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Прегледни научни рад

GIS MULTICRITERIA MODEL OF PATHS PLANNING FOR POTENTIAL MINI-UAV ATTACKS

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Abstract: This paper presents the application of the spatial model in assessing the threat of critical infrastructure from potential terrorist mini Unmanned Aerial Vehicles (UAV) attacks. The proposed model is based on the combined use of the Geographic Information System with Fuzzy Multicriteria Overlay Weighted Least Cost Path (GIS-FMWO-LCP) and analysis of the best-worst flight path assessment of UAVs. The model was applied to the case study of critical infrastructure in the southern Serbia. The implementation of the model showed that out of a total of 12 test sites, 67% are suitable for the use of mini-UAVs in a potential terrorist attack. The proposed spatial model can be successfully used in the assessment of the threat of terrorist attacks of mini-UAVs in a similar geographical area. Also, the proposed model is suitable for planning the flight of UAVs for the needs of transport and assistance in technological and natural disasters, fire protection monitoring.

Keywords: Geographical Information System; Spatial Analysis; Unmanned Aerial Vehicle; Corridors.

1. INTRODUCTION

In the last few decades, the use of Unmanned Arial Vehicle (UAV) has become mass in different areas. In this context, the term means unmanned Arial System (UAS) has a broader meaning where it implies a complex system consisting of a spacecraft, a terrestrial station and an operator (Coban and Oktay, 2017). Looking at the experiences of the latest conflicts in the Middle East, it was found that DAESH most commonly used commercial multi propeller UAVs for with improvised explosive devices (IEDs) (Balkan, 2017). The current threat of increasingly frequent use of mini-UAVs for terrorist purposes requires appropriate countermeasures. The aforementioned anti-drone measure involves military training in surveillance, listening, recognition and reporting on the direction of the mini-UAVs flight (Terzić, 2022). According to the recommendations Yaacoub et al. (2020) one of the protectors could be the elaboration of method detection and alarm on the UAV's run-in, enabling them to be neutralized from a safe distance. This requires an assessment of the flight capabilities of the mini-UAVs in accordance with the geographical conditions of the use area. In this context, finding methods for assessing the optimal flight of the UAVs in the function of protection is a research problem of this. Assessing the geographical space for flying around critical infrastructure would allow optimization of anti-drone measures to reduce the risk of collateral damage to traffic infrastructure.

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2. STUDY AREA

Vranje-Bujanovac valley is between 42°10´ and 42°41´ northern latitudes, 21°35´ and 22°05´ eastern latitudes (Figure 1). The lowest relief object or river catchment is Preševo saddle (459 m). It´s a 367.43 km² space. It's a stretch between the watershed of the South Morava River in the north, and the Vardar River basin to the south. The climate is moderate-continental with a stronger impact on the Mediterranean climate.. Average annual temperature is 11.9° C, minimum -6.8° C. maximum 18.1° C, precipitation 377 mm. Stronger winds are 8-10 m/s from NNW and N direction. In demographic and confectionary terms, space is heterogeneous and spatially uneven.

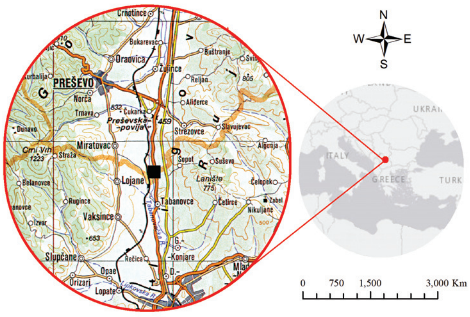

Figure 1.Geographical location of the study area.

Area represents Middle East warring area migrant route to EU with a high probability of migrant abuse for radical terrorist targets. State border due to the large volume of crossings, the long retention of large numbers of vehicles is exposed to potential terrorist attacks.

3. MATERIALS AND METHODS

Given that it is about predicting the flight of potential mini-UAVs with IEDs, this requires choosing an adequate method to include a realistic assessment of the geographical route from the launch site to the ultimate goal. One of the most applicable GIS tools is the Cost Path (LCP) routing. Cost Path is a flexible GIS method applicable in different areas, where the "cheapest" linear object or infrastructure needs to be found at the founding of multilevel analysis as an alternative procedure for traditional routing methods (Chandio et al., 2012). This supports not finding the shortest distance but the most profitable route, when it comes to multifactorial evaluation (MCE) (Abudu and Williams, 2015). Modifying the Cost surface with conditional and restrictive variables such as spatial length, bridges and tunnels resulted in the getting of relisted routes (Atkinson et al., 2005). When it comes to planning the UAVs flight corridor for civilian purposes, similar requirements must be met. A particular problem is planning Cost Paths across a continuous raster surface with discreet vector networks, where different transport surfaces and means need to be integrate (Choi et al.,2014). Integration of non-spatial and spatial data in analysis of UAVs flight routes is important due to technical and spatial flight restrictions of UAVs. A particular problem is the prediction of flight IED UAVs because due to the surprise flight paths may vary in relation to the safe or limited by administrative regulations of civil use. In this sense, it is necessary to anticipate the potential flight paths of mini-UAVs in a certain range of values that may deviate from the ideal. The solution imposes Fuzzy Membership expressed through a continuous range of 1 (full membership) up to 0 (full nonmember ship) u combined with a Multicriteria Cost Path GIS analysis could contribute to solving this problem. Applying fuzzy logic membership function in combination with the Cost Path model increases the objectivity and realism of the routes obtained even when it comes to multi-negative analysis designed in linear Geography Overlay Weighted methods (Choi et al., 2009). Considering previously stated research, to solve the problem of our research we applied the GIS Fuzzy Multicriteria Overlay Weighted Least Cost Path model (GIS-FMWO-LCP). GIS FMWO-LCP the model was first applied to address the problem of assessing the protection of critical infrastructure from attacks with mini-UAVs. It is a complex model designed to evaluate geographical criteria (test path) and technical limitations of flight UAVs (control path). The main idea of the proposed concept is to compare the two routes obtained based on different flight criteria and assessment methods. The final result should result in a spatial map with potential realistic flight routes IED UAVs from launch site to object of action. This should increase the objectivity of the assessment. This first phase consists of identifying, studying problems, and modeling steps in research. Solving the problem of assessing the optimal flight route stems from the relationship between geographical factors and technical flight possibilities of mini-UAVs (Table 1).

Table 1.Technical specification of mini-UAV.

Model	Max flight height (m) a.g.l.	Max flight distance (km)	Wind resistance (m/s)	Temperature use (°C)	Max Transmission Distance/ radio band (m/GHz)
DJI Mavic2	120	18	8-10	-10 to 40	5000-8000/2.4-5.8
Parott-Anafi	100	4	13	-10 to 40	4000/2.4- 5.8

Note. Adapted from Shenzhen DJI Sciences and Technologies 2018; Parrot Drones 2020).

Since mini-UAVs have limited technical capabilities as it shown, it is necessary for the price of the flight route to be optimized. The relevant spatial criteria are chosen and grouped into clusters were selected. Physical geography criteria: elevation (C1), slope (C2) and vegetation (C3). Socio-economic geographical criteria: (settlement area (C4) and power line (C5). Technical navigation criteria: radio coverage (C6) and visibility coverage (C7). Technical navigation criteria are used for the control evaluation of obtained UAV flight routes. Next step is preparation of geospatial data and entering them into GIS. Used data sources are original maps, digital data, technical instructions, meteorological data (Table 2).

Table 2.Used data for geospatial geoprocessing.

Criteria	Data and scale	Geoprocessing	Modeling goals
Elevation	Digital Elevation Model (DEM) 25m x 25m	Surface spatial modeling, Reclassify	Avoid high relief route of flight
Slope			Avoid steep route of flight
Radio coverage			Determining radio coverage zone for UAV navigation
Visibility coverage			Determining visual line for UAV navigation
Vegetation	Digital Topographic map scale 1:300.000 (DTK300)	Vector line drawing, Buffering, Raster transformation, Reclassify	Avoid fly routes with high trees and forest complex
Settlement and threat area			Avoid fly routes with urban complex and high buildings
Power line		Vector point drawing, Raster transformation, Reclassify	Avoid fly routes near power line
IUAVB take-off locations			Determination for test take-off locations of IUAVB
IUAVB Target location			Determination for terrorist target location

Note. Adapted from Military Geographical Institute 2003 and 2006.

In the next phase for the Fuzzy logic membership function was applied, integrated in the tools of ArcGIS Desktop 10.8 software. For the purposes of our model, we opted for a simple Fuzzy Linear function, which creates linear realization for values 0 through 1 between the minimum and maximum values defined by criteria (1).

$$\mu(x) = \begin{cases} 0;\ x < min \\ 1;\ x > max \\ \dfrac{(x - min)}{(max - min)} \end{cases} \tag{1}$$

The result of this step is phased criterion maps obtained from the Physical and Socio-economy geography criteria as shown in Figure 2.

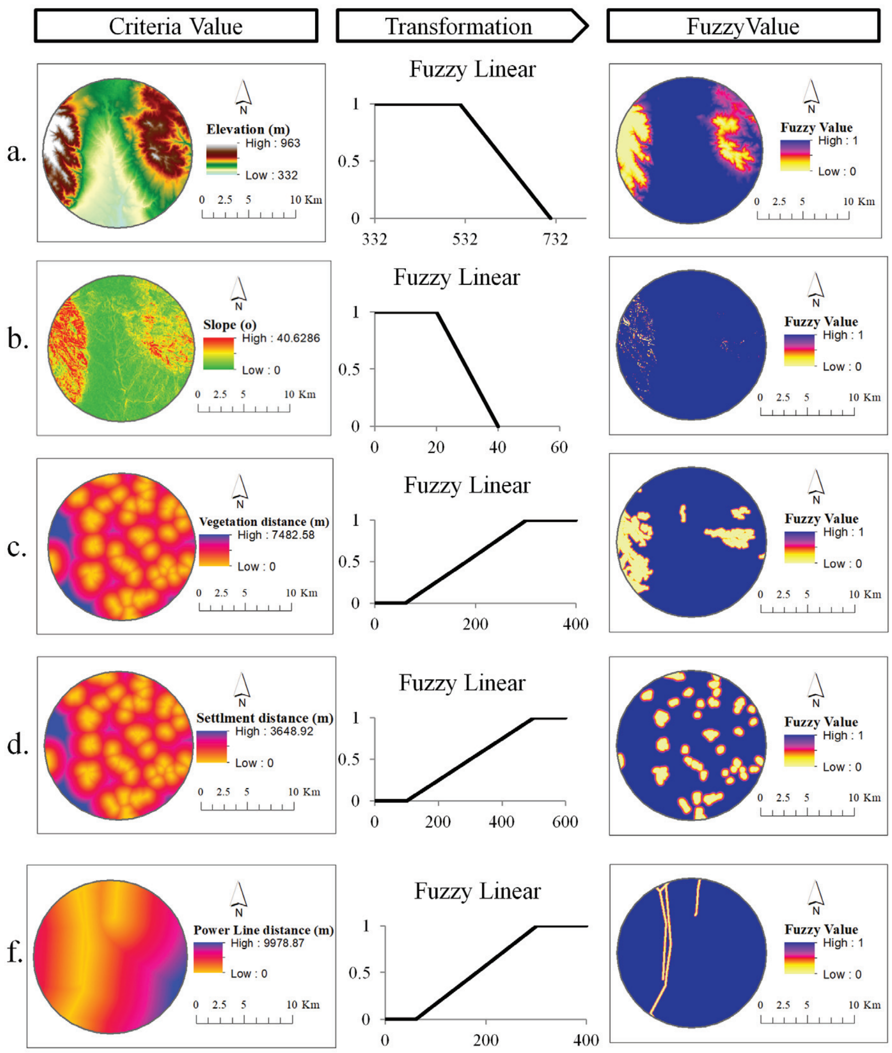

Figure 2.Fuzzied criterion maps.

For each of the processed criteria, a buffer zone of 8 km was selected, with a geometric center in accordance with the technical characteristics of the maximum transmission distance for the UAVs fly in ideal conditions. A summary was performed to obtain a CS layer by applying raster calculators, previously phased criterion maps. However, the obtained CS layer is not suitable for analysis in LCP (Least Cost Path), as the most suitable values of the stretcher should have the lowest cell value. In this sense, an inversion of cell values of the CS raster was applied, where the CS* (Invert Cost Raster) was obtained, as shown in the statement (2).

$$CS^* = ((CS - max) * -1) + min \tag{2}$$

The final result of this step is the Invert CS layer (Figure 3) where the lower values of the raster cells represent the areas above which the mini-UAVs flight is suitable while the higher values are unsuitable.

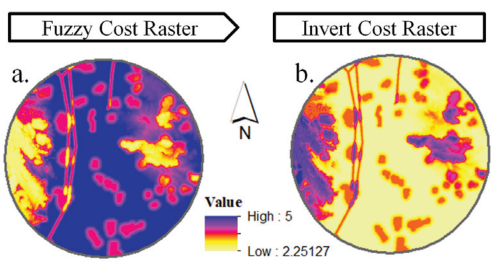

Figure 3.Invert CS layer.

In the next step, it was executed the creation of Cost Distance (CD) and Cost Back Link (CB) layers is performed on the basis of a previously modeled CS layer and the test locations of the UAVs flight. The CD layer is modeled raster with the least accumulative cost distance (Ac) for each cell to the nearest source from the start locations over a cost surface (3).

$$Ac = \sum_{k=1}^{n} Ak = A1 + A2 + A3 + \ldots + An \tag{3}$$

Using the equation (4), the method of calculating values between adjacent cells for horizontal and vertical cost distance is shown.

$$A1 = \frac{cost1 + cost2}{2} \tag{4}$$

For diagonal cell movement, the method of calculating cell values is shown in equation (5).

$$A1 = \sqrt{2}\,\frac{\mathrm{cost1} + \mathrm{cost2}}{2} \tag{5}$$

The CB layer contains values of 1 through 8. Each value defines the clockwise direction or identify the next neighboring cell along the least accumulative cost path from a start point (source cell) to reach its least cost source to final destination. The value 0 is reserved for source cells or start location. Distribution of cell values is performed on the basis of CS raster. Cost Path (CP) tool calculates the LCP from a source to a destination (Figure 5).The entire procedure is repeated for each segment between all 12 test locations and final target location.

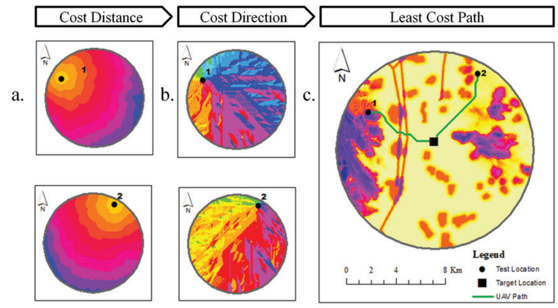

Figure 4.Test processing CD and CD layer to final LCP map.

In addition to the previously described procedure, a test of the routes obtained for the UAVs flight was conducted. For this purpose, we used a technical-navigational set of criteria. ArcGIS Tools Viewshed and Military GIS Radio Coverage were used to create criterion maps. A simple Multicriteria Weighted Overlay (MWO) method was used to make the CS disperser, which was shown in equation (6).

$$CS = \sum_{k=1}^{n} W\mathrm{k}R\mathrm{k} = W1R1 + W2R2 + \ldots + W\mathrm{n}R\mathrm{n} \tag{6}$$

Both raster is assigned an equal weight Wk whose value is defined between 0 and 1. The sum of all weights should be W1 + W2 +... + Wn = 1. Further LCP procedure for obtaining flight control routes to UAVs was the same for all 12 test locations as in the basic procedure (Figure 5).

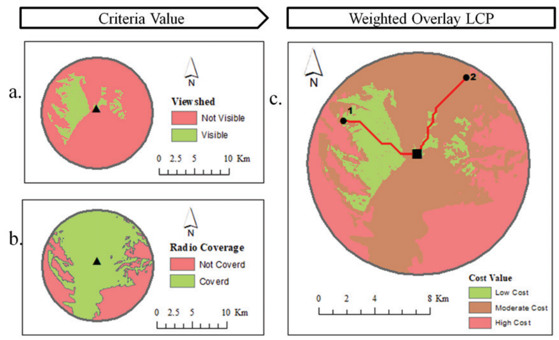

Figure 5.Control processing and CD layer to final LCP map.

In the end, the visualization and merging of all potential basic and control routes of the mini-UAVs flight was performed, where the final map (Figure 6) was obtained.

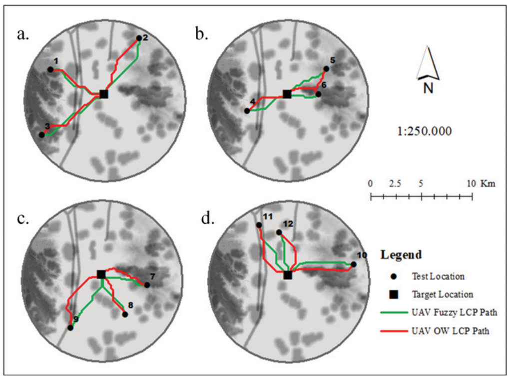

Figure 6.Final map of mini-UAVs flight route.

The green path is a path derived from the application of the LCP-Fuzzy method and a combination of physical and geographical and socio-economic basic criteria. The red path was obtained by applying the LCP-MWO method and by combining technical navigation control criteria. In order to evaluate the results of basic and control testing and to rank the most optimistic flight pathways of the drone for the purposes of this research, we have developed drone Fly Path Shape Coefficient (DFPSC) which is attached through a statement (7).

$$DFLSC = \frac{\mathrm{S_{max}}}{\mathrm{S_{min}}} \tag{7}$$

The DFPSC represents the actual flight path ratio of the drone while respecting the limiting flight criteria (Smax) and the ideal or straight-line flight path between the starting and end points (Smin). The share value is thought to be 1 and the further increase in the value of flight paths is curved, indicating a number of obstacles in the flight path.

3. RESULTS AND DISCUSSION

As final phase result of use GIS LCP-Fuzzy-MWO it was obtained the final map of potential mini-UAVs flight routes. The routes obtained are ranked from 1 to 12. The ranking was based on the ratio of flight length and number of obstacles within the route, visibility of the drone operator and radio network coverage (Table 3). However, in the event of strong winds, this would not be possible. Routes from test sites 1, 5, 6 and 7 are partially suitable. The site's ranking was most affected by a large number of obstacles in the form of frequent changes in tilt, obstacle height and visibility. In this case, the success of drone management would depend on the operator's situational awareness and his knowledge of the terrain. Routes obtained from test sites 2, 4, 8 and 12 are best suited for the use of mini drones. Few obstacles and good navigational conditions meet the requirements for a mini-drone flight even in poor weather conditions. Poor weather conditions would affect the reduction of distance between the target of the eventual attack and the launch location of the mini-UAVs. High and low temperatures affect lithium batteries in the UAVs, resulting in a reduction in flight time. This fact suggests that the greatest significance would be the launch locations of the UAVs that are closer to the object of a terrorist attack.

The distance of communications from launch locations could indicate clear spatial forms. Initially determining potential launch locations of UAVs before modeling flight paths using GIS LCP-Fuzzy-MWO represents the weakness of this research. It is not possible to predict a potential terrorist attack without considering previous spatial patterns. When it comes to this work, this perceived weakness may be compensated. To that end, more mini-UAV launch locations are required to obtain a realistic assessment of the object's endangerment, and the resulting results of flight paths should be grouped into larger clusters or avenues of approach. Further research will require testing of other more complex Fuzzy methods through which comparison would conclude which is the most reliable model of flight prediction of mini-UAVs.

Table 3.Results comparison of LCP-Fuzzy and LCP-MWO model.

Test locations	Shortest Fly Path	Fuzzy-LCP		Overlay-LCP		Rang
	Length (m)	Length (m)	DFPFC	Length (m)	DFPFC	
1	5823	6360	1.09	6260	1.08	5
2	6582	6941	1.05	6966	1.06	2
3	7381	7821	1.06	7927	1.07	12
4	4295	4617	1.07	4603	1.07	4
5	4667	4931	1.06	5371	1.15	6
6	3101	3363	1.08	3630	1.17	7
7	4687	4964	1.06	5423	1.16	8
8	4597	4862	1.06	4888	1.06	1
9	6112	6445	1.05	7345	1.20	10
10	6614	7107	1.07	7041	1.06	11
11	5708	6092	1.07	6534	1.14	9
12	4299	4499	1.05	5135	1.19	3

4. CONCLUSION

The application of the LCP-Fuzzy model has successfully demonstrated a simple and effective assessment of the endangerment of objects from potential mini-UAVs attacks. The main advantages of this approach are the flexibility and ability to integrate Fuzzy logic numbers with GIS. The application of the GIS-FMWO-LCP model in the assessment of the optimal flight path of mini-UAVs proved to be successful and valid because based on the adopted criteria it successfully differentiated parts of space in relation to their limiting factor. The applied methodology defined 12 potential flight trajectories of mini UAVs. For each fly route, a spatial analysis was performed based on physical, socio-economic and technical navigation geography group of criteria. The results show us that the most suitable route for a potential terrorist attack using mini-UAVs was obtained from test location number 8. The analysis of the verifiability of the results by changing the defined flight criteria and the comparison of the DFPSC showed a high degree of model stability. The results of this study will help decision makers in preparing appropriate plans to protect critical infrastructure from potential terrorist attacks by mini-UAVs. This model expands the theoretical framework of knowledge in the field of selection and planning of flight trajectories of UAVs. The existing problem is considered by the new methodology, which creates a basis for further theoretical and practical research upgrades. Also, the presented model highlights new criteria that have not been considered in previous UAVs fly paths models, and which are important for this issue. In addition to the good sides presented in the work, there are certain weaknesses. It is important to note that the applied criteria for the selection of mini UAVS fly paths vary in different regions and depend on geographical factors. Therefore, this procedure allows the inclusion of other criteria, which were not included in this study. The second is that the proposed LCP-Fuzzy model is applicable to the commerce mini-UAV. Other categories of drones, flying at higher altitudes, part of the proposed flight criteria has no impact. To that end, further research needs to focus on the impact of meteorological factors on the mini-UAV flight. Also, an analysis of spatial patterns of use of mini-UAVs by terrorists would improve the proposed LCP-Fuzzy-MWO model. The weaknesses outlined would also pose a need for further research and upgrade of the LCP-Fuzzy-MWO model.

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