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A Decision Support System for Dynamic Heterogeneous Unmanned Aerial System Fleets

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Abstract

The Dynamic Unmanned Aerial System Routing Problem (DUASRP) is a variant of the classic Vehicle Routing Problem (VRP) in which both planned and unplanned targets are observed by a fleet of Unmanned Aerial Systems (UASs). In the dynamic environment of UAS, the rapid response for the new important targets is a very critical process, especially for the military operations in battle space conditions. This study describes a heuristic method for the solution of the dynamic heterogeneous UAS routing problems without causing the initial tour to be completely changed. For the dynamic routing of Unmanned Aerial Vehicles (UAV), it is necessary to determine a combination of the least additional costs of vehicle routes through a set of geographically scattered targets, and quick responses for immediate targets during the reconnaissance missions. The most frequent cases assumed in the existing literature of classical DUASs consider all UASs as identical (homogenous), all targets as having two geographical coordinates, and the thread of the targets are ignored. In this paper, a dynamic routing decision support system based on both fuzzy clustering and leveraged cheapest insertion neighborhood method is studied for pop-up threat in the case where the UAV fleet is heterogeneous, and targets have both three-dimensional information and threads. Instead of selecting an a priori code, the proposed control methodology dynamically starts with the route based on observed behavior of the new target and the routes. It describes an efficient heuristic method capable of producing quick dynamic solutions on a series of empirical test problems.

1. INTRODUCTION

The UAVs have used in various military operations with increasing purposes. Like many governments, the US government has published Unmanned Systems Integrated Roadmaps. The importance of the current UASs in the operational theater and future military UAS strategies are detailed in these documents. In today's military, unmanned systems are highly desired by combatant commanders for their versatility and persistence in that context [1].

Goraj [2] announces the highly-risky, scientific and economically efficient missions for the most three important UAV applications. Shima and Rasmussen [3] assert that UAVs provide not only cost efficient solutions but also new operational challenges.

In this sense, VRP is a vital business for the effective usage of UAVs. The VRP is defined on a graph of $G=(V,E)$ and $V=\{0,\ldots\ldots,n\}$ is a vertex set [4]. Well known VRPs deal with finding efficient routes beginning from and ending at a central place to serve the customers by a fleet of vehicles. Toth and Vigo [5] give an overview of the VRPs and their variants. In VRPs, each customer is served by just one vehicle and once under the condition which provide the given restrictions such as capacity, endurance, duration or time window. "Targets" are considered as "customers" in our model.

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Most of the existing works in the literature of VRP focused on static versions or dynamic problems for other “on the ground” types of vehicles with two dimensional, like most of the existing studies in “on-board” UAVs focused on design and avionic optimization of them. Airborne version of VRP is more difficult than the ground based application due to the fact that the latter presents only bidimensional degrees of freedom. This paper focuses on not static VRP and UAV design optimization problems but on the dynamic intersection of these two aspects. The usage of heuristics for the dynamic aspect of the routing problem is necessary due to the facts that VRPs are NP-Hard problems and require quick responses in the combat applications.

2. DYNAMIC UAV ROUTING PROBLEMS

Psaraftis [6] defines the static routing problem as *“If the output of a certain formulation is a set of preplanned routes that are not re-optimized and are computed from inputs that do not evolve in real-time”*, while the dynamic routing problem is described as “…*the output is not a set of routes, but a policy that prescribes how the routes should evolve as a function of those inputs that evolve in real-time*” [7].

It is the varying conditions during the mission that makes the routing problem “dynamic”. As it may not be possible to forecast the dynamic situations, the UAV route planning system should adapt to the changes as they occur in the field. For more details about the dynamic vehicle routing systems and classifications, see Larsen et al. [8].

DVRP has been studied widely after 1980s. Modern information technologies and decision system requirements that can simulate the real situations better are declared as the main two major factors triggering this tendency [9]. Dynamic vehicle routing survey articles are also studied by many researches including Powell et al. [10], Lund et al. [11], Bianchi [12], and Psaraftis [6, 13]. Several of DVRP studies are presented below and researches prior to 2000 can be seen in Larsen et al. [8]. Among numerous studies, few papers have been proposed for solving DVRP for UAVs.

Gendreau et al. [14] study DVRP for a courier service for real-time customers with a soft time window constraint. O'Rourke et al. [15] propose reactive tabu search for dynamic routing of UAVs for the US Air Force’s operational usage. Paepe [16] gives a thorough analysis of the on-line version of the dial-a-ride problem in which a single capacitated vehicle serves a set of customers that request to be picked-up at some place to be transported to another location. Chitty and Hernandez [17] define a DVRP in which the total mean transit time and the total variance time are minimized simultaneously. In Angelelli et al. [18]’s work, the orders arriving have to be completed either at that time period or the next. Branke et al. [19] aim to maximize the probability of being able to service an additional immediate request customer in their paper. Another DVRP using the ant colony system paradigm is studied by Montemanni et al. [20] in the same year.

Other interesting models have been proposed by many others. Among them, Ichoua et al. [21] propose a strategy for the probabilistic requests in real time. Jin et al. [22] study on the cooperated UAVs’ responses to targets while the DVRP of UAVs without full information is studied by Kim et al. [23]. Shetty et al. [24] consider the combat VRP for predetermined targets. A novel coordinated trajectory replanning for multi-UAVs based by using the max-min adaptive ant colony optimization is proposed by Duan et al. [25]. This work is based on the 2-D space with the assumption that all individual UAVs fly at the same altitude. Murray and Karwan [26] consider a framework for the battlespace responses. They also give a comparison of related UAV routing models. Mufalli et al. [27] consider simultaneous sensor selection and routing for UAVs. The paper by Royset et al. [28] considers the UAV routing problem using constrained shortest path.

In the dynamic routing literature of UAVs, diverting of a UAV to observe a new target instead of its current target is a challenging issue. Presenting the dynamic situations, a DSS which considers targets appear in real time in three dimensional during the heterogeneous UASs’ reconnaissance operations and an empirical study of the proposed solution are discussed in the scope of this study. Thanks to the recent developments in technology, on line or so-called real time information may be used for more efficient performance of UAV rerouting decision processes. It is assumed in this study that control station can facilitate communication with and among different UAVs at all-time via satellite with a negligible delay time.

It is well known that a DSS is a methodology for supporting decision-making. Turban et al. [29] describes it as an interactive, flexible, adaptable computer based information system especially developed for supporting nonstructural management problem. According to the authors, “DSS uses data, provides an easy user interface, and can incorporate the decisionmaker's own insights”. In this context, our paper proposes an efficient DSS not only to solve the dynamic solution but also support the decision makers in case of there is no dynamic solution.

3. THE PROBLEM DEFINITION AND SOLUTION APPROACH

Many examples of dynamic situations may be occurred in the operation area of responsibility (AoR) for UAV fleets such as failure of an UAV, a new available UAV, capability of aerial refueling of UAVs during the mission, new available ground control station (airport), addition of a new dynamic target to the route, subtraction of a pre-planned target from the route, new available way (from target to target for UAV), moving targets, restriction of a pre-allowed way (from target to target) and many others.

This study is motivated from a real world case dealing with a UAV rerouting problem for unplanned and important target’s assignment to strategic heterogeneous UAV fleet’s route. The aim is to assign the new “unplanned” target into the pre-assigned routes, in real time while minimizing the undesirable route time increases and route changes. The threat is considered in 3-D unlike 2-D study in Duan et al. [25].

Generally, the UAVs are expected to follow pre-determined routes and updates are not applicable for them. These kinds of targets are called “advance targets” and can be referred to as static targets as these plans for mission have been received before the routing process was begun. No new targets are expected to arrive over time.

Another aspect of targets is “pop-up priority” target. In the dynamic version of the problem, new targets may appear as the time goes by during the flight and new situation may change the routes after they have been planned. These immediate targets can be referred to as dynamic targets where they dynamically appear in an air reconnaissance missions. The dynamic question is “in which UAV’s route should the new evolving target be included and what should be the new target sequence in the assigned UAV’s route at a minimum cost?”

DVRPs need for real time processes of which the new and important target should be considered. Since the reconnaissance missions are very critical and expensive for Armed Forces, the response time for dynamic solution shall be very short. There are two important reasons for this: Firstly, speed of strategic UAVs is very high, and secondly if there is a new target at the strategic level, it must be taken into account immediately.

After a new target appears in the system, the static VRP converts to a dynamic one. One way to approach the DVRP is to simply re-run the original static method for every planning iteration. While all the targets may have moved, it is quite possible that the changes are small enough that the plan from the static situation is still valid [30]. Yang and Sukkarieh [31] highlight the computational complexity as the ultimate requirement because of the need of fast vehicle dynamics for very quick path planning. In the DVRP, time-dependent information is updated as time goes on. Time varying information affects the solution and process time as well.

Let “t” denote a “real time” after the initial time 0, when a new target emerges. In the dynamic version, all UAV routes and targets can be categorized into four parts at the time “t”: Observed target/targets, the place of each UAV of the fleet, the first unobserved target for each UAV and unobserved target/targets. As aforementioned, process time is very critical for rerouting of strategic UAVs. The amount of computation time, allocated to the solution process, must be related to the rate at which new events occur.

The information from the previous static planning are preserved for the development of the new theater. A vital issue in the design of a neighborhood search algorithm is the choice of the neighborhood structure, that is, the manner in which a neighborhood is defined [32]. Chu and Hayva [33] support the idea that the fuzzy clustering approach is better than conventional clustering. It provides the degree of membership of a new target associated with the routes and provides flexibility in determining the routes. For the dynamic solution, “fuzzy clustering and leveraged cheapest insertion neighborhood method” is used to demonstrate the smart way of selecting the candidate route and least-cost neighbor target.

This approach is not only easy and rapid to implement but also appropriate for DUAV operations where time pressure is very rigid for the fast moving UAVs. To minimize the computational cost of the insertion method, fuzzy clustering is used. In the suggested method, algorithm decides the most likely appropriate route to begin and then decides on the most alike unobserved target for neighborhood. New target is assigned prior to or after the most probable target according to their three dimensional geographical similarities in the selected route.

Four key issues should be taken into consideration in the DVRP solutions:
1. Computer processing time,
2. Policy for deciding to transform to dynamic situation,
3. Degree of dynamism,
4. The case when there is no dynamic solution.

These issues can be described as follows respectively:
Since the computational time of deterministic and complete algorithms grows exponentially with the dimension of the configuration space, these algorithms do not provide an adequate solution for real time UAV path planning in unknown natural environments [34]. Solving dynamic applications requires huge computational resources. The computer processing time (Δt) for the dynamic solution shall be concordant with the time of new target. Clearly, if “Δt” is too small, then the time for the optimization process may not be enough. Otherwise, diversion opportunities may be missed. Ichoua et al. [21] considers three rules to set “Δt”:
Rule 1: “Δt” is the time where the optimization procedure ends before any vehicle begins at its targeted destination.
Rule 2: “Δt” is pre-fixed time as an interval average time between the occurrences of two requests.
Rule 3. The average time per request is defined as “the length of some time horizon (X) /number of requests on the planned routes found within that horizon (l_x)”. The interval is $\Delta t=\alpha(X/ l_x)$.

The processing time “Δt”, allocated for the proposed solution time, is selected as the minimum time for any UAV in the heterogeneous fleet to reach its first unserved target. By this way, neither should the UAVs have to change their routes nor will the algorithm need to keep track of the UAVs and targets during the solution process.

In other words, one of the UAV of the fleet reaches its initial unserved target firstly after “Δt” times later than new target’s appearance at the time “t”. To decide the planning routes dynamically, either until a certain number of requests has been received by the operation center or a certain amount of time has elapsed since the last planning was performed, three batching strategies are introduced, the first two of them proposed by Larsen [7]:
Size driven method: “Immediate requests are collected into sets of *n* requests. Whenever a set has been collected, the insertion heuristic will be called”.
Time driven method: “This batching strategy is based upon re-optimization at fixed points in time (for instance every 10^{th} minute)”.
Size in time driven method: Immediate requests at fixed points in time are collected into sets of *n* requests. Whenever a set has been collected in pre-defined period or a fixed point in time is formed, then the insertion heuristic will be called (for instance 3 targets in every 10^{th} minute).

Lund et al. [11] propose a framework for DVRPs and define the degree of dynamism as “the number of dynamic requests relative to the total”. In the strategic UAV applications, the response time shall be low due to UAVs' high speeds, newly emerged (immediate) strategic targets' importance and sensitivity of the mission. Naturally, in real military application of *strategic* UAVs, the number of dynamic targets (degree of dynamism) is expected to be low. It is proposed that the dynamic targets for strategic UAVs are weakly dynamic system while response times shall be minimized as the aforementioned reasons.

Note that, if the program can't return the solution for dynamic situation due to the constraints, reassigning or rerouting modules should be called to give additional information for the planners as proposed by Murray and Karwan [26].

4. A NEW HEURISTIC APPROACH

It is known that there are many exact solution models for VRP. However, exact solutions may not be so useful because of the nature of the NP-Hard problems like VRP. As stated by numerous authors, exact algorithms may not yet be capable of handling the DVRPs because of the NP-hardness and the high complexity nature of the problem. In the time sensitive UAV routing operations, heuristics might be preferable to optimal solutions due to the time pressure. Therefore, a new heuristic approach based on fuzzy clustering cheapest insertion method is proposed in this paper in an attempt to contour this quick response time issue.

Thanks to the technology, as diversion of UAVs is applicable now, new target may be inserted into one of the following three cases:
1. During "on the air" UAV's current position and its first destination,
2. Among unobserved targets,
3. Between the last unobserved target and the airport.

To decide the insertion sequence in the proposed method, "the time" and "the geographical position" of the new target are two very important inputs to the dynamic system. To the best of our knowledge, this is the first time that a dynamic version of the UAV routing problem in which the 3 dimensional information of targets with their special safety distances, describe the minimum flying height for any UAV, is introduced. And that makes this study different from Beard et al. [35], Zucker et al. [30], and Duan et al. [36] who study on avoiding from the threats in the theater. A study for the optimization of a decentralized task assignment strategy for heterogeneous UAVs in a probabilistic engagement scenario is investigated by Kwak et al. [37].

It is assumed that the system disposes of on-line communication with all UAVs and has on-line information about the targets and the UAV dynamic positions from a ground control station (airport). All kinds of dynamics such as targets arriving at any time, at any coordinate with any safety altitude are considered in the proposed model. The response time shall not bigger than the time required for any UAV to reach its current destination target. The program flowchart of the proposed model is illustrated in Figure 1.

The programming steps of proposed heuristic algorithm for dynamic solution can be detailed as:

Step 1: Be aware of the static environment; get all the data related with static situation which includes planned targets in each route, coordinates, safety altitude and priority of each target, assigned UAV for each route, speed, endurance and the planned route for each assigned UAV.
Remark: All information relevant to the plan of the routes is assumed to be known, while the information about the coordinates, safety altitude, priority and time of the new emerged target are not known by the planner before the dynamic process begins.

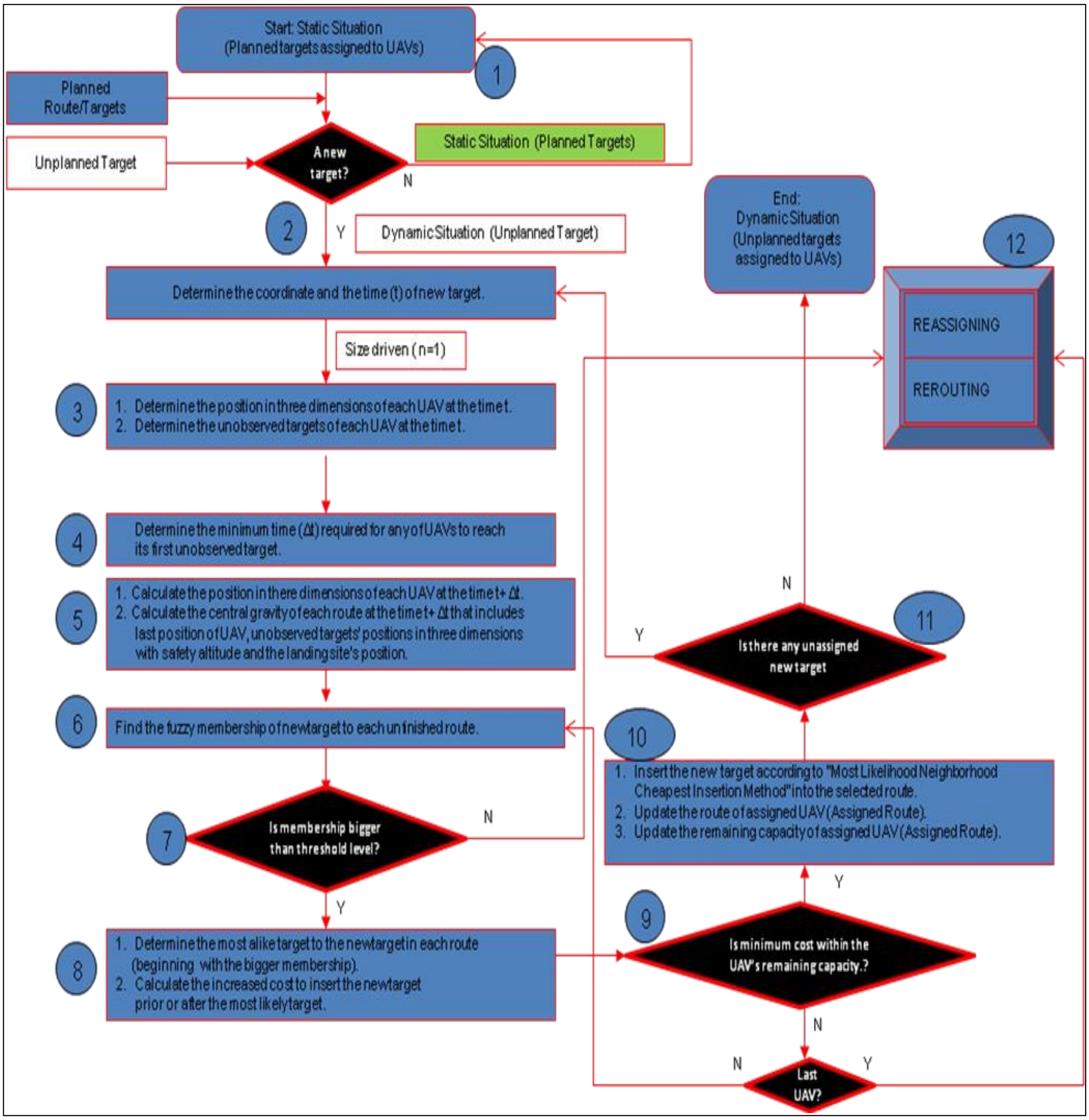

Figure 1. *Flowchart of the proposed model*

The initial situation of dynamic VRP is determined by the last situation of static environment. Initially, the static route is determined as Gencer et al. [38] proposed:

Notations:

n = Number of targets,

NV = Number of the UAVs,

K_v = Capacity of UAV "v",

T_v = Maximum endurance time of UAV "v",

d_i = Demand at target "i" (d_1=0),

t_i^v = Serving time for UAV "v" at the target "i" (t_{1v} =0),

t_{ij}^v = Travelling time for UAV "v" from the target "i" to target "j" ($t_{iiv} = \infty$),

c_{ij} = Travelling cost from the target "i" to target "j",

x_{ij}^v = If UAV "v" travels from the target "i" to the target "j" then x_{ij}^v=1, otherwise 0.

Objective Function:

$$Min \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{v=1}^{NV} c_{ij} x_{ij}^{v} \tag{1}$$

The objective is to minimize the total cost (the total distance) for all heterogeneous UAVs.
Constraints:

$$\sum_{i=1}^{n}\sum_{v=1}^{NV} x_{ij}^{v} = 1 \qquad (j = 2,...,n) \tag{2}$$

$$\sum_{j=1}^{n}\sum_{v=1}^{NV} x_{ij}^{v} = 1 \qquad (i = 2,...,n) \tag{3}$$

The first and second constraint: All the targets must be observed and this must done by just one UAV.

$$\sum_{i=1}^{n} x_{ip}^{v} - \sum_{j=1}^{n} x_{pj}^{v} = 0 \qquad (v = 1,..., NV; \quad p = 1,...,n) \tag{4}$$

The third constraint: All targets must be observed by a UAV. If a UAV goes to a target, the UAV must leave that target.

$$\sum_{i=1}^{n} d_i \left(\sum_{j=1}^{n} x_{ij}^{v} \right) \le K_v \qquad (v = 1,..., NV) \tag{5}$$

The forth constraint: All UAVs must finish their mission and return to the airport before their endurance finish.

$$\sum_{i=1}^{n} t_i^{v} \sum_{j=1}^{n} x_{ij}^{v} + \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}^{v} x_{ij}^{v} \le T_v \qquad (v = 1,..., NV) \tag{6}$$

The fifth constraint: The total time constraint.

$$\sum_{j=2}^{n} x_{1j}^{v} \le 1 \qquad (v = 1,..., NV) \tag{7}$$

$$\sum_{i=2}^{n} x_{i1}^{v} \le 1 \qquad (v = 1,..., NV) \tag{8}$$

The sixth and seventh constraints: To perform the mission within the given number of UAVs and not to exceed the given number of UAVs.

$$X \in S \tag{9}$$

Step 2: Get the coordinates, safety altitude, priority, and the time "t" of the new unplanned target.
Remark: If any unplanned sensitive target emerges and needs to be considered in this reconnaissance planning period, it triggers the dynamic situation.

The first size driven strategy described in the previous section is used for batching methodology. Size (n) is adjusted as 1 because of the sensitivity of each new immediate target at the strategic level which means that whenever an immediate target emerges, the algorithm shall be called.

The time and the location of the immediate target are very critical data for the dynamic solution. The importance of the new target’s time is clarified in steps 3, 4, 5, 6, 8 and 10 while the importance of the new target’s location is considered in steps 3, 5, 6, 8 and 10.

Step 3. Calculate the geographical coordinates and determine the unobserved pre-planned targets on the route for each UAV at the time “t”.
Remark: Euclidian distances in 3 dimensions are calculated dynamically to model the real world in a more realistic approach.

Step 4. For all UAVs, calculate the time to reach their first unobserved target. Find the minimum time required for any UAV to reach its first unobserved destination which is called “Δt”.
Remark: “Δt” determines the amount of time allocated for processing of the solution. In other words, the algorithm must solve the problem within “Δt”. In the proposed model, “Δt” is assigned to the time which requires any UAV begins its service at its current destination, due to the nature of the strategic UAV route planning. As discussed before, the weakly dynamic features of the problem doesn’t need to consider the intensity but the computation time.

Step 5. Calculate the geographical positions for all UAVs at the time “$t+\Delta t$”. Calculate the central gravity of each route at the time “$t+\Delta t$”.
Remark: Central gravity of each route is constructed by regarding the last position of UAV assigned to each route, unobserved targets with their safety altitude in the route and the geographical position of landing site.

Since they identify the last position of each UAV and the central gravity of each route, the time “t” and “Δt” are very critical. Whenever “t” or “Δt” changes, the last positions of the UAVs and the central gravities of each route may change dynamically.

Step 6. Find the fuzzy membership of new target to each ongoing route at the time “$t+\Delta t$”.
Remark: In the classical clustering theory, a new target is a member of a route or not. If it is not a member of one route, it is a member of another. In our model which is based on fuzzy clustering membership, the new target’s fuzzy membership to each route is calculated according to their dynamic central gravities by the help of likelihood of new target’s position and routes’ central gravities.

Each route has its own unique central gravity at any (t) time. Central gravity of each route is calculated in 3 dimensions (x, y and z) by regarding the last position of UAV assigned to each route, unobserved targets with their safety altitude in the route and the geographical position of landing site. For each route's central gravity: The X coordinate of the central gravity is calculated according to x coordinates of unobserved targets (including the x coordinate of the landing site) with the x coordinate of the assigned UAV to the route. Likely, Y and Z coordinates of the route central gravity are calculated.

All the routes are not to be considered in the case. The threshold (Th) level determines the routes to be considered. The control methodology dynamically starts with the route based on observed behavior of the new target and the existing routes instead of selecting a coding schedule a priori.

Step 7. If the fuzzy membership of new target to a route is higher than threshold level, do the next steps beginning with the highest fuzzy membership. If not, go to step 12.
Remark: For the quick response of the program, the threshold level can be fixed a priori or can be determined according to the number of UAVs.

Step 8. Calculate the likelihood to the new target for each unobserved targets in the selected route. Beginning with the most alike unobserved target, calculate the increased cost to insert the new target prior or after the selected pre-planned target.
Remark: The likelihood of each unobserved targets is calculated according to their Euclidean distances (with safety altitude) to the new target.

Step 9. If the minimum increased cost to insert the new target prior or after the selected pre-planned target is within the UAV remaining capacity, go to Step 10, or to consider the next UAV go back to step 6, otherwise if all the routes are checked then go to step 12.
Remark: The time “t+Δt” is considered in the calculation of remaining capacity.

Step 10. Insert the immediate target by the help of “likelihood neighborhood cheapest insertion” method. Update the route and the remaining capacity of the assigned UAV.

Step 11. Although we consider our problem as weakly dynamic one, there might be a second immediate target while we process the first one. In that case go to step 2. Otherwise finish the program.

Step 12. In the DVRP, there might not be a solution. If the program cannot find the solution for dynamic situation due to the constraints, reassigning or rerouting modules is called.

In the proposed model, dynamism of the problem depends on not only dynamic time but also dynamic coordinate of the new target. The position at time “t” and the last position at time “t+Δt” of each UAVs vary according to the both dynamic “t” and “Δt” variables.

The first aim of the proposed model is to place the new immediate sensitive target in one of the current routes. If this cannot be achieved due to the constraints, the successor aim of the model is to insert the immediate target in the place of one of the pre-planned targets which has a lower priority in one of the current routes (rerouting module). Otherwise, valuable information is given to the planner for the next planning period (reassigning module). Reassigning module gives the required information about the periodic planning while rerouting module inserts the new target in the place of a pre-planned target based on target priorities.

5. IMPLEMENTATION AND COMPUTATIONAL RESULTS

A case-based empirical study with two scenarios is conducted to test the performance of the proposed heuristic approach. Consider a case where a group of six heterogonous UAVs are required to transition through some of 24 known target locations in a reconnaissance mission. In the AoR, there are 24 a priori and one "pop-up unplanned” targets which needs to be observed by one of these 6 heterogeneous UAVs.

There is a dynamic solution in case A while case B does not return a dynamic solution because of the endurance constraint of the UAVs but returns a rerouting solution. Target data, shown in Table 1, are used to perform the test in the empirical example for the two worst cases.

Following cases are considered as the worst ones:

- “Δt” is very close to zero,
- New target emerges at the time when none of the UAVs reach their first planned target,
- New target emerges at the time when most UAVs are heading for landing,
- In the case that there is no dynamic solution due to the constraints,
- All the planned targets and new target have the same priorities,
- The fuzzy memberships of the new target to the all of the routes are nearly the same,
- The fuzzy memberships of the new target to the more than one routes are the same.

The new target (target-25) data which are used in both cases are given in Table 2. For testing, 120 seconds after all UAVs have taken off from the target 0 (landing site airport), a new target emerges. The proposed algorithm solves the DVRP, and then the new target is injected in one of the ongoing UAV routes (case-1) (without eliminating one of the preplanned targets) or new target is inserted instead of one of the planned targets (by eliminating one of the preplanned targets) (case-2).

The specifications/names for all UAVs and for all targets in the tables are generically produced ones to show the solution within the constraints and make them easy for the readers to follow.

***Table 1**. Target Information (Case-A and Case-B)**

TARGETS												
No	**X**	**Y**	**Z**	**Safety Altitude**	**Priority**		**No**	**X**	**Y**	**Z**	**Safety Altitude**	**Priority**
0*	100	100	100	0	1		13	34	444	600	100	2
1	112	676	600	100	2		14	435	100	232	0	1
2	333	676	600	100	2		15	527	232	332	867	2
3	376	55	555	666	2		16	235	25	255	25	1
4	327	634	111	63	1		17	55	55	55	733	2
5	333	555	611	555	2		18	233	556	950	947	2
6	466	42	56	725	2		19	313	55	555	666	2
7	527	462	625	867	1		20	444	354	111	63	1
8	266	556	985	968	2		21	666	555	846	968	1
9	553	556	950	947	2		22	678	890	678	543	1
10	457	233	333	543	1		23	231	432	600	100	2
11	98	447	47	477	2		24	3661	123	345	725	1
12	722	173	65	47	2		0*	100	100	100	0	1

* Target-0 is the same airport which is used by UAVs for landing and taking off.

***Table 2.** New Target Information (Case-A and Case-B)*

No	X Coord	Y Coord	Z Coord	Safety Altitude	Priority	Time (sec)
New Target (25)	887	676	600	100	1	120

Case A: In the first case, UAV specifications listed in Table 3 are used. As seen in the table, the endurances and speeds are different due to the fact that they are heterogeneous UAVs.

The Result: To test the result, the user interface has been developed on visual basic because the package programs used in UAV route planning usually use destination lists in excel table forms as input. The flexibility of the decision support system is thus ensured. The program returns the dynamic solution shown in the Figure 2. In the solution, the new target is assigned to UAV-3, named RJ. In the route of UAV-3, the target-12 is selected as the most likely target to the new target. The new target is assigned before the target-10 (the most likely target) in the route of RJ. Since the new target is assigned to the UAV-3, the sequences of the targets for other UAV routes are not changed. In the route of UAV-2 for example, Gözcü observed target 5 and is continuing toward to target-1 and will continue to targets-1, 4, 2, 3 and lastly to the landing site (0), while in the assigned route, RJ observed target 2 and will observe the targets-7, 9, ***25 (new target)***, 10, 11, 12 and 0 respectively after the time “t+Δt”.

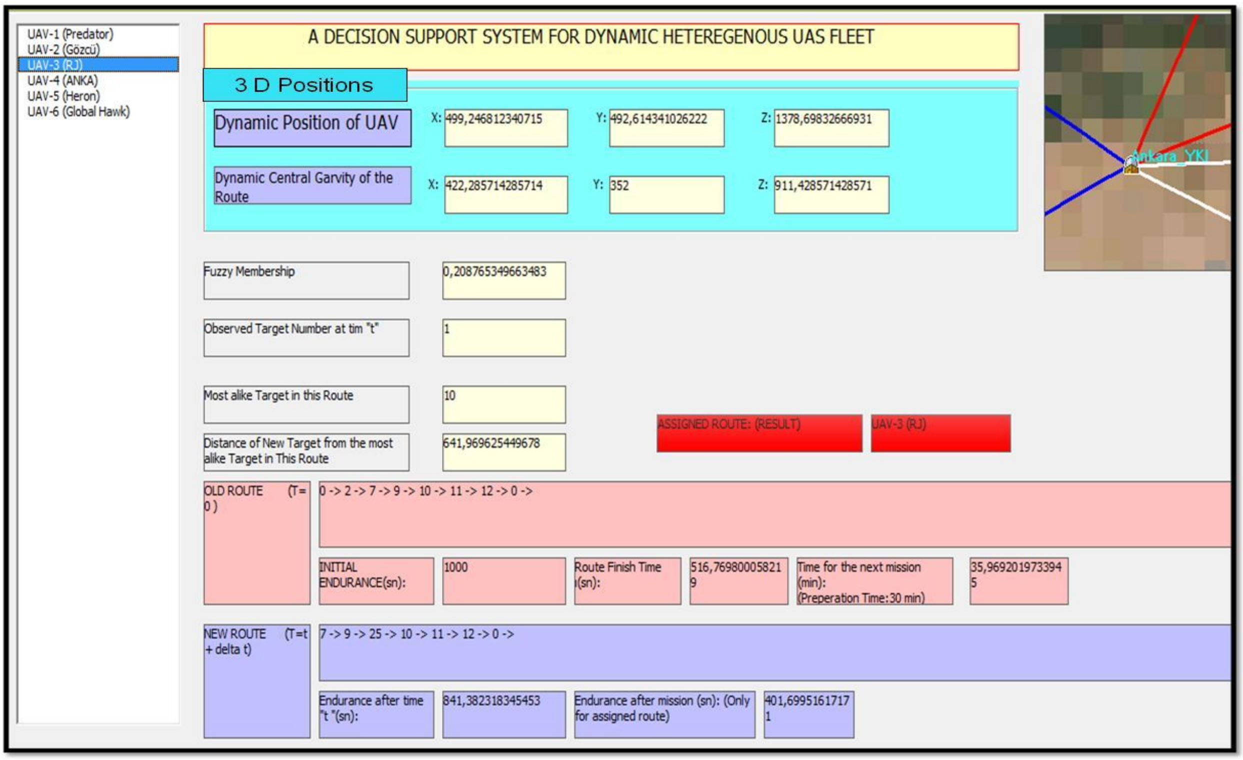

Figure 2. *Dynamic Solution Result*

Table 3. *UAV Information at the very beginning of the mission (Case-A)*

UAVs					
No	**UAV**	**Speed (m/sec)**	**Endurance (sec)**	**Number of Planned Targets**	**Route (Targets)**
1	UAV-1 (Predator)	10	1000	2	0→5 →0
2	UAV-2 (Gözcü)	10	1000	6	0→5 →1 →4 →2 →3→ 0
3	UAV-3 (RJ)	10	1000	7	0 →2 →7 →9 →10→ 11 →12→ 0
4	UAV-4 (ANKA)	7	2000	9	0 →6 →8 →14→ 20→ 21→ 22→23→ 24 →0
5	UAV-5 (Heron)	9	999	6	0 →13 →15 →17→ 18→ 19→ 0
6	UAV-6 (Global Hawk)	111	111	5	0 →13 →14→ 9→ 16 →0

Case B: In the second case, UAV specifications shown in Table 4 are used. The only difference from the previous one is the endurances.

If the program cannot return the dynamic solution because of the constraints like endurances, the rerouting process may be done according to the targets' priorities. In this way, new target is inserted in the place of the less important target by considering both the fuzzy membership of the new target to the routes and the remaining endurances of flying UAVs.

The Result: If there is no solution because of the constraints like endurance, the program may not return the dynamic solution; instead it can present rerouting solution. The rerouting solution is presented as shown in Table 5. In the solution, the new target is assigned to UAV-5 (Heron). As seen in the Table, new target (25) is inserted in the place of the target-18 which was in the previously planned route of UAV-5. As shown in the Table 5, the sequences of the targets for other UAV routes are not changed. For example, in the route of UAV-4, ANKA will continue to observe the targets 8, 14, 20, 21, 22, 23, 24 and 0, while the UAV-5 (Heron) must follow targets 15, 17, 25 (instead of 18), 19 and 0 after the time "t+Δt".

Table 4. *UAV Information (Case-B)*

UAVS					
No	**UAV**	**Speed (m/sec)**	**Endurance (sec)**	**Planned Targets Amount**	**Route (Targets)**
1	UAV-1 (Predator)	10	237	2	0→5 →0
2	UAV-2 (Gözcü)	10	478	6	0→5 →1 →4 →2 →3→ 0
3	UAV-3 (RJ)	10	517	7	0 →2 →7 →9 →10 → 11 →12→ 0
4	UAV-4 (ANKA)	7	2064	9	0 →6 →8 →14→ 20→ 21→ 22→23→ 24 →0
5	UAV-5 (Heron)	9	589	6	0 →13 →15 →17→ 18→ 19→ 0
6	UAV-6 (Global Hawk)	111	46	5	0 →13 →14→ 9→ 16 →0

Table 5: *Rerouting Solution Result (Case-B)*

No	**UAV**	**Planned Route (Targets)**	**New Route After the Time "t+Δt" (Targets)***
1	UAV-1 (Predator)	0→5 →0	→0
2	UAV-2 (Gözcü)	0→5 →1 →4 →2 →3→ 0	→1 →4 →2 →3→ 0
3	UAV-3 (RJ)	0 →2 →7 →9 →10→ 11 →12→ 0	→7 →9 →10→ 11 →12→ 0
4	UAV-4 (ANKA)	0 →6 →8 →14→ 20→ 21→ 22→23→ 24 →0	→8 →14→ 20→ 21→ 22→23→ 24 →0
5	**UAV-5 (Heron)**	0 →13 →15 →17→ 18→ 19→ 0	→15 →17→ **25 (instead of 18)**→ 19→ 0
6	UAV-6 (Global Hawk)	0 →13 →14→ 9→ 16 →0	→13 →14→ 9→ 16 →0

* Only the route of UAV-6 is changed, other UAVs will continue their mission as planned.

6. CONCLUSIONS AND RECOMMENDATIONS

UASs have become important force multipliers for many armed forces. Among the many open issues to be addressed in the UAVs is that of dynamic route planning. Dynamic routing of UAVs that perform cooperative tasks has many military applications for situational awareness and thus has been the subject of much recent applications. Most of the existing UAV routing applications have focused on static pre-planned situations; however, planning and updating military reconnaissance operations at the strategic level requires dynamic solutions.

Although DVRPs have attracted more and more interest recently, the relatively number of papers indicate that this domain is still young. In this paper, a DSS for dynamic solution of a new target for the strategic level heterogeneous UAVs, capable of taking into account dynamic time as well as dynamic position and priority, is studied using fuzzy clustering and leveraged cheapest insertion neighborhood method. Steps related to the proposed model are explored for both the empirical case studies and the worst case cases (as proposed by [39]). Fuzzy clustering overcomes some limitations of existing nearest neighborhood method approaches, particularly handling changes to update beginning from the best route without causing the initial tour to be completely changed.

The highlights of the paper can be summarized as a dynamic DSS for heterogeneous UAVs with targets having 3-D, priority and thread is proposed for the military operations in battlespace with survivable trajectories. Instead of selecting a priori code, the control methodology is based on the observed behavior of the new target and the dynamism of the routes. The computer processing time, the policy for deciding to transform to dynamic situation, the degree of dynamism and the cases when there is no dynamic solution are considered in the solution. To shorten the computation time, fuzzy clustering based insertion method with leveraged cheapest insertion neighborhood approach is proposed. Updated route is calculated by a policy that evolves as a function of inputs instead of a set of routes.

For the further studies; other examples of dynamic situations such as failure of an UAV, a new available UAV, capability of aerial refueling of UAVs during the mission, new available ground control station (airport), addition of a new dynamic target to the route, subtraction of a pre-planned target from the route, new available way (from target to target for UAV), moving targets, restriction of a pre-allowed way (from target to target) may be studied. On the other hand, test problems for the dynamic VRPs may be produced. Highly dynamic VRP problems and Game theory approaches may be other interesting research area.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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