meanwhile, the content of educational and guidance documents is often different, which makes it difficult for a unified algorithm for common actions, particularly in emergencies. Cooperative practical training of aviation professionals is used to avoid potential conflicts between the decisions and actions of CDM participants in actual flight situations [12].

Publication [13] describes a technique for collective training of aviation specialists (pilots and air traffic controllers (ATCO)), [14] – a game-oriented model for implementing CDM at one of the top airports in Europe, and [15] deals with the partnership programs involving aviation training organizations and air companies. The authors propose new ways to enhance the CDM between a variety of aviation specialists (UAV operators, pilots, flight dispatchers (FDs), air traffic safety electronics personnel (ATSEP), ATCOs, rescuers, technicians, etc.) during professional activities (intelligent decision support systems [16–18]) and practical training (machine learning [19], artificial neural network for pre-simulation training [20], intelligent integrated training system “CDM - Education” [21]), taking into account the influence of environmental factors [22] in emergencies. Human and Artificial (Hybrid) Intelligence could be applied to improve the CDM procedures among all aviation stakeholders based on complete information about the performance of the flight and the emergency [23–25].

The authors have developed the following CDM methods [16–22]:

- Method for the integrating of non-stochastic, stochastic, and deterministic decision-making models in uncertainty, risk, and certainty conditions.
- Method for the management of the development of flight situations using the integration of deterministic, stochastic, non-stochastic decision-making models, and CDM models (individual and collective decision-making models).

- Objective-subjective CDM method based on individual and collective decision-making models.
- CDM modeling method based on the objective factors' priority.
- CDM modeling method based on the varying Hurwitz criterion.
- "CDM-Education" method.
- Multi-stage CDM method based on a dynamic programming model with the gradual involvement of additional aviation specialists.

Optimal CDM using each method requires specialized data pre-processing, taking into account the specifics of the flight situation and the characteristics of the human-operators activity.

The purpose of this publication is improvement the collective practical training of aviation specialists based on a comparison of the pre-processing results obtained by the CDM during the joint performance of practical tasks in the emergencies "Engine failure" and "Cargo fire" considering objective and subjective factors' priority.

3. Collaborative decision-making models in the emergencies considering factors' priority

The individual decision-making matrix (DMM) for operator O_l in uncertainty conditions considering objective factors' priority is presented in Table 1 [22].

Table 1
The individual matrix for participant of decision-making (operator O_l)

The individual matrix	Priority of objective factors affecting decision-making in emergency, f_j						Solutions, c_{il}			
Factors	f_1	f_2	…	f_j	…	f_n	W	L	H, α	S
R_j	R_1	R_2	…	R_j	…	R_n	-	-	-	-
δ_j	δ_1	δ_2	…	δ_j	…	δ_n	-	-	-	-
θ_j	θ_q	θ_2	…	θ_j	…	θ_n	-	-	-	-
DMM with the priority of objective factors										
A_1^*	$\theta_1 u_{11}^*$	$\theta_2 u_{12}^*$	…	$\theta_j u_{1j}^*$	…	$\theta_n u_{1n}^*$	W_1	L_1	H_1, α	S_1
…	…	…	…	…	…	…	…	…	…	…
A_i^*	$\theta_1 u_{i1}^*$	$\theta_2 u_{i2}^*$	…	$\theta_j u_{ij}^*$	…	$\theta_n u_{in}^*$	W_i	L_i	H_i, α	S_i
…	…	…	…	…	…	…	…	…	…	…
A_m^*	$\theta_1 u_{m1}^*$	$\theta_2 u_{m2}^*$	…	$\theta_j u_{mj}^*$	…	$\theta_n u_{mn}^*$	W_m	L_m	H_m, α	S_m

In Table 1: R_j is the objective factors' ranks; δ_j is the interim estimates; θ_j is the weighting coefficients; f_j is the objective factors affecting decision-making in an emergency; c_{il} is the solutions for each participant based on the priority of objective factors; u_{ij}^* is the anticipated results under affecting objective factors; A_i^* is the alternative decisions based on the priority of objective factors. The optimal solution c_{ilopt} for each participant is based on the Wald (W), Laplace (L), Hurwitz (H), and Savage (S) criteria. The factors' priorities for decision-making in a particular emergency are defined using the experts' opinions and the Expert Judgment Method (EJM), based on statistics, and in the availability of Big Data applying an Intelligence System. The collective DMM for all operators in uncertainty conditions considering subjective factors' priority is presented in Table 2 [17]. In Table 2: c_{il}'' is the solutions for each participant from the individual matrices based on the priority of subjective factors (their opinions); A_i'' is the alternative decisions based on the priority of objective and subjective factors.

Table 2
The collective matrix for all participants of decision-making

The collective matrix	Results of solutions by all participants of decision-making, c''_{il}					
	c_1	c_2	$\dots$	c_l	$\dots$	c_L
A''_1	c''_{11}	c''_{12}	$\dots$	c''_{1l}	$\dots$	c''_{1L}
$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$
A''_i	c''_{i1}	c''_{i2}	$\dots$	c''_{il}	$\dots$	c''_{iL}
$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$
A''_m	c''_{m1}	c''_{m2}	$\dots$	c''_{ml}	$\dots$	c''_{mL}

The optimal collective solutions for all participants c''_{ilopt} are defined using the Wald (W), Laplace (L), Hurwitz (H), and Savage (S) criteria of decision-making under uncertainty with maximal safety and minimal loss considering objective and subjective factors' priority.

4. Collaborative decision-making models in the emergency "Engine failure" considering factors' priority

There is presented an example of CDM in the emergency "Engine failure" [17]. Engine failure is one of the most frequent and complex failures and accounts for 13% of the total number of incidents [26]. An engine failure can have major effects, such as loss of control of the aircraft, stalling, power supply problems, pressurization problems, etc. Depending on the pilot's responsibility, such a situation can be either urgent or emergency. Initial contact, and if deemed necessary, any further communications of the aircraft in distress, should start with the MAYDAY message. The PAN-PAN message should be utilized in the same way for an urgent situation [27]. As a result, engine failure may force a landing at the nearest available aerodrome. The decision-making for selecting an alternate aerodrome involves several aviation specialists, such as the pilot, ATCO, and FD.

The consequence of an engine failure at a high altitude is an imminent descent due to a large decrease in thrust. The pilot must perform the drift descent procedure [28]: set the maximum continuous thrust for the operating engine that can be used without restriction and at the minimum speed that ensures a steady level flight at a certain altitude.

Initial data:

1. Heavy aircraft Boeing 737-800 (mass is close to maximum landing mass 66360 kg).
2. Flight route (Figure 2) from departure aerodrome Lviv (UKLL) (A_1) to destination aerodrome Kharkiv (UKHH) (A_2).
3. Flight level FL350.
4. Alternate aerodromes:

- Dnipro (UKDD) (A_3),
- Boryspil (UKBB) (A_4).

5. The meteorological conditions at Lviv, Dnipro, Boryspil, Kharkiv responds to the minimum of category I (CAT I) (visibility of at least 800 m, of at least 60 m). Winter, the temperature is close to zero, precipitation, medium braking action.
6. Three operators are taken part in the CDM procedures: pilot (O_1), ATCO (O_2), and FD (O_3). Each operator has compiled a decision matrix, where alternatives are accessible aerodromes along the route "Lviv - Kharkiv" (Figure 2), and each operator has reviewed the identical factors in the actual situation, but with varying priorities. Factors affecting decision-making for each operator:

- $\{q\}$ are factors that are reviewed by operator O_1 (pilot),
- $\{r\}$ are factors that are reviewed by operator O_2 (ATCO),
- $\{s\}$ are factors that are reviewed by operator O_3 (FD).

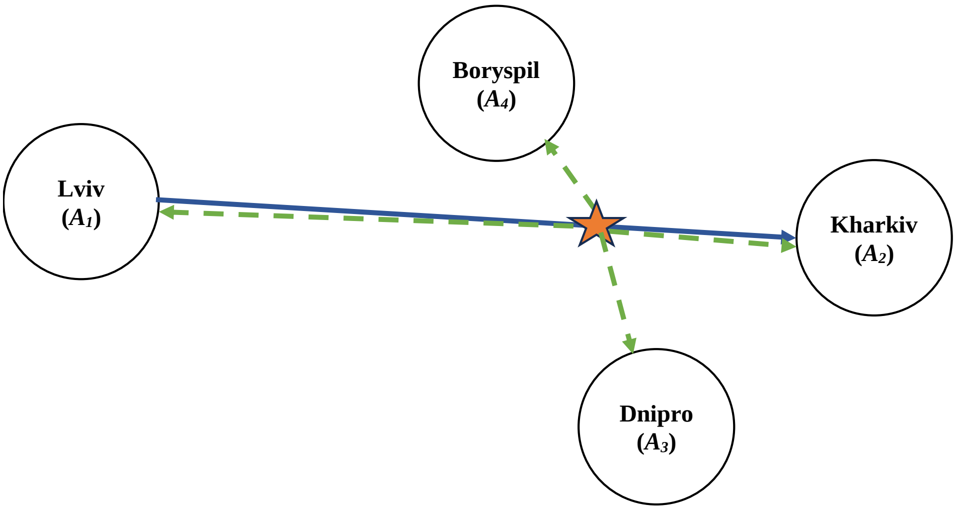

Figure 2: Schematic illustration of the flight route Lviv (A_1) – Kharkiv (A_2).

When selecting the optimal alternative, every operator (q_j, r_j, s_j) is guided by the shared objective factors [17; 18]:

- q_1, r_1, s_1 are fuel supply on board,
- q_2, r_2, s_2 are distance of the alternate aerodrome,
- q_3, r_3, s_3 are technical characteristics of the runway,
- q_4, r_4, s_4 are weather conditions at the alternate aerodrome,
- q_5, r_5, s_5 are light signaling system for approaching the landing,
- q_6, r_6, s_6 are accessible system of approach,
- q_7, r_7, s_7 are accessible navigation means,
- q_8, r_8, s_8 are flight and technical characteristics of the aircraft,
- q_9, r_9, s_9 are radio communication link,
- q_{10}, r_{10}, s_{10} are intensity of air traffic,
- q_{11}, r_{11}, s_{11} are business essence.

The individual DMM for all operators in emergency "Engine failure" based on the Wald (*W*) criterion, Laplace (*L*), Hurwitz (*H*), and Savage (*S*) criteria are in Tables 2–4. Results anticipated by the pilot (operatorO_1) are represented in Table 3. Factors' priority for the pilot are q_3, q_4, q_8 (green color in Table 3). The optimal landing aerodromes when approaching en route "Lviv – Kharkiv" as decided by the pilot are (red color in the matrix): by the Wald criterion (*W*) - Kharkiv (A_2); by the Laplace criterion (*L*) - Boryspil (A_4); by the Hurwitz criterion (*H*) - Kharkiv (A_2); by the Savage criterion (*S*) - Kharkiv (A_2). Results anticipated by the ATCO (operator O_2) are represented in Table 4. Factors' priority for the ATCO are r_3, r_4, r_8 (green color in Table 4).

The optimal landing aerodromes when approaching en route "Lviv - Kharkiv" as decided by the ATCO are (red color in the matrix): by the Wald criterion (*W*) - Kharkiv (A_2); by the Laplace criterion (*L*) - Boryspil (A_4); by the Hurwitz criterion (*H*) - Kharkiv (A_2); by the Savage criterion (*S*) - Kharkiv (A_2).

The DMM of possible results of FD decision-making when selecting the optimal landing aerodrome at the flight-planning step is represented in Table 5. Factors' priority for the FD are s_3, s_4, s_{10} (green color in Table 5).

Table 3
The individual DMM for the pilot (operator O_1)

DMM 1		Factors affecting the pilot (operator O_1) decision-making											Solutions			
Alternative decisions $\{A\}$		q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8	q_9	q_{10}	q_{11}	W	L	H, α=0.5	S
Departure aerodrome	*Lviv* (A_1)	4	1	10	10	9	10	9	10	8	3	3	1	7.0	5.5	9
Desti-nation aerodrome	*Kharkiv* (A_2)	8	7	9	5	8	8	8	9	7	9	10	5	8.0	7.5	5
Alternate aero-dromes	*Dnipro* (A_3)	4	5	7	8	9	8	8	9	8	5	10	4	7.4	7	6
	Boryspil (A_4)	7	8	7	7	10	10	10	10	9	4	10	4	8.4	7	6

Table 4
The individual DMM for the ATCO (operator O_2)

DMM 2		Factors affecting the ATCO (operator O_2) decision-making											Solutions			
Alternative decisions $\{A\}$		r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	W	L	H, α=0.5	S
Departure aerodrome	*Lviv* (A_1)	4	1	10	9	9	10	9	10	8	2	7	1	7.2	5.5	9
Desti-nation aerodrome	*Kharkiv* (A_2)	8	7	9	6	8	8	8	9	7	6	8	6	7.6	7.5	3
Alternate aero-dromes	*Dnipro* (A_3)	4	5	7	7	9	8	8	9	8	2	6	2	6.6	5.5	7
	Boryspil (A_4)	7	8	7	7	10	10	10	10	9	1	8	1	7.9	5.5	9

Table 5
The individual DMM for the FD (operator O_3)

DMM 3		Factors affecting the FD (operator O_3) decision-making											Solutions			
Alternative decisions $\{A\}$		s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	W	L	H, α=0.5	S
Departure aerodrome	*Lviv* (A_1)	5	5	10	9	9	9	9	10	8	2	7	2	7.5	6.0	8
Desti-nation aerodrome	*Kharkiv* (A_2)	8	6	9	6	8	8	8	9	7	6	8	6	7.5	7.5	3
Alternate aero-dromes	*Dnipro* (A_3)	5	5	7	7	9	9	9	9	8	2	6	2	6.9	5.5	7
	Boryspil (A_4)	7	6	7	7	10	10	10	10	9	1	8	1	7.7	5.5	9

The optimal landing aerodromes when approaching en route "Lviv – Kharkiv" as decided by the FD are (red color in the matrix): by the Wald criterion (W) - Kharkiv (A_2); by the Laplace criterion (L) - Boryspil (A_4); by the Hurwitz criterion (H) - Kharkiv (A_2); by the Savage criterion (S) - Kharkiv (A_2). To determine the coherence of the operators, the collective DMM were built, in which the factors for the operators (pilot (O_1), ATCO (O_2), and FD (O_3)) are similar, and the operator's solution are taken from individual DMM (Tables 6-8).

Table 6
The collective DMM for operator's together (Wald criterion)

Alternate aerodromes	Pilot	ATCO	FD	CDM
	O_1	O_2	O_3	Wald criterion
Lviv (A_1)	1	1	2	1
Kharkiv (A_2)	5	6	6	5
Dnipro (A_3)	4	2	2	2
Boryspil (A_4)	4	1	1	1

Table 7
The collective DMM for operator's together (Laplace criterion)

Alternate aerodromes	Pilot	ATCO	FD	CDM
	O_1	O_2	O_3	Laplace criterion
Lviv (A_1)	7.0	7.2	7.5	**7.0**
Kharkiv (A_2)	8.0	7.6	7.5	**7.5**
Dnipro (A_3)	7.4	6.6	6.9	**6.6**
Boryspil (A_4)	8.4	7.9	7.7	**7.7**

Table 8
The collective DMM for operator's together (Hurwicz criterion)

Alternate aerodromes	Pilot	ATCO	FD	CDM
	O_1	O_2	O_3	Hurwicz criterion
Lviv (A_1)	7.5	7.5	7.5	**7.5**
Kharkiv (A_2)	7.0	5.5	5.5	**5.5**
Dnipro (A_3)	7.0	5.5	5.5	**5.5**
Boryspil (A_4)	5.5	5.5	6.0	**5.5**

The CDM matrices use subjective factors, such as the opinions of operators.

The optimal CDM when this is a scheduled flight (Wald criterion) is presented in Table 6. In this event, the optimal landing aerodrome is defined by the objective factors (fuel supply on board; a distance of the alternate aerodrome; technical characteristics of the runway; weather conditions at the alternate aerodrome; light signaling system for approaching the landing; accessible system of approach; accessible navigation means; flight and technical characteristics of the aircraft; radio communication link; the intensity of air traffic, and business essence) and subjective factors (opinions of the pilot, ATCO, and FD) is destination aerodrome Kharkiv (A_2) (red color in the matrix). The optimal CDM under the assumption that this flight is regular (Laplace criterion) is presented in Table 7- is Boryspil (A_4) (red color in the matrix). Optimal CDM by different approaches using the optimism-pessimism ratio $\alpha = 0.5$ (Hurwicz criterion) is presented in Table 8 - is Lviv (A_1). The coherence of decisions grows with an increasing ratio of optimism, with a decreasing ratio in the pessimism direction, the discrepancy rises.

The coherence of decisions using the Savage criterion (the post-flight recalculation), is defined for the loss initial matrix (Table 9).

The collective loss matrix is presented in Table 10. It indicates risks if operators do not select the optimal team solution. The minimum risks are chosen, which are then mitigated.

The optimal landing aerodrome in the emergency "Engine failure", defined by both objective and subjective factors, is destination aerodrome Kharkiv (A_2) by the Wald and Savage criteria; alternative aerodrome Boryspil (A_4) by the Laplace criterion; or departure aerodrome Lviv (A_1) by the Hurwicz criterion.

To compare decision-making in different situations, the emergency "Fire" is considered. The problem is solved taking into account decision-making priorities (main factors: f_1, f_2, f_3, f_8). Individual decisions of the pilot, ATCO, and engineer (ATSEP) are presented in the Table 11.

Table 9
The collective DMM for operators' together (Savage criterion – recalculation)

Alternate aerodromes	Pilot	ATCO	FD	CDM
	O_1	O_2	O_3	Savage criterion
Lviv (A_1)	4	6	5	6
Kharkiv (A_2)	0	0	0	0
Dnipro (A_3)	1	4	4	4
Boryspil (A_4)	1	6	6	6

Table 10
The collective loss DMM for operators' together (Savage criterion)

Alternate aerodromes	Pilot / loss	ATCO / loss	FD / loss	Max loss
	O_1	O_2	O_3	Savage criterion
Lviv (A_1)	4	6	5	6
Kharkiv (A_2)	0	0	0	0
Dnipro (A_3)	1	4	4	4
Boryspil (A_4)	1	6	6	6

Table 11
The collective DMM for operator's together (Wald criterion)

Alternate aerodromes	Pilot	ATCO	ATSEP	CDM
	O_1	O_2	O_3	Wald criterion
Lviv (A_1)	0.076	0.076	0.076	**0.076**
Kharkiv (A_2)	0.076	0.061	0.076	**0.061**
Dnipro (A_3)	0.106	0.091	0.106	**0.091**
Boryspil (A_4)	0.121	0.121	0.121	**0.121**
Gostomel (A_5)	0.121	0.121	0.121	**0.121**

The third participant in the process is an engineer, the alternative aerodrome Gostomel (A_5) is added to the alternative solutions as the most suitable for landing (minimum distance). Priority of factors for the participants: pilot, ATCO, and engineer is presented in Figure 3.

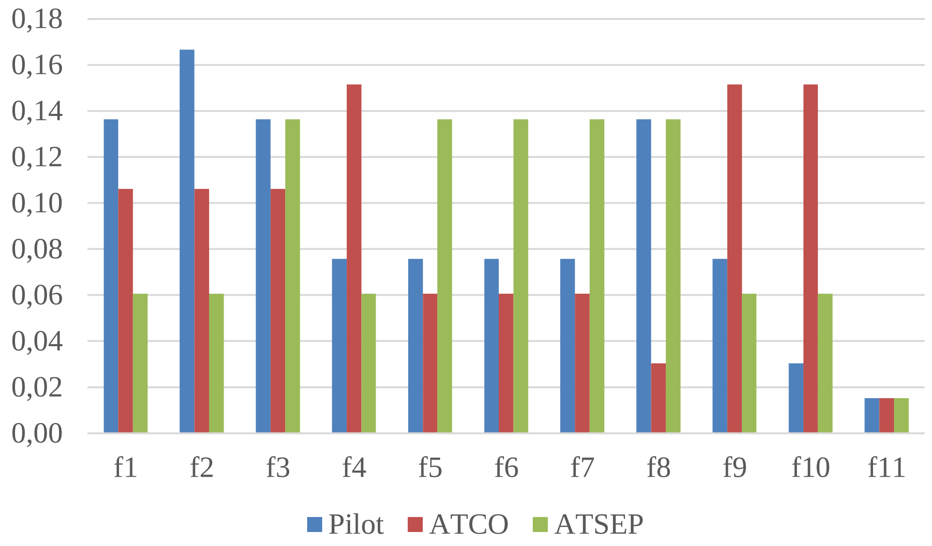

Figure 3: Priority of factors on the flight route Lviv – Kharkiv.

In the learning process of students, trainings were held to optimize CDM by aviation specialists during practical training, taking into account the priority of factors.

5. Collaborative decision-making models in the emergency "Cargo fire" considering factors' priority

"Consider example of CDM in case of "Cargo fire" [22] when approaching the same en-route Lviv (A_1) - Kharkiv (A_2) and taking into account similar objective and subjective factors with other anticipated results under their affecting. The significant proportions of incidents are engine failure (13 percent) and smoke/fire on the aircraft (11 percent), as reported by the Transportation Safety Board of Canada collected for the period from 2007 to 2017 [29].

An onboard fire is one of the most dangerous incidents for an aviation crew. A fire on an aircraft can rapidly cause a disastrous aircraft loss if the crew fails to take active measures. If a fire does break out, the likelihood that the crew will be able to eliminate it is very low. In the case of a fire on board, the pilot has an estimated 17 minutes to return the aircraft to the ground. Unrestricted fire can burn down an aircraft in as few as 20 minutes. Fire can totally destroy a smoke-filled cabin in 6-10 minutes. Time is of the utmost importance when extinguishing fires in flight. Fires on aircraft can occur in various places and for numerous reasons. Aircraft fires are usually classified into three categories: engine, cabin, and hidden fire [30]. Fires in the cockpit, passenger compartment, baggage compartment, and cargo compartment occur during flight for many reasons, such as faulty wiring, electrical components, lithium-ion batteries, and chain protection. Many fires in the cabin are caused by human factors (e.g., incorrect battery storage in gadgets, dangerous goods, or terrorism).

Four operators are taken part in the CDM procedures: pilot (O_1), ATCO (O_2), FD (O_3), and engineer (ATSEP) (O_4). Factors affecting decision-making for each operator:

- $\{q\}$ are factors that are reviewed by operator O_1 (pilot)
- $\{r\}$ are factors that are reviewed by operator O_2 (ATCO)
- $\{s\}$ are factors that are reviewed by operator O_3 (FD)
- $\{t\}$ are factors that are reviewed by operator O_4 (ATSEP)

The individual DMM for all operators in emergency "Cargo fire" based on the Wald (*W*) criterion, Laplace (*L*), Hurwitz (*H*), and Savage (*S*) criteria are in Tables 12–15. Results anticipated by the pilot (operator O_1) are represented in Table 12. Priority of factors for the pilot are q_3, q_4, q_8 (green color in Table 12).

Table 12
The individual DMM for the pilot (operator O_1)

DMM 1		Factors affecting the pilot (operator O_1) decision-making											Solutions			
Alternative decisions $\{A\}$		q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8	q_9	q_{10}	q_{11}	W	L	H, α=0.5	S
Departure aerodrome	*Lviv (A_1)*	3	3	10	6	9	9	9	9	9	8	3	3	7.1	6.5	7
Destination aerodrome	*Kharkiv (A_2)*	8	8	9	6	9	9	9	9	9	9	9	6	8.5	7.5	3
Alternate aerodromes	*Dnipro (A_3)*	8	8	9	6	8	8	8	7	9	9	9	6	8.1	7.5	3
	Boryspil (A_4)	8	8	10	6	10	10	10	9	9	7	7	6	8.5	8.0	4

The optimal landing aerodromes when approaching en route "Lviv - Kharkiv" as decided by the pilot are (red color in the matrix): by the Wald criterion (*W*) - Kharkiv (A_2), Dnipro (A_3), and Boryspil (A_4); by the Laplace criterion (L) - Kharkiv (A_2) and Boryspil (A_4); by the Hurwitz criterion (*H*) - Boryspil (A_4); by the Savage criterion (*S*) - Kharkiv (A_2) and Dnipro (A_3).

Results anticipated by the ATCO (operator O_2) are represented in Table 13. Factors' priority for the ATCO are r_3, r_4, r_8 (green color in Table 13).

The optimal landing aerodromes when approaching en route "Lviv - Kharkiv" as decided by the ATCO are (red color in the matrix): by the Wald (W), Laplace (L), Hurwitz (H), and Savage (*S*) criteria - Boryspil (A_4).

Table 13
The individual DMM for the ATCO (operator O_2)

DMM 2		Factors affecting the ATCO (operator O_2) decision-making											Solutions			
Alternative decisions $\{A\}$		r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	W	L	H, α=0.5	S
Departure aerodrome	*Lviv (A_1)*	6	6	9	8	8	8	8	6	8	6	5	5	7.1	7.0	4
Destination aerodrome	*Kharkiv (A_2)*	7	8	8	7	7	8	7	6	7	4	6	4	6.8	6.0	4
Alternate aerodromes	*Dnipro (A_3)*	8	7	8	7	7	8	7	5	7	5	7	5	6.9	6.5	3
	Boryspil (A_4)	8	8	9	8	9	9	8	7	9	7	8	7	8.2	8.0	2

The DMM of possible results of FD decision-making when selecting the optimal landing aerodrome at the flight-planning step is represented in Table 14. Factors' priority for the FD are s_3, s_4, s_{10} (green color in Table 14).

The optimal landing aerodromes when approaching en route "Lviv - Kharkiv" as decided by the FD are (red color in the matrix): by the Wald (W), Laplace (L), Hurwitz (H), and Savage (*S*) criteria - Boryspil (A_4).

Table 14
The individual DMM for the FD (operator O_3)

DMM 3		Factors affecting the FD (operator O_3) decision-making											Solutions			
Alternative decisions $\{A\}$		s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	W	L	H, α=0.5	S
Departure aerodrome	*Lviv (A_1)*	6	6	9	8	8	8	8	6	8	6	5	5	7.1	7.0	4
Desti-nation aerodrome	*Kharkiv (A_2)*	7	8	8	7	7	8	7	6	7	4	6	4	6.8	6.0	4
Alternate aero-dromes	*Dnipro (A_3)*	8	7	8	7	7	8	7	5	7	5	7	5	6.9	6.5	3
	Boryspil (A_4)	8	8	9	8	9	9	8	7	9	7	8	7	8.2	8.0	2

The DMM of possible results of ATSEP decision-making when selecting the optimal landing aerodrome is represented in Table 15. Factors' priority for the FD are t_3, t_4, t_{10} (green color in Table 15).

The optimal landing aerodromes when approaching en route "Lviv - Kharkiv" as decided by the ATSEP are (red color in the matrix): by the Wald (W), Laplace (L), Hurwitz (H), and Savage (S) criteria - Boryspil (A_4).

Table 15
The individual DMM for the ATSEP (operator O_4)

DMM 4		Factors affecting the ATSEP (operator O_4) decision-making											Solutions			
Alternative decisions $\{A\}$		t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	W	L	H, α=0.5	S
Departure aerodrome	*Lviv (A_1)*	7	7	8	7	8	8	7	5	8	6	5	5	6.9	7.7	4
Desti-nation aerodrome	*Kharkiv (A_2)*	7	8	7	6	7	8	7	6	7	4	5	4	6.5	7.6	3
Alternate aero-dromes	*Dnipro (A_3)*	8	6	7	7	7	7	6	5	6	5	7	5	6.5	7.7	3
	Boryspil (A_4)	8	8	8	8	9	9	7	6	8	6	6	6	7.5	8.7	0

To determine the coherence of the operators, the collective DMM were built, in which the factors for the operators (pilot (O_1), ATCO (O_2), FD (O_3), and ATSEP (O_4)) are similar, and the operators' solutions are taken from individual DMM, represented in Tables 15–17. The CDM matrices use subjective factors, such as the opinions of operators.

The optimal CDM when this is a scheduled flight (Wald criterion) is presented in Table 16. In this event, the optimal landing aerodrome is defined by the objective factors (fuel supply on board; distance of the alternate aerodrome; technical characteristics of the runway; weather conditions at the alternate aerodrome; light signaling system for approaching the landing; accessible system of approach; accessible navigation means; flight and technical characteristics of the aircraft; radio communication link; intensity of air traffic, and business essence) and subjective factors (opinions of the pilot, ATCO, FD, and ATSEP) is alternative aerodrome Boryspil (A_4) (red color in the matrix).

Table 16
The collective DMM for operators' together (Wald criterion)

Alternate aerodromes	Pilot	ATCO	FD	ATSEP	CDM
	O_1	O_2	O_3	O_4	Wald criterion
Lviv (A_1)	3	5	5	5	**3**
Kharkiv (A_2)	6	4	4	4	**4**
Dnipro (A_3)	6	5	5	5	**5**
Boryspil (A_4)	6	7	7	6	**6**

The optimal CDM under the assumption that this flight is regular (Laplace criterion) is presented in Table 17 – is Boryspil (A_4) (red color in the matrix).

Table 17
The collective DMM for operators' together (Laplace criterion)

Alternate aerodromes	Pilot	ATCO	FD	ATSEP	CDM
	O_1	O_2	O_3	O_4	Laplace criterion
Lviv (A_1)	7.1	7.1	7.1	6.9	**6.9**
Kharkiv (A_2)	8.5	6.8	6.8	6.6	**6.6**
Dnipro (A_3)	8.1	6.9	6.9	6.5	**6.5**
Boryspil (A_4)	8.5	8.2	8.2	7.6	**7.6**

Optimal CDM by different approaches using the optimism-pessimism ratio $\alpha = 0.5$ (Hurwicz criterion) is presented in Table 18 – is Lviv (A_1). The coherence of decisions grows with an increasing ratio of optimism, with a decreasing ratio in the pessimism direction, the discrepancy rises.

Table 18
The collective DMM for operators' together (Hurwicz criterion)

Alternate aerodromes	Pilot	ATCO	FD	ATSEP	CDM
	O_1	O_2	O_3	O_4	Hurwicz criterion
Lviv (A_1)	6.5	7.0	7.0	7.7	6.5
Kharkiv (A_2)	7.5	6.0	6.0	7.6	6.0
Dnipro (A_3)	7.5	6.5	6.5	7.7	6.5
Boryspil (A_4)	8.0	8.0	8.0	8.7	8.0

The optimal landing aerodrome in the emergency "Cargo fire", defined by both objective and subjective factors, is alternative aerodrome Boryspil (A_4) by the Wald, Laplace, and Hurwicz criteria.

6. Results and discussions

The individual and collective matrices for participants of decision-making in uncertainty conditions considering objective and subjective factors' priority are developed. An example of selecting the optimal landing aerodromes when approaching the same en route "Lviv – Kharkiv" in emergencies "Engine failure" and "Cargo fire" determined by similar objective factors (fuel supply on board; distance of the alternate aerodrome; technical characteristics of the runway; weather conditions at the alternate aerodrome; light signaling system for approaching the landing; accessible system of approach; accessible navigation means; flight and technical characteristics of the aircraft; radio communication link; intensity of air traffic, and business essence) and subjective factors (opinions of the aviation specialists) with another anticipated results under their affecting are:

- in the emergency "Engine failure" (three operators: pilot (O_1), ATCO (O_2), and FD (O_3)) – are destination aerodrome Kharkiv (A_2) by the Wald and Savage criteria; alternative aerodrome Boryspil (A_4) by the Laplace criterion; or departure aerodrome Lviv (A_1) by the Hurwicz criterion,
- in the emergency "Cargo fire" (four operators: pilot (O_1), ATCO (O_2), FD (O_3), and engineer (ATSEP) (O_4)) – is alternative aerodrome Boryspil (A_4) by the Wald, Laplace, and Hurwicz criteria.

The calculations using the Wald (maximal safety) and Savage (minimal loss) criteria have demonstrated an interrelation between safety and cost of the flight, as well as the dependence of the anticipated results of decision-making on the priority of the effect of both objective and subjective factors.

To compare decision-making in different situations, the emergency "Fire" when approaching en route "Lviv – Kharkiv" is considered. The problem is solved taking into account decision-making priorities (main factors: fuel supply on board; distance of the alternate aerodrome; technical characteristics of the runway; flight and technical characteristics of the aircraft) by the pilot (O_1), ATCO (O_2), and engineer (ATSEP) (O_3). The alternative aerodrome Gostomel (A_5) is added to the alternative solutions as the most suitable for landing (minimum distance).

In the learning process of students, trainings were held to optimize CDM by aviation specialists during practical training, taking into account the priority of factors.

7. Conclusions

In 2023, the factors that led to aviation incidents and accidents involving Ukrainian civil aircraft were distributed as follows: 8 (16%) – human factors (5 (10%) aircraft crews and 3 (6%) maintenance personnel); 23 (47%) – technical factors (failures of systems and components for technical reasons); 17 (35%) – external environment (including ornithology); 1 (2%) – unspecified factors. The accident rate for aviation work and training flights remained unchanged at zero, the same as in 2022. The volume of flight hours decreased by 250 hours (6.9%) compared to 2022. When operating aircraft of certified companies and training organizations, the overall accident rate for high-level events (catastrophes, accidents, serious incidents) decreased (improved) by three times compared to 2022, and amounts to 1.2 events per 100 000 flight hours.

This paper presents a novel aspect of the practical training for aviation specialists utilizing CDM methods, required particularly in emergencies. Although components and procedures in the air navigation system have improved, human factors still have a major influence on flight safety: 80 percent of accidents are caused by human mistakes, and 42 percent of mistakes are caused by incorrect decision-making. At the same time, humans are the main link in the aviation system. Thus, reducing the impact of human factors on flight safety remains a pressing issue.

CDM is a procedure for involving individual and collective data by diverse interacting aviation personnel in professional decisions. Effective use of the CDM requires harmonization of decisions taken by stakeholders, sharing of relevant data, and efficient balancing of safety and cost in-group decisions. It is essential to ensure that a joint, comprehensive decision can be made with colleagues at an appropriate level of efficiency. This is accomplished by the comprehensiveness and accuracy of the available data, as well as coordinated cooperation between aviation specialists, their distinct and proper interpretation of job responsibilities, and their roles in the completion of a joint task.

Collective practical training of aviation specialists is a major phase of professional education and performs a considerable role in further assuring flight safety. The authors have proposed the improvement of collective practical training of aviation specialists based on a comparison of the pre-processing results obtained by the CDM during the joint performance of practical tasks in the emergency situations of “Engine failure” (the most frequent) and "Cargo failure" (the most danger) considering objective and subjective factors’ priority. Based on the EJM and the Wald, Laplace, Hurwitz, and Savage criteria in uncertainty conditions, models of individual and collective decision-making when selecting the optimal aerodrome for forced landing taking into account the objective and subjective factors are developed.

Aviation specialists have a great deal of commonality in the features of the learning professional environment in relation to the creation of their core competencies. Since CDM cognitive processes are the most important for supporting a holistic mental picture of operational awareness and air situation development, it is suggested to implement them in the training programs, as an integral part of the realization of the CDM concept in conditions of a common educational environment (CDM-E), cooperative work in emergencies for aviation personnel. The basic benefits of implementing a common educational environment in the learning of future aviation specialists are presented in [21]: enhanced of communications, flight safety, collaboration, and the economic efficiency of training.

Further research will be aimed firstly at data pre-processing for planning and modeling situations in Intelligent (Hybrid) Integrated Training System CDM-E [21] based on Machine Learning and Big Data analyzing tools. It will allow for optimizing the CDM of aviation specialists (manned and unmanned aircraft pilots, ATCOs, FDs, ATSEP, maintenance staff, ground services personnel, etc.) in emergencies considering the objective and subjective factors’ priority.

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