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Decision Support System of Unmanned Aerial Vehicle's Operator for Choosing of the Alternate Aerodrome/Place in the Case of Emergency Landing

Decision Support System of Unmanned Aerial Vehicle's operator for choosing of the alternate aerodrome/place in the case of emergency landing has been developed.

Problem statement. Remotely Piloted Aircraft Systems (RPAS) are a new component of the aviation system, where the ICAO, States and the industry are working to understand, define and safe integrate into non-segregated airspace. These systems are based on cutting-edge developments in aerospace technologies, offering advancements which may open new and improved civil/commercial applications as well as improvements to the safety and efficiency of all civil aviation. Unmanned aircraft have several advantages, namely low operating cost, good concealment and flexibility, simplicity and availability of technology compared to manned aircraft and Unmanned Aerial Vehicles (UAV) can be used in cases where the usage of manned aircraft is impractical, expensive or risky [1]. The goal of ICAO in addressing unmanned aviation is to provide the fundamental international regulatory framework through Standards and Recommended Practices (SARPs), with supporting (Procedures for Air Navigation Services) PANS and guidance material.

The ICAO documents present the vision of an integrated, harmonized, and globally interoperable Air Traffic Management (ATM) system [2]. The Flight & Flow Information for a Collaborative Environment (FF-ICE) describes the information environment in support of that vision. The key aspects include support for a Performance-Based Approach (PBA), SMART (Specific, Measurable, Achievable, Relevant, Time-bound), Collaborative Decision Making (CDM), System-Wide Information Sharing and Management (SWIM).

Most importantly the introduction of remotely piloted aircraft into non-segregated airspace and at aerodromes should in no way increase safety risks to manned aircraft [3]. Safety can never fall below minimum acceptable levels. In fact, it should be argued that any change to the ATM system for an outcome not directly aimed at enhancing safety should, nonetheless, strive to achieve its net increase (Fig. 1). The safety balance model indicates that, on the whole, the system needs to retain a safety tension to achieve an acceptable level of safety. The optimization of the interaction of safety and economic efficiency, one of the stages in the evolution of human factor models, presented by the authors [4] and has further applied development [5].

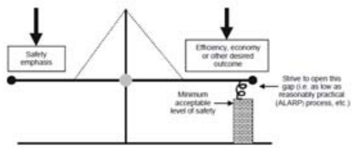

Fig. 1. Safety balance model [2]

The main advantage of using UAVs is tasks that involve risk to humans and efficiency in solving economic problems. Obviously, UAVs are effective in monitoring forest fires, search and rescue operations in the processing of agricultural crops, relay communications and the movement of goods. In this sense, the usage of UAVs is more appropriate: to relay communications at places where the antenna coverage cannot be set because of difficult terrain, in agriculture, aerial photography, moving cargo, for military purposes. Emergency situations may occur when flying both in manual and in the autonomous management. For operations carried out "manually" plays an important role in the human factor and a significant part of emergency arises due to wrong actions of the operator.

The purpose of the publication is the development of the multifunctional model for choosing of alternate aerodrome/place for the economic effectiveness of UAV's flight realization which will be used in RPAS for decision making support of UAV's operator.

Main part. To show the Decision Support System (DSS) we use the individual works of the aviation students from National Aviation University (Kyiv) during the courses "Efficiency of RPAS" and "Efficiency of ATM". In this example, the task of choosing of alternate aerodrome/place in the case of the emergency landing (for example, in difficult meteorological conditions) is solved by the methods of decision making (DM) in uncertainty with using Wald, Laplace, Savage, Hurwicz criteria.

The Algorithm of the finding of optimal landing aerodrome/place (alternate aerodrome/place) for return operation in an emergency situation on board of UAV that is caused by meteorological conditions:

1. Formation of the set of alternative decisions $\{A\}$:

$$\{A\} = \{A_{ADest}\ U\ A_{ADep}\ U\ \{A_{AAP}\}\} = \{A_1, A_2, \ldots, A_i, \ldots, A_n\},$$

where A_{ADest} – is an alternative decision to land at the destination aerodrome/place A_{Dest}; A_{ADep} – is an alternative decision to return to the aerodrome/place of departure A_{Dep}; $\{A_{AAP}\}$ – is a set of the alternate aerodromes/places $A_{AP.}$

2. Formation of the set of factors (states of nature) $\{\lambda\}$ that influence on the alternative decision in case of the landing of the UAV:

$$\{\lambda\} = \lambda_1, \lambda_2, \ldots, \lambda_j, \ldots, \lambda_m,$$

where 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.

3. Formation of the set of possible results $\{U\}$ that influence on the alternative decision in case of the landing of the UAV:

$$\{U\} = U_{11}, U_{12}, \ldots, U_{ij}, \ldots, U_{nm}.$$

where U_{ij} – are the possible results that have been determined with the method of expert estimates by rating scales according to the regulations.

4. Formation of the decision matrix $M=||Mi||$.

5. Selection of criteria of DM in uncertainty for a task of choosing of the optimal landing aerodrome/place in the emergencies: Wald criterion (W); Laplace criterion (L); Hurwitz criterion (H); Savage criterion (S).

Wald criterion (maximin) is based on a conservative careful behavior and reduced to select the best alternative from the worsts. According to Wald criterion, an optimal decision provides guarantee result – the best solution of the worst alternatives – and completely excludes a risk. This criterion is used in cases when decisions are made rarely, for instance in case of the first flight or flights performed sporadically:

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

Laplace criterion is based on the principle of insufficient grounds, according to which all factors are assumed to be equally probable. This criterion is used in cases of often, regular flights:

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

where m – is a number of possible states of nature.

Hurwitz criterion covers a number of different approaches to DM – from the most optimistic to the most pessimistic (conservative). The optimum solution for Hurwitz criterion determines by the epy rule:

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

where α – is an optimism index ($0 \le \alpha \le 1$).

If $\alpha = 0$ Hurwitz criterion is conservative because its usage is equivalent to the usage of usual maximin criterion. If $\alpha = 1$, Hurwitz criterion is too optimistic because expect the best of the best conditions. The degree of optimism or pessimism is specified by selecting α value in the interval [0, 1]. If there is no pronounced tendency to optimism or pessimism, and in accordance with the requirements of the balance [3-5], the most optimal will be $\alpha = 0{,}5$.

Savage criterion (minimax regret criterion) seeks to mitigate the conservatism of the maximin criterion by replacing the losses matrix to the risk matrix (the matrix of regret). Savage minimum risk criterion recommends using a strategy in which the maximum risk is minimizing in the worst conditions as an optimal one. The optimum solution for the Savage criterion determined by the condition:

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

where $r_{ij}(A_i, \lambda_j)$ – are the elements of the risk matrix that correspond to alternative A_i and factors λ_j:

$$r_{ij}(A_i,\lambda_j) = \underset{A_i}{\Delta} = \max_{\lambda_k} u_{ij}(A_i,\lambda_j) - u_{ij}(A_i,\lambda_j).$$

As the first example let's calculate the optimal landing aerodrome/place for big UAV flying from Kharkiv to Kyiv (Borispol) (Fig. 2) in a case of bad weather conditions: flight regular; for the first time; after two weeks. As the second example for this task in Masters diploma of O. Fomin (2018) was presented small UAV flight from Bila Tserkva aerodrome to Konotop with possible alternate destinations at Vasylkiv, Berezan' Nizhyn and Pryluky (Fig. 3).

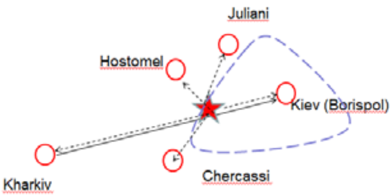

Fig. 2. The route for UAV flight from Kharkiv to Kyiv

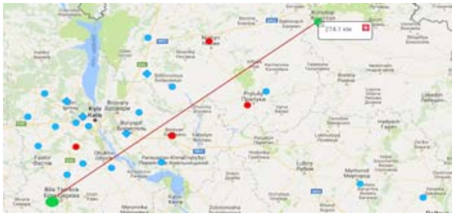

Fig. 3. The possible alternate destinations for UAV flight from Bila Tserkva to Konotop

The results of DM for choosing of landing aerodrome/place of UAV are in Table 2 (example 1) and Table 3 (example 2).

Table 1

The payoff matrix of possible results of DM for landing aerodrome

Alternative decisions		Factors that influence DM						Solutions			
A_i	A_{AAs}	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	W	L	H	S
A_1	A_{ADest}	1	1	9	6	5	7	1	4,83	5	8
A_2	A_{ADep}	8	9	9	2	8	8	2	**7,33**	**5,5**	7
A_3	A_{AAP1}	5	6	3	3	6	3	**3**	4,33	4,5	**3**
A_4	A_{AAP2}	6	5	2	5	5	2	2	4,17	4	6
A_5	A_{AAP3}	5	7	7	4	4	1	1	4,7	4	6

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

The optimal solutions in both examples are highlighted in bold.

For DM using four criteria of estimation, such as Wald, Laplace, Hurwicz, and Savage, the computer program "Classic Decision Criteria: Wald, Laplace, Hurwitz, and Savage" [6] has been designed (Fig. 3).

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.

Fig. 3. A final result of the program

Conclusion

The algorithm and the computer program of the finding of optimal landing aerodrome/place for decision support of UAV's operator in the emergency situation have been developed. It is based on the methods of DM in uncertainty and used Wald, Laplace, Savage, Hurwicz criteria.

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 Socio-technical System by an operator of aviation system, chemical production, energy, military industry, etc.

Developing of Intelligent 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 using Intelligent DSSs.

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