Applied Artificial Intelligence for Air Navigation Sociotechnical System Development

Tetiana Shmelova[1[0000-0002-9737-6906]], Yuliya Sikirda[2[0000-0002-7303-0441]], Mykola Kasatkin[3[0000-0002-2501-1756]]

[1]National Aviation University, Komarova av., 1, 03058, Kiev, Ukraine
shmelova@ukr.net
[2]Flight Academy of National Aviation University,
Dobrovolskogo Street, 1, 25005, Kropyvnytskyi, Ukraine
sikirdayuliya@ukr.net
[3]Kharkiv National University of Air Forces named by I. Kozhedub,
Sumska Street, 77/79, 61023, Kharkiv, Ukraine
kasatik_79@ukr.net

Abstract. Nowadays the evolution of Human Factor's models has included implementation of Artificial Intelligence (AI) in aviation as an innovative technology for enhancing security and the characteristic ability to learn, improve, and predict. The AI is presented in models of decision making in Air Navigation Sociotechnical system as Expert Systems, Decision Support Systems for pilots of manned and unmanned aircraft, for air traffic controllers in the emergencies.

Keywords: Air Traffic Controller, Collaborative Decision Making, Expert System, Human-Operator, Unmanned Aerial Vehicle.

1 Introduction

Nowadays in documents of International Civil Aviation Organization (ICAO) defined new added approaches for achieving the main goal of ICAO enhancing the effectiveness of global aviation security, and improving the practical and sustainable implementation of preventive aviation security measure. The Global Aviation Security Plan (GASP) identifies five key outcomes for improving effectiveness, such as [1]:

- enhancing awareness and response of risk;
- development of security culture and human capability;
- improving technological resources and foster innovation;
- improving oversight and quality assurance;
- increasing cooperation and support between states.

So, the quality of decisions dependences from the development and using of innovative technology in aviation nowadays such as Artificial Intelligence (AI) [2]. Developing of AI in Air Navigation System (ANS) as Sociotechnical system (STS) such as Expert Systems (ES), Decision Support Systems (DSS), are considering new concepts in aviation need with using modern information technologies and modern courses: Data Science, Big Data, Data Mining, Multi-Criteria Decision Analysis, Collaboration Decision Making (CDM), Blockchain, etc.

The purposes of the work are: analysis of the benefits of using AI models in the Air Navigation Sociotechnical System (ANSTS); AI models and methods; problems of CDM by ANS personnel (human-operators (H-O): pilots of manned and unmanned aerial vehicles (UAV), air traffic controllers (ATC), engineers).

2 Artificial Intelligence Systems in Air Navigation Sociotechnical System

Today, AI capabilities are proliferating across the transport sector. The AI systems have high potential in Air Traffic Management (ATM), specifically in areas which involve decision making (DM) under uncertainty (e.g. conflict detection and resolution) and prediction with limited information (e.g. trajectory prediction) [3; 4]. For example, validation based on one month of ADS-B data, the AI system is able to predict ATC actions, for complex traffic scenarios, at an accuracy – AN-Conf/13-WP/232 of above 70%. In addition to developing solutions to support en-route operations, AI can be applied in speech recognition to act as an additional safety net to detect read-back errors; trajectory synchronization of aircraft ground movements that provide optimised taxiing strategies that comprehensively accounts for arrivals and departures as well; and predicting the most optimal runway configuration for a given arrival sequence and departure schedule so as to maximize the runway throughput [2]. It is very important to create highly intelligent joint DM systems for engineers, pilots, air traffic controllers and new airspace users, such as unmanned aircraft systems. As a rule, systems are significant for work and for personal training.

Therefore, it is necessary to present ANS as STS and to applicate AI methods for development capacity of ANSTS. Examples of applied AI in education course “Informatics of Decision Making” for aviation students and future personal of ANS in Table 1. AI is the simulation of human intelligence processes by modeling, computer systems, and machines. These processes include: learning (the acquisition of information and rules for using the information); reasoning, estimation, and modeling (using rules to reach conclusions (approximate or definite results)); self-correction (estimation of obtained models); particular applications of AI include ES; DSS; automated systems; systems of pattern recognition, speech recognition, and machine vision, etc. Many cases of using AI technology are driven by emergence, availability, and accessibility. The differentiating factor of an AI system from a standard software system is the characteristic ability to learn, improve, and predict. Through training, an AI system is able to generate knowledge and apply it to novel situations not encountered before. In AI, an ES is a computer system that simulates the decision making ability of a human. The ESs are designed to solve complex problems by reasoning through bodies of knowledge, represented mainly as if-then rules rather than through conventional procedural code. The first ESs were created in the 1970s and then proliferated in the 1980s. Expert systems were among the first truly successful forms of AI software. The ICAO documents recommend developing Intelligent Expert Systems in aviation to support DM of operators [1; 2]. For the education of aviation personals in AI developed training, such as:

- Expert Judgment Method (EJM) / Multi-criteria decision problems.
- Deterministic models. Network planning. Decision making in an emergency.
- Stochastic models. Decision making in Risk. Decision making in an emergency.
- Game Theory. DM in uncertainty. Optimal aerodrome of landing.
- Dynamic programming (DP) and GRID analyzes of the problem. The DP method to solve the problem of minimal cost, climbing an aircraft.

Table 1. Applied AI in education course "Informatics of DM".

Content	Pilot	ATC	Engineer	UAV operator
Aviation man-machine system (MMS)	Analysis and synthesis of aviation using the theory of automatic control			
	MMS "pilot – aircraft" Analysis and synthesis of aviation using theory of automatic control	MMS "ATC-aircraft"	MMS	MMS "Operator of UAV"
Aviation expert system of quantitative estimation	Expert Judgment Method / Multi-criteria decision problems			
	Significance (complexity) of the phases of flight of the aircraft	Controller's workload for aircraft service	Significance of the Landing System (GNSS, ILS, VOR, VOR/DME)	Significance of the UAVs, phases of flight of the UAVs
Decision Support System of H-O in ANS	Models of DSS: deterministic and stochastic models of DM			
	DM of a pilot in the emergency	DM of ATC in emergency	DM of an engineer in service / emergency	DM of unmanned pilot
Decision making in certainty	Network planning of action of H-O in service/ emergency			
	Graph of procedures of the pilot in the emergency	Graph of procedures of ATC in emergency	Graph of procedures in the service of equipment	Graph of procedures of an unmanned pilot in an emergency
Design making in risk	Design tree of forecasting of action of H-O in emergency			
	DM in emergency	DM in emergency	DM in service of equipment	DM in emergency
Decision making in uncertainty	Criteria Wald. Laplace, Hurwitz, Savage optimal DM in uncertainty			
	Optimal landing aerodrome in emergency	Optimal landing aerodrome in emergency	Optimal action in emergency	Optimal landing aerodrome/place in emergency
Neural Networks	Forecasting of outcomes in emergencies			
Markov Networks	Neural network admission student to simulator training			
GERT-models	Development and forecasting the emergency situation / Preventing catastrophic situation			
Fuzzy logic	Quantitative estimation of the outcomes /risk in emergencies			
ANSTS	Analysis of ANS as STS and diagnostics, monitoring of the factors (professional and non-professional) that influence on DM by the H-O in STS (individual-psychological, socio-psychological and psychophysiological factors)			

For example, training 1 “Expert Judgment Method (EJM) / Multi-criteria decision problems” [5; 6]:

Theory. Basic of EJM for ANS (Classification of methods of DM. The algorithm of EJM. The matrix of individual and group preferences. Coordination of experts’ opinion. Multi-criteria decision problems).

Practice. *Tasks*: Quantitative estimation of the complexity of the aircraft flight. Definition of significance (complexity) of the phases of flight of the aircraft (Fig. 1).

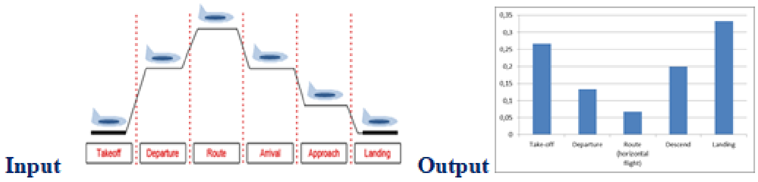

Fig. 1. The process of applying solutions to many similar tasks in the quantitative estimation of the complexity of the aircraft’s flight stages.

To show the DSSs we use tasks of alternate aerodrome/place in the case of an emergency landing (difficult meteorological conditions, etc.) by the method of DM in uncertainty is means of the criteria of DM in uncertainty: Wald, Laplace, Savage, Hurwicz [7]. For example, the results matrix of DM for choosing of landing aerodrome/place of UAV for route of UAV flight from Bila Tserkva aerodrome to Konotop with possible alternate destinations at Vasylkiv, Berezan’ Nizhyn and Pryluky (Table 2). Input data are: λ_1 – is an availability of fuel/energy onboard of UAV; λ_2 – is a distance from UAV to A_{Dest}, A_{Dep}, A_{AP}; λ_3 – are the tactical and technical characteristics of the runways of A_{Dep}, A_{Dest}, A_{AP}; λ_4 – are the meteorological conditions at A_{Dep}, A_{Dest}, A_{AP}; λ_5 – is a reliability of C2 lines for connection with UAV; λ_6 – is a possibility of communication with ATC units; λ_7 – are the navigational aids at A_{Dep}, A_{Dest}, A_{AP}; λ_8 – is a possibility of communication with ATC units; λ_7 – are the lighting systems at A_{Dep}, A_{Dest}, A_{AP}; etc. Formation of possible results in matrix determined with the EJM by rating scales according to the regulations.

Table 2. The results matrix of DM for choosing of landing aerodrome/place of UAV.

Alternative decisions		Factors that influence DM							Solutions			
A_i	A_{AAs}	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	W	L	H	S
A_1	Bila Tserkva	9	2	5	8	0	3	9	0	5,14	4,5	9
A_2	Konotop	3	5	7	9	2	4	9	2	5,57	4,5	7
A_3	Vasylkiv	2	8	8	9	2	4	10	2	6,14	6	8
A_4	Berezan’	7	1	8	7	1	7	7	1	5,43	5	7
A_5	Nizhyn	6	4	8	6	6	5	8	**4**	6,14	4,5	**4**
A_6	Pryluky	4	8	9	8	4	6	6	**4**	**6,43**	**6,5**	5

For the last years, the authors have developed computer programs for DSS of the aircraft pilot, air traffic controllers, flight dispatcher, UAV’s operator, etc. In Masters Diploma “Remote expert air traffic management system“ decision making in a common environment FF-ICE presented decentralized-distributed UAVs control system using blockchain technology (Fig. 2). There are many advantages of this approach such as enhanced security, security, big data analysis, and record keeping, real-time constant data exchange, etc.

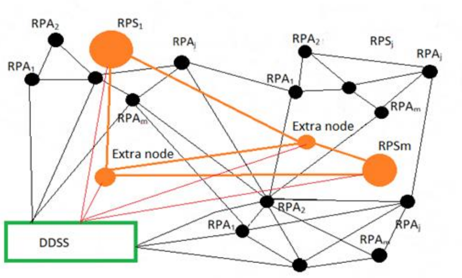

Fig. 2. Decentralized-distributed UAV's control system

For today, the key to ensuring the safety of flights is the problem of the organization of Collaborative Decision Making (CDM) by all the operational partners – airports, air traffic control services, airlines and ground operators – on the basis of general information on the flight process and ground handling of the aircraft in the airport [8]. Blockchain technology is ideal as a new infrastructure to secure, share, and verify learning achievements and CDM too.

The problem of optimizing the interaction between pilot and ATC can be solved by the way of development and synchronization (maximal alignment over time) of deterministic models of H-O CDM, which will minimize the critical time needed to solve EC, by definition the optimal sequence of execution of technological procedures. The parallel process of simultaneous execution of pilot and ATC technological operations in the emergency case can be represented as a consolidated dual-channel network. For a consistent optimization of such a network in order to achieve the cross-cutting efficacy of joint decisions, it is advisable to use a multi-criteria approach: achieving a minimum time for parity of emergency case with maximum safety / maximum harmonization over the time of H-O actions.

In this context, the use of flight simulators during ATC professional training is relevant. They will help ATC's to get acquainted with the situation in the flight crew cabin and the parameters of the aircraft's devices during the emergency case. At the same time the ATC: will receive the experience of the crew members during the emergency case; will pay attention to how the intervention of the dispatcher can disrupt crew members; will complete exercises on the use of radio during the emergency case; will complete the checklist in the emergency case; will participate in captain decision making during the emergency case; will observe the features of the go-around procedure. In the emergency case, ATC is advised to use a checklist that will help to handle incidents in order to establish optimal actions to achieve better cooperation between pilot and ATC. A supervisor who works with ATC, using a checklist, can provide better support as it will more clearly understand the traffic control in emergencies.

3 Conclusion

The AI technologies in aviation were clustered in the following seven capabilities: Machine Learning (ML); Natural Language Processing (NLP); Expert Systems; Vision and Speech; Planning; Robotics.

Further research should be directed to the solution of the problem in prerequisites of emergency situations and preventing catastrophic situations too. Models of flight emergency development and of DM by an operator in-flight emergency will allow predicting the operator's actions with the aid of the informational-analytic and diagnostics complex for research of operator behavior in extreme situations. It is necessary to develop modern DSSs of Air Navigation System's operator (pilots, air traffic controllers, flight dispatchers, UAV's operators) in-flight emergencies and in other situations, to investigate applied tasks of the DM in Sociotechnical System by an operator of aviation system, chemical production, energy, military industry, etc.

Developing of Intelligent ES, DSSs considering new concepts in aviation (FF-ICE, PBA, SMART, CDM, SWIM, etc.) for different operators and each stage, process, which are problems, with using modern information technologies Data Science, Big Data, Data Mining, Multi-Criteria Decision Analysis, etc. It is necessary to analyze all factors influencing the DM of operators in these systems in order to predict the development of the technogenic catastrophe and prevent it with AI.

References

1. Global Aviation Security Plan (GASP). International Civil Aviation Organization, Canada, Montreal (2017)
2. Potential of Artificial Intelligence (AI) in Air Traffic Management (ATM). In: Thirteenth Air Navigation Conference ICAO, Montréal, Canada, 9-19 October 2018 (2018)
3. International Civil Aviation Organization Global Air Traffic Management Operational Concept: Doc. ICAO 9854 (1st ed.). International Civil Aviation Organization, Montreal, Canada (2005)
4. Air Traffic Management: Doc. ICAO 4444-RAC/5011 (5th ed.). International Civil Aviation Organization, Montreal, Canada (2007)
5. Shmelova, T., Sikirda, Yu., Rizun, N., Lazorenko, V., Kharchenko, V.: Machine Learning and Text Analysis in an Artificial Intelligent System for the Training of Air Traffic Controllers: Chapter 1. In: T. Shmelova, Yu. Sikirda, N. Rizun, D. Kucherov, K. Dergachov (eds.). Automated Systems in the Aviation and Aerospace Industries: manuscript. USA, Hershey, IGI Global, 1-50 (2019)
6. Kharchenko, V., Shmelova, T., Sikirda, Y.: Methodology of Research and Training in Air Navigation Socio-technical System. Proceedings of the National Aviation University, vol. 1, 8–23 (2018)
7. Shmelova, T., Sikirda, Y., Rizun, N., Salem, A.-B. M., Kovalyov, Y.: Socio-Technical Decision Support in Air Navigation Systems: Emerging Research and Opportunities: manuscript. USA, Hershey, IGI Global (2018)
8. Manual on Collaborative Decision-Making (CDM): Doc. ICAO 9971 (2nd ed.). International Civil Aviation Organization, Montreal, Canada (2014)