Optimization of decisions when planning a UAV group mission with alternative depots

Leonid Hulianytskyi and Oleh Rybalchenko

Introduction

The paper considers the problem of optimizing decisions when planning a UAV group mission in the presence of alternative depots. To solve this problem:

- a substantive formulation and mathematical model has been presented
- a max-min algorithm of ant systems has been developed
- the results of a computational experiment are presented

Abstract

The formulated problem is solved under the following assumptions.

- Each target is visited by only one UAV and only once
- UAVs have limitations on the flight resource
- Replenishment of the flight resource of the UAV is carried out in one of the available depots
- There are enough means and supplies to replenish the flight resource of the UAV (batteries, fuel)
- It is assumed that UAV energy consumption occurs according to a linear law
- The route of a specific UAV can consist of sub-routes, each of which starts and ends at a given depot
- Tasks for UAVs in which their carrying capacity is not a limiting factor are considered
- For reasons of expediency, some depots may be inactive

Mathematical model

The objective function

$$\min \sum_{k\in M}\sum_{i\in B\cup N}\sum_{j\in B\cup N} e_k d_{ij} x_{ijk} + \sum_{k\in M}\sum_{i\in N}\sum_{j\in B\cup N} e_k v_k T_{kj} x_{ijk}$$

determines the total cost of the plan for the choice of a depot for UAVs along with the construction of routes for flying over targets and the time spent on their maintenance.

Constraints

$$\sum_{k\in M}\sum_{i\in B\cup N} x_{ijk} \le 1,\ \ j \in N; \tag{1}$$

$$\sum_{k\in M}\sum_{j\in B\cup N} x_{ijk} \le 1,\ \ i \in N; \tag{2}$$

$$\sum_{i\in B}\sum_{j\in N} x_{ijk} \le 1,\ \ k \in M; \tag{3}$$

$$\sum_{i\in B}\sum_{j\in N} x_{jik} \le 1,\ \ k \in M; \tag{4}$$

$$u_i - u_j + x_{ijk}\sum_{s\in B\cup N}\sum_{t\in B\cup N} x_{stk} \le \sum_{s\in B\cup N}\sum_{t\in B\cup N} x_{stk} - 1,\ \ k \in M; \tag{5}$$

$$\sum_{i\in B}\sum_{j\in B} x_{jik} = 0,\ \ k \in M; \tag{6}$$

$$d_{ij} = \infty,\ \ i, j \in B; \tag{7}$$

$$\sum_{i\in B\cup N}\sum_{j\in B\cup N} e_k d_{ij} x_{ijk} + \sum_{i\in N}\sum_{j\in B\cup N} e_k v_k T_{kj} x_{ijk} \le R_k,\ \ k \in M; \tag{8}$$

$$x_{ijk} \in \{0,1\}, i, j \in B \cup N,\ \ k \in M; \tag{9}$$

$$y_i \in \{0,1\},\ \ i \in B. \tag{10}$$

Initial placement

Zero base – the point at which all available UAVs are placed before the algorithm starts. This base is part of the graph of the problem consisting of the following components:

- initial and zero bases
- targets
- edges connecting all targets and initial bases in pairs
- edges connecting the zero base with the initial ones

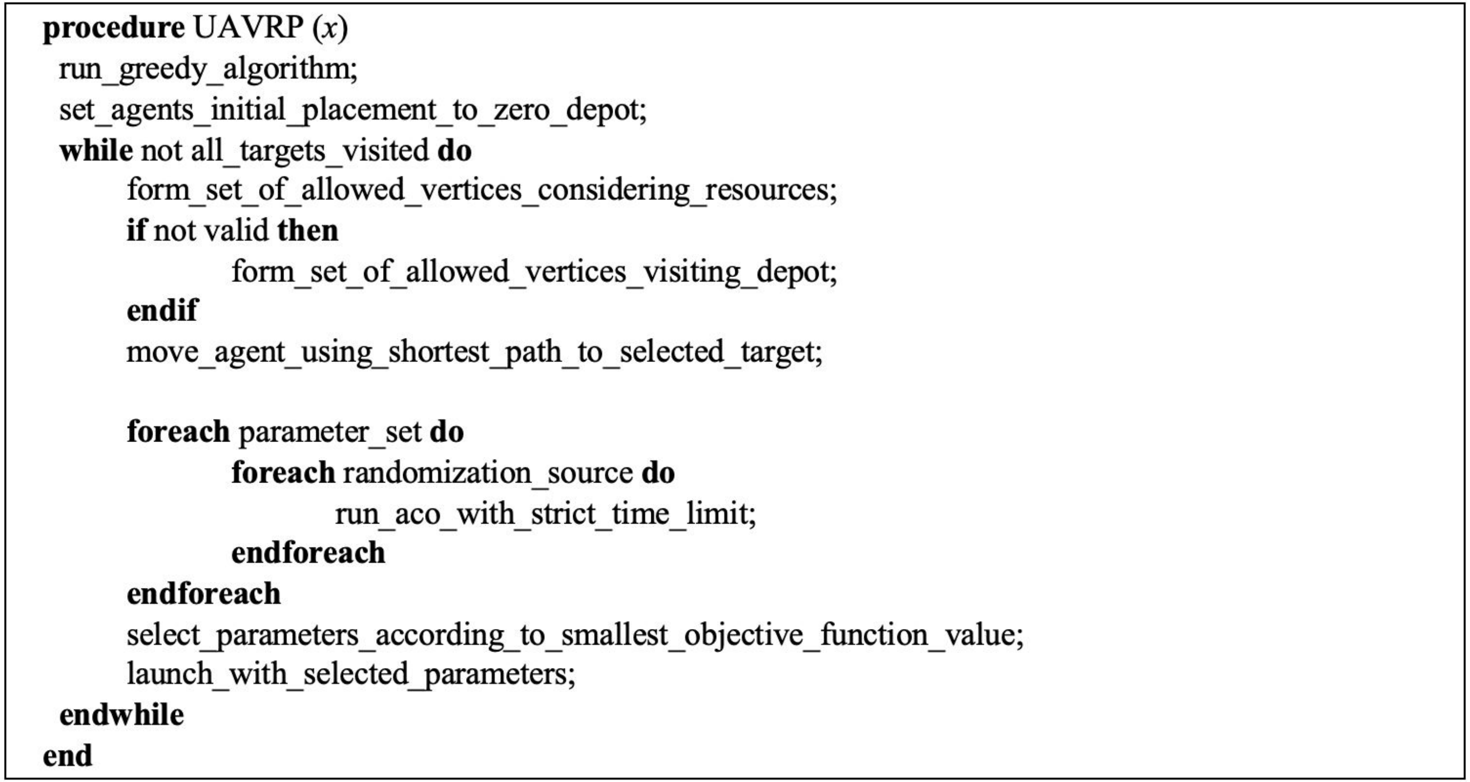
Returning to the zero base and moving from the zero base directly to targets are prohibited.

All edges from the zero base have zero length

The movement from the zero base to the target is the consecutive movement to the initial base closest to the target (the length of such movement is zero) and the movement from this base to the target. Thus, the length of the movement is determined by the formula:

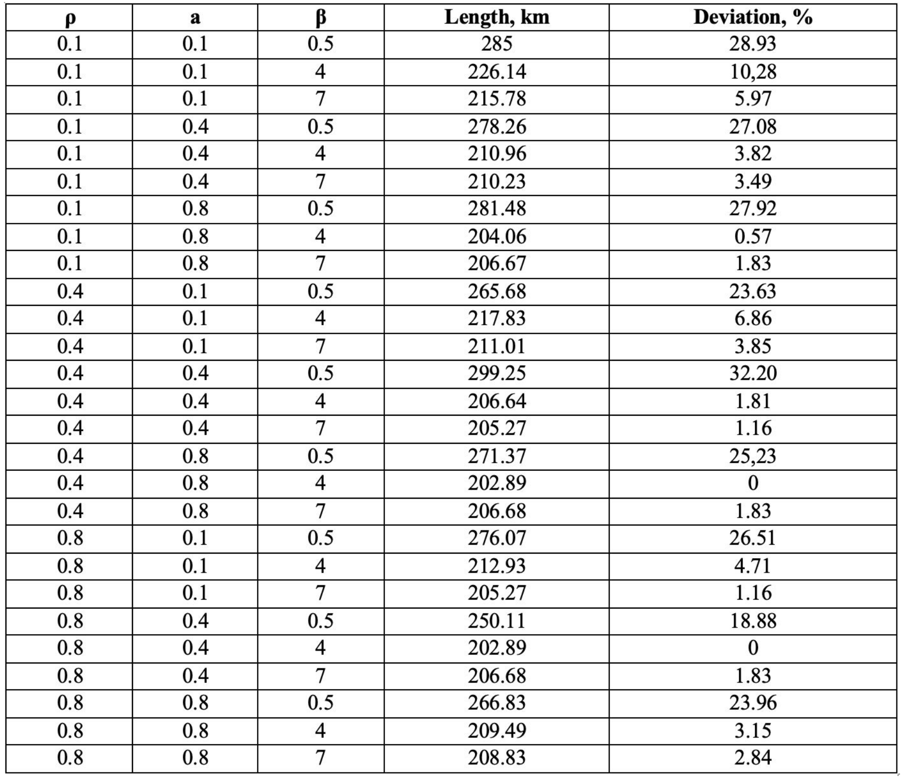
$$d_{st} = \min\{d_{kt}\} \text{ where } s \in D, k \in B, t \in N.$$

Determining parameters



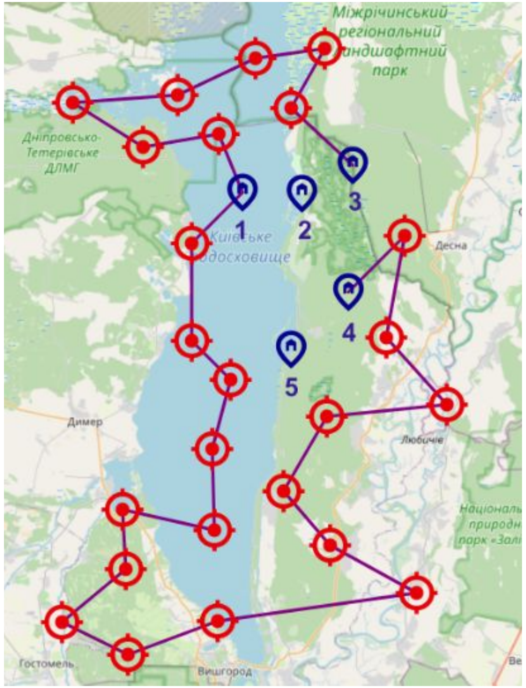
```
procedure UAVRP (x)
 run_greedy_algorithm;
 set_agents_initial_placement_to_zero_depot;
 while not all_targets_visited do
     form_set_of_allowed_vertices_considering_resources;
     if not valid then
         form_set_of_allowed_vertices_visiting_depot;
     endif
     move_agent_using_shortest_path_to_selected_target;

     foreach parameter_set do
         foreach randomization_source do
             run_aco_with_strict_time_limit;
         endforeach
     endforeach
     select_parameters_according_to_smallest_objective_function_value;
     launch_with_selected_parameters;
 endwhile
end
```

Determining parameters

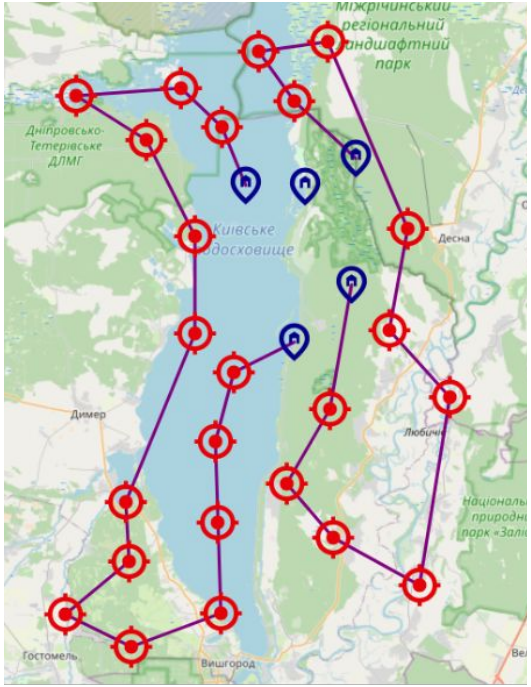


ρ	a	β	Length, km	Deviation, %
0.1	0.1	0.5	285	28.93
0.1	0.1	4	226.14	10,28
0.1	0.1	7	215.78	5.97
0.1	0.4	0.5	278.26	27.08
0.1	0.4	4	210.96	3.82
0.1	0.4	7	210.23	3.49
0.1	0.8	0.5	281.48	27.92
0.1	0.8	4	204.06	0.57
0.1	0.8	7	206.67	1.83
0.4	0.1	0.5	265.68	23.63
0.4	0.1	4	217.83	6.86
0.4	0.1	7	211.01	3.85
0.4	0.4	0.5	299.25	32.20
0.4	0.4	4	206.64	1.81
0.4	0.4	7	205.27	1.16
0.4	0.8	0.5	271.37	25,23
0.4	0.8	4	202.89	0
0.4	0.8	7	206.68	1.83
0.8	0.1	0.5	276.07	26.51
0.8	0.1	4	212.93	4.71
0.8	0.1	7	205.27	1.16
0.8	0.4	0.5	250.11	18.88
0.8	0.4	4	202.89	0
0.8	0.4	7	206.68	1.83
0.8	0.8	0.5	266.83	23.96
0.8	0.8	4	209.49	3.15
0.8	0.8	7	208.83	2.84

Algorithm effectiveness



Specialized ACO – 202.89 km



Specialized DLS – 223.58 km

Further development

The direction of further research may be considering the battery discharge process in the mathematical model the characteristics of the, taking into account prohibited areas for flight, weather conditions (wind direction).

It is promising to improve the algorithm involving diversified algorithms for finding solutions, and parallel implementation of the island model of the ACO algorithm.