



# Collaborative Decision Making (CDM) in Emergency Caused by Captain Incapacitation: Deterministic and Stochastic Modelling


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## ABSTRACT

The authors present a new approach to decision-making to ensure the proper collaboration of different personnel. Models are used in intelligent integrated decision support systems, especially for actions in emergencies. Behavioral deterministic models are used for synchronization actions of all operators, to support and timely predicting of operators' actions in an emergency. To determine the quantitative characteristics of risk levels, models for collaborative decision making (CDM) under uncertainty by the operators (pilots, air traffic controllers, flight/dispatch), and other invited specialists, have been developed. The decision-making modeling of a group of operators in case of an emergency situation such as “pilot incapacitation” was presented. The methodological basis for CDM in certainty is network planning, in conditions of Stochastic uncertainty – is a decision tree, in conditions of non-stochastic uncertainty – is a matrix of decisions, and outcomes are made this using the expert judgment method for obtaining quantity estimations.

## KEYWORDS

Collaborative Decision Making (CDM), Decision Making in Risk, Decision Making in Uncertainty, Deterministic, emergency, Intelligent Integrated Decision Support System, Modelling, Stochastic

## 1. INTRODUCTION

Analysis of aviation events shows that the cause of more than 80% of is the human factor. Generally, most aviation specialists are sufficiently trained as professionals (International Civil Aviation Organization [ICAO], 2002a, 2004; Aviation Accident Statistics [AAS], 2017; Leychenko et al., 2006). As of now ICAO constantly develops and improves proactive, based on the evaluation of the risks, and methods, directed at the further decrease in the number of aviation events in the world. There are many circulars, documents, and reports of ICAO presented conceptual models of human factors (ICAO,

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2002a, 2004, 2013) starting from a well-known model SHEL model (Software (procedures) - Hardware (machines) - Environment - Liveware), and next evolution of models to SHELL and SCHELL. The components such as “Culture” and the influence of society are important for safety in aviation, for example, SCHELL model (ICAO, 2004; Shmelova, et al., 2017). The component “Culture” means the ongoing interaction of a group of people with their environment. Culture develops and changes due to technological, physical, and social changes in the environment. Culture is embedded in four general contexts: political, physical, social, economic, etc. The component “Liveware - Liveware” means rational interaction between operators in aviation systems and Air Navigation Systems (ANS). ANS is presented as Socio-Technical System with determining the influence of the factors (professional and non-professional) that influence DM by the H-O in STS (individually psychological, socio-psychological, and psychophysiological factors) on professional activity and preventing catastrophic situations (Kharchenko, et al., 2012; 2016). The last modern models are related to the next directions:

- Flight & Flow Information for a Collaborative Environment (FF-ICE) (ICAO, 2012)
- Collaborative Decision Making (CDM) (ICAO, 2014).
- System-Wide Information Sharing and Management (SWIM) (ICAO, 2015).
- Global Aviation Security Plan (GASP) (ICAO, 2017).
- Artificial Intelligence (AI) and Intelligence Decision Support system (ICAO, 2017; 2018).
- Remotely Piloted Aircraft System (RPAS) Concept of operations (CONOPS) (ICAO, 2019).
- Year of Security Culture (YOSC) (ICAO, 2021)
- Integrated Communications, Navigation, Surveillance, and Spectrum (ICNSS) (ICAO, 2022).

The relevant modern concepts are the information and intelligent support (AI) of collective solutions (CDM) of different specialists in an emergency (ICAO, 2017; International Air Transport Association [IATA], 2019). The Concept of operations (CONOPS) describes the operating environment of Manned and Unmanned Aerial Vehicles (UAV) in integrated airspace (ICAO, 2020). The introduction of new technological solutions for modeling CDM and intelligent support of collective solutions requires the use of a modern information environment based on the concepts of SWIM, ICNSS, CONOPS and FF-ICE, for the joint use of airspace and integration of Communications, Navigation, Surveillance (CNS) systems (ICAO, 2009, 2002b, 2005, 2012, 2015, 2022; IATA, 2019). The effectiveness of CDM modeling is especially relevant in the event of an emergency in flight but in a critical situation as usually many specialists and many solutions too! The main specialists who participate in the collective solutions are presented in Figure 1.

The occurrence of an emergency in flight is characterized by incompleteness and uncertainty of information. Decision-making (DM) takes place in conditions of acute shortage of time and significant psycho-physiological load, which is one of the reasons for violations and mistakes (ICAO, 2004, 2013, 2021; Shmelova, et al., 2017). Finding the best solution in such conditions requires processing much more information than under normal flight conditions.

There are a lot of professionals involved in the provision of safety during the performance of flights such as pilots, air traffic controllers, flight dispatchers, all flight crew, maintenance staff, ground handling personnel, etc. Each of them plays a major role at different stages and in different situations and they strictly follow the manuals and legal documents approved in the field of their professional activity. The main activities of aviation specialists in accordance with the stage of aircraft operation are presented in Table 1 (Shmelova & Sikirda, 2021; Shmelova, et al., 2021, 2022).

Sometimes specialists from other fields, such as emergency and ground services, and medical staff may be involved in CDM (Figure 2). For example, in case of pilot incapacitation, digital health and telemedicine in emergencies are applied, allowing to invite qualified medical personnel for a consultation in case of incapacitation of one of the pilots or one of the passengers too (Salem, 2020; Digital Medicine [DM], 2022; Air Care International (ACI), 2022). The work is dedicated to the

Figure 1. Main specialists - participants in CDM

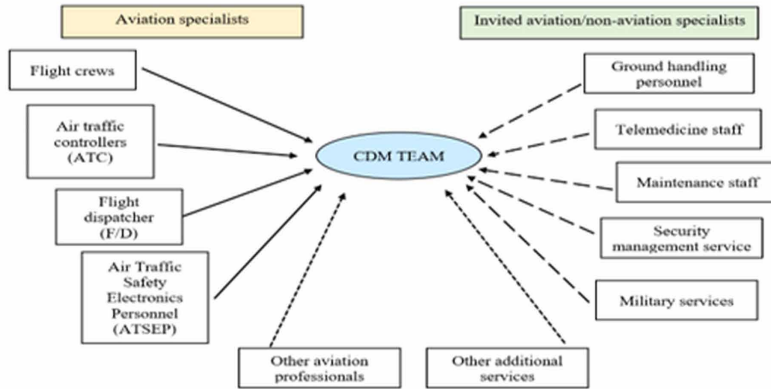


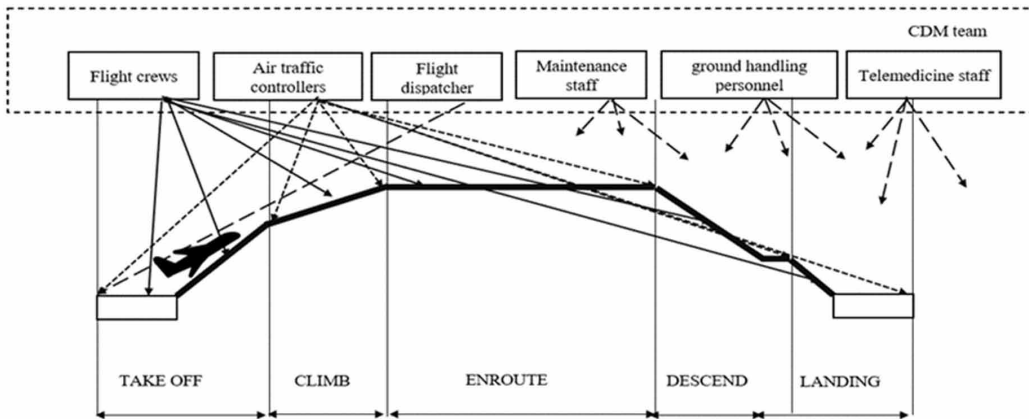
Table 1. The main actions of aviation specialists according to the stage of aircraft operation

Aviation specialist	Stage of flight	Operations	Documents, sources
Pilot-in-command (PIC)	Flight	Is holding the full right of DM before departure and taking all responsibility in flight, following existing aircraft flight and operations manuals, Quick Reference Handbooks (QRH) in emergency and abnormal conditions according to the type of aircraft	State aviation authority of Ukraine, 2005, FAA, 2020, QRH, 2013
Air traffic control officer (ATCO), Air traffic controller (ATO)	Safety of flights of aircraft in the control sector of airspace	Ensures required aircraft separation minima are established in each sector of airspace and provides flight crews with assistance in emergencies, according to the instructions defined and approved within particular air traffic control sector, by national laws, letters of agreement between neighbouring countries, and handbooks in case of aircraft emergencies	ICAO, 2007, EUROCONTROL, 2003, Torres, 2012. Shmelova et al., 2021, 2022
Flight dispatch (FD)	Planning	Responsible for flight planning and organization, for choice of the optimal flight route, alternate aerodromes, and proper fuel amount calculation for definite flights, regulated by international and national documents, orders, and instructions for the normal and abnormal operational environment of aircraft	ICAO, 1998. Shmelova et al., 2021, 2022
Other invited specialists	All stages	According to solved problems such as all flight crew, maintenance staff, ground handling personnel, qualified medical personnel etc.	Regulatory documents in accordance with the profession

problem of predicting developing emergency “pilot incapacitation” as an actual case in flight (AAS, 2017; Federal Aviation Administration [FAA], 2020; SkyBrary, 2022a).

The DM process gets more complicated if added some technical malfunction or environmental hazards or a combination of them, and the level of complexity will be increased over time. The risk of human error for remaining pilots increases gradually too. It will be so helpful to have intelligence support for the pilot (on board of aircraft) or IDSS with modeling CDM by all participants to minimize the risk of making the wrong decisions and decrease the level of stress in process of flight operation.

Figure 2. The team of human-operators involved in CDM during the flight stage of aircraft operation



*The authors propose to build* an Intelligent Decision Support System (IDSS) to find the CDM using hybrid (man-machine) intelligence. An effective decision is made by a group of participants such as operators (pilots, ATCOs, medicine specialist) and AI, for example, when incapacitating the captain of an aircraft during take-off.

The CDM modeling in IDSS uses a Method of subjective-objective CDM in an emergency (Shmelova, et al., 2021; 2022) and the Method of Integration of DM models (deterministic and stochastic) in an emergency (Shmelova, 2019; Shmelova, et al., 2021, 2022).

## 2. LITERATURE REVIEW

The latest demands of international aviation organizations are directed toward the implementation of an integrated approach for the improvement of aviation safety. Many ICAO documents describe the problems in aviation and include recommending the creation of effective timely support of operators, especially in the support of pilots in emergencies (ICAO, 2012, 2014, 2019, 2022; IATA, 2019). There is an approach, founded on the characteristics (Performance-Based Approach – PBA) (ICAO, 2009, 2013, 2022), and based on the next three principles:

1. Strong focus on desired/required results.
2. Informed DM driven by those desired/required results.
3. Reliance on facts and data for DM.

The principle of “using facts and data while DM” admits that tasks shall comply with the widely known management criteria SMART (Mulder, 2007; Kharchenko, et al., 2012, 2016; Sikirda & Shmelova, 2021):

- Specific
- Measurable
- Achievable
- Relevant
- Time-bound.

But if solutions are in a unique environment (aviation) it is a systematic approach to the mental process used by pilots to consistently determine the best course of action in response to a given set of circumstances. It is what a pilot intends to do, based on all the latest information he has (FAA, 2020).

The classic structure of DSS in ANS has problems with obtaining initial data in solutions, lack of data, and the minimum number of typical situations. There are standards and regulations to DM in every situation in flight, but every situation is unique and unrepeatable. Pilots have some experience, and pilots have obligatory training to support their skills in simulators, every six months. As a rule, pilots have simulator training and work out DM in emergencies according to the type of aircraft (ICAO, 2007; EUROCONTROL, 2003; Torres, 2012; Flight Crew Training Manual [FCTM] Boeing 737, 2005; Shmelova et al., 2021, 2022). When creating intelligent support for operators (pilots), especially in emergency situations the problem is solved using CDM modeling with the participation of different operators (pilots, air traffic controllers, flight dispatchers, all flight crew, maintenance staff, ground handling personnel, etc.)

Nowadays ICAO encourages aviation communities to recognize the importance of adherence to the single global approach for safety improvement and monitoring (ICAO, 2013; 2022). Manuals of ICAO's "Global Air Traffic Management Operational Concept" (ICAO, 2005; 2013) present basic methods and benefits of the support of aviation operators in their professional operations for using DSS for difficult or emergencies. Proper collaboration is possible through the provision of air traffic management (ATM) system members with an environment that ensures enough storage of significant information and its proper usage among ATM systems (ICAO, 2007, 2013, 2014, 2020). In this environment, all members closely interact with each other in making common decisions and achieving the so-called CDM and effective integration of systems. These concepts foresee the improvement of the whole performance of the ATM system in general taking into consideration the individual performance of ATM system members. The key aspects include support for a PBA, FF-ICE, CDM, and SWIM by flight trajectory and give the information environment in support of that process (ICAO, 2017, 2018, 2020). Expected benefits of these approaches such as (ICAO, 2015, 2017, 2020, 2022):

1. *From an airspace user (pilots)* - safety systems will be more effective (greater airspace access, to timely and meaningful information for decision support, including conflict management).
2. *From a service provider (ATM)* - safety system will be perspective, the ability to operate within an information-rich environment, with real-time data, as well as predictive data, fused with a range of DSS or DM tools, will enable optimization of services to airspace users.
3. *From a regulator perspective* - safety systems will be robust and open, allowing safety not only to be more easily measured and monitored, but compared, and integrated for continuous improvement.

A lot of research is being done for improving the work of DSSs in different areas. The problems of DSS's informational provision have been considered in the works of scientists, there DSS is defined as "an interactive computer system intended to support different types of actions during the decision-making including poorly structured and unstructured problems" (Tarasov & Gerasimov, 2007; Gerasimov & Lokazyuk, 2007; Sirodza, 2002; Zhang, 2007). The Applied Research Laboratory (RAL) presents some DSSs used to support people in difficult conditions (RAL, 2022) such as Maintenance DSS to make effective decisions in winter maintenance; Four-Dimensional Weather System (4DWX) for improving meteorological support in experience flights; Global Climatology Analysis Tools (GCAT) for analysis fine-scale climatological analyses anywhere around the globe; etc. In (Weckman et al., 2006) DSS for modeling jet engine life and predicting deadlines of maintenance. In (Yu & Wang, 2013; Kashyap, 2019a, 2019b) Intelligent DSS for Vehicle Maintenance combines both virtual maintenance, and fault diagnosis together using an expert system, Data warehouse (DW), automatic generation of fault tree, and intelligent interface. In (Svenmarck & Dekker, 2003) reviews the problem of decision support in a highly complex and time-pressurized environment and instead of expert systems, cognitive modeling is used.

The presented systems use the knowledge of experts from one area to solve a specific problem, in aviation for building DSS the problem is the initial data (Big Data), for an effective solution of a single problem needs the participation of many different specialists. It is proposed to combine data to find the optimal solution and to obtain data from different specialists - experts if they are directly related to solving the problem, statistical data, and using Artificial Neural Networks (ANN) with Machine Learning (ML) (Shmelova et al., 2022). For comprehensive accounting of the factors influencing the CDM process by the pilot/air traffic controller in a flight emergency, a conceptual model of the Intelligent System for Supporting CDM (ISSCDM), which considers dynamic, static, and expert information about the aircraft, environment, and operators were built (Sikirda et al., 2021). ISSCDM is recommended to use in the process of joint training of the pilots and ATCO for CDM in an emergency, which will increase situational awareness of operators, create a unified flight image to develop skills of active air surveillance, and improve the interaction between pilot and ATCO. The examples of the individual and collective models of DM by the pilot, ATCO, and engineers in the emergency “Engine failure during take-off due to bird strike” (aircraft: Antonov An-148-100A,) are presented (Sikirda et al., 2022). The input data required for the formation of decisions by the IDSS are included static, dynamic, and expert data (characteristics of aircraft, landing airdromes, opinions of operators and engineers). Models of CDM where participant operators (pilots, air traffic controllers, engineers) and AI participate together in DM in an “Engine failure” emergency were obtained (Shmelova et al., 2023).

To control AI solutions, it is necessary to introduce Hybrid (man-machine) Intelligence that uses both human and machine competence (Alharbi & Prince, 2020, Dolgikh, 2020). Intelligent Decision Support Systems are created for different situations and use the opinions of experts relevant to the situation under consideration. For example, in CDM modeling in an emergency, “pilot incapacitation” participants are operators (pilots, ATCOs, medicine specialists) and the next data of AI in the future (Shmelova et al., 2023).

### **3. INTELLIGENT DECISION SUPPORT SYSTEM (IIDSS) FOR CDM BY OPERATORS IN AN EMERGENCY “PILOT INCAPACITATION”**

Intelligent Decision Support Systems (IDSSs) represent a special kind of knowledge-based system, and that imitates the human mind and collects data from a few DSSs of the operators in an emergency. IDSSs are created for different situations and use the opinions of experts relevant to the situation under consideration. Some CDM in emergency “Depressurization”, “Engine Failure During Take-Off”, “Bird strike”, “Bad weather conditions”, and “Engine failure during take-off due to bird strike” were obtained in previous research (Shmelova & Sikirda, 2020, 2021, 2022; Shmelova et al., 2023). The development of AI in aviation, associated with an anthropocentric approach and the principles of human-oriented automation, required new approaches to solving human-machine interface problems (ICAO, 2002, 2005, Shmelova & Sikirda, 2012, 2016, 2019, 2021). One of the effective means of improving flight safety is the inclusion of local DSS in the global IDSS systems to bring together process participants and CDM (pilots, unmanned aircraft operators, ATCOs, and other operators performing DM in an emergency (Kharchenko et al., 2012, 2016; Shmelova & Sikirda, 2021).

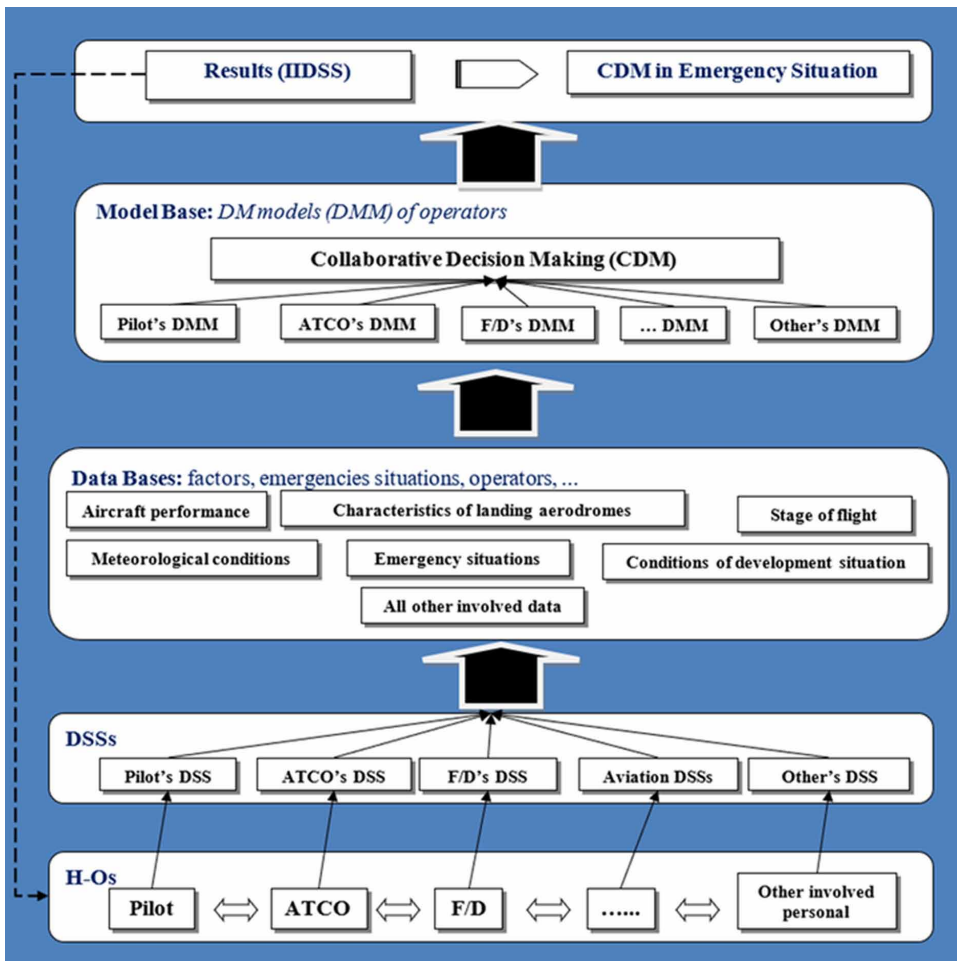
For CDM models in an emergency “pilot incapacitation”, participants are operators (pilots, ATCOs, medicine specialists). In the future, with the accumulation of data, it is planned to create modules for IDSS with the participation of AI. An AI participant is included in the participant group for the CDM. The data shows that the cause of approximately three accidents per thousand (15 per 1,000 deaths) is the result of pilot incapacitation (SkyBrary, 2022). In process of DM modelling in case of emergency “Pilot incapacitation” was used the recommendations of the Flight Crew Training Manual “Two communication rule” (SkyBrary, 2022; FCTM, 2005). Take-off is the most critical case when pilot incapacitation requires immediate decision and prompt actions. Proper crew coordination and the use of standard callouts are vital. Human failure (medical incapacitation) is compared with acceptable failure rates in other safety-critical system, such as aircraft engines. So, most commercial aircraft are multi-crew – two pilots involved in the aircraft operation process. In this case risk of

unsafe completion of the flight increase gradually. The remaining pilot stays only with the support of autopilot/autothrottle systems and may some support from other involved participants.

IDSS for CDM by operators in an emergency caused by captain incapacitation at take-off proposed (Figure 3), which includes components related to data, algorithms, and user interface. Data-related components consist of modules that receive data, format data, store data, transmit data, and archive data. Algorithms and model-related components use various methods such as peer review, rule-based algorithms, fuzzy logic algorithms, statistical algorithms, DM algorithms under certainty, uncertainty, and risk, data mining algorithms, and AI methods (Sikirda et al., 2021; Shmelova et al., 2023).

To evaluate the options the knowledge of experts, sophisticated analytical calculations, scientific research, and information technologies are used. Questions of decision support at all stages of the process (goal identification, development, DM, organization, and implementation of control) are becoming more relevant. In fact, the problem consists of the collection of solutions of the operators according to emergency “Captain incapacitation at take-off». There are three fundamental components of DSS architecture are the database (or knowledge base) – is an information structure that reflects the status and relationship of objects analysed; the model base – is a set of mathematical, logical, linguistic, and other models used for comparative analysis of multi-alternative decisions; the user interfaces.

Figure 3. Integrated Intelligent Decision Support System (IDSS) for CDM by Operators in an emergency



Pilot incapacitation is defined as any condition which affects the health of a crew member during the performance of duties - associated with the duty/position assigned to him which renders him incapable of performing the assigned duties. The definition includes either total or partial incapacitation which does not allow the fulfilment of duties in the “normal” way (FCTM, 2020). Pilot incapacitation has been of concern for as long as powered flight has existed. It represents an operational risk, and it can therefore be defined operationally as “any physiological or psychological state or situation that adversely affects performance.” There are sound reasons for considering an operational definition. From the operational standpoint, it is irrelevant whether degraded performance is caused by a petit mal episode, preoccupation with a serious personal problem, fatigue, problematic use of psychoactive substances or a disordered cardiac function. The effects may be similar, and often other crew members will not know the difference. A great deal about pilot incapacitation has been learned over the past decades. One of the most important things is that the risk to aviation safety in situations where a pilot is physically incapacitated can be virtually eliminated in air transport (multi-crew) operations by training the pilots to cope with such events (SkyBrary, 2021, 2022). The next events that list Incapacitation as a causal factor are described is given in Appendix -1.

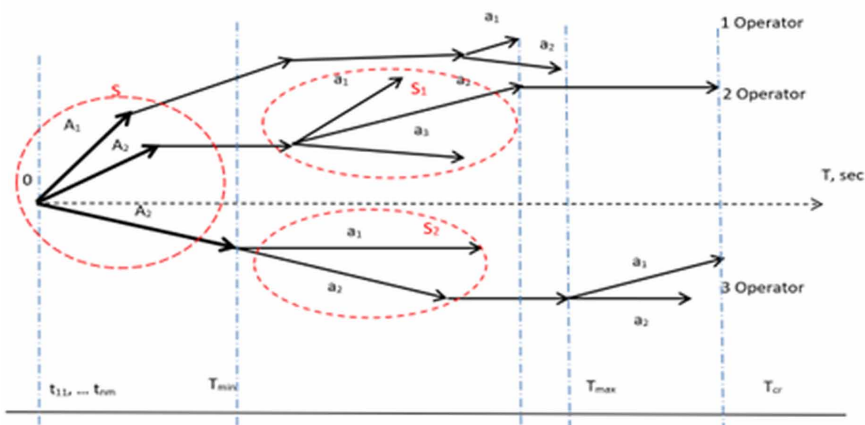
#### 4. METHODOLOGY OF CDM OF OPERATORS IN EMERGENCY

For the effectiveness of CDM of operators of the ANS in emergency two methods have been proposed: Method of integration of Stochastic, and Non-stochastic models and Subjective-Objective Method for CDM in emergency (Shmelova, 2021; Shmelova, at al., 2021, 2022).

##### 4.1 Method of Integration of Stochastic and Non-Stochastic Models:

1. Analysis of the development of the emergency and synthesis of DM models in accordance with conditions, factors, potential participants, and stages of the development of the event.
2. Building deterministic DM models using Network Planning methods and determining output results (Figure 4):
  - Critical times  $T_{cr}$ ;  $T_{mid}$ ;  $T_{min}$ ;  $T_{max}$  and critical paths of performance of actions of operators in an emergency.
  - Determine ambiguous situations ( $S, S1, S2$ ), and synchronization of operators’ actions using stochastic models (DM in Risk or DM in uncertainty) (Shmelova, 2019).

Figure 4. Deterministic model (DM in Certainty) - synchronization actions of 3 operators





3. Building stochastic and non-stochastic uncertainty DM models (Taha, 2020; Shmelova, 2019; Shmelova & Sikirda, 2018).
  - Having statistical information about the development of the emergency, the widespread mathematical model of DM in Risk is used such as the decision tree, for example situation  $S$  (Figure 5).
  - If don't have information about the event, DM in the condition of uncertainty (non-stochastic uncertainty model) is used (Table 2).

Figure 5. Non-stochastic uncertainty model (DM in Risk) – decision tree (for  $S$ )

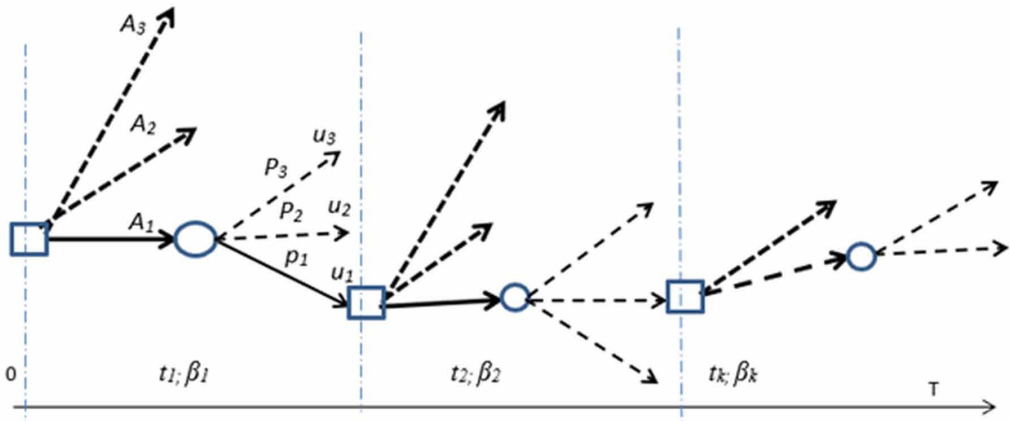


Table 2. The DM-matrix in uncertainty for operator  $O_i$  (subjective matrix)

The matrix $O_i$	$\{A\}$	Factors influencing on DM for $O_i$						Optimal solutions by $O_i$
		$\lambda_1$	$\lambda_2$	...	$\lambda_j$	...	$\lambda_n$	
Alternative actions in emergency	$A_1$	$u_{11}$	$u_{12}$	...	$u_{1j}$	...	$u_{1n}$	$U^*_{11}$
	$A_2$	$u_{21}$	$u_{22}$	...	$u_{2j}$	...	$u_{2n}$	$U^*_{21}$
	...	...	...	...	...	...	...	...
	$A_i$	$u_{i1}$	$u_{i2}$	...	$u_{ij}$	...	$u_{in}$	$U^*_{i1}$
	...	...	...	...	...	...	...	...
	$A_m$	$u_{m1}$	$u_{m2}$	...	$u_{mj}$	...	$u_{mn}$	$U^*_{m1}$

#### 4.2 Subjective-Objective Method for CDM in Emergency.

*Subjective matrixes.* Formation of the matrix of solutions for each operator. CDM modeling for all operators using mathematical methods such as DM in uncertainty. The DM-matrix in uncertainty for operator  $O_i$  (subjective matrix) presented in Table 2. In this DM matrix:

- Alternative actions  $\{A\} = \{A_1, A_2, \dots, A_i, \dots, A_m\}$ , actions of operator in emergency: aerodromes of take-off ( $A_1$ ), landing ( $A_2$ ) and alternate aerodromes ( $A_3; A_4; A_5, \dots$ ).

- Factors  $\{\Lambda\} = \{\lambda_1, \lambda_2, \dots, \lambda_p, \dots, \lambda_n\}$ , factors influence on DM in emergency. For all operators the same set of factors!
- Outcomes  $\{U\} = u_{11}, u_{12}, \dots, u_{ip}, \dots, u_{nm}$ , outcomes of DM matrix depend on factors that influence the actions of operators.
- The optimal solutions  $A^*(O_i)$  are found using classical DM criteria under uncertainty (criterion Wald (maximin), criterion Laplace, criterion Hurwitz, criterion Savage). Wald's criterion is based on conservative careful behavior and reduced to select the best alternative from the worsts.

According to Wald's criterion, an optimal decision provides a guaranteed result and minimization of risk. This criterion is used in cases when decisions are made rarely, for instance in the case of the first flight or flights performed rarely:

$$A^* = \max_{A_i} \left\{ \min_{\lambda_j} u_{ij} (A_i, \lambda_j) \right\} \quad (1)$$

$A_i$  – alternative solution from set  $\{A\}$ .  $B_j$  – factor from set of factors  $\{\lambda\}$ .

Criterion of Laplace - if this flight is regular:

$$A^* = \max_{A_i} \left\{ \frac{1}{m} \sum_{j=1}^n u_{ij} (A_i, B_j) \right\} \quad (2)$$

Criterion of Hurwitz – different approach using optimism-pessimism coefficient  $\alpha$ :

$$A^* = \max_{A_i} \left\{ \alpha \max_{B_j} u_{ij} (A_i, B_j) + (1 - \alpha) \min_{B_j} u_{ij} (A_i, B_j) \right\} \quad (3)$$

$\alpha$  - optimism-pessimism coefficient,  $0 \leq \alpha \leq 1$ , 0 – extreme of pessimism and 1 - extreme of optimism.

Criterion of Savage – recalculation result after flight:

$$A^* = \min_{B_j} \max_{A_i} r_{ij} (A_i, B_j) \quad (4)$$

$r_{ij}$  – loss matrix for recalculations after DM:

$$r_{ij} (A_i, B_j) = \Delta = \max_{A_k} u_{kj} (A_k, B_j) - u_{ij} (A_i, B_j) \quad (5)$$

Similar subjective matrices are formed for all operators  $\{A_j^*(O_i)\}$ . Optimal solutions obtained in subjective matrices are factors for objective matrices.

*Objective matrixes.* Formation of the collective matrix for all operators (Table 3) where alternative actions  $\{A\}$  - potential collective solutions, actions of all operators in emergency; factors  $\{A_j^*(O_i)\}$  - opinions of operators from the previous step, outcomes  $\{U\}$  - depend on collective actions of all operators (optimal solutions of operators from the previous step).

For each case, depending on the conditions of the situation, the type of flight, and the priorities of DM, a specific criterion has been chosen.

Table 3. The CDM matrix of DM in Uncertainty for operators

The collective matrix	$\{A\}$	Results of optimal solutions by operators					Optimal solutions by all operators	
		$A(O_1)$	$A(O_2)$	$A(O_3)$	$A(O_j)$	...		$A_n(O_n)$
Alternative actions in emergency	$A_1$	$U^*_{11}$	$U^*_{12}$	$U^*_{13}$		...	$U^*_{1n}$	$U^{**}_{11}$
	$A_2$	$U^*_{21}$	$U^*_{22}$	$U^*_{23}$		...	$U^*_{2n}$	$U^{**}_{21}$
	...	...	...	...	....	...	....	...
	$A_i$	$U^*_{i1}$	$U^*_{i2}$	$U^*_{i3}$	$U^*_{ij}$	...	$U^*_{in}$	$U^{**}_{i1}$
	...	...	...	...	....	...	...	...
	$A_m$	$U^*_{m1}$	$U^*_{m2}$	$U^*_{m3}$		...	$U^*_{mn}$	$U^{**}_{m1}$

### 4.3 Example of Calculation CDM Models by Operators in Emergency “Captain Incapacitation in Take-Off”

*Characteristic of situation.* In process of DM modelling in case of emergency “Pilot incapacitation” was used the recommendations of the Flight Crew Training Manual “Two communication rule” and CHASE mnemonic (Transport Canada, 2022). The key to early recognition of pilot incapacitation is the regular use of crew resource management concepts during flight deck operation. Proper crew coordination involves checks and crosschecks using verbal communications. Routine adherence to standard operating procedures and standard profiles can aid in detecting a problem. Suspicion of some degree of gross or subtle incapacitation should also be considered when a crewmember does not respond to any verbal communication associated with a significant deviation from a standard procedure or standard flight profile. Failure of any crewmember to respond to a second request or a checklist response is cause for investigation (FCTM, 2005). Take-off is the most critical phase when pilot incapacitation requires immediate decision and prompt actions. Proper crew coordination and the use of standard callouts are vital. Next characteristic of development of situation in emergency “captain incapacitation in take-off” presented in Appendix - 2.

Initial data:

1. Route UKKK (Kyiv Zhuliany) - UKOO (Odesa) (Figure 6).
2. Flight – performed for the first time.
3. Aircraft – Boeing 737 – 800, TOW – 67000kg, Flaps 1.
4. Aerodromes (Appendix 3, Table 4, Figure 9):
  - Departure ( $A_1$ ), UKKK (Kyiv Zhuliany).
  - Destination ( $A_2$ ), UKOO (Odesa)
  - Alternate ( $A_3$ ) UKBB (Kyiv Boryspil).
5. Emergency – “pilot incapacitation”.
6. The place of the event in-flight – take-off.
7. Participants - pilot, ATCO, medical officer.

1) Factors:

- $\lambda_1$  – fuel amount on board of the aircraft (always controlled).
- $\lambda_2$  – meteorological situation (of departure, destination, alternate aerodromes, en-route).
- $\lambda_3$  – aircraft capabilities (available equipment on board, MEL peculiarities, existing operating limitations).

Figure 6. Route UKKK (Kyiv Zhuliany) - UKOO (Odesa)



$\lambda_4$  – aerodrome capabilities (available approach systems, technical characteristics of the runways and taxiways, lightning system, service hours restrictions, aerodrome category, firefighting and search and rescue category, emergency service).

$\lambda_5$  – crew capability (crew operating minima, crew duty time).

$\lambda_6$  – location of obstacles in approach, missed approach and departure sectors.

$\lambda_7$  – air situation (intensity of air traffic control sector, radio frequency overload).

$\lambda_8$  – commercial point (airport charges, distance from destination aerodrome, passenger and cargo service facilities, the presence of contracts with handlers, the presence of customs, border and migration control service, etc.).

$\lambda_9$  – crew health and mental condition, etc.

All characteristics necessary for making decisions in an emergency are presented in Appendix 3.

*Deterministic models of DM in emergency caused by captain incapacitation.* DM modelling in the event of an emergency is considered at the two stages of take-off at a speed of 80 knots and “VI”. During the take-off run, the pilot has the right to DM and refuse to take off up to speed VI (if necessary, for example, in an emergency). After the indicated speed VI, the pilot continues the take-off (SkyBrary, 2021; QRH, 2013). Decomposition of the emergency “Pilot incapacitation”, the list and the average time ( $t$ , sec) of the pilot’s actions at 80 knots are given in Table 5. The duration of the procedure is determined with the help of specialists-experts (or on a simulator). In the structural-time Tables 5 and Tables 6 - the average time ( $t$ , second) for each procedure (action), 10 experts, and the coordination of the experts were determined using Expert Judgment Method (EJM) (Shmelova, at al., 2021).

According to the structural and temporal table, a DM deterministic model in the emergency is constructed in the form of a network graph, the critical time of execution of all actions by the pilot ( $T_{cr} = 198$  s), critical path ( $a_p, a_6, a_7, a_8, a_9, a_{10}$ ) is determined (Figure 7).

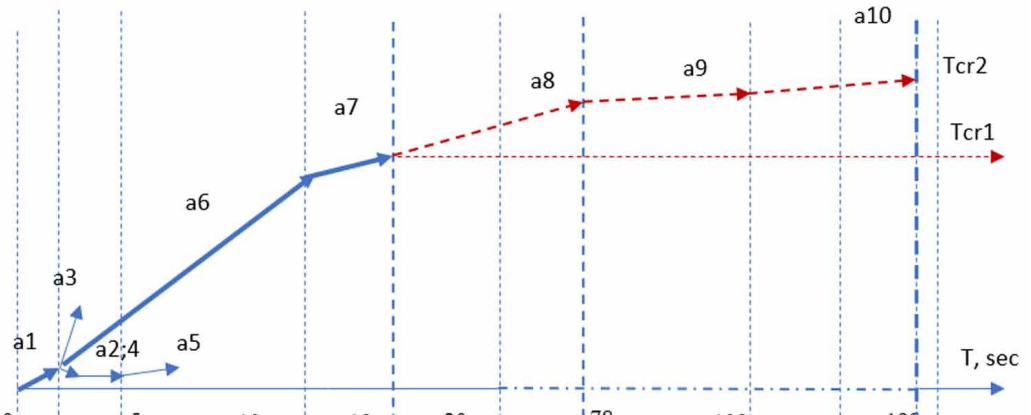
Decomposition of the emergency “Pilot incapacitation”, the list and the average time ( $t$ , sec) of the pilot’s actions at a decision speed VI (Appendix - 3) are given in Table 6.

According to the structural and temporal table, a DM deterministic model in the emergency is constructed in the form of a network graph, the critical time of execution of all actions by the pilot ( $T_{cr} = 988$  s), critical path is determined (Figure 8). The time ( $t$ , sec) to the procedures in the structure-time tables 5 and 6 is determined with the help of experts or simulators.

Table 5. Structural-time table “Captain incapacitation at 80 knots”

N°	Actions in case of «pilot incapacitation»	Action	Order	t, sec.
1	Call for intention of take control and reject take-off: « <b>Reject, My controls</b> »	$a_1$	-	2
2	Thrust Levers close	$a_2$	$a_1$	1
3	A/T (Automatic transmission) disengage	$a_3$	$a_1$	1
4	Apply brakes and rise the speedbrakes manually	$a_4$	$a_2$	2
5	Apply reverse thrust as required;	$a_5$	$a_4$	3
6	Keep directional control with pedals and differential braking, when required;	$a_6$	$a_1$	12
7	Stop the aircraft, set parking brakes, announce “Attention Cabin Crew! At stations!”, and	$a_7$	$a_6$	4
8	Inform ATC and request assistance (stairs, etc).	$a_8$	$a_7$	60
9	Call cabin crew to help incapacitated pilot.	$a_9$	$a_8$	60
10	Vacate the active RW, when requested by ATC.	$a_{10}$	$a_9$	60

Figure 7. DM deterministic model in the event of “Pilot incapacitation at 80 knots”



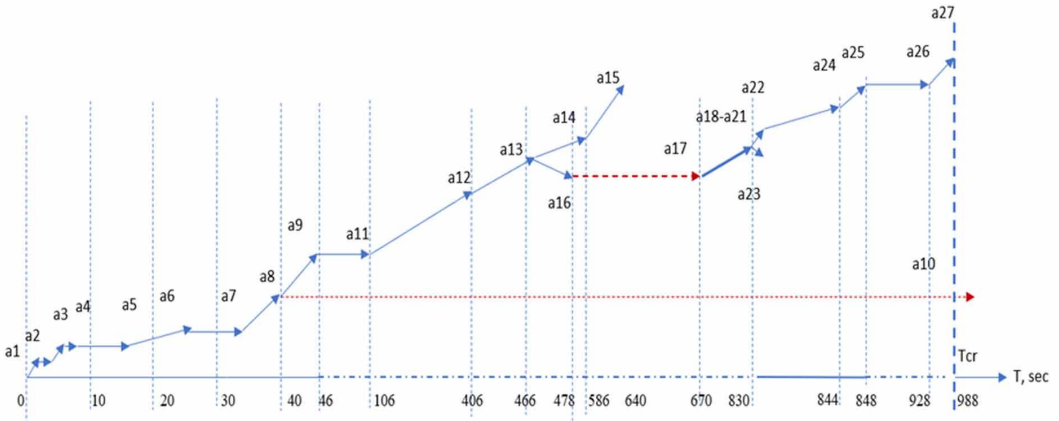
*Stochastic models of DM in emergency “captain incapacitation”.* The possible consequences  $U_{ij}$  are defined by means of using the EJM according to data from the regulatory documentation and opinions of  $O_i$  operators (pilot, ATC, medical specialist, and other aviation specialists if needed). Formation of an individual (subjective) matrix of decisions and obtaining optimal solutions for operators:

- $\{A\}$  – alternative aerodromes.
- $\{f\}$  – factors influence DM of operators.
- $\{u\}$  – outcomes - decisions of operators.
- $A_1^* = A(O_1)$  - solutions of pilot  $A(O_1)$ .
- $A_2^* = A(O_2)$  - solutions ATCO.
- $A_3^* = A(O_3)$  - solutions medical specialist/TM.

Table 6. Structural-time table “Captain incapacitation at V1”

N°	Actions in case of «pilot incapacitation»	Action	Order	t, sec.
1	Call for intention of take control and continuation take-off: «Continue, My controls»	$a_1$	-	2
2	Rotate aircraft at rotation speed $V_R$	$a_2$	$a_1$	2
3	Retract landing gear when positive rate of climb	$a_3$	$a_2$	2
4	Engage AP (Autopilot) at 400' feet AGL (above ground level)	$a_4$	$a_3$	2
5	Check the position of essential controls and switches	$a_5$	$a_4$	10
6	Accelerate aircraft to flaps retraction speed	$a_6$	$a_5$	12
7	Retract flaps	$a_7$	$a_6$	8
8	Inform ATC	$a_8$	$a_7$	6
9	Call cabin crew to help incapacitated pilot.	$a_9$	$a_8$	6
10	Follow the SID (Standard Instrument Departure)	$a_{10}$	$a_8$	....
11	Brief cabin crew to restrain the incapacitated pilot and provide other assistance	$a_{11}$	$a_9$	60
12	<i>Pilot:</i> Check weather, type of approach and airport facilities at departure airdrome to evaluate ability to come back or choose appropriate alternate. <i>Cabin crew:</i> Restrain the incapacitated pilot and slide the seat back, assess him medical condition, provide with necessary care, call other cabin crew to find doctor on board.	$a_{12}$	$a_{11}$ $a_{12}$	300
13	DM to proceed suitable airdrome according to actual situation	$a_{13}$	$a_{12}$	60
14	Prepare cabin for approach	$a_{14}$	$a_{13}$	120
15	Brief cabin crew for approach	$a_{15}$	$a_{14}$	60
16	Declare “MAY DAY” and request vectoring for approach and medical assistance	$a_{16}$	$a_{13}$	12
17	Proceed as instructed by ATC	$a_{17}$	$a_{16}$	.....
18	Slow the aircraft to extend flaps and gear	$a_{18}$	$a_{17}$	20
19	Extend flaps and gear for landing	$a_{19}$	$a_{18}$	60
20	Read with a help of cabin crew landing check list	$a_{20}$	$a_{19}$	20
21	Perform landing	$a_{21}$	$a_{20}$	60
22	Check activation of autobrakes and speedbrakes systems or apply manually brakes and rise speedbrakes lever	$a_{22}$	$a_{21}$	2
23	Apply reverse thrust	$a_{23}$	$a_{21}$	2
24	Keep directional control with pedals and differential braking, when required	$a_{24}$	$a_{22}$	12
25	Stop the aircraft, set parking brakes, and announce “Attention Cabin Crew! At stations!”, and	$a_{25}$	$a_{24}$	4
26	Inform ATC and request assistance (stairs, etc).	$a_{26}$	$a_{25}$	60
27	Take the left seat for further taxi, when requested by ATC to vacate the active RW (runway)	$a_{27}$	$a_{26}$	60

Figure 8. DM deterministic model in the event of “Pilot incapacitation at V1”



Formation of the collective (objective) matrix of solutions (CDM), where:

- $\{A\}$  – alternative aerodromes.
- $\{\lambda\}$  – optimal opinions of all operators ( $O_1$  pilot,  $O_2$  ATCO,  $O_3$  medical specialist, and  $O_i$  - other aviation specialists if needed) from individual matrixes.
- $\{u\}$  – outcomes - decisions of operators.

The outcomes  $\{u\}$  in the decision matrix are determined depending on the influence of factors  $\{f\}$  on the choice of approach aerodrome, the outcomes  $\{u\}$  are determined using the opinions of operators, using AI, and statistical data (nominal scale, 1- worst solution, 10 - the best solution). Formation of the matrixes of solutions for operator  $O_1$  - pilot (Table 7). In the decision matrixes (Table 7), the outcomes were determined based on a survey of 10 experts from among the experienced pilots of the airline, during the simulator training and the exercise “pilot incapacitation”. Using the EJM, the consistency of expert opinions was determined.

According to Wald’s criterion, an optimal decision – Kyiv - Boryspil ( $A_3$ ):

$$A_1^* = \min \{6, 3; 3, 3; 6, 7; 7, 0; 2, 3; 7, 0; 5, 0; 7, 7; 6, 3\} = 2, 3$$

$$A_2^* = \min \{8, 0; 8, 0; 8, 0; 8, 0; 6, 0; 8, 0; 8, 7; 1, 7; 1, 7\} = 1, 7$$

$$A_3^* = \min \{8, 7; 6, 0; 9, 3; 10, 0; 7, 3; 8, 7; 5, 3; 8, 0; 9, 3\} = 5, 3$$

$$A^* = \max \{2, 3; 1, 7; 5, 3\} = 5, 3 = A_3$$

Table 7. The DM matrix in Uncertainty for operator  $O_1$  (pilot)

The matrix 1		Factors influence DM for operator, $O_1$ - pilot									Solutions			
Alternative decisions $\{A\}$		$f_1$	$f_2$	$f_3$	$f_4$	$f_5$	$f_6$	$f_7$	$f_8$	$f_9$	$W$	$L$	$H, \alpha=0,5$	$S$
Departure	$UKKK (A_1)$	6,3	3,3	6,7	7,0	2,3	7,0	5,0	7,7	6,3	2,3	0,6	4,2	5,3
Destination	$UKOO (A_2)$	8,0	8,0	8,0	8,0	6,0	8,0	8,7	8,7	1,7	1,7	0,8	4,7	7,0
Alternate	$UKBB (A_3)$	8,7	6,0	9,3	10,0	7,3	8,7	5,3	8,0	9,3	<b>5,3</b>	<b>0,9</b>	<b>5,4</b>	<b>4,7</b>

Table 8. The loss-DM matrix of criterion Savage for operator  $O_1$  (pilot)

The matrix 1		Factors influence DM for operator, $O_1$ - pilot									Solutions
Alternative decisions {A}		$f_1$	$f_2$	$f_3$	$f_4$	$f_5$	$f_6$	$f_7$	$f_8$	$f_9$	S
Departure	UKKK ( $A_1$ )	1,3	4,3	1,0	0,7	5,3	0,7	2,7	0,0	1,3	5,3
Destination	UKOO ( $A_2$ )	0,7	0,7	0,7	0,7	2,7	0,7	0,0	0,0	7,0	7,0
Alternate	UKBB ( $A_3$ )	1,3	4,0	0,7	0,0	2,7	1,3	4,7	2,0	0,7	<b>4,7</b>

The loss-DM matrix of criterion Savage for operator  $O_1$  - pilot (Table 8). Optimal solutions in DM matrix (Table 7) are obtained by formulas (1) – (4), in table 8 - by formula (5).

The optimal landing airdrome in case of captain incapacitation on the route “Kyiv (Zhuliany) - Odessa” in accordance with the pilot’s decision is as follows:

- by Wald criterion – Kyiv - Boryspil ( $A_3$ )
- by Laplace criterion - Kyiv - Boryspil ( $A_3$ )
- by the Hurwitz criterion - Kyiv - Boryspil ( $A_3$ ) ( $\alpha=0,5$ )
- according to the Savage criterion – Kyiv Boryspil ( $A_3$ )

Expected outcomes considered by the air traffic controller / ATC (operator  $O_2$ ) represented in Table 9 and in Table 10. Formation of the matrixes of solutions for operator  $O_2$  - ATCO (Table 9) and the outcomes were determined based on a survey of 10 experts from among the experienced ATCO of the airline, during the simulator training and the exercise “pilot incapacitation”.

The loss-DM matrix of criterion Savage for operator  $O_2$  (ATCO) (Table 10). Optimal solutions in DM matrix (Table 10) are obtained by formulas (1) – (4), in Table 11- by formula (5).

The optimal landing airdrome during the approach on the route “Kyiv (Zhuliany) - Odessa” in accordance with the ATC’s decision is as follows:

Table 9. The DM matrix in Uncertainty for operator  $O_2$  (ATC)

The matrix 1		Factors influence DM for operator, $O_2$ (ATC)									Solutions			
Alternative decisions {A}		$f_1$	$f_2$	$f_3$	$f_4$	$f_5$	$f_6$	$f_7$	$f_8$	$f_9$	W	L	H, $\alpha=0,5$	S
Departure	UKKK ( $A_1$ )	4,3	7,0	8,0	7,7	8,7	8,0	3,7	8,0	7,7	3,7	0,8	4,7	5,0
Destination	UKOO ( $A_2$ )	8,7	6,0	9,3	10,0	7,3	8,7	5,3	8,0	9,3	<b>5,3</b>	<b>0,9</b>	<b>5,4</b>	<b>4,7</b>
Alternate	UKBB ( $A_3$ )	6,0	9,0	9,3	10,0	8,7	9,3	3,7	5,0	8,7	3,7	<b>0,9</b>	<b>5,4</b>	6,3

Table 10. The loss-DM matrix of criterion Savage for operator  $O_2$  (ATC)

The matrix 1		Factors influence DM for operator, $O_2$ (ATC)									Solutions
Alternative decisions {A}		$f_1$	$f_2$	$f_3$	$f_4$	$f_5$	$f_6$	$f_7$	$f_8$	$f_9$	S
Departure	UKKK ( $A_1$ )	4,3	1,7	0,7	1,0	0,0	0,7	5,0	0,7	1,0	5,0
Destination	UKOO ( $A_2$ )	1,3	4,0	0,7	0,0	2,7	1,3	4,7	2,0	0,7	<b>4,7</b>
Alternate	UKBB ( $A_3$ )	4,0	1,0	0,7	0,0	1,3	0,7	6,3	5,0	1,3	6,3



- by Wald criterion – Odessa ( $A_2$ )
- by Laplace criterion - Odessa ( $A_2$ ), Kyiv-Boryspil ( $A_3$ )
- by the Hurwitz criterion - Odessa ( $A_2$ ), Kyiv-Boryspil ( $A_3$ ) ( $\alpha=0,5$ )
- according to the Savage criterion - Odessa ( $A_2$ )

Evaluation of optimal alternate aerodrome for landing in case of captain incapacitation by medical specialist according to health condition. Matrix of possible outcomes of decision-making by medical specialist during choosing of alternate aerodromes according to health condition in Table 11 and in Table 12.

The optimal landing airdromes during the approach on the route “Kyiv (Zhuliany) - Odessa” in accordance with the medical specialist ‘s decision is as follows - Odessa ( $A_2$ ), Kyiv-Boryspil ( $A_3$ ) (only for Laplace criterion).

Table 11. The DM matrix in Uncertainty for operator  $O_3$  (medical specialist)

The matrix 1		Factors influence DM for operator, $O_3$									Solutions			
Alternative decisions {A}		$f_1$	$f_2$	$f_3$	$f_4$	$f_5$	$f_6$	$f_7$	$f_8$	$f_9$	W	L	H, $\alpha=0,5$	S
Departure	( $A_1$ )	10,0	9,3	10,0	10,0	3,3	10,0	10,0	1,0	8,7	1,00	0,89	5,45	9,0
Destination	( $A_2$ )	8,3	9,3	10,0	10,0	5,7	10,0	10,0	1,0	9,3	1,00	<b>0,91</b>	5,45	9,0
Alternate	( $A_3$ )	8,3	9,3	10,0	10,0	5,7	10,0	10,0	1,0	9,3	1,00	<b>0,91</b>	5,45	9,0

Table 12. The loss-DM matrix of criterion Savage for operator  $O_3$  (medical specialist)

The matrix 1		Factors influence DM for operator, $O_3$									Solutions
Alternative decisions {A}		$f_1$	$f_2$	$f_3$	$f_4$	$f_5$	$f_6$	$f_7$	$f_8$	$f_9$	S
Departure	UKKK ( $A_1$ )	0,0	0,7	0,0	0,0	6,7	0,0	0,0	9,0	1,3	9,0
Destination	UKOO ( $A_2$ )	1,7	0,7	0,0	0,0	4,3	0,0	0,0	9,0	0,7	9,0
Alternate	UKBB ( $A_3$ )	1,7	0,7	0,0	0,0	4,3	0,0	0,0	9,0	0,7	9,0

*Collective solutions – CDM.* To determine the consistency of operators, collective matrices were constructed, in which the factors in the decision matrices for the operators (pilot ( $O_1$ ), ATC ( $O_2$ ), medical specialist ( $O_3$ )) and are identical, the solutions of the operators and are taken from matrices, presented in Table 13, Table 14 and Table 15. In the CDM matrixes are using subjective factors ( $\lambda$ ) – opinions of operators. The optimal CDM if this flight is performed for the first time presented in the Table 13 (Wald criterion). In this case, the optimal landing aerodrome, determined by objective (fuel reserve on board of the aircraft; meteorological situation; crew, aircraft, and aerodrome capabilities; location of obstacles in approach; air situation and commercial point) and subjective factors (pilot, ATC, medical specialist) is alternative aerodrome Kyiv-Boryspil ( $A_3$ ).

The optimal CDM if this flight is regular (Criterion of Laplace) presented in the Table 14 – aerodrome Kyiv-Boryspil ( $A_3$ ).

Collective decisions according to criterion Hurwitz were analysed with varying degrees of optimism. The optimal solutions in different approaches using optimism-pessimism coefficients:  $\alpha = 0,5$  (rational solution);  $\alpha = 0$  (extreme pessimism);  $\alpha = 1$  (extreme optimism) are presented in Table 15. The optimal solution – is Kyiv-Boryspil ( $A_3$ ). The consistency of decisions increases

Table 13. The CDM matrix for all operators (criteria Wald)

Alternate aerodromes	pilot	ATC	medical specialist	CDM
	$\lambda_1$	$\lambda_2$	$\lambda_3$	Criterion Wald
	$O_1$	$O_2$	$O_3$	
<i>UKKK</i> ( $A_1$ )	2,33	3,67	1,00	2,33
<i>UKOO</i> ( $A_2$ )	1,67	5,33	1,00	1,67
<i>UKBB</i> ( $A_3$ )	5,33	3,67	1,00	<b>3,67</b>

Table 14. The CDM matrix for all operators (criteria Laplace)

Alternate aerodromes	pilot	ATC	medical specialist	CDM
	$\lambda_1$	$\lambda_2$	$\lambda_3$	Criterion Laplace
	$O_1$	$O_2$	$O_3$	
<i>UKKK</i> ( $A_1$ )	0,64	0,78	0,89	0,77
<i>UKOO</i> ( $A_2$ )	0,80	0,90	0,91	0,87
<i>UKBB</i> ( $A_3$ )	0,90	0,86	0,91	<b>0,89</b>

Table 15. The CDM matrix for all operators (criteria Hurwitz)

Alternate aerodromes	pilot	ATCO	medical specialist	Criterion Hurwitz		
	$\lambda_1$	$\lambda_2$	$\lambda_3$	CDM	CDM	CDM
	$O_1$	$O_2$	$O_3$	$\alpha=0,5$	$\alpha=1$	$\alpha=0$
<i>UKKK</i> ( $A_1$ )	4,15	4,72	5,45	4,80	5,45	4,80
<i>UKOO</i> ( $A_2$ )	4,73	5,45	5,45	5,09	5,45	5,09
<i>UKBB</i> ( $A_3$ )	5,45	5,43	5,45	<b>5,44</b>	5,45	<b>5,44</b>

with an increase in the coefficient of optimism, with a decrease in the coefficient in the direction of pessimism, the mismatch increases.

The solutions according to rational balance between cost and helping in incapacitation pilot (using the Savage criterion) are not defined.

To solve the complex tasks of finding a compromise between the time of DM by operators under the influence of various factors in uncertainty conditions and the critical time of emergency parry in certainty conditions it is proposed to use ANN with ML and analyzing tools of Big Data. To control AI solutions by human-operator it is necessary to introduce Hybrid Intelligence Systems that use both human and machine competence (Alharbi, Prince, 2020, Dolgikh, 2020). IDSSs are created for different situations and use the opinions of experts relevant to the situation under consideration. For example, in CDM modeling in an emergency “pilot incapacitation” participants are operators (pilots, ATCOs, medicine specialists) and data of AI.

## 5. CONCLUSION

The paper considers a new approach to collective decision-making. For ensuring proper collaboration of different personnel in emergencies proposed deterministic and stochastic modeling. Deterministic models are used for synchronization actions of all operators, to support and timely predicting of

operators' actions in the emergence. The main advantages of deterministic models are the determination of critical time and the critical way of DM. The method of Integration of DM models is used for the synchronization actions of different participants. To optimal collective solutions in an emergency is used Method of subjective-objective CDM. Participants in process and DM are groups consisting of different operators (pilots, air traffic controllers, flight/dispatch), and invited specialists according to the development of the situation. The DM modeling of a group of operators in case of an emergency such as "pilot incapacitation" was presented. The methodological basis for CDM in certainty is a deterministic model, in conditions of stochastic uncertainty – is a decision tree, in conditions of non-stochastic uncertainty – is a DM matrix. IDSS to find the CDM using man-machine intelligence and CDM models.

*In the future*, with the accumulation of data, it is planned to create modules for IDSS with the participation of AI. An AI participant is included in the participant group for the CDM. Some solutions of CDM in emergency "Depressurization", "Engine Failure During Take-Off", "Bird strike", "Bad weather conditions", and "Engine failure during takeoff due to bird strike" were obtained (Shmelova et al., 2022; Sikirda, et al., 2021). In order to prepare correct and effective solutions in an emergency, training procedures must be able to simulate flight situations as close as possible to real events. Steps in the process of creating models: a careful and in-depth analysis of the accident; intelligent data processing; situation identification; formalization of the situation using integrated models; decomposition of a complex situation into subsystems; integration of deterministic and stochastic models to actions determined by AI. In the case of large and complex data, methods can be integrated into traditional and hybrid DM systems with potentially high data rates and in near real-time, creating a structured representation of input data in clusters corresponding to common types of situations (Dolgikh, 2018).

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## APPENDIX 1

**Aviation accidents connected with emergency “pilot incapacitation”** (Skybrary, 2022).

*B772, en-route, north of Bahrain, 2017.* On 27 September 2017, a Boeing 777-200LRF Captain left the flight deck to retrieve their crew meal about 40 minutes after departing Abu Dhabi but whilst doing so he collapsed unconscious in the galley and despite assistance subsequently died. A MAYDAY was declared and a diversion to Kuwait successfully completed by the remaining pilot. The Investigation determined that the cause of death was cardiopulmonary system collapse due to a stenosis in the coronary artery. It was noted that the captain’s medical condition had been partially concealed from detection because of his unapproved use of potentially significant self-medication.

*A321, a-route, north of Kaohsiung Taiwan, 2019.* On 29 October 2019, an Airbus A321 was descending towards its destination, Kaohsiung, when the First Officer suddenly lost consciousness without warning. The captain declared a MAYDAY and with cabin crew assistance, he was secured clear of the flight controls and given oxygen which appeared beneficial. He was then removed to the passenger cabin where a doctor recommended continuing oxygen treatment. On arrival, he had fully regained consciousness. Medical examination and tests both on arrival and subsequently were unable to identify a cause although a context of cumulative fatigue was considered likely after three consecutive nights of inadequate sleep. (SkyBrary, 2022).

The safe operation of an aircraft places many demands on the pilot and crew. To meet these demands, a crew member requires good mental and physical health, which firstly influences the safety of flight. Given certain conditions, anyone can become incapacitated, how best to avoid it, and how to deal with it are stated in the source (Transport Canada, 2022). There are a lot of DM mnemonics which include simple algorithms of actions in case of emergency to help pilots or other participants to stay with a problem and minimise level of stress in this situation. In case of pilot incapacitation one of them is *CHASE* which can help organize remaining pilot actions (Transport Canada, 2022).

*CHASE* means:

1. *Control* the aircraft. Take command.
2. *Help!* Declare an emergency and alert another crew.
3. *Assess* the situation. Take time to determine the status of the flight. How much fuel do you have? Is your destination still the best choice, given the situation? Are other airports with better facilities and better weather close by?
4. *Secure* the victim and cockpit. If possible, enlist the help of other crew or passengers to prevent the victim from interfering with control of the aircraft. Your responsibility is to safely fly the aircraft to the nearest suitable aerodrome for landing.
5. *Explain* your plan to ATC and other crew members.

## APPENDIX 2

**Characteristic of development of situation in emergency “captain incapacitation in take-off”** (FCTM, 2005. QRH, 2013).

**Failure of the Captain to timely respond and/or act on “80 Knots” and “V1” call-outs** will require the following immediate actions from First Officer.

1. **The first stage is “80 knots”.** Ordering of actions:

If the Captain doesn’t respond, repeat the call about the higher speed already reached. If no reply, abort T/O:

- Call out “Reject, My controls”.
- Thrust Levers close.
- A/T disengage.
- Apply brakes and rise the speed brakes manually.

- Apply reverse thrust as required.
- Keep directional control with pedals and differential braking, when required.
- Stop the aircraft, set parking brakes.
- Inform ATC and request assistance (stairs, etc).
- Call cabin crew to help Captain.
- Take the left seat for further taxi, when requested by ATC to vacate the active RW.

*Note:* Normally FO is not trained to taxi the aircraft (has no skill to use nose wheel steering, has no feelings of aircraft dimensions, has no ground movement orientation that means does not know the time when need start turn to stay aircraft at central line of taxiway if need, etc). So, when RW vacated, the best way is to stop the aircraft, set the parking brake, and request any assistance (steps and medical service to present stop position to help captain). If it is not possible, request a track to tow aircraft to the best parking position where steps, ambulance, and passenger buses can be available. Continuation of taxi may be possible when instructed by ATC and when FO has full consideration that this movement will be safe and can be accomplished properly (in all times aircraft should be under control to a full stop and the parking brake is set) with a purpose to save the life in a short period of time. After parking, the incapacitated flight crew member shall be offloaded as quickly as possible by medical personnel.

**2. The second stage “V 1”. Ordering of actions:**

If the Captain doesn't respond, take over controls and perform the Take-off:

1. Call out “Continue, My controls”.
2. Retract landing gear when the positive rate of climb.
3. Engage AP at 400' feet AGL.
4. Check the position of essential controls and switches.
5. Retract flaps.
6. Follow the SID.
7. Inform ATC.
8. As soon as possible call Cabin Crew using all available methods and request to:
  - Restrain the incapacitated pilot and slide the seat back.
  - Provide other assistance required (to assess the medical condition of the incapacitated pilot, provide him with necessary care, read the checklists, etc).
  - Choose a further course of action and aerodrome for landing taking into account the medical conditions of the incapacitated pilot.
  - Ensure safe completion of the flight and medical assistance available immediately upon landing (stairs, ambulance, etc).

Incapacitated pilot care:

- The cabin crew will take over the responsibility for the incapacitated pilot from the moment they have been requested.
- Pilot care includes evaluation of physical and mental conditions, medical treatment, restraining on pilots' seat or relocation to forward galley as well as assistance from a doctor, if available on board, etc.

**Further course of actions.** The remaining pilot shall fly the aircraft from their normal position – no seat change is permitted, and consideration must be given to the following items:

- Check weather, type of approach, and airport facilities at departure airdrome to evaluate the ability to come back or choose an appropriate alternate.
- Report ATC about intentions and request all needed services and assistance.

Recommendation:

- Allow sufficient time to prepare the flight deck for landing.
- Request whenever possible a long, straight-in approach.
- Perform the approach checklists earlier than normal (request assistance from other crewmembers or “capable” persons).
- Request radar vectoring whenever possible.



*Note:* Where possible the diversion aerodrome should have weather conditions at or above CAT I minima. This is not a limitation.

*Note:* As good airmanship, continuous use of standard procedures including reading aloud the standard call-outs for aircraft re-configuration and completion of appropriate procedures and checklists is highly recommended.

### APPENDIX 3

All characteristics necessary for making decisions in an emergency “captain incapacitation in take-off” (FCTM, 2005. QRH, 2013).

Table 4. Aerodromes

<i>Departure airdrome (A<sub>1</sub>):</i>	<i>Destination airdrome (A<sub>2</sub>):</i>	<i>Alternate airdrome (A<sub>3</sub>):</i>
<i>UKKK (Kyiv Zhuliany) RW 08 – 2310m lengths, Condition – wet, LVTO – RVR = 400m, ILS CAT I</i>	<i>UKOO (Odesa) RW 16 – 2800m lengths, Condition – wet, ILS CAT I</i>	<i>UKBB (Kyiv Boryspil) RW 36R – 4000m lengths, Condition – wet, ILS CAT IIIA</i>

#### Weather:

UKKK 300300Z 06002KT 250 R08/400 FZFG VV002 01/01 Q1001 NOSIG. Kyiv Zhuliany airport current weather at 03.00 UTC. Wind is 060 degrees 02 knots. Visibility is 250 metres. Runway visual range on Runway 08 is 400 metres. Freezing fog. Vertical visibility is 200 feet. Temperature is 01. Dew point is 01. Pressure QNH is 1001 hPa. No significant weather changes in the next two hours. UKBB 300300Z 03004KT 800 R36R/1200 FZFG VV002 01/01 Q1001 NOSIG. Kyiv Boryspil airport current weather at 03.00 UTC. Wind is 030 degrees 04 knots. Visibility is 800 metres. Runway visual range on Runway 36R is 1200 metres. Freezing fog. Vertical visibility is 200 feet. Temperature is 01. Dew point is 01. Pressure QNH is 1001 hPa. No significant weather changes in the next two hours. UKOO 300300Z 00000KT 1000 R16/1700 OVC003 02/01 Q1002 NOSIG. Odesa airport current weather at 03.00 UTC. Wind is calm. Visibility is 1000 metres. Runway visual range on Runway 16 is 1700 metres. Overcast clouds with base 300 feet. Temperature is 02. Dew point is 01. Pressure QNH is 1002 hPa. No significant weather changes in the next two hours.

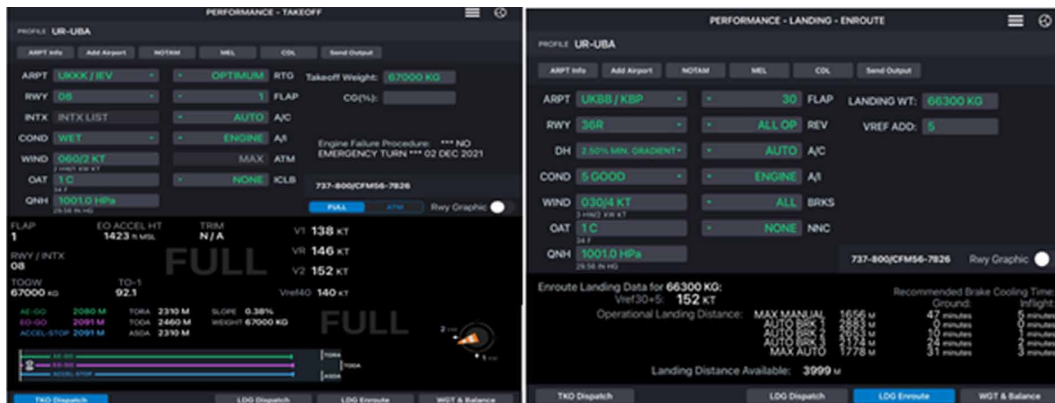
Captain incapacitation at decision speed  $V_1$ .

Boeing 737–800 performing take off from airdrome UKKK in low visibility condition.

Low visibility condition is in force, take off minima RVR=250m, weather according to minima RVR=400m, flight crew properly trained for these conditions. Take off mass are less than maximum structural and less than performance limited masses with equal 67000kg. All actual distances are less than available (Figure 9). Airplanes are properly serviced and loaded for flight; crew are ready too. Departure and destination alternate is UKBB. Weather at destination and alternate is according to minima. Departure and destination alternate is UKBB. For take-off are used flaps position 1, derate thrust 24K, engine anti-ice system is ON. Pilot flying is captain.

During take-off roll at decision speed  $V_1$  no response from captain for standard call out “ $V_1$ ” twice and no proper action at rotation speed, first officer take control and continue take off. After rotation when positive rate of climb achieved, retract landing gear. At 400 ft AGL he engages autopilot and check the position of essential controls and switches, accelerate aircraft, and retract flaps, inform ATC about take-off and comply with instruction to follow SID. Call on passenger address “Number one to the cockpit immediately” and instruct cabin crew to help captain, restrain and slide the seat

Figure 9. Actual departure performance (a) and landing performance (b)



back, assess him medical condition, provide with necessary care, call other cabin crew to find doctor on board. As determined captain loose conciseness. Decision is not proceeded to destination UKOO. Choosing suitable airdrome to come back:

Check weather and type of approach at UKKK and UKBB (preferable weather conditions at or above CAT I minima):

1. UKKK: ILS approach RW08, standard minima DA/H 767'/207', RVR 550m – weather less than minima.
2. UKBB: ILS approach RW36R, standard minima DA/H 632'/210', RVR 550m – weather according to minima.

Check performance and suitable service upon arrival at UKBB:

1. Landing mass 66300kg less than maximum 66360kg.
2. Actual landing distance less than available.
3. Nearest time to provide medical assistance to save the life.
4. All needed services are available on arrival and continuation of flight after crew change.

Best variant in this case is proceed to UKBB. FO needs to prepare flight deck for approach and get briefing to cabin crew to prepare cabin for landing in UKBB. Instruct flight attendant to read all check lists and request ATC for medical service and vectoring for approach at UKBB (whenever possible a long, straight-in approach).

Proceed as instructed, reconfigure aircraft for landing and perform landing. Stop the aircraft and set parking brake. Call on PA “Attention Cabin Crew! At stations!”. Request any assistance to ATC.

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