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MODELLING OF DECISION MAKING OF UNMANNED AERIAL VEHICLE'S OPERATOR IN EMERGENCY SITUATIONS

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Abstract

Purpose: *lack of recommendation action algorithm of UAV operator in emergency situations; decomposition of the process of decision making (DM) by UAV's Operator in emergency situations; development of the structure of distributed decision support system (DDSS) for remotely piloted aircraft; development of a database of local decision support system (DSS) operators Remotely Piloted Aircraft Systems (RPAS); working-out of models DM by UAV's Operator.* ***Methods:*** *Algoritm of actions of UAV operator by Wald criterion, Laplace criterion, Hurwitz criterion.* ***Results:*** *The program "UAV_AS" that gives to UAV operator recommendations on how to act in case of emergency.* ***Discussion:*** *The article deals with the problem of Unmanned Aerial Vehicles (UAV) flights for decision of different tasks in emergency situation. Based on statistical data it was analyzing the types of emergencies for unmanned aircraft. Defined sequence of actions UAV operator and in case of emergencies.*

Keywords: algorithm, decision making process, emergency situation, unmanned aircraft system.

1. Introduction

Unmanned aircraft has 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; 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 in those places - where the antenna coverage cannot be set because of difficult terrain, agriculture, with aerial photography, moving cargo. In addition, UAVs were used for military purposes since 1961 [1].

The disadvantages of unmanned aircraft include the limited capacity due to the small size of UAV that can be satisfied for the group flight usage [2].

Emergency situations may occur when flying both in manual, and in the autonomous management. For operations carried out "manually", plays an important role the human factor and a significant part of emergency arises due to 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 state-controlled UAVs, for his safety and for the safety of the environment and people.

Let we have some UAV that performed different tasks purposes. Air traffic controller using technological procedures "ASSIST" (Acknowledge, Separate, Silence, Inform, Support, Time) decides in emergency situations of flight. At a certain stage of flight is probable extraordinary or emergency situations (for example: loss of control, engine failure, etc.), where it is some risk to lost UAVs. 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 Decision support system (DDSS) and has models of the Decision Making (DM) by H-O under Certainty, Risk and Uncertainty [3].

The purposes of the article are: lack of recommendation action algorithm of UAV operator in emergency situations; decomposition of the process of DM by UAV's Operator in Emergency Situations; development of the structure of DDSS for remotely piloted aircraft; development of a database of local DSS operators Remotely Piloted Aircraft Systems (RPAS); working-out of models DM by UAV's Operator (DM under Certainty, DM under Risk and DM under Uncertainty).

2. Distributed control system for remotely piloted aircraft

Advantages of UAV's are to perform the tasks associated with the risk for man and effectiveness in solving economic problems. In this sense, the use of UAVs is more appropriate: to relay communications in those places - where the antenna coverage cannot be set because of difficult terrain, agriculture (group of spraying fields), with photo/video monitoring (group survey of large areas, monitoring of forest fires, patrol areas, etc.), moving cargo [2]. Obviously is the usage of UAVs for military purposes.

Noted additional useful properties: faster coverage of area fragment and consequently more effective at photo/video monitoring, relay communications, agricultural operations - owned group compared UAV using one UAV [4 - 8]. But despite a number of advantages there are some drawbacks, namely the main problem associated with the use of airspace allocation of the frequency range for UAVs management and transmission of information from the board to the ground; lack of recommendation action algorithm of UAV operator in case of emergency situations [5; 6].

In [2; 7; 8] investigated an emergency engine stop, electrical problems, in excess of the maximum and minimum the display height of the flight of the parachute release is done automatically, with transferring the coordinates of the forced landing site to the operator's monitor. The use of a parachute landing system will not only provide reliable survival craft in an emergency situation, but also to simplify its operation.

When a loss of communication with the UAV made an immediate report to the ATM unit. The report states the time and place of loss of communication, the height of the UAV flight, the estimated remaining time of flight and follow the course of landing area (falling) UAV [2]. When hovering UAV in the crown of the trees must be up to the crown, fix the UAV tether and if necessary, to cut the branches and holding, drop to the ground [2].

Remotely piloted aircraft controlled with remote piloting station (RPS) with the management and control line (C2). Together with other components such as the starter equipment and equipment for the return, if it is used, remotely piloted aircraft (RPA), remote piloting station RPS and the line C2 constitute RPAS [9].

3. Aims of the work

1. Lack of recommendation action algorithm of UAV operator in emergency situations.
2. Decomposition of the process of DM by UAV's Operator in Emergency Situations;.
3. Development of the structure of DDSS for remotely piloted aircraft; development of a database of local DSS operators Remotely Piloted Aircraft Systems (RPAS).
4. Working-out of models DM by UAV's Operator (DM under Certainty, DM under Risk and DM under Uncertainty).

4. Estimation of situation's complexity in case of PCS with the help of fuzzy sets method

There are following classification of UAV's that is shown on Table 1 [6]. The type of UAV designs are divided into sets, which are made of airplane (fixed - wing) and helicopter (rotary - wing) schemes and devices with flapping wings.

The type of take-off UAVs are divided into sets of take-off from the runway and a vertical take-off (usually used depending of the purpose).

Unmanned aerial vehicles are classified by way of take-off and landing, airfield and non-airfield, also taking off from the runway or with a catapult; landing to the runway or by parachute or by using snares [8].

Table 1

UAV types

№	Class	Classification	Subclass	Code name
1	A	UAV classification by purposes	Surveillance UAVs	A_1
			Agricultural UAVs	A_2
			Relays communications UAVs	A_3
			…	A_n
2	B	UAV classification by duration of the flight	UAV of a short flight (1 hour)	B_1
			Medium-flight UAV's(from 1 to 6 hours),	B_2
			Early flight UAV's (6 hours).	B_3
			…	B_n
3	C	UAV classification by weight.	Micro UAVs (to 1kg).	C_1
			Small 1 - 100 kg.	C_2
			Lightweight 100 - 500 kg.	C_3
			Medium 500 - 5000kg.	C_4
			Heavy 5000 - 15000 kg.	C_5
			Superheavy 15,000 kg or more	C_6
			…	C_n
4	D	UAV classification by the type of aircraft	UAVs airplane (fixed-wing)	D_1
			UAVs helicopters (rotary-wing)	D_2
			UAVs with flapping wings.	D_3
			…	D_n
5	E	UAV classification by way of take-off	Airfield take off UAV	E_1
			Non-airfield UAV taking off from a catapult;	E_2
			Non-airfield UAV taking off from hands	E_3
			…	E_n
7	F	UAV classification by landing way	Airfield landing UAV	F_1
			Non-airfield UAV landing with the help of parachute;	F_2
			Non-airfield UAV landing with the help of snares;	F_3
			…	F_n
8	G	UAVs by the number of applications	UAV of single usage	G_1
			UAV of repeated usage	G_2
			…	G_n

By the purpose, the UAV classified as agricultural, surveillance, search and rescue, cargo and relays communications. As the number of applications classified as single and multiple applications. Typically, these UAVs are used in monitoring forest fires and search and rescue operations where there is a high probability of loss of the aircraft. For the duration of the flight of the UAV are classified on the aircraft a short flight (1 hour), medium-flight (from 1 to 6 hours), and early flight (6 hours). Given the rather large variety of UAVs also classified by weight. Micro to 1kg., Small 1 - 100 kg., Lightweight 100 - 500 kg., Medium 500 - 5000kg., Heavy 5000 - 15000 kg., Extra heavy 15,000 kg or more. All the above types of UAVs by weight are classified depending on flight distance and maximum take-off weight [7]. So, according to ASSIST there are such types of emergency situations which can be on a board of UAV: bird strike, brake problems, communication failure, electrical problems, emergency descent, engine failure, fire on a board, fuel problems, gear problems, problems with the hydraulic system, icing, fuel dumping, emergency landing, take off abort, low oil pressure. And actions of UAV's operator almost the same like actions of a pilot of a civil aircraft [3; 6; 9].

For example, let us consider the pre-flight preparing of UAV Birdeye 500 (Fig. 1). There are 7 main steps of preparing (Table 2, 3):

1. Make sure that the system is deployed, all cables are connected and the power is turned on remote controll and UAVs.
2. As data channel, set the channel maintenance.
3. Ensure you have a strong signal reception of UAV.
4. Put terrestrial channel to mode «Чисто».
5. Check for a strong signal transmission.
6. Set the working channel.
7. Set the operating mode Secure (if necessary), and set the number sequence.

The middle index of t_n is shown in Table 3, for example time of 1st step

$$t_1 = \{t_{11}, t_{12}, \ldots, t_{1n}\} = 5$$

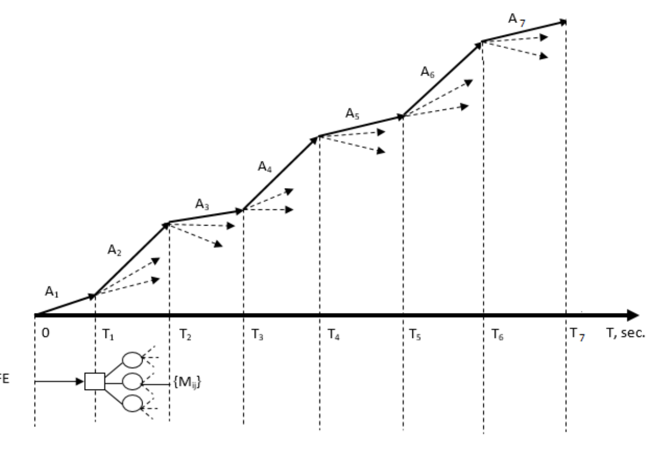

Fig 1. Determination grapf of preparing process

So, according to ASSIST there are such types of emergency situations which can be on a board of UAV: birdstrike, bomb warning, brake problems, communication failure, electrical problems, emergency descent, engine failure, fire on a board, fuel problems, gear problems, problems with the hydraulic system, icing, fuel dumping, emergency landing, takeoff abort, low oil pressure. And actions of UAV's operator almost the same like actions of a pilot of a civil aircraft (Fig.2).

For planning and flight control UAV developed a distributed Adoption Support System Solutions (ASSS), which represents a complex system with complex interactions geographically distributed local ASSS operators of UAS.

Table 2

Generalized structural-hourly table of the technology of the air traffic controller work in FE

№	Contents of the work	Designation of the work	Set of the operations	Support on the work	Time of the performing the work
	Setting of primary connection				
1.	Make sure that the system is deployed, all cables are connected and the power is turned on remote controll and UAVs.	A_1	$\{a_{11}, a_{12}, \ldots, a_{1n}\}$	–	$\{t_{11}, t_{12}, \ldots, t_{1n}\}$
2.	As data channel, set the channel maintenance.	A_2	$\{a_{21}, a_{22}, \ldots, a_{1n}\}$	A_1	$\{t_{21}, t_{22}, \ldots, t_{2n}\}$
3.	Ensure you have a strong signal reception of UAV	A_3	$\{a_{31}, a_{32}, \ldots, a_{3n}\}$	$A_1 \cap A_2$	$\{t_{31}, t_{32}, \ldots, t_{3n}\}$
4.	Put terrestrial channel mode ***Чисто***.	A_4	$\{a_{41}, a_{42}, \ldots, a_{4n}\}$	A_1 U A_2 U A_3	$\{t_{41}, t_{42}, \ldots, t_{4n}\}$
5.	Check for a strong signal transmission.	A_5	$\{a_{51}, a_{52}, \ldots, a_{5n}\}$	$A_1 \cap A_2 \cap A_3 \cap A_4$	$\{t_{51}, t_{52}, \ldots, t_{5n}\}$
6.	Set the working channel.	A_6	$\{a_{61}, a_{62}, \ldots, a_{6n}\}$	$A_1 \cap A_2 \cap A_3 \cap A_4 \cap A_5$	$\{t_{61}, t_{62}, \ldots, t_{6n}\}$
7.	Set the operating mode ***Secure*** (if necessary), and set the number sequence.	A_7	$\{a_{61}, a_{62}, \ldots, a_{7n}\}$	$A_1 \cap A_2 \cap A_3 \cap A_4 \cap A_5 \cap A_6$	$\{t_{11}, t_{12}, \ldots, t_{1n}\}$

Table 3

Main steps of preparing

Setting of primary connection	Make sure that the system is deployed, all cables are connected and the power is turned on remote controll and UAVs.	5 minutes
	As data channel, set the channel maintenance.	15 seconds
	Ensure you have a strong signal reception of UAV	5 seconds
	Put terrestrial channel modeЧисто.	5 seconds
	Check for a strong signal transmission.	5 seconds
	Set the working channel.	30 seconds
	Set the operating mode Secure (if necessary), and set the number sequence.	30 seconds

During the flight UAVs may be controled by remote piloting station (RPS). At any given time t_i k-UAV must piloted by only one j-th RPS, if necessary, at time t_{i+1} to be transmitted to the control (j + 1) th RPS (Fig. 3). This transfer flight control of the j-th RPS to (j + 1) -th RPS to be safe and effective, which is provided through the local DSS operators UAV.

At any given time t_i k-RPA can be controlled from only one *j-th* RPS, if necessary, at time t_{i+1} to be transmitted to the control *(j + 1)th* RPS for using DDSS (Figure 1). This transfer flight control of the j-th RPS to *(j + 1) -th* RPS to be safe and effective, which is provided through the local DSS operators RPAS (Figure 2). According to the recommendations of the ICAO guidelines [9] task system can perform one or more nodes (local DSS operators RPAS). With the formation of the database addresses issues related to the inclusion of RPA the existing regulatory framework of civil air navigation system; description and classification of UAVs and related components; rules of flight, such as instrument flight rules (IFR) and Visual Flight Rules (VFR) flights in the visual line of sight (VLOS) and beyond line of sight (BVLOS) [9].

To coordinate interaction and exchange of information between remoted pilots developed database of local RPS NoSQL [10]. During developing a database of local RPS, UAV users, it was made UAS components analysis, UAV, RPS, C2, and so on.

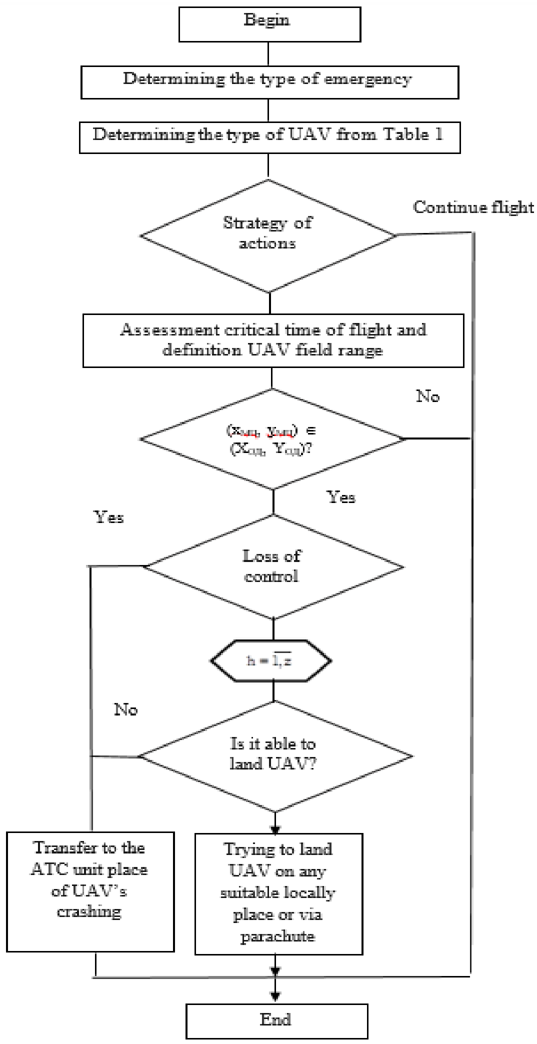

Fig. 2. Algoritm of actions of UAV operator

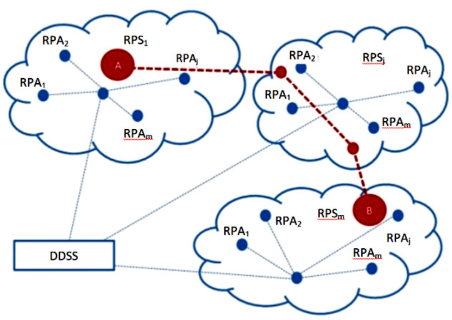

Fig 3. The structure of distributed RPS Mission Control UAVs

For optimization the solution of problems are developed models of determination the optimal landing site in case of an extraordinary situation, search for optimal flight routes UAS with the module «ASSSIST». The investigation into the processes of modelling the DM by UAV's operator in the normal and unusual situations enabled to build the following models: DM under Certainty, DM under Risk and DM under Uncertainty [3-6]. For example, for determine of the optimal landing aerodrome in flight emergencies (FE) we using model of DM under Uncertainty [3;11;12].

Pre-flight planning should include consideration to alternate aerodromes / recovery sites, as appropriate, in the event of the emergency or meteorological-related contingency. Before selecting an alternate recovery / landing, location the remote pilot should consider the adequacy fuel / energy, reserves, reliability of C2 links with the RPA, ATC communication capability as necessary and meteorological conditions at the alternate. For using known criteria of decision making under uncertainty are finding optimal landing aerodrome in FE [9].

To coordinate interaction and exchange of information between remoted pilots developed database of local RPS NoSQL [8]. During developing a database of local RPS, UAV users, it was made UAS components analysis, UAV, RPS, C2, and so on. Taking into account the UAVs operating procedure that includes the purpose of the flight, flight rules, flight areas, functional level C2 lines and other standards (Fig. 4).

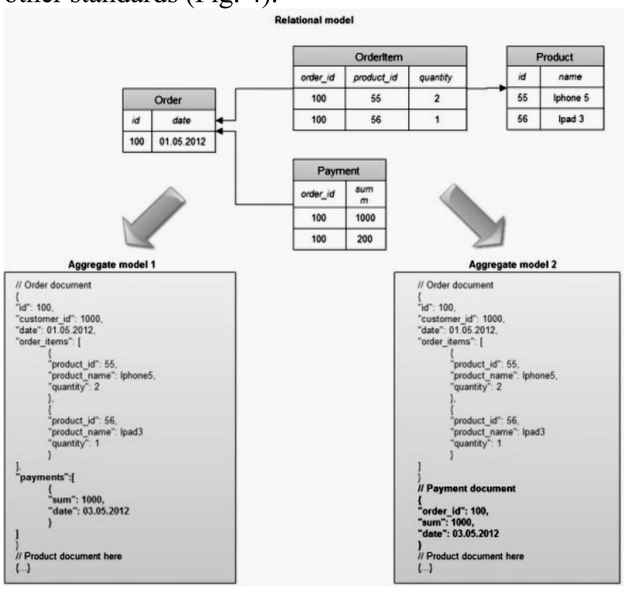

Fig. 4. Fragment of NoSQL database of local RPS UAVs users

Algorithm of determination of the optimal landing aerodrome in flight emergencies:

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

$$\{A\} = \{A_{dest} \cup A_{dep} \cup \{A_{alt}\}\} = \{A_1, A_2, \ldots A_i, \ldots, A_n\},$$

where

A_{dest} – is an alternative decision to land at the destination aerodrome; A_{dep} – is an alternative decision to return to the aerodrome of departure; A_{alt} – is a set of the alternative decision to alternate aerodromes / recovery sites.

2. Formation of the set of factors {λ}, influencing the choice of alternate aerodromes / recovery sites:

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

where

$\lambda_1, \lambda_2, ..., \lambda_j$ – is set of factors (fuel level, remoteness of the aerodromes, technical characteristics of runways of destination aerodromes, meteorological conditions, reliability of C2 links with the RPA, etc.).

3. Formation of the set of possible results of decision making under the influence of specified factors in FE, that were determined by the method of expert estimates by rating scales according to the regulations:

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

4. Formation of the decision matrix $M = \|M_i\|$ (Table 1). It was created computer program [11] for optimal solutions using criteria decision making under uncertainty (Fig. 5).

The program "UAV_AS" gives to UAV operator recommendations on how to act in case of emergency. To start you must select the file UAV_AS.exe and run it. After starting the main file software opens the main window (Fig. 6).

Choosing of the optimal aerodrome, in case of forced landing is carried out by the methods of decision making under uncertainty [10]. Selection of criterion of DM under uncertainty (Wald, Laplace, Hurwitz, Savage) is conducted according to the type of flight.

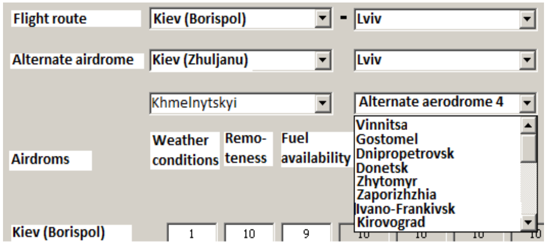

Fig. 5. The program „UAV_AS": choosing of alternate airdrome

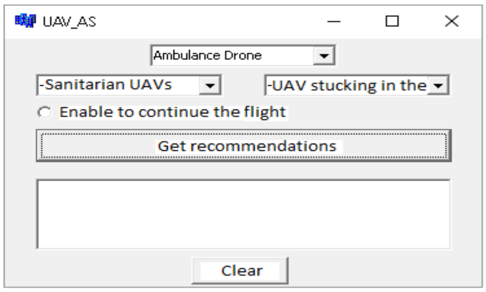

Fig. 6. The program „UAV_AS": the main window

Wald criterion (min/max) is based on the principle of "conservative attitude", and is applied if it is necessary to find a guaranteed solution in case of primary flight:

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

Laplace criterion is based on the principle of "insufficient reason" and applied is in case of regular flight:

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

Hurwitz criterion uses coefficient of a pessimism-optimism α (0 ≤ α ≤ 1) and is applied in case of flight once in 2 weeks:

$$A^* = \max_{A_i}\left\{\begin{array}{l}\alpha \max\limits_{\lambda_j} u_{ij}(A_i, \lambda_j) + \\ +(1-\alpha)\min\limits_{\lambda_j} u_{ij}(A_i, \lambda_j)\end{array}\right\}$$

Table 4

Matrix of possible results of decisions in the task of choosing of the optimal landing aerodrome / recovery site

Alternative decisions		Factors influencing the decision making					
		adequacy fuel /energy on RPA	remoteness of the aerodromes / recovery sites	technical characteristics of runways of aerodromes / recovery sites	meteorological conditions at aerodromes / recovery sites	reliability of C2 links with the RPA	ATC communication capability
A_1	A_{dest}	u_{11}	u_{12}	…	u_{1j}	…	u_{1n}
A_2	A_{dep}	u_{21}	u_{22}	…	u_{2j}	…	u_{2n}
A_1	A_{alt}	u_{11}	u_{12}	…	u_{1j}	…	u_{1n}
A_n	A_{alt}	u_{m1}	u_{m2}	…	u_{mj}	…	u_{mn}

The optimal solution for the Savage criterion can be found using matrix of “regret”. In case of win the elements of the “regret” matrix $r_{ij}(A_i, \lambda_j)$ are defined as the difference between the maximum value u_{ij} in the row and other values in the row. Then, with the help of the “regret” matrix according to the min/max principle the minimum deviations are determined:

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

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

Thus the person, who makes a decision, expresses with the help of matrix $\|r_{ij}\|$ his “regret” if he can’t make a best decision in the condition λ_j. Making this decision the person, who makes a decision, has a guarantee that in the worst conditions the obtained income would be not lower than the found income. If flight of UAV is a scheduled one, Laplace and Hurwitz ($0 \le \alpha \le 0.5$) criteria are used for decision making. If the flight of UAV is performed for the first time, Vald, Savage and Hurwitz ($0{,}5 \le \alpha \le 1$) criterions are used for decision making.

5. Conclusions

Further research should be directed to the solution of practical problems of actions UAV’s operator in case of emergencies, software creation. Models of FE development and of DM by UAV’s in FE will allow to predict the H-O’s actions with the aid of the informational-analytic and diagnostics complex for research H-O behavior in extreme situation.

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Моделювання прийняття рішень оператором дистанційно пілотованого літального апарату в аварійних ситуаціях

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Мета: Відсутність алгоритму рекомендацій дій оператора БПЛА в надзвичайних ситуаціях, розкладання процесу прийняття рішень оператором БПЛА в надзвичайних ситуаціях, розробка структури системи підтримки прийняття рішень для оператора БПЛА, розробка моделей прийняття рішень оператором БПЛА. **Методи:** Створення алгоритму прийняття рішень за допомогою критеріїв Вальда, Гурвіца, Ла Пласа. **Результати:** програма "UAV_AS", що дає рекомендації оператору БПЛА про те, як діяти в разі виникнення надзвичайної ситуації. Авторами розроблено алгоритм дій рекомендації оператора БПЛА в надзвичайних ситуаціях. Представлений процес прийняття рішень оператором БПЛА в надзвичайних ситуаціях у вигляді детермінованої моделі із застосуванням методів мережевого моделювання. Побудовано мережевий граф, за яким визначено критичний час на парирування надзвичайної ситуації у разі польоту БПЛА. Розроблено структуру розподіленої СППР для колективного управління пілотованих та безпілотних літальних апаратів оператором. Авторами розроблено бази даних для локальних СППР операторів управління БПЛА, Розроблено моделі прийняття рішень оператором БПЛА в умовах ризику та в умовах невизначеності у разі аварійної посадки БПЛА. **Обговорення:** У статті розглядаються проблеми польотів безпілотних літальних апаратів для вирішення різних завдань в надзвичайній ситуації, засноване на статистичних даних від аналізу типів надзвичайних ситуацій для безпілотних літальних апаратів. Визначається послідовність дій оператора БПЛА в разі виникнення надзвичайних ситуацій.

Ключові слова: алгоритм; безпілотні авіаційні системи; надзвичайна ситуація; процес прийняття рішень.

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Моделирование принятия решений оператором дистанционно пилотируемых летательных аппаратов в аварийных ситуациях

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Цель: Отсутствие алгоритма рекомендаций действий оператора БПЛА в чрезвычайных ситуациях, разложение процесса принятия решений оператором БПЛА в чрезвычайных ситуациях, разработка структуры системы поддержки принятия решений для оператора БПЛА, разработка моделей принятия решений оператором БПЛА. **Методы исследования**: Создание алгоритма принятия решений с помощью критериев Вальда, Гурвица, Ла Пласа. **Результаты:** программа "UAV_AS", что дает рекомендации оператору БПЛА о том, как действовать в случае возникновения чрезвычайной ситуации. Авторами разработан алгоритм действий рекомендации оператора БПЛА в чрезвычайных ситуациях. Представлен процесс принятия решений оператором БПЛА в чрезвычайных ситуациях в виде детерминированной модели с применением методов сетевого моделирования. Построено сетевой граф, по которому определено критическое время на парирование чрезвычайной ситуации в случае полета БПЛА. Разработана структура распределенной СППР для коллективного управления пилотируемых и беспилотных летательных аппаратов оператором. Авторами разработаны базы данных для локальных СППР операторов управления БПЛА, Разработаны модели принятия решений оператором БПЛА в условиях риска и в условиях неопределенности в случае аварийной посадки БПЛА. **Обсуждение:** В статье рассматриваются проблемы полетов беспилотных летательных аппаратов для решения различных задач в чрезвычайной ситуации, основанное на статистических данных от анализа типов чрезвычайных ситуаций для беспилотных летательных аппаратов. Определяется последовательность действий оператора БПЛА в случае возникновения чрезвычайных ситуаций.

Ключевые слова: алгоритм; беспилотные авиационные системы; аварийные ситуации; процесс принятия решений.

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