Determination of Strategic Location of UAV Stations

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Abstract. The strategic importance of unmanned aerial vehicles (UAV) has attracted the attention of many researchers. Nowadays, there are numerous serious projects and researches that have gained momentum in recent years, particularly in order to improve the technical performance of the system and to increase the search and practice skills of the model. UAVs, which are the latest technological inventions, are very advantageous in terms of practicality, flexibility, cost advantage and multitude of usage areas.

UAV technology effectively demonstrates its benefits in both civilian applications (disaster management, agricultural applications, health services, etc.) and military platforms (counter terrorism, reconnaissance activities, smuggling etc.). Their unique features vary according to implementation purposes, and so decision makers can determine the size of automation system, altitude time, speed, and capacity of the vehicles' according to the application area and specific requirements. In this study, the most suitable mini-UAV ground control stations in the area of responsibility were selected according to the maximum coverage model regarding different characteristics for civil and military applications. Thus, in order to reach the optimal solution, UAV stations and service areas to be established within the coverage distance will be defined in the specified zones by using different scenario analysis. The study is expected to help researchers and strategic decision makers working on this hot topic.

Keywords: Optimization · Location selection · UAV · Maximal covering problem · Strategic decision model

1 Introduction

Location models generally attempt to establish facilities in a landscape, often in a network of nodes and arcs, to meet public demands [1].

Quantitative decision models have been emerged as useful tools to assist policy makers, strategists, and process managers in determining where to set up site sets as optimal location of the specified/projected region. In the maximal covering location problem, the goal is to establish a fixed number of facilities on a network to maximize the number of population-weighted demand points covered or served over a given distance or time.

The selection of some strategic locations requires serious optimization applications. Strategically important points such as hospitals, air/naval bases, blood centres, and unmanned aerial vehicle (UAV) stations that will provide civil/military services should be placed in the most rational, lowest cost and widest service area [2].

In location selection problems, the aim is to ensure that as many people as possible (in the widest coverage area) receive service while the distance between the facility to be established and the service area is expected to be close. Facilities should be assigned to the closest point to service zones or the centres of need, all which should be settled conveniently and rationally in order to take service from the nearest neighbouring facility.

The increasing importance and prevalence of UAVs around the world has led to the rapid start of research and studies on this subject for the efficient usage of UAVs. Therefore, installation of the most suitable UAV station and serving the region with the highest coverage rate is an important decision criterion in terms of technological, social, and economic aspect.

UAVs have many different functions across the world such as civilian, commercial attempts, as well as military goals and efforts. Civilian applications mostly cover healthcare, conservation, cargo transport, measurement for pollution monitoring, agriculture, manufacturing, disaster relief and nowadays for pandemic response efforts [3]. In military practice, UAVs are employed for reconnaissance, attack, defence, and for some criminal/terrorist purposes.

The main aims of UAVs can be considered as data transfer/evaluation, flying aircraft, and providing specific images [2]. The obtained information is analysed by combining other sources to serve/ensure a useful common tactical and strategic outcome. It is important to process and transfer the obtained meaningful data results to take quick action for reliable operations.

In this study, we aimed to decide strategic locations of the UAV stations under certain restrictions such as population rate, number of daily cases, transportation availability and number of agricultural and irrigation activities in terms of military and civilization aims considering high level of service area with aspect of maximal coverage model. It has been stated that the use of scenario analysis with different distance areas and need points at different importance levels provide important results according to the objective function.

Then, the areas to be covered based on distance (with various field length) are determined with a maximal coverage modelling framework. In this model, it is aimed to maximize the number of centres that will receive service with a certain number of facilities to be opened. In case of different situations, scenario analyses were developed and tested.

2   Literature Review

In the literature, several studies exist about maximum covering location problem [4]. Farahani et al. [5] and Daskin [6] ensured a comprehensive survey on various maximum covering location problems and related solution approaches. Albareda-Sambola et al. [7] aimed to minimize cost whereas maximize coverage using capacity and distance constrained plant-location approach.

According to literature, there are numerous studies focusing on the maximum coverage problem under the location selection problem for UAVs. Caillouet and Razafindralambo [8] proposed UAVs to cover targets which is a complicated issue since each target should be covered, while the operation cost and the UAV altitudes try to guarantee good communication value. They employed a bi-objective linear programming model to solve the problem with a fair trade-off optimal solution. Otto et al. [9] ensured a detailed review of all optimization studies based on civil utilizations of UAVs. According to the authors, the study is the first application regarding drone energy consumption as an equation of payload and distance calculations within a drone maximum coverage location problem context. Chauha et al. [10] studied a maximum coverage facility location problem with drone employment according to real-life UAV battery and weight constraints, and then they provided two solution technique depend on greedy search alg. and three-stage heuristic. Huang et al. [11] developed an unconstrained mathematical model to search the optimal sites of the UAVs on the street graph to maximize UE coverage and to minimize the interference impact. Karatas et al. [12] proposed a bi-objective location-allocation model for UAVs acting in a hostile region. The aim is to obtain the locations to position UAVs for surveillance activities. In the study, the first aim is to maximize search activities' success and the second aim is to minimize threats to UAVs. They developed a metaheuristic approach, namely, elitist non-dominated sorting genetic algorithm to solve such large-scale problem.

As can be seen from the literature review, there is a need for more applications on the subject due to the limited number of studies and the serious impact of UAV issue.

3   Methodology

A.   *Maximal Covering Problem*

Maximal Covering Problem (MCP) is a kind of location selection problem which effectively applied in different areas such as health care, emergency planning, ecology, and security works [13]. MCP is modelled by Church and ReVelle [4] and traditional formulation is given as follows:

$$Y_j = \begin{cases} 1, & \textit{if demand node j is covered} \\ 0, & \textit{o.w} \end{cases}$$

$$x_i = \begin{cases} 1, & \textit{if candidate site i is sited} \\ 0, & \textit{o.w} \end{cases}$$

$$a_{ij} = \begin{cases} 1, & \textit{if demand node i can be covered by a facility at candidate site j} \\ 0, & \textit{o.w} \end{cases}$$

$$d_j = \textit{demand at node j}$$

$$P = \textit{number of facilities to locate}$$

$$\max Z \sum_{j \in J} d_j Y_j$$

$$Y_j \leq \sum_{i \in I} a_{ij} x_i \quad \forall_j \in J$$

$$\sum_{i \in I} x_i \leq P$$

$$x_i \in \{0, 1\} \quad \forall_i \in I$$

$$Y_j \in \{0, 1\} \quad \forall_j \in J$$

where, the objective function allows to maximize the number of demand points covered. The first constraint provides an element can only be covered only if at least one of the sets containing the element is selected. The following constraint gives the number of facilities is to be placed and finally decision variables are considered as binary variable.

Due to the maximal covering problem is a kind of combinatorial optimization problem, several solution approaches are utilized to obtain optimal solution such as exact algorithms (Branch and Bound alg., Lagrange relaxation) and heuristic algorithms (Greedy search, Genetic alg., Bee Algorithm etc.) to deal with larger size problems.

4   Application of the Model and Analysis Results

The location selection of UAV stations was previously considered as a maximum coverage problem. The developed maximal coverage model aims to increase the security level of the region and satisfaction rate of citizens to meet the instant needs coming from the security units. In this study, we assumed fifteen eligible sites to effectively allocate UAV stations in rural areas, considering the needs of the relevant region. To create the constraints that consider regional differences, weight values were given to each candidate point in the light of the opinions of the expert team working in the region for the feature of UAV such as flight availability, number of daily cases, population rate and transportation availability. All these factors are the main criteria taken into account in determining the locations and areas of responsibility of UAV stations.

The following tables (Tables 1 and 2) show the importance weights of the determined criteria. For military activities such as intelligence, surveillance, and reconnaissance requests, we considered significant determinants as the daily case number, population rate and transportation availability under the importance levels of 0.5, 0.3, 0.2, respectively. Similarly, for civil activities such as agriculture, irrigation, land control activities, we evaluated important indicators as population ratio, civil activities and transportation availability under the following importance levels of 0.3, 0.5, 0.2, consecutively. The deployment of ground control stations of UAVs differs depending on the regional characteristics of each land segment.

Agriculture, irrigation, land control works are assumed to be in civil activities.

Table 1. Importance weights of military applications

Pop. rate (w1)	Daily case number (w2)	Transportation availability (w3)	Wort
0.0553	0.0301	0.071	0.0459
0.0664	0.0602	0.119	0.0738
0.0775	0.0904	0.095	0.0875
0.0620	0.0452	0.071	0.0555
0.0752	0.0753	0.048	0.0697
0.0797	0.0964	0.048	0.0816
0.0974	0.1355	0.095	0.1160
0.0581	0.0512	0.048	0.0526
0.0395	0.0211	0.071	0.0367
0.0470	0.0331	0.024	0.0354
0.0498	0.0392	0.024	0.0393
0.0653	0.0512	0.048	0.0547
0.0686	0.0602	0.071	0.0650
0.0863	0.1205	0.095	0.1052
0.0719	0.0904	0.071	0.0810

Table 2. Importance weights of civil activities

Pop. rate (w1)	Civil activities (w2)	Transportation availability (w3)	Wort
0.0553	0.051	0.071	0.0562
0.0664	0.084	0.119	0.0860
0.0775	0.095	0.095	0.0896
0.0620	0.034	0.071	0.0498
0.0752	0.057	0.048	0.0608
0.0797	0.101	0.048	0.0841
0.0974	0.118	0.095	0.1074
0.0581	0.044	0.048	0.0489
0.0395	0.020	0.071	0.0363
0.0470	0.030	0.024	0.0341
0.0498	0.037	0.024	0.0383
0.0653	0.041	0.048	0.0494
0.0686	0.061	0.071	0.0653
0.0863	0.118	0.095	0.1041
0.0719	0.108	0.071	0.0899

Table 3. Distance between facilities (km.)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	15.56	19.68	25.34	28.78	35.55	38.78	42.85	45.75	49.09	32.65	45.5	20.25	32.75	18.5
2	15.56	0	12.34	11.56	7.89	25.36	45.36	40.23	42.26	35.5	38.78	9.9	35.35	40.3	15.6
3	19.68	12.34	0	9.96	24.36	44.36	40.89	25.5	41.25	43.45	27.26	10.75	45.47	48.45	12.6
4	25.34	11.56	9.96	0	17.75	33.36	24.5	26.36	39.85	37.62	48	15.59	30.36	30.35	25.8
5	28.78	7.89	24.36	17.75	0	12.11	10.36	23.23	45.26	40.1	30	16.78	22.3	20.2	17.8
6	35.55	25.36	44.36	33.36	12.11	0	9.56	8.85	11.25	34.69	11.17	20.22	45.36	39.85	36.45
7	38.78	45.36	40.89	24.5	10.36	9.56	0	46.35	30.12	38.75	19.25	25.25	20.2	34.36	30.3
8	42.85	40.23	25.5	26.36	23.23	8.85	46.35	0	26.89	42.13	36.4	30.33	23	27.56	25.68
9	45.75	42.26	41.25	39.85	45.26	11.25	30.12	26.89	0	47.76	10.5	32.36	25.36	18.75	20.38
10	49.09	35.5	43.45	37.62	40.1	34.69	38.75	42.13	47.76	0	40.45	45.48	42.32	40.52	36.87
11	32.65	38.78	27.26	48	30	11.17	19.25	36.4	10.5	40.45	0	49.8	35.35	30.56	40.4
12	45.5	9.9	10.75	15.59	16.78	20.22	25.25	30.33	32.36	45.48	49.8	0	25.2	20.56	24.68
13	20.25	35.35	45.47	30.36	22.3	45.36	20.2	23	25.36	42.32	35.35	25.2	0	30.36	32.75
14	32.75	40.3	48.45	30.35	20.2	39.85	34.36	27.56	18.75	40.52	30.56	20.56	30.36	0	40.4
15	18.5	15.6	12.6	25.8	17.8	36.45	30.3	25.68	20.38	36.87	40.4	24.68	32.75	40.4	0

The utilized notation of the study is given below.

$$i, j = number\ of\ facilities\ to\ locate \quad i, j = 15$$

$$t = type\ of\ UAV\ station \quad t = 1,\ 2$$

$$y_{jt} = \begin{cases} 1, & if\ demand\ node\ j\ is\ covered\ by\ UAV\ station\ type\ t \\ 0, & o.w \end{cases}$$

$$x_{ij} = \begin{cases} 1, & if\ demand\ node\ j\ is\ covered\ by\ a\ station\ located\ at\ candidate\ site\ i \\ 0, & o.w \end{cases}$$

$$m_{ij} = \begin{cases} 1, & if\ demand\ node\ i\ can\ be\ covered\ by\ a\ facility\ at\ candidate\ site\ j \\ & according\ to\ the\ defined\ distance \\ 0, & o.w \end{cases}$$

$$w_{it} = the\ importance\ level\ of\ UAV\ type\ t\ located\ at\ site\ i$$

$$C = number\ of\ facilities\ to\ locate$$

$$\max Z \sum_{i \in I t \in T} w_{it} x_{ij}$$

$$x_{ij} \leq \sum_{i \in I} m_{ij} y_{j,t} \quad \forall_j \in J$$

$$\sum_{j \in J} y_{j,t} \leq C$$

$$x_i \in \{0, 1\} \quad \forall_i \in I$$

$$y_j \in \{0, 1\} \quad \forall_j \in J$$

The objective function provides to maximize the total covered demand. The second constraint ensures that if demand node *j* is not covered by site *i*, the corresponding variables x_{ij} is forced to take value of 0. The third constraint states the number of opened facilities equals to *C*. Binary decision variables are given in the last constraint.

As seen from the analysis, the obtained results occur depending on the number of facilities and the distance between candidate eligible sites/points (Table 3), according to the developed mathematical model.

In the first case, we assume installation of three UAV stations in a ten km. and twenty km. range circle and then we considered five and eight UAV stations in ten and twenty km. range circle respectively. We evaluated the allocated regions and the allocated station types by expanding our constraints step by step.

The obtained optimal solution of the model using GAMS software is given in Table 4. According to the analysis results, when the number of UAV stations equals to three in a ten km distance, the identified UAV station locations are emerged as two of both type of UAV stations and six of the first type UAV. Moreover, if the second UAV station is installed, five and twelve regions/points receive service and, if the sixth UAV station is installed, the seventh region/points receive service. For the first case, the objective function equals to 0.458.

Similarly, if eight UAV stations installed in the twenty km range area, seven (2, 3, 4, 5, 6, 12, 15) UAV stations from initial type of UAV station and just one station (5) of the second type UAV have been assigned to sites (as seen from Table 4). Moreover, if the second UAV station is installed, the region 3, the region 4, the region 5, the region 12 and the region 15 get service in the identified area (20 km). If the third UAV station is installed, the close zones are the 2nd region, 4th region, 12th region and 15th region all which can take service, and when the fourth UAV station is installed, fifth region get service and if the fifth UAV station is established, the second and the sixth regions satisfy their regional requirements. If the sixth UAV station is established, fifth region satisfies rural requirements. And if the seventh UAV station is installed, fifth and sixth regions meet their needs. If the twelfth UAV station is installed, fifth location meets demands, and finally the fifteenth UAV is established in the region, 2nd, 3rd and 5th sites satisfy the regional needs.

All facilities allocated to meet each specified district's military and civil requirements and expectations (fifteen subsets). The optimal maximal covering plan regarding the minimum number of facilities has been provided a satisfactory and successful result (Fig. 1).

Table 4. Scenario analyses and the obtained results

x_{ij}	y_{jt}	Z	C: 3 K:10
$x_{5,2}$	$y_{2,1}$		
$x_{7,6}$	$y_{2,2}$	0.458	
$x_{12,2}$	$y_{6,1}$		

x_{ij}	y_{jt}	Z	C: 3 K:20
$x_{3,2}$	$y_{2,1}$		
$x_{5,2}$	$y_{5,1}$		
$x_{5,6}$	$y_{6,1}$		
$x_{6,5}$		1.392	
$x_{7,5}$			
$x_{7,6}$			
$x_{15,2}$			
$x_{15,5}$			

x_{ij}	y_{jt}	Z	C: 5 K:10
$x_{5,2}$	$y_{2,1}$		
$x_{12,2}$	$y_{4,1}$		
$x_{3,4}$	$y_{6,1}$	0.635	
$x_{7,6}$	$y_{2,2}$		
	$y_{4,2}$		

x_{ij}	y_{jt}	Z	C: 8 K:10
$x_{5,2}$	$y_{2,1}$		
$x_{12,2}$	$y_{4,1}$		
$x_{3,4}$	$y_{6,1}$		
$x_{7,6}$	$y_{8,1}$		
$x_{8,6}$	$y_{2,2}$	0.902	
$x_{6,8}$	$y_{4,2}$		
	$y_{6,2}$		
	$y_{8,2}$		
	$y_{4,2}$		

x_{ij}	y_{jt}	Z	C:5 K:20
$x_{2,3}$	$y_{2,1}$		
$x_{2,5}$	$y_{3,1}$		
$x_{3,2}$	$y_{5,1}$		
$x_{4,5}$	$y_{6,1}$		
$x_{5,2}$	$y_{5,2}$		
$x_{5,6}$			
$x_{6,5}$		2.092	
$x_{7,5}$			
$x_{7,6}$			
$x_{12,5}$			
$x_{15,2}$			
$x_{15,3}$			
$x_{15,5}$			

x_{ij}	y_{jt}	Z	C: 8 K:20
$x_{2,3}$	$y_{2,1}$		
$x_{2,4}$	$y_{3,1}$		
$x_{2,5}$	$y_{4,1}$		
$x_{2,12}$	$y_{5,1}$	3.103	
$x_{3,2}$	$y_{6,1}$		
$x_{3,4}$	$y_{12,1}$		
$x_{3,12}$	$y_{15,1}$		
$x_{4,5}$	$y_{5,2}$		

(*continued*)

Table 4. (*continued*)

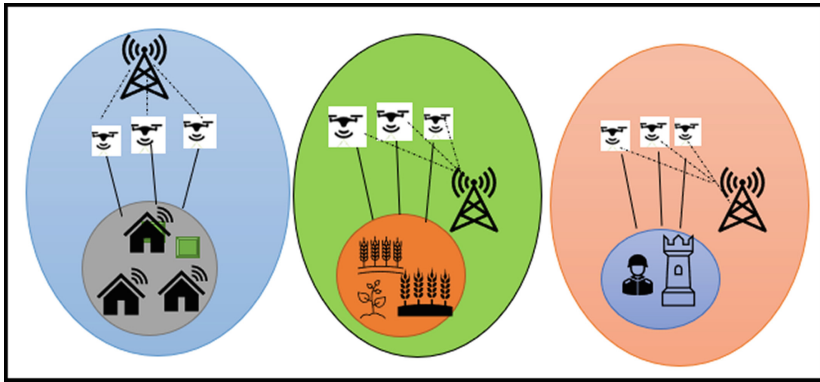|			
$x_{5,2}$			
$x_{5,6}$			
$x_{6,5}$			
$x_{7,5}$			
$x_{7,6}$			
$x_{12,5}$			
$x_{15,2}$			
$x_{15,3}$			
$x_{15,5}$			
$x_{2,15}$			
$x_{3,15}$			

Fig. 1. Civil and military applications of UAVs

5   Conclusion and Future Research

Ideal location/site selection issues have always been a substantial research topic, for instance, the appropriate location of UAV stations provides strategic, operational, and tactical advantages over their competitors. The most significant purpose of location selection problems is to be close to demand points and to reach all requirement points in the given restrictions. In this study, the topic of UAVs, which has become one of the most current issues in recent years, and the optimum position (s) of UAV stations utilized for civil or military purposes all which evaluated under the maximum coverage modelling approach. In this study, the aim is to find the UAV station assignments that will cover the most convenient target according to their priority values.

In the model, the simultaneous deployment of two different types of UAVs with different coverage distances to diverse points in terms of their technical characteristics has been examined for two various types of UAVs with distinct coverage distances. The determination of candidate points was made according to expert opinions. In order to reflect the effect of regional conditions on the model, the weight values of the candidate points where the station will be established were added to the model. UAV station assignments are performed according to criteria such as the number of cases in the region, transportation status and population ratio.

To minimize the uncertainty in the selection of candidate points and to reflect the effect of regional conditions on the model, the weight values of the positions to be located were added to the model.

When the developed UAV types and terrain conditions adjust, the possibilities and capabilities of UAV stations will also change. For this reason, it should be taken into account that the covering distance of each UAV system will alter according to various situations. Coverage distances in the model are based on the technical possibilities and capabilities of the UAV types. For future studies, the model can be extended by adding new constraints, new decision variables and new dynamic conditions for diverse application areas.

Alternatively, stochastic programming method can be considered for probabilistic structure or uncertain environments such as weather conditions, transfer efficiency ratios, service ratio etc.

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