Integration of Decision-Making Models for Decision Support System of UAVs Operator in Emergencies

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Abstract. The investigation into the processes of modeling the decision making (DM) by UAV operators in the normal and unusual situations with the integrated models: stochastic, non-stochastic uncertainty models, and deterministic models for effective collaborative decision making. Algorithm of the finding of optimal landing aerodrome/place/vertiports for UAV operation in the case of the emergency situation given on example decision making in an emergency with UAV in approach to destination aerodrome in town in bad weather conditions. The authors made an analysis of the International civil aviation organization (ICAO) documents on risk assessment. To determine the quantitative characteristics of risk levels, models for DM by the operators of the for Remotely Piloted Aircraft System under risk and uncertainty have been developed. Estimation of factors that influence the selection of optimal landing aerodrome is realized with the help of the Expert Judgment.

Keywords: Unmanned Aerial Vehicle, Remotely Piloted Aircraft System, Decision Making in Risk and in Uncertainty, Decision Making in Certainty, Urban Air Mobility, Emergency Bad Weather Condition, vertiport, Smart- town, Decision Support system

1 Introduction

Remotely pilot aircraft (RPA) are quickly becoming an indispensable part of modern aviation. Last time, Unmanned Aerial Vehicles (UAV)s have been developing rapidly. The development of Unmanned Aerial Systems (UAS)s is currently being carried out by virtually all industrialized countries in the world. Until recently, UAVs had a military purpose, but now the use of UAVs is effective in both military and civilian tasks, for example, for support in dealing with emergencies, natural disasters; using in agricultural, and support of mobility in smart-city; for reconnaissance, and aerial photography [1, 2, 3]. Unmanned aerial vehicles have a number of advantages, namely: low cost of operation, stability, and flexibility, simplicity, and availability of technology compared to manned aircraft, in logistics as the safe, cheap, and fast method of transportation of cargo; for aerial photography; for controlling road traffic. UAVs can be used in cases where the use of manned aircraft is impractical, expensive, or risky [1, 4].

Nowadays UAVs are used to perform many tasks that were previously difficult to solve such as observation and monitoring missions in hard-to-reach places (forest, mountains, sea, rivers, lakes, big parks); monitoring forest fires; search and rescue operations; alternative performance of a difficult agricultural activity (aviation chemical work); relaying of communication signals in places where antenna coverage cannot be set because of terrain; for first aid to people in various life situations [1, 5, 6]. The use of group drone flights increases the efficiency of these target tasks. It is obvious that the efficiency of group UAV flights in some operations more preferable such as monitoring forest fires, search and rescue operations, agriculture in crop processing, communication relay, and cargo movement. The main advantage of using UAVs is areas with extra high risks to humans or large and inaccessible areas with the necessity in control using single or group UAVs flights in cities or agriculture terrain [6, 7].

The use of a single-operating or a group of UAVs is opening a big variety and a principally new level of complexity of target tasks and missions lowering the presence of a human itself while task execution of smart governance in the future cities as smart-cities [8]. So, the disadvantages of UAV include the limited capacity due to the small size of UAV that can be satisfied with the group flight usage [7, 8]. And additional useful properties such as faster coverage of big area fragment of urban and minimal risk in the movement of UAVs in town as in “smart-city” [9, 10].

Nowadays Urban Air Mobility (UAM) - is a new concept for Remotely Piloted Aircraft System (RPAS) operations — most prominently, scheduled/on-demand flights of “passenger UAV”. In UAM, RPAS will be capable of routinely flying published routes above cities (and their aerodromes) at low levels or conducting short-range flights between metropolitan areas [11, 12]. Each UAV has dual control features. On the one both, a UAV is controlled by an external pilot, therefore, the decision-making (DM) algorithm in an emergency should correspond to the type of aircraft [12, 13]. As known in accordance with the rules of operations, the actions of the pilot in an emergency are included in the Flight Operations Manual for concrete the type of UAV. On the other both, UAV control must be coordinated with the air traffic controller in accordance with the rules for the performance of UAV flights [14, 15]. Therefore, it is necessary to create UAV action algorithms in an emergency satisfying the requirements of the pilot and the controller [16, 17]. In addition, in order to minimize the human-factor (HF) in the preparation of the UAV operator, it is necessary to take into account the psycho-physiological qualities of the UAV operator, both the pilot and the dispatcher [18].

The purposes of the work are:

- decision-making algorithms of UAV operator in an emergency or in pre/flight programming of autonomous UAV flights;
- decomposition of the process of DM by UAV’s operator in an emergency;
- working-out of models DM by UAV’s Operator (DM in Certainty, DM in Risk, and DM in Uncertainty) for the search of the optimal solution in an emergency.

2 The integration Stochastic and Non-Stochastic Uncertainty Models to Deterministic Model of Multi-Decision Making

2.1 Multi-Decision Models in Emergency

Remote piloted aviation is integrated actively and becomes a part of the aviation system. The operational procedures of RPAS are determined by the aim of flight, rules of flights, areas of flights, and functional data link from RPA. The main rule of effective realization of flight for piloted and unnamed aviation too is the mandatory performance of pre-flight preparation including review and maintenance of the RPAS and remote pilot station (RPS). The operational procedures of RPAS are determined by the aim of flight, rules of flights, areas of flights, and functional data link from RPA. Within the pre-flight planning, alternate aerodromes/places/vertiports for return procedures should be effectively defined with maximum safety and minimum cost. These aerodromes/places/vertiports will be used in an emergency situation or an urgent situation that could be caused by inappropriate meteorological conditions, an interruption of the C2 link, other abnormal operating conditions of UAV.

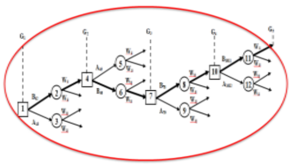
The basic requirements of the organization and realization of RPAS usage are defined by the governance of the International Civil Aviation Authority (ICAO). It is pointed out by ICAO that RPAS is related to systems that are grounded on the newest developments in the area of aerospace technologies [12, 13]. The remote pilot-in-command (PIC) is expected to have continuous control over the RPA under normal operating conditions. An interruption of the C2 link is considered an abnormal operating condition. ICAO documents recommend RPAS design should, therefore, take into account the potential interruption of the C2 link, changing of operating conditions. The duration of the interruption or complex phase of flight may elevate the situation to an emergency. Appropriate ab-normal or emergency procedures should be established to cope with any C2 link interruption commensurate with the probability of occurrence [11, 12, 13].

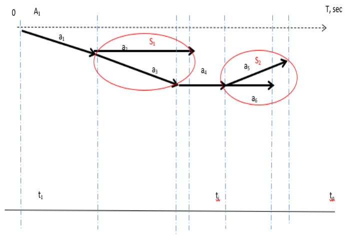
With the aim to optimize the pre-flight preparation the automated systems of pre-flight preparation information and Decision Support Systems (DSS) were created [18]. The application of the models in these systems depends on the type of flight (regular; for the first time; after 2 weeks); a calculated route of direction; the characteristics of aerodromes of departure, destination, and the alternate aerodromes according to calculated route; the class of situation; level of complexity of the situation, choosing the optimal actions of PICs. Within the pre-flight planning, effective alternate aerodromes/places/vertiports for return procedures should be defined [19].

Let UAV perform the target task. At a certain stage of flight are probable extraordinary or emergency situations (for example loss of control, engine failure, bad weather conditions) and it is some risk to lost UAVs. The air traffic controller decides in emergency using technological procedures “ASSIST” (Acknowledge, Separate, Silence, Inform, Support, Time) [14, 15]. Taking into account the high cost of UAVs it is proposed to build an algorithm of UAV’s operator actions using module «ASSSIST» (Acknowledge, Separate, Synergetic ((Coordinated, Cooperation, Consolidation)) Silence, Inform, Support, Time) for each type of UAV. Module «ASSSIST» includes in distributed DSS and has models of the DM by human-operator (H-O) under certainty, risk and uncertainty [18, 19, 20].

In the recent documents, ICAO defined new approaches - application of artificial intelligence (AI) models the organization of Collaborative Decision Making (CDM) by all aviation operators using collaborative DM models (CDMM) based on general information on the flight process and features of the emergency situation [15, 16, 17].

In the process of analysis and synthesis of DM models in emergency situations makes sense to simplify complex models and solutions. So, for example, stochastic and non-stochastic of uncertainty, neural, the Markov, and GERT (Graphical Evaluation and Review Technique) - models, reflexion models, dynamic models may be integrated into deterministic models (Figure 1). The models for decision and predicting the emergency situation using CDMM [19]. For the formation (modeling) of DM, H-O (PIC) has the property such as the ability to apply different levels of DM complexity depending on the factors that influence the DM.





	Factors influence DM						
		λ_1	λ_2	...	λ_j	...	λ_n
Alternative actions	A_1	U_{11}	U_{12}	...	U_{1j}	...	U_{1n}
	A_2	U_{21}	U_{22}	...	U_{2j}	...	U_{2n}
	...	...	...	...	...	...	...
	A_i	U_{i1}	U_{i2}	...	U_{ij}	...	U_{in}
	...	...	...	...	...	...	...
	A_m	U_{m1}	U_{m2}	...	U_{mj}	...	U_{mn}

Fig. 1. The integration risk and uncertainty DM models in certainty model

Emergency situations may occur when flying both in manual and in the autonomous control. For operations carried out "manually", plays an important role in the HF, and a significant part of emergencies was due to the wrong actions of the operator. Using a constant two-way radio comes to continuous manual control device parameters, which leads to certain restrictions and inconveniences - the operator can’t be distracted from the management and takes full responsibility for the controlled UAVs, for his safety and for the safety of the environment and people. Autonomous UAV flights must be programmed to make decisions in an emergency [19].

The analysis of the emergency situation, the flight situation's development from normal to complicated, difficult, emergency or catastrophic in accordance with DM action by PICs gave a chance to obtain the optimal solution and prevent emergency situations.

The multifunctional model of a selection of alternate aerodrome/place/vertiports of RPA is proposed for economical effectiveness of flight realization of RPA which is used in the remote DSS of UAV’s operator. The transition from complex (stochastic and non-stochastic uncertainty models) to simple (deterministic) models are using different methods of DM and AI [16 - 19].

2.2 Stochastic and Non-Stochastic Uncertainty Models in Emergency

The selection task of an optimal alternate aerodrome/place/vertiports in the case of an emergency landing using the method of DM under uncertainty was obtained by means of the criteria of DM under uncertainty: Wald, Laplace, Savage, Hurwicz [18]. Each of the criteria has a set of differences in application. The main difference is the different levels of uncertainty of problem, types of flight (for the first time; regular flight or after 2 weeks), and complexity in-flight situation. For instance, the Laplace criterion is grounded on more optimistic assumptions (regular flight); the Wald criterion is grounded on more pessimistic assumptions is used to find the optimal solution in case of if a flight is a performance for the first time. The coefficient of optimism-pessimism is used in the Hurwicz criterion that can be used in different approaches from the most optimistic to the most pessimistic value (flight after 2 weeks and the real experience of a pilot). The Savage criterion is used in after-flight for re-calculation aeronautical fees minimizes the losses.

For example, finding optimal landing aerodrome/place/vertiports (possible aerodromes/places/vertiports such as aerodrome of departure A1, an aerodrome of destination A2, alternate aerodromes/vertiports AC1, AC2, AC3) for return operation in the case of an emergency situation that is caused by meteorological conditions (Figure 2).

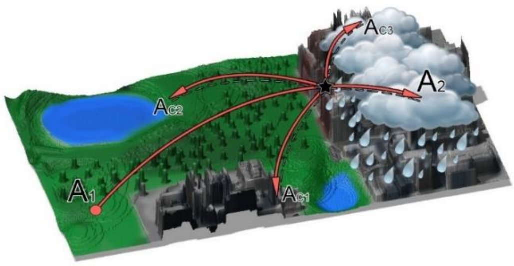


Fig. 2. The emergency situation "difficult meteorological conditions" in approach to destination aerodrome in town

For DM in the selection optimal alternate aerodrome/place/vertiports in the case of emergency landing need next output data:

1. a calculated route of direction;
2. an aerodrome of departure (ADep) and its characteristics;
3. an aerodrome of destination (ADest) and his characteristics;
4. a list of alternate aerodromes (AA) according to the calculated route;
5. a type of RPA and its tactical and technical characteristics (TTC);
6. current flight situation (difficulties in conditions of flight realization, difficult situation)
7. additional factors that influence on air traffic:

- adequacy of fuel/energy reserve;

- distance to the alternate aerodrome/place;
- reliability of C2 lines for connection with RPA;
- possibility of communication with air traffic control (ATC) units;
- meteorological conditions on the alternate aerodromes/places/ vertiports.

Algorithm of finding of optimal landing aerodrome/place/vertiport for approach in an emergency:

1. Formation of a multiplicity of alternative decisions $\{A\}$ from ADep, ADest, AAP:

$$\{A\} = \{A_{\text{ADest}} \text{ U } A_{\text{ADep}} \text{ U } \{A_{AP}\}\} = \{A_1, A_2, \ldots A_{\text{i}}, \ldots, A_n\},$$

where

A_{ADest} – alternate decision about landing ADest;

A_{ADep} - alternate decision about return to ADep;

A_{AP} - multiplication of alternates APs (list of alternative places for landing);

2. Formation of factors $\{\lambda\}$, that influence on selection of AP in the case of DM in conditions of emergency landing of RPA:

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

where

λ_1 - meteorological conditions on ADep, ADest, APs;

λ_2 - distance of RPA from ADep, ADest, APs;

λ_3 - TTC of APs, ADep, ADest;

λ_4 - availability of fuel/energy onboard of RPA;

λ_5 – reliability of C2 lines for connection with RPA;

λ_6 - possibility of communication with ATC units;

λ_7 - subjective factor (logistics, aeronautical fees, priority of AP).

3. Formation of possible consequences $\{U\}$ that influence on selection of aerodrome/place in case of emergency landing (ADep, ADest, AP):

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

where

U_{ij} - is defined according to the evaluation scale / regulatory documentation data.

4. Estimation of factors that influence the selection of optimal landing aerodrome, alternative decisions and expected outcomes are realized with the help of the Expert Judgment Method (EJM) [18, 20].

4.1 Matrix of individual preferences - determine opinion of the experts and their systems of individual preference (R_i)

4.2 Matrix of group preferences - determine opinion of the group of experts (R_{grj}) and their systems of group preference:

$$R_{grj} = \frac{\sum_{i=1}^{m} R_i}{m}$$

4.3 The coordination of experts' opinion:

Dispersion for each factor:

$$Dj = \frac{\sum_{i=1}^{m} \left(R_{grj} - R_i\right)^2}{m - 1}$$

Square average deviation:

$$\sigma_j = \sqrt{D_j}$$

Coefficient of the variation for each factor:

$$v_j = \frac{\sigma_j}{R_{grj}} \bullet 100\%$$

Kendal's coefficient of concordance for all factors:

$$W = \frac{12S}{m^2(n^3 - n) - m\sum_{j=1}^{m} T_j}$$

Rating correlation Spirman coefficient R_s :

$$R_{si} = 1 - \frac{6\sum_{j=1}^{n}(x_{ij} - y_{ij})^2}{n(n^2 - 1)}.$$

4.4 Significance of the calculations using criterion - χ^2 (and Student's t – criterion):

$${\chi_f}^2 = \frac{S}{\frac{1}{2}m(n+1) - \frac{1}{12(n-1)}\sum_{j=1}^{m} T_j} > {\chi_t}^2,$$

4.5 Weight coefficient w_j that means expected outcomes U_{ij}:

$$U_{ij} = w_j = \frac{C_j}{\sum_{j=1}^{n} C_j};$$

where $C_j = 1 - \frac{R-1}{n}$

5. Formation of decision matrix (Table 1) $M = \| M_i \|$.

Table 1. The matrix of DM in Uncertainty

	Factors influence DM in emergency						
	AP	λ_1	λ_2	…	λ_j	…	λ_n
Alternative aerodrome /place of RPA	A_1	U_{11}	U_{12}	…	U_{1j}	…	U_{1n}
	A_2	U_{21}	U_{22}	…	U_{2j}	…	U_{2n}
	…	…	…	…	…	…	….
	A_i	U_{i1}	U_{i2}	…	U_{ij}	…	U_{in}
	…	…	…	…	…	…	…
	A_m	U_{m1}	U_{m2}	…	U_{mj}	…	U_{mn}

6. Obtaining the optimal solution in the case of emergency landing using methods of DM under uncertainty: Wald, Laplace, Savage, Hurwicz.

The decision of selection task of alternate aerodrome/place in the case of emergency landing in bad weather conditions (BWC) presented on Figure 2.

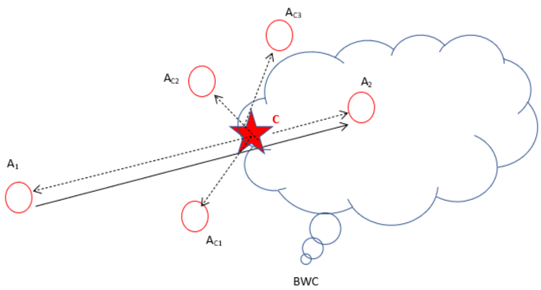


Fig. 3. The emergency with UAV – bad weather condition in approach to destination aerodrome in town

When analyzing a critical situation in a team, each operator determines his actions to solve this problem. After building a structural-timing table of operational procedures with time on the operating procedures (using EJM for obtaining solution times) building network graphs of operating procedures for PIC on Figure 3.

There are DM potential solutions: flights to an aerodrome of departure A_1, an aerodrome of destination A_2, alternate aerodromes/vertiports A_{C1}, A_{C2}, A_{C3}) for operations in the case of an emergency situation that is caused by meteorological conditions.

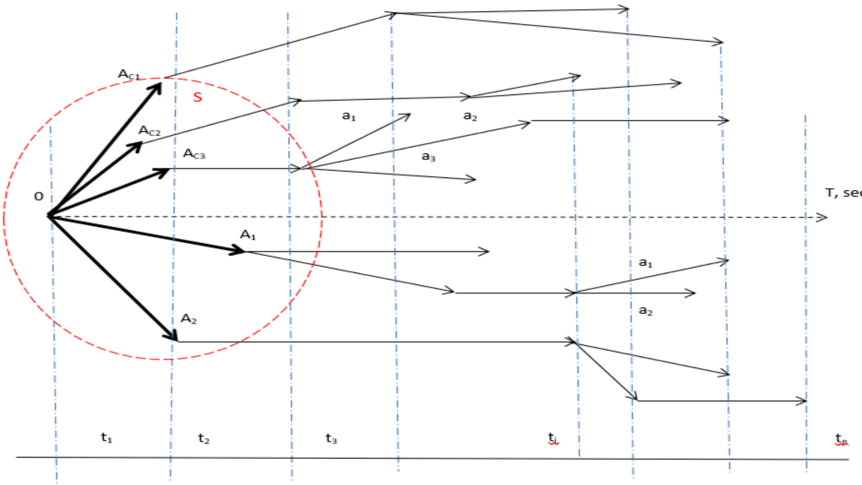


Fig. 4. Deterministic models of DM in emergency with UAV – bad weather condition in approach to destination aerodrome in town

Results of the definition of the expected outcomes of flight in influence factor λ_1 "meteorological condition on aerodromes" ADep(A_1), ADest(A_2), AP (A_{C1}, A_{C2}, A_{C3}) in Table 2 - matrix of individual preferences.

Table 2. Matrix of individual preferences for estimation of a meteorological conditions on landing aerodromes - factor λ_1

AP	A_1	A_2	A_{C1}	A_{C2}	A_{C3}	r_{sum}	$\boldsymbol{R_1}$
A_1		1	1	1	1	4	**1**
A_2	0		0	0,5	0	0,5	**3,5**
A_{C1}	0	1		1	1	3	**2**
A_{C2}	0	0,5	0		0,5	0,5	**3,5**
A_{C3}	0	1	0	0,5		1,5	**5**

The matrix of group preferences for 5 experts and results of coordination of experts' opinion, or all alternative places, received values of coefficients variation $v \leq \%$ and weight coefficients w_j as expected outcomes of flight in influence factor λ_1 "meteorological condition on aerodromes" presented in Table 3, where:

$$w_j = \lambda_{1i}$$

Table 3. Matrix of group preferences for estimation of a meteorological conditions on landing aerodromes

A	R_1	R_2	R_3	R_4	R_5	Rgr	D	σ	v, %	C	$w_j = \lambda_1$
A_1	1	1,5	1,5	1,5	2	1,5	0,125	0,353553	23,57023	0,9	0,3
A_2	3,5	5	4	4	4,5	4,2	0,325	0,570088	13,57352	0,36	0,1
A_{C1}	2	1,5	1,5	1,5	1	1,5	0,125	0,353553	23,57023	0,9	0,3
A_{C2}	3,5	4	5	4	4,5	4,2	0,325	0,570088	13,57352	0,36	0,1
A_{C3}	5	3	3	4	3	3,6	0,8	0,894427	24,8452	0,48	0,2

The results of similar calculations for other factors that influence DM when choosing a landing aerodrome such as distance from RPA to places of landing (λ_2); characteristics of aerodromes/places/vertiports (λ_3); availability of fuel/energy onboard of RPA (λ_4); reliability of C2 lines for connection with RPA in routes (λ_5); the possibility of communication with ATC units (λ_6); satisfaction of requirements of logistics in the task or expected aeronautical fees (λ_7) in routes presented in Table 4 and Figure 4.

Table 4. Multi-Factor estimation of landing aerodromes / places/ vertiports

A	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
A_1	0,3	0,1	0,3	0,3	0,3	0,3	0,3
A_2	0,1	0,3	0,1	0,1	0,3	0,3	0,2
A_{C1}	0,3	0,2	0,3	0,3	0,2	0,2	0,2
A_{C2}	0,1	0,2	0,2	0,1	0,1	0,2	0,1
A_{C3}	0,2	0,2	0,1	0,2	0,1	0,1	0,2

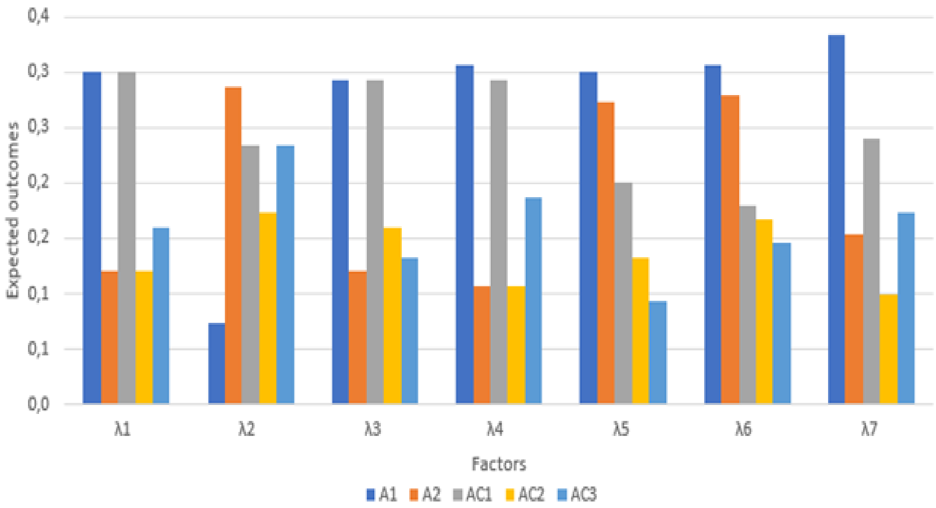


Fig. 5. Graphical presentation Multi-Factor estimation of landing aerodromes/places/ vertiports

2.3 Decision Making in Uncertainty in Emergency with UAV in approach to destination aerodrome in town

For task “landing in bad weather conditions” special emergency case: on the approach of UAV to A2 aerodrome lightning strike happened. Need to make a choice of the optimum landing aerodrome using decision criteria: Wald (if the flight is performed the first time), Laplace (if the flight is regular), Hurwicz (if the flight is performed after the break and with different optimism level) and Savage (re-calculation of air navigation fee).

Limited or inaccurate information in the task leads to two types of situations: DM in risk and DM in uncertainty (Figure 5):

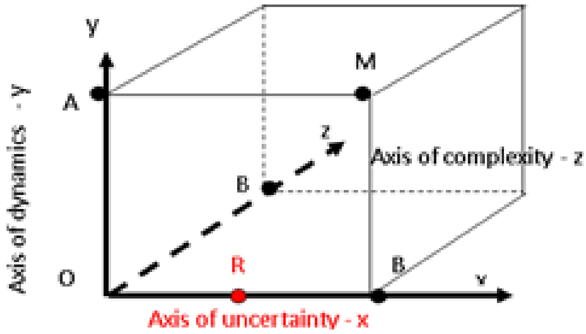


Fig. 6. Location of tasks with DM in risk and DM in uncertainty in DM tasks

1. DM in risk - the degree of incompleteness of the data is expressed in terms of the distribution density function (Figure 5, point *R*).

2. DM in conditions of uncertainty - data for solving a problem is expressed formatted a payoff - matrix, where are alternatives (*A*), factors influence on DM (*F*), and expected outcomes (*U*) (Figure 5, point *B)*.

That is, risk occupies an intermediate situation between certainty and uncertainty (point *R*): axis *x* “measure of uncertainty”, axis of dynamics – *y*; axis of complexity – *z*; probabilistic data – (at point *R* “risk” - DM in risk *R*), uncertain data - (at point *B* - DM in uncertainty).

Formulas for finding the optimal landing place for a UAV in an emergency are presented in Table 5 – DM in Risk and DM in Uncertainty.

If the initial data (*U*) in the problem is "profit", then according to the Wald criterion, the optimal solution is determined as a “maximin”. If the initial data in the problem is "costs / risks", then the optimal solution is determined as “minimax”.

In the Table 5 for DM in Risk – minimal optimal solution (risk), for DM in the uncertainty the optimal solution is the “maximum” benefit, profit / collective decisions.

There are PR tasks in uncertainty of 3 types [18 - 21]:

- expenses (cost/risk),
- income (profit),
- collective decisions.

Table 5. DM formulas in Risk /Uncertainty in Emergency with UAV

DM in Risk	
Situation with statistic data - distribution density function	$A_{opt} = \min\{R_m\}$, $R_m = F_m(t_m;\{A,\alpha,p,u\}) = t_m(\sum_{k=1}^{n} p_k u_k + \alpha_k)$, where R_m and $(<;>)R_{m-1}$.
DM in Uncertainty	
Criterion	Payoff matrix
Wald / the flight is performed the first time	$A^* = \max\limits_{A_i}\left\{\min\limits_{B_j} u_{ij}(A_i, B_j)\right\}$
Laplace/ the flight is regular	$A^* = \max\limits_{A_i}\left\{\frac{1}{m}\sum\limits_{j=1}^{n} u_{ij}(A_i, B_j)\right\}$
Hurwicz/ the flight is performed after the break and with different level of optimism	$A^* = \max\limits_{A_i}\left\{\alpha \max\limits_{B_j} u_{ij}(A_i, B_j) + (1-\alpha)\min\limits_{B_j} u_{ij}(A_i, B_j)\right\}$
Savage / re-calculation of air navigation fee	$A^* = \min\limits_{B_j}\max\limits_{A_i} r_{ij}(A_i, B_j)$, $r_{ij}(A_i, B_j) = \underset{A_i}{\Delta} = \max\limits_{B_k} u_{ij}(A_i, B_j) - u_{ij}(A_i, B_j)$

Results of calculations optimal solution by criterion Wald (W), Laplace (L), Hurwicz (H), Savage (S) for task “landing in bad weather conditions / lightning strike” presented in Table 6 and Table 7.

By Wald criterion optimal solution - A_{c1} aerodrome. By Laplace criterion optimal solution - A_1 aerodrome. By Hurwicz criterion optimal solution - A_{c1} aerodrome (for example, for coefficient $\alpha=0,5$ – rationalism).

Table 6. DM in uncertainty results – criterion Wald (W), Laplace (L), Hurwicz (H) (coefficients of optimism-pessimism $\alpha=0,1$; $\alpha=0,5$; $\alpha=1$)

AP	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	W	L	H	H	H
										$\alpha=0,5$	$\alpha=1$	$\alpha=0,1$
A_1	0,3	0,1	0,3	0,3	0,3	0,3	0,3	0,07	0,32	0,19	0,3	0,1
A_2	0,1	0,3	0,1	0,1	0,3	0,3	0,2	0,11	0,22	0,20	0,3	0,1
A_{C1}	0,3	0,2	0,3	0,3	0,2	0,2	0,2	0,18	0,29	0,24	0,3	0,2
A_{C2}	0,1	0,2	0,2	0,1	0,1	0,2	0,1	0,10	0,16	0,14	0,2	0,1
A_{C3}	0,2	0,2	0,1	0,2	0,1	0,1	0,2	0,09	0,19	0,16	0,2	0,1

By Savage criterion optimal solution - A_{c1} A_{c2} A_{c3} aerodromes (Table 7), where presented loss-matrix. As can be seen from the results of choosing the optimal landing aerodrome in the case of an emergency, it depends on the level of complexity of the task, type of flight, level of optimism in solving.

Table 7. DM in uncertainty results, loss-matrix – criterion Savage (S)

AP	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	S
A_1	0	0,2	0	0	0	0	0	0,2
A_2	0,2	0,0	0,2	0,2	0	0	0,1	0,2
A_{C1}	0	0,1	0	0	0,1	0,1	0,1	0,1
A_{C2}	0,1	0	0	0,1	0,1	0,0	0,1	0,1
A_{C3}	0,0	0	0,1	0,0	0,1	0,1	0	0,1

The minimizatcy risk in an emergency situation using decision-tree – method of DM at risk. For example, for the decision tree in Figure 6 chain of events (3 stages of situation development) is defined as:

$$R_3(A_{41}; A_{42}) = A_{41}, \text{ because } A_{41} < A_{42},$$

where solution on stage 3 (points A_{41} and A_{42}):

$$A_{41} = t_3(p_{411}u_{411} + p_{412}u_{412}) + \alpha_{41};$$

$$A_{42} = t_3(p_{421}u_{421} + p_{422}u_{422}) + \alpha_{42}$$

Analogically for stages 2 and 1:

$$R_2(A_{31}; A_{32}) \text{ and } R_1(A_{11}; A_{12}):$$

$$R_2(A_{31}; A_{32}) = A_{32},\ A_{31} > A_{32}, \text{ and } R_1(A_{11}; A_{12}) = A_{12},\ A_{11} > A_{12}.$$

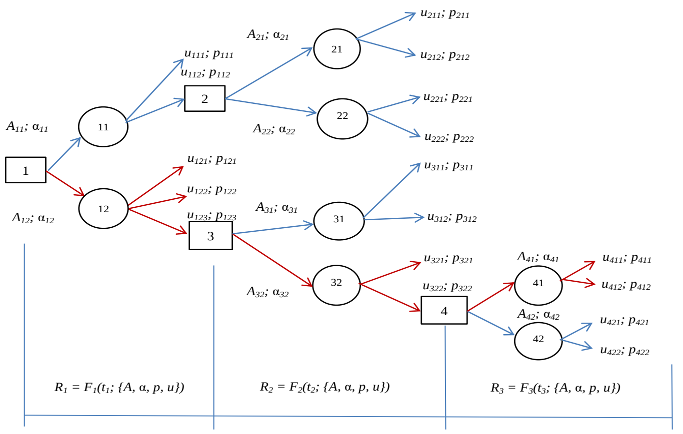


Fig. 6. Decision tree for example DM in emergency: t – is a time of DM stage; A – is an alternative of decision; α – is a shift in the risk of developing situation according to stages on decision tree; p – is a probability of adverse effects; u – is a damage due to negative solution.

After determining the minimum risks and maximum safety, it is necessary to perform procedures in certainty in accordance with ASSSIST» for selected type of UAV. A simplified model is a aggregated deterministic model with integrated stochastic models is shown in Figure 7. Ways to optimize the network graph for performing procedures by operators in the critical situation by minimizing time with maximum safety. In example, optimal solution - return to an aerodrome of departure (A_1).

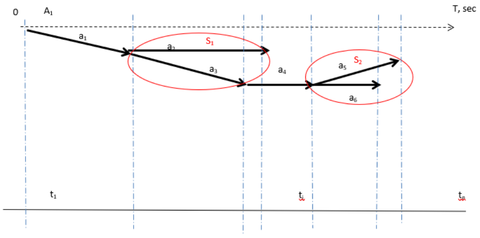


Fig. 7. The aggregated deterministic model with integrated stochastic models

3 Conclusion

The integrated models (stochastic, non-stochastic uncertainty models, and deterministic) for effective DM by UAV operators in the normal and unusual situations obtained. To determine the quantitative characteristics of risk levels, models for DM by the operators of the RPAS under risk and uncertainty have been developed. Algorithm of the finding of optimal landing aero-drome/place/vertiport for UAV in the emergency situation given on example decision making in an emergency with UAV in approach to destination in town in bad weather conditions. The evaluation of factors that influence the selection of optimal landing aero-drome is realized with the help of the Expert Judgment Method. The decision of selection task of an optimal landing aerodrome/place/vertiport in the emergency landing by means of the criteria Wald, Laplace, Savage, Hurwicz (DM in uncertainty), and decision-tree (DM in Risk) obtained. The decision-making algorithms using in DSS for the UAV operators in an emergency or in pre/flight planning of autonomous UAV flights presented. The algorithms may use for UAM systems for RPAS operations. And each UAV has dual control features. On the one both, a UAV is controlled by an external pilot, therefore, the decision-making algorithm in an emergency should correspond to the type of aircraft. On the other both, UAV control must be coordinated with the air traffic controller. The requirements of the pilot and the controller will satisfy future research in collaborative DM models. In addition, in order to minimize the BSF in the preparation of the UAV operator, it is necessary to take into account the psycho-physiological qualities of the UAV operator, both the pilot and the dispatcher.

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