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CHEMICAL ACCIDENT AREA RECONNAISSANCE BY UNMANNED AIRCRAFT*

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Chemical accidents, as unexpected events, occur in contemporary society relatively often, and the resulting consequences can be different – from very small to catastrophic. Within the integrated response to chemical accidents, chemical reconnaissance of the accident area takes a significant place.

This paper presents the possibility of prioritizing the criteria and attributes of the criterion for selecting unmanned aircraft for reconnaissance of the chemical accident area. By analyzing the content of the available literature, the criteria for evaluating the alternatives of the offered "mini-unmanned aircraft" are set out.

This paper deals with testing using the questionnaire, processing the obtained data and prioritization of the criteria and attributes using the fuzzy AHP method and examination of the results consistency by the consistency degree. Testing of the obtained results and selection of optimal unmanned aircraft using the TOPSIS method has been carried out, as well.

Due to the extreme danger that personnel are exposed to during the chemical reconnaissance of the accident area (high concentrations of dangerous chemicals, long-term wearing of protectiveequipment, increased psychophysical stress, etc.), this paper considers the possibility of using unmanned aircraft. Furthermore, this paper suggests the way of selecting optimal UA as an element for reconnaissance in a particular chemical accident.

Key Words: *chemical accident, integrated response, chemical reconnaissance, unmanned aircraft, fuzzy AHP method, TOPSIS method*

Introduction

As chemical substances are naturally aggressive in relation to humans and the environment, their uncontrolled release can lead to unforeseeable consequences. The risk of such accidents exists in the chemical industry, devices, installations and equipment, transport facilities and others, where chemical substances are produced,

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processed, stored, transported or otherwise use hazardous chemical substances (hereinafter TC). Chemical accidents represent a particular price for the industrial development of the modern society. Chemical accident represents the sudden, unexpected and uncontrolled release of large amounts of toxic, flammable or explosive substances into the atmosphere, watercourses and the soil, which may have a harmful effect on humans, material goods and the environment. The consequences that can arise (great human and material losses, disturbance of regular activities, environmental degradation, etc.) have imposed the need for implementing adequate measures of the integrated response to the chemical accident (Indjić *et al.*, 2015).

One of the initial (and the most important) measures of the integrated response to the chemical accident is reconnaissance of the place where the accident occurred. In the Republic of Serbia, these tasks are mainly performed by the forces (teams) of the Sector for Emergency Management (the Ministry of Internal Affairs), the Public Health Institute (the Ministry of Health), the local government (municipalities – the city where chemical accident occurred) and the specialized units of the Serbian Armed Forces (primarily NBC units) (Indjić, 2014).

When performing this extremely complex task, the people that are involved are at great risk due to the following specificity of chemical accident:

– extremely high concentrations of TC in the hot spot of an accident (deadly for humans);

– high temperatures and possibility of explosion – fire (depending on the type and characteristics of released TC), (Rajić *et al*., 2013);

– long-term wearing of protective equipment (several hours in the case of major chemical accidents), (Jovanovic *et al.,* 2016);

– increased psychophysical stress (Karkalić *et al.,* 2015), etc.

Bearing in mind the mentioned hazards to the humans, this paper considers the possibility of using unmanned aircraft (UA) for this task. Of course, the advantage of UA is the ability to collect 3D information from the airspace that is hardly accessible from the ground (Roca *et al*., 2016).

The terminology used today for non-human crews is still not completely defined. The name that has been most frequently used in the development of these devices in numerous professional publications is "Unmanned Aerial Vehicle" (UAV). In the Republic of Serbia, the term "unmanned aircraft" (UA) is most often used for this type of device, so we will use this term. This paperoffers the following definition: "Unmanned aircraft is a type of aircraft controlled by a computer that is on an aircraft or whose flight is remotely operated by an operator on the ground". (Law on Emergency Situations, 111/2009, 92/2011 and 93/2012) In order to acquaint yourself with the method of choosing UA for the performance of the task of chemical reconnaissance of the accident area, the paper presents scheme of integrated response to chemical accidents in the Republic of Serbia, UA categorization, methodology of evaluating the criteria for selecting optimum UA using the fuzzy AHP method, estimation of criteria prioritization for UA selection, as well as UA selection using scientific methods: fuzzy AHP and TOPSIS.

Having in mind the aforementioned, the research has been carried out with the overall goal: evaluation of criteria for selection of modern BV for reconnaissance of the chemical accident area by using scientific methods: fuzzy AHP and TOPSIS.

The application of these scientific methods enables group decision- making process by taking into account the uncertainties of the evaluation of the experts, which makes the research scientifically and methodologically justified. In its essence, this procedure can be applied in any case of evaluating the criteria for the selection of various systems that can be used in emergencies, as well as when choosing a wide range of technological solutions in other spheres of social life, which makes this research practically justified.

Integrated Response to Chemical Accident

In order to perform optimum engagement of the forces of the society (chemical companies, local government, health institutions, police, army, etc.) in an integrated response to the chemical accident, it is necessary to apply the appropriate methodology in the decision-making process of selection of forces to be used in such situation (Figure 1) (Indjić, 2014).

The diagram below shows the asymmetric strategy of the integrated response to chemical accidents according to O^3 methodology: discovery – O^1, decide – O^2, disable (enable) – O^3, in relation to the NATO decision-making process in combat conditions according to D^3 methodology: Detect – D^1, Decise – D^2, Destroy – D^3 (Mučibabić, 2003; Kelemeniš, 2016).

In the NATO methodology, the focus is given on the superior technique where the goal is first detected, then the decision on optimal use is made and in the end there is the effective destruction of the chosen target.

In the Serbian Armed Forces (SAF) the term destroy is replaced with the term disable (enable), due to the restrictions that the SAF have (primarily material, technical and financial constraints). This kind of strategy prevents the enemy from achieving the goal in a certain area when using weapons of mass destruction, i.e. enabling the survival of its own units during the execution of various tasks in such complex conditions.

Considering these two methodologies of modeling the forces for integrated response to the chemical accident, we can conclude that the use of the O^3 methodology is quite acceptable because chemical accidents mostly happen in peace. Therefore, the term $Destroy^3$ is replaced by the expression $Enable^3$ meaning that the forces participating in the integrated response must create adequate conditions for the implementation of assigned tasks of removing the consequences of the accident.

In this paper, the focus is on the first segment of the integrated response *Discovery – O^1*, i.e. the examination of the consequences of chemical accident.

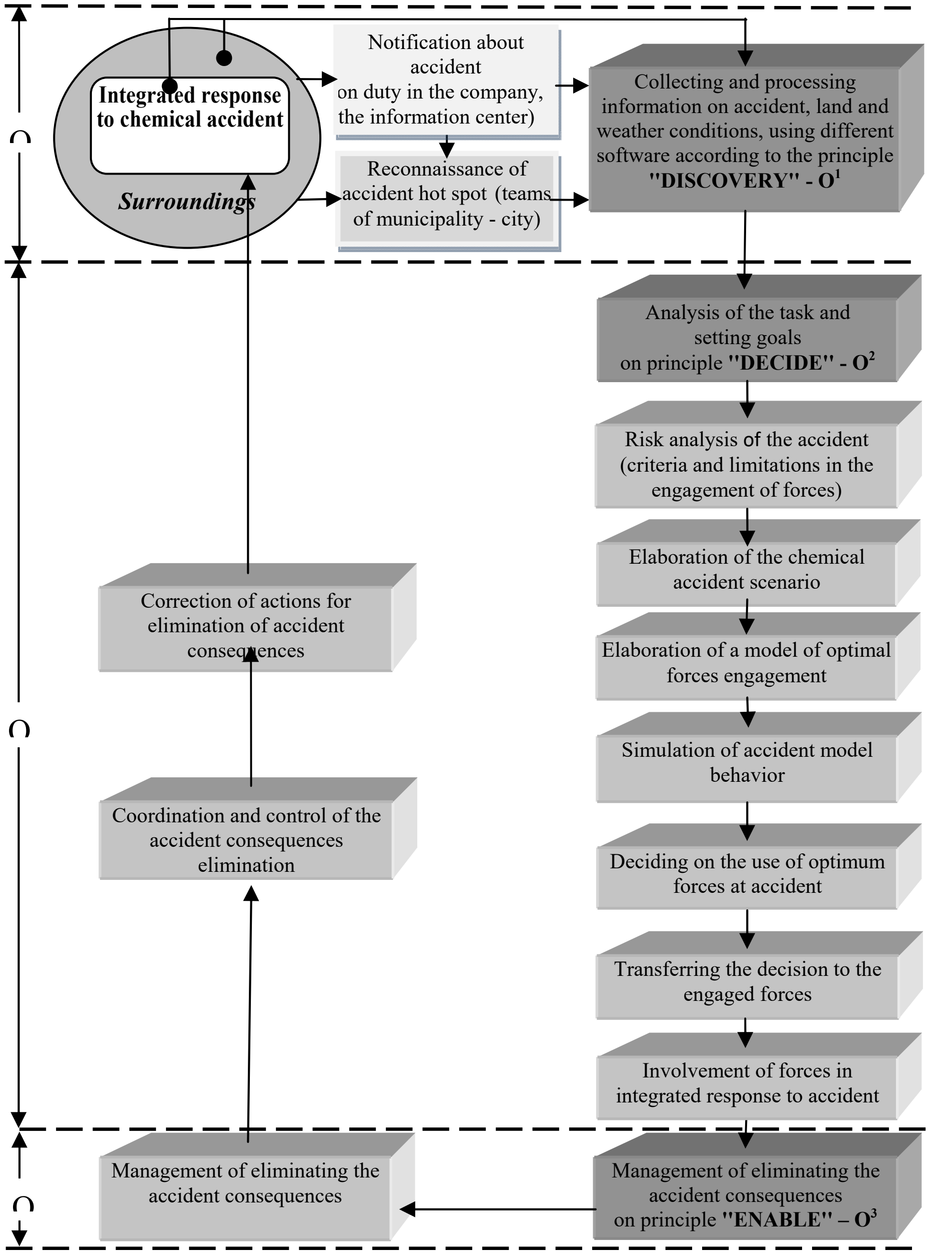

Figure 1 – *Model of engaging the society forces in the integrated response to the chemical accident according to the O^3 methodology: discovery – O^1, decide – O^2, disable (enable) – O^3 (Indjić, 2014)*

Categorization of Unmanned Aircraft

In order to establish the choice of UA for the task of accident area reconnaissance, the initial parameters must be considered. If we consider UA from the same category, certain restrictions apply to: height and flight speed, range, load capacity, possibility of sensor installation (detectors), costs, etc.

In order to examine and select the optimal UA model for accident area reconnaissance, we have conducted an analysis of their classification by different methodologies, such as NATO (North Atlantic Treaty Organization), EUROCONTROL (European Organization for the Safety of Air Navigation) and UAVS (Unmanned Aerial Vehicle Systems Association).

The UA classification in the NATO Alliance is shown in Table 1.

Table 1 – *Classification of UA according to NATO methodology* (www.globalsecurity.org)

Class	**Category**	**Level of application**	**Maximum flight altitude(ft)**	**Range (km)**	**Basic command support.**	**Representative**
Class 1 (under 150 kg)	Micro < 2kg	Team - squad, individual	Beneath 200	5	Team - squad	Black Widow
	Mini 2-20kg	Unit of the company level	Beneath 3000	25	Platoon/company	Raven
	Small > 20kg	Tactical unit	Beneath 5000	50	Battalion	Hermes 90
Class 2 (150 до 600 kg)	Tactical	Tactical formation	Beneath 10000	200	Brigade	Hermes 450
Class 3 (over 600 kg)	Operative	Operative	Beneath 45000	Unlimited	Staff	Predator
	Strategic	Strategic	Beneath 65000		Joint staff	Global Hawk
	Combat					

The UA classification according to the EUROCONTROL methodology is shown in Table 2.

Table 2 – *Classification of UA according to EUROCONTROL methodology* (www.eurocontrol.int)

Class	**Maximal weight (kg)**	**Range**	**Range (km)**	**Maximum flight altitude (ft)**
Class 0	Under 25	Small range	Beneath 10	1000
Class 1	25 – 500	Short range	10 – 100	15000
Class 2	501 – 2000	Medium range	100 – 500	30000
Class 3	Above 2000	Long range	Over 500	Over 30000

According to theUAVS, UA are classified in the manner shown in Table 3.

Table 3 – *Classification of UA according to UAVS methodology (Kolarek, 2010)*

Category name	Abbreviation	Aircraft weight (kg)	Range (km)	Maximum flight altitude (m)	Endurance (h)
micro	micro	<5	<10	250	1
mini	mini	25-150	<10	150-300	<2
small range	CR	25-150	10-30	3000	2-4
short range	SR	50-250	30-70	3000	3-6
medium range	MR	under 1250	70-200	5000	6-10
durable medium range	MRE	under 1250	>500	8000	10-18
deep penetration at low altitudes	LADP	under 350	>250	50-9000	0,5-1
long durability at low altitudes	LALE	<30	>500	3000	>24
durability at low altitudes	MALE	under 1500	>500	14000	24-48

In the Republic of Serbia, the UA flight is regulated by the Rulebook on Unmanned Aircraft. The same Rulebook has done the UA classification according to three criteria: the management mode, thepurpose and the operating mass and performance. (Rulebook on Unmanned Aircraft, 2015)

According to the management mode, UA are classifiedin the following way:

• unmanaged UA;

• automatically managed UA;

• remote controlled UA, operated by a pilot located in a station or on-board cabin.

According to the purpose UA are classified in the following way:

– UA used for economic purposes;

– UA used for non-commercial purposes (models used for scientific, educational and other purposes).

According to the operating mass and performance, UA are classified into:

• category 1 – includes UA whose operating mass is less than 0,5 kg, with a maximum flight height of up to 50 m, a maximum flight speed of up to 30 m/s and a maximum range of up to 100 m;

• category 2 – includes UA with an operating weight of 0,5 kg to 5 kg, with a maximum flight height of up to 150 m, a maximum flight speed of up to 30 m/s and a maximum range of up to 2500 m;

• category 3 – includes UA with an operating weight of 5 kg to 20 kg, with a maximum flight height of up to 500 m, a maximum flight speed of up to 55 m/s and a maximum range of up to 2500 m;

• category 4 – includes UA whose operating weight is from 20 kg to 150 kg, without limitation of height, flight speed and range.

If a particular UA in terms of the operating mass or some of the performances (flight height, flight speed or range) belongs to different categories of UA, it is considered to belong to a higher category.

Finally, Table 4 gives a review of UA categories with the examples of characteristic aircraft (systems) for each category. Ceiling (m) Autonomy (h) Range (km)

Table 4 – *Overview of unmanned aircraft categories (Bento, 2008)*

Groups	Category (acronym)	Maximum weight (kg)	Maximum flight altitude (m)	Autonomy (h)	Range (km)	EXAMPLES	
						Mision	Aircrafts (systems)
Micro/ mini	Micro	0,10	250	1	< 10	Scouting, NBC sampling, surveillance inside buildings	Black Widow, MicroStar, Microbat, FanCopter, QuattroCopter, Mosquito, Hornet, Mite
	Mini	< 30	150-300	< 2	< 10	Film and broadcast industries, agriculture, pollution measurements, surveillance inside buildings, communications relay and EW	Mikado, Aladin, Tracker, DragonEye, Raven, Pointer II, Carolo C40/P50, Skorpio, R-Max and R-50, Robo-Copter, YH-300SL
Tactical	"Closed" range	150	3,000	2-4	10-30	RSTA, mine detection, search and rescue, EW	Observer I, Phantom, Copter 4, Mikado, RoboCopter 300, Pointer, Camcopter, Aeriel, i AgriculturalRMax
	Short range	200	3,000	3-6	30-70	BDA, RSTA, EW, mine detection	Scorpi 6/30, Luna, Silver Fox, EyeView, Firebird, R-Max Agri / Photo, Hornet, Raven, Phantom, GoldenEye 100, Flyrt, Neptune
	Medium range	150-500	3,000-5,000	6-10	70-200	BDA, RSTA, EW, mine detection, NBC sampling	Hanter B, Mücke, Aerostar, Sniper, Falco, Armor X7, Smart UAV, UCAR, Eagle Eye+, Alice, Extender, Shadow 200/400
	Long range	–	5.000	6-13	200-500	RSTA, BDA, communications relay	Hanter, Vigilante 502
	High authority	500-1.500	5.000-8.000	12-24	> 500	BDA, RSTA, EW, communications relay, NBC sampling	Aerosonde, Vulture II Exp, Shadow 600, Searcher II, Hermes 450S/450T/700
	Medium height, high authority	1.000-1.500	5.000-8.000	24-48	> 500	BDA, RSTA, EW weapons delivery, communications relay, NBC sampling	Skyforce, Hermes 1500, Heron TP,MQ-1 Predator, Predator-IT, Eagle-1/2, Darkstar, E-Hunter, Dominator
Strategic	High altitude and authority	2.500-12.500	15.000-20.000	24-48	> 2.000	BDA, RSTA, EW, communications relay, boost phase intercept launch vehicle, airport security	Global Hawk, Raptor, Condor, Theseus, Helios, Predator B/C, Libellule, EvroHawk, Mercator, SenzorCraft, Global Observer, Pathfinder Plus

Groups	Category (acronym)	Maximum weight (kg)	Maximum flight altitude (m)	Autonomy (h)	Range (km)	EXAMPLES	
						Mision	Aircrafts (systems)
For special tasks	Lethal	250	3.000-4.000	3-4	300	Anti-radar, anti-ship, anti-aircraft, anti-infrastructure	MALI, Harpy, Lark, Marula
	Decoys	250	50-5.000	< 4	0-500	Aerial and naval deception	Flyrt, MALD, Nulka, ITALD, Chukar
	Stratospheric	TBD	20.000-30.000	> 48	> 2.000	-	Pegasys
	Exo-stratospheric	TBD	> 30.000	TBD	TBD	-	MarsFlyer, MAC-1

Considering the purpose of UA for reconnaissance of the accident area, the UA analysis of the "mini-unmanned aircraft" category has been carried out. In order to choose the optimal model of UA, and in accordance with the described categorizations, criteria for the selection of the optimal model of unmanned aircraft are defined.

On the basis of the collected data from the experts, the criteria for choosing the optimal UA in this paper are the following: load capacity(A), flight height (V), autonomy (S), range (D), possibility of upgrading (E), economy (F) and usage simplicity (G) (Kutnjak, 2017).

Evaluation Methodology of Criteria for Unmanned Aircraft Selection

The fuzzyAHP (Analytic Hierarchy Process) method has been used to evaluate the criteria for choosing optimal UA. In order to form an initial matrix of even comparisons, the data have been collected by the questionnaire, which was formed by Saaty in the form of nine-point scale of importance between two elements (Saaty, 1980). Prioritization, or determination of the relative weight of the elements based on their values, has been performed using the geometric mean method (Dağdeviren *et al.,* 2009). The questionnaire was filled in by six experts, who made a comparison of the criteria. Bearing in mind the small number of experts and dispersion of the obtained values, the crisp values (the integral mean value of the received expert responses) have been processed using the triangular fuzzy number (application of one of the approaches to group decision-making).

The procedure of fuzzy process has been carried out in the following way:

The fuzzy set A for each real number a has a value $\mu(a)$, where $\mu(a)$ is the degree of affinity a for the triangular fuzzy number A' and moves in the interval $[0,1]$. In general, the fuzzy set is represented in the following way A= $\{a, \mu(a)\}$.

For each crisp value a_{ij} two values are assigned by which the fuzzy number is formed, and it can be displayed in the following vector form:

$a'_{ij} = \{a_{ij} - \alpha, a_{ij}, a_{ij} + \alpha\}$, где је $\frac{1}{2} \leq \alpha \leq 1$, where, in this case, it is equal to 0.6 (Zhu *et al.,* 1999).

The mentioned fuzzy number characteristics are shown in Figure 2.

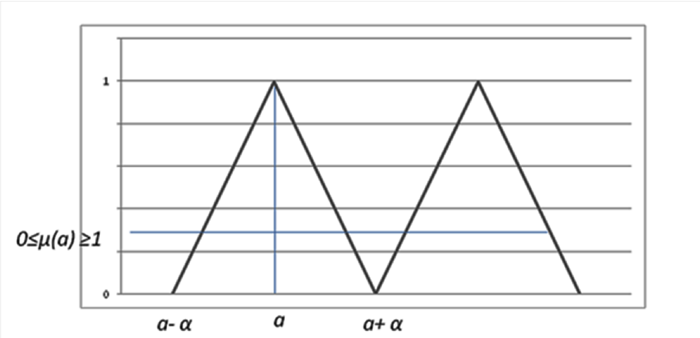

Figure 2 – *Construction of the fuzzy numbers in a matrix*

Bearing in mind that the calculation was performed using the geometric mean method, the rules in the work with fuzzy number are as follows:

$$1/a_{ij} = \left\{ \frac{1}{a_{ij}+\alpha}, \frac{1}{a_{ij}}, \frac{1}{a_{ij}-\alpha} \right\}, \tag{1}$$

$$a'_1 \oplus a'_2 = \{a'_{11} \oplus a'_{21}, a'_{12} \oplus a'_{22}, a'_{13} \oplus a'_{23}\}, \tag{2}$$

$$a'_1 \div a'_2 = \{a'_{11} \div a'_{23}, a'_{12} \div a'_{22}, a'_{13} \div a'_{21}\}, \tag{3}$$

where

$$a'_1 = \{a'_{11}, a'_{12}, a'_{13}\}$$

$$a'_2 = \{a'_{21}, a'_{22}, a'_{23}\}$$

Defining fuzzy numbers into the crisp value w was done as follows:

$$w = \frac{(w'_{11}, w'_{12}, w'_{13})}{3} \tag{4}$$

The consistency of all the obtained results was tested at the initial crisp value from the matrix of even comparison as follows (Pamučar, 2017):

$$CR = \frac{CI}{RI} \tag{5}$$

CI – consistency index

where $CI = \frac{\lambda_{\max} - n}{n-1}$ (6)

$\lambda_{\max}$ – maximum own value of the comparison matrix (formula number 7):

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\lambda_i \tag{7}$$

$$\lambda_i = \frac{b_i}{w_i} \tag{8}$$

The value is calculated as follows (formula number 9):

$$\begin{bmatrix} b_1 \\ b_2 \\ b_n \end{bmatrix} = \begin{bmatrix} a_{11}\, a_{12}\, a_{1n} \\ a_{21}\, a_{22}\, a_{2n} \\ a_{n1}\, a_{n2}\, a_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_n \end{bmatrix} \tag{9}$$

RI - random index, which depends on the number of rows – columns of matrix n (Saaty, 1980). If $CR \leq 0.10$ then the result meets the needs of the research.

After prioritization of the criteria, the optimal type of UA was selected using the TOPSIS method (four UA types were offered).

Estimation of Criteria Prioritization for the Selection of Unmanned Aircraft

On the basis of the described procedure, the initial matrix of the even comparison was formed according to the experts' response. The average matrix of the even comparison is obtained by finding medium of corresponding answer values, which were added the values of α and then the rule 1 was applied. In this way the procedure of fuzzy process of crisp values into triangular fuzzy numbers has been done.

Table 5 – *Average matrix of even comparison*

c	*A*	*B*	*C*	*D*	*E*	*F*	*G*
A	(1,1,1)	(1.77,2.17,2.77)	(0.25,0.3,0.37)	(0.32,0.4,0.53)	(0.27,0.32,0.39)	(1.4,2,2.6)	(0.73,1.33,1.93)
B	(0.36,0.46,0.64)	(1,1,1)	(0.21,0.24,0.28)	(0.34,0.43,0.58)	(0.23,0.27,0.33)	(0.9,1.5,2.1)	(0.41,0.5,0.71)
C	(2.77,3.33,3.93)	(3.57,4.17,4.77)	(1,1,1)	(1.07,1.67,2.27)	(0.73,1.33,1.93)	(3.4,4,4.6)	(2.23,2.83,3.43)
D	(1.9,2.5,3.1)	(1.73,2.33,2.93)	(0.44,0.6,0.94)	(1,1,1)	(0.57,0.85,1.76)	(1.9,2.5,3.1)	(1.07,1.67,2.27)
E	(2.57,3.17,3.77)	(3.07,3.67,4.27)	(0.52,0.75,1.36)	(0.57,1.17,1.77)	(1,1,1)	(3.4,4,4.6)	(1.4,2,2.6)
F	(0.38,0.5,0.71)	(0.48,0.67,1.11)	(0.22,0.25,0.29)	(0.32,0.4,0.53)	(0.22,0.25,0.29)	(1,1,1)	(0.41,0.55,0.81)
G	(0.52,0.75,1.36)	(1.4,2,2.6)	(0.29,0.35,0.45)	(0.44,0.6,0.94)	(0.38,0.5,0.71)	(1.23,1.83,2.43)	(1,1,1)

On the basis of the values of the triangular fuzzy numbers given in Table 5, the values of the relative weight coefficients in the form of the triangular fuzzy number w_i (Table 6) were obtained using the following formulas (Dağdeviren *et al.*, 2009):

$$w'_{i1} = \frac{\left(\prod_{j=1}^{n} a'_{ij1}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a'_{ij3}\right)^{1/n}} \tag{10}$$

$$w'_{i2} = \frac{\left(\prod_{j=1}^{n} a'_{ij2}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a'_{ij2}\right)^{1/n}} \tag{11}$$

$$w'_{i3} = \frac{\left(\prod_{j=1}^{n} a'_{ij3}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a'_{ij1}\right)^{1/n}} \tag{12}$$

$$w_i = (w'_{i1}, w'_{i2}, w'_{i3}) = \frac{\left[\left(\prod_{j=1}^{n} a'_{ij1}\right)^{1/n}, \left(\prod_{j=1}^{n} a'_{ij2}\right)^{1/n}, \left(\prod_{j=1}^{n} a'_{ij3}\right)^{1/n}\right]}{\sum_{i=1}^{n}\left[\left(\prod_{j=1}^{n} a'_{ij1}\right)^{1/n}, \left(\prod_{j=1}^{n} a'_{ij2}\right)^{1/n}, \left(\prod_{j=1}^{n} a'_{ij3}\right)^{1/n}\right]} \tag{13}$$

In this case $j = i = 7$

The same table shows the crisp value determined by formula 4 and the final values of the relative weights W_i of the criteria obtained after the normalization of the crisp values.

Table 6 – *Weighting coefficients for criteria*

c	w_i	w_i	W_i	*Ранг*
A	(0.06,0.1,0.16)	0.11	0.10	5
B	(0.04,0.06,0.1)	0.07	0.06	6
C	(0.17,0.28,0.44)	0.30	0.27	1
D	(0.1,0.17,0.31)	0.19	0.18	3
E	(0.13,0.23,0.38)	0.25	0.23	2
F	(0.04,0.06,0.1)	0.06	0.06	7
G	(0.06,0.1,0.18)	0.11	0.11	4

Based on the formula 7, we get $\lambda_{\max} = 7.12$ and $CI = 0.02$. For $n = 7 \Rightarrow RI = 1.35$ (Saaty, 1980). Using formula 5, value $CR = 0.01$ was obtained, which is less than 0.1. Based on the abovementioned, it has been concluded that the results are consistent (the experts are consistent in the even comparison of the criteria significance).

Selection of Optimal Unmanned Aircraft

After the prioritization of the criteria, the optimal type of unmanned aircraft was selected using TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution) (Hwang and Yoon, 1981). This method is based on ranking alternatives in relation to the ideal and negative ideal solution. The ideal solution maximizes the criteria of benefit type and minimizes criteria of cost type, while the negative ideal solution maximizes criteria of cost type and minimizes the criteria of benefit type. The offered alternatives are ranked on the basis of distance from the ideal solution.

The optimal alternative, in the Euclidean sense, is the one closest to the ideal and the farthest from the negative ideal alternative (Srđević *et al.,* 2002).

The first step in applying the TOPSIS method is the formation of a quantitative initial decision - making matrix, and then the normalization of the matrix value is carried out as follows (Pamučar, 2017):

$x_{ij} = r_{ij} \Big/ \sqrt{\sum_{i=1}^{n} r_{ij}^2}$ for elements of matrix that belong to criteria of benefit type,

$x_{ij} = 1 - r_{ij} \Big/ \sqrt{\sum_{i=1}^{n} r_{ij}^2}$ for elements of matrix that belong to criteria of cost type. (14)

In the next step, the multiplication of the normalized matrix values with values of the relative weight of the criteria is carried out:

$v_{ij} = x_{ij} w_j ; i = 1,2,...n$, n - number of alternatives; $j = 1,2,...m$, m - number of criteria (15)

Based on previous relations, a new weighted normalized matrix with elements is obtained.

The ideal solution is the following vector (Hwang and Yoon, 1981):

$$A^* = \{(\max v_{ij}, j \in G), (\min v_{ij}, j \in G^-)\} = \{v_1^*, v_2^*, ..v_m^*\}.$$

Negative ideal solution represents the following vector:

$$A^{-} = \{(\min v_{ij}, j \in G), (\max v_{ij}, j \in G^{-})\} = \{v_1^{-}, v_2^{-}, .. v_m^{-}\}.$$

G – criteria which are maximizing,

G^{-} – criteria which are minimizing.

In the next step, the distance of alternatives from the ideal are determined using the following formula (Hwang and Yoon, 1981):

$$S_i^{*} = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^{*})^2}, \ i = 1,..., n \tag{16}$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^{-})^2}, i = 1,..., n \tag{17}$$

In the next step, for each alternative, relative closeness to the ideal solution is determined (Hwang and Yoon, 1981):

$$Q_i^{*} = S_i^{-} / (S_i^{*} + S_i^{-}), \ 0 \le Q_i^{*} \le 1 \tag{18}$$

In the last step, alternatives areranked. The optimal alternative is the one that has the highest value Q_i^{*} (Hwang and Yoon, 1981).

In this paper, optimal UA is selected from four offered alternatives, as shown in Table 7.

Table 7 – *Characteristics of offered alternatives to unmanned aircraft*

Model UA (mini unmanned aircraft)	**Load capacity (kg)**	**Height of flight (m)**	**Autonomy (min)**	**Range (km)**	**Sensor fit-out**[1]	**Possibility of upgrading**	**Economy**	**Easy of usage**
Model 1	1	50	10	0,1	1 camera	small	60$	easy
Model 2	1	200	10	0,5	1 camera	no	50$	easy
Model 3	2	6000	25	2	1 camera	medium	300$	medium
Model 4	2	6000	30	5	1 camera	high	400$	medium

[1] Since each unmanned aircraft has a built-in camera (at least one), it is not taken as a criterion for selection of unmanned aircraft.

Quantitative and qualitative characteristics of UA are given by the manufacturer. The possibility of upgrading and ease of usage represent qualitative characteristics that are arranged using the Likert scale (Table 8).

Table 8 – *Likert scale for alternatives evaluation*

No	**Linguistic designation**	**Numerical value**	**Possibility of upgrading**	**Ease of usage**
1.	Very good (VG)	5	High	Easy
2.	Good (G	4	-	-
3.	Medium(M)	3	Medium	Moderately
4.	Bad (B)	2	Small	-
5.	Very bad (VB)	1	-	Complex

Based on the data in Tables 7 and 8, a quantitative initial matrix of decision is formed (Table 9).

Table 9 – *Quantitative initial matrix of decision*

Type	**A 0.10**	**B 0.06**	**C 0.27**	**D 0.18**	**E 0.23**	**F 0.06**	**G 0.11**
A1	1	50	10	0,1	2	60	5
A2	1	200	10	0,5	1	50	5
A3	2	6000	25	2	3	300	3
A4	2	6000	30	5	5	400	3
Criterion	max	max	max	max	max	min	max

After normalizing values (Formula 14), a weighted normalized matrix was obtained using formula 15 (Table 10).

Table 10 – *Weighted normalized matrix of decision*

Type	*A*	*B*	*C*	*D*	*E*	*F*	*G*
A1	0.032	0.000	0.065	0.003	0.074	0.053	0.067
A2	0.032	0.001	0.065	0.017	0.037	0.054	0.067
A3	0.063	0.042	0.163	0.067	0.110	0.024	0.040
A4	0.063	0.042	0.195	0.166	0.184	0.013	0.040

Ideal solution is:

$$A^* = \{0.063, 0.042, 0.195, 0.166, 0.184, 0.013, 0.067\}$$

Negative ideal solution is:

$$A^{-} = \{0.032, 0, 0.065, 0.003, 0.037, 0.054, 0.04\}.$$

Using the formulas 16 and 17, the Euclidean distances of alternatives to the ideal and negative ideal solution were obtained (Table 11).

Table 11 – *Euclidean distance of the alternatives*

Type	S_i^*	S_i^-
A1	0.24514	0.04549
A2	0.25580	0.02983
A3	0.13153	0.15026
A4	0.02668	0.26398

The relative proximity of alternatives to the ideal solution is calculated by using formula 18, and then the ranking of the alternatives has been performed (Table 12).

Table 12 – *Ranking of alternatives*

Type	Q^*	*Rank*
A1	0.15653	3
A2	0.10444	4
A3	0.53324	2
A4	0.90820	1

Discussion

On the basis of the obtained results, the optimal variant is the A4 (the unmanned aircraft *model 4*). Of course, it is necessary to install a modern sensor or a chemical detector on the selected UA, by which we will determine the type and quantity of TC, the spread direction of the contaminated cloud, certain meteorological parameters, etc.

The best example for this is the National Aeronautics and Space Administration (NASA), which developed a sensor that is easily converted to a chemical detector by simply connecting it to the "iPhone". According to the producer, currently this sensor successfully detects the presence of ammonia, chlorine and methane (Kutnjak, 2017).

The chip used for detection is made of silicone. It is extremely small in size (the size of a postage stamp) and can easily be installed on unmanned aircraft. In addition to detection, the chip is equipped with an alarm that informs the user of the danger (Hsu, 2009).

Due to its small dimensions, it does not represent load during installation on a particular UA, and in the subsequent period the focus is on increasing the number of TCs that the chip can detect.

The idea is that the massive use of these and similar detectors increases the security of the population, and that the authorities responsible for responding in crisis situations provide quick information about the site, the time of the accident, the type of contaminant, etc. The existence of such devices will significantly improve the system of response to the crisis caused by chemical accidents, i.e. to facilitate the work of teams in the integrated response to the accident.

Furthermore, modern UA can be equipped with sensors that can provide precise information about the weather conditions of interest to the end user. In this way, it is possible to quickly obtain the necessary data for the assessment of the consequences and information on the degree of ecological vulnerability of the area, where the chemical accident occurred (Gaston and Anderson, 2013).

The prioritization of the criteria and attributes of the criteria for the selection of UA for the reconnaissance of the accident area, has not been the subject of the scientific research so far. To some knowledge, the evaluation of criteria and attributes (total of 7 criteria) using the AHP method is carried out (Kutnjak, 2017). According to its results, the most important criterion is "autonomy" with a relative weight of 0.244, while the least important criterion is "economy" with a relative weight of 0.054. In this research prioritization has also been done for seven criteria (load – A, height of the flight – V, autonomy – S, range – D, possibility of upgrading – E, economy – F and ease of usage – G).

In this paper, the most important criterion is "autonomy", while the least important criteria are "height of the flight" and "economy".

Prioritization has been done using the fuzzy AHP method, which is one of the group decision-making tools, where the number of respondents is small (in this case six). It is also necessary to emphasize that the paper refers to the need for prioritization of the criteria for the selection of UA for reconnaissance of the chemical accident area from the point of view of use in peace (chemical accidents can also occur in combat conditions). The criteria for selection of UA are the following: autonomy – 0.27, possibility of upgrading – 0.23, range – 0.18, ease of use – 0.11, load capacity – 0.10, height of the flight – 0.06 and economy – 0.06.

On the basis of the results of the research, it can be concluded that the experts, nevertheless, consider that the "autonomy" and the "possibility of upgrading" UA (hardware and software components) have a major influence on the selection and application of UA (bearing in mind the work of UA over a long period of time and different types of built-in sensors). It is also interesting to note that greater significance is given to "range" of UA than to "simplicity of use" and "load capacity", while "flight height" and "economy" are the last. It is obvious that the experts consider that the tendency for the acquisition of UA for the reconnaissance of the accident area is to be focused on the procurement of aircraft that can operate independently and with as many built-in sensors (for collecting data about TCs, meteorological conditions, monitoring of contamination, etc.), which would protect the people engaged in the integrated response to the chemical accident and at the same time reduce the impact of TCs. A possible explanation for the small significance of "ease of usage" and "load capacity" is that the management of UA is carried out by trained service personnel and this is a category of "mini-unmanned aircraft" that normally carries very small load. The explanation for the significance of the "height of the flight" criterion would be relatively quickly falling to the ground in case of chemical accident, even when they are carried by wind (and even then they do not go to high altitudes because they are exposed to terrestrial currents). Regarding the criteria "economy", it is at the last place considering the scope of possible consequences for people, material goods and the environment.

By the precise implementation of the scientific method TOPSIS we have obtained the following order of alternatives, i.e. the UA models from the category "mini unmanned aircraft".

- A4 (fourth alternative) – 0.90820 (1st in ranking),
- A3 (third alternative) – 0.53324 (2nd in ranking),
- A1 (first alternative) – 0.15653 (3rd in ranking),
- A2 (second alternative) – 0.10444 (4th in ranking).

From this we can conclude that the fourth alternative, model 4, has the highest total value (0.90820), so it is the most favorable (optimal). This UA model is quite acceptable because it meets the most important criteria for choosing UA, which are "autonomy", "upgradability" and "range" and it has the best results compared to other considered UA models.

The next alternative is UA model 3 (best in terms of "height of the flight" and "load capacity"), then UA model 1 (best according to "ease of usage" criterion) and finally UA model 2 (best according to "economy" criterion).

On the basis of the results of the research it can be concluded that the aim of the research is completely fulfilled. The proposed model can be improved by applying more fully-qualified, modified methods of multi-criteria decision-making.

Conclusion

The paper discusses the possibility of using UA for reconnaissance of the chemical accident area within the integrated response of the state (society) to the accident situation. The choice of optimal UA for use in a particular chemical accident is shown on the basis of the criteria defined by the experts in the subject area.

After a comprehensive analysis, it can be concluded that for the needs of reconnaissance of the chemical accident area UA can be efficiently used.

The use of UA as an element for reconnaissance, within the integrated response to the accident, has many advantages:

– UA can be used in the contaminated environment without fear of the TC effects on persons, who collect data on the substance that caused the chemical accident,

– UA can carry a sensor for measuring a wide range of parameters that can be entered into the responsive monitoring software for prediction of the spread of the contaminated zone. In addition to using the most modern sensors for research, it is important to emphasize minimizing costs and maximizing simplicity for the purpose of different parameters monitoring (Valavanis and Vachtsevanos, 2014),

– UA can carry modern optoelectronic devices, thermal and 3D cameras, as well as other devices for operation in different exploitation conditions,

– monitoring measured parameters changes in order to make estimating the spread of the contaminated clouds faster and more realistic, so the design of the contaminated zone spread and the time for making the decision to take concrete measures is much better and faster.

The selection of optimum UA for reconnaissance of the chemical accident area within the integrated response to accident situation is presented in the final part of the paper, based on defined criteria and using the FUZZY - AHP and TOPSIS methods.

In this way, we have demonstrated one of the ways to choose the optimum UA for the needs of reconnaissance of the chemical accident area, of course with the previous upgrading of a particular sensor or chemical detector to UA (a means by which we will determine the type and amount of TC, the meteorological parameters, direction of the spread of the contaminated cloud, etc.).

In further studies, it is necessary to verify the results stated in the paper through practical research in real-life conditions (on the ground), where the results obtained by mathematical models using the unmanned aircraft would be checked in practice. With regard to this, it should develop and optimize the number of UA, which participate in the realization of O^1 phase and overflow their performance in O^2 phase.

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