Research on Unmanned Aerial Vehicle Disaster Relief System

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Abstract: Aiming at Puerto Rico's UAV disaster relief system, an optimal configuration model of UAV based on linear programming and simulated annealing algorithm is developed. The optimal solution achieves the lowest cost and has the maximum number of days for relief and a wide range of exploration. Due to flight distance limits, we are unable to explore all areas and thus mainly focus on the north-east and parts of the east and south-east. To save loading space, we put the Medical bag in the Drone Cargo Bay in advance and let the drone fly along the road without considering recycling. We divide the studied Area into two parts: AreaIand AreaII, according to the Medical demand of hospitals and the longest distance of any two hospitals using method of the fuzzy average division. Each Area is supplied by a single container. Container in AreaIis responsible for the 4th and 5th hospital and container in AreaII for the 1st, 2nd, 3rd hospital. According to the maximum flight distance of drone, we can roughly decide the position of each container by linear programming. Once selecting drones that meets hospital requirement, consider all possible combinations of delivering packages. Each combination is considered to be a unit. By means of annealing algorithm and numerical experiments, we find the maximum number of units, which is equivalent to the longest rescue day. The largest range of B type drone is added to containers for reconnaissance. Finally, using Type-B drones that have not been used to explore paths without hospitals. Then let drones that are used for delivering Medical packages fly along different routes. By graph theory and detailed enumeration method, we can list the longest coverage of the situation road and the shortest number of days, in order to achieve the flight route and schedule.

1. Introduction

In the 2017, the territory of Puerto Rico in the United States was hit by the worst hurricane ever. In particular, along the eastern and south-eastern coasts of Puerto Rico, the combined destructive power of hurricane storm surges and wave effects has caused extensive damage to buildings, houses and roads [1]. The storm hit 80% of Puerto Rico's poles and transmission lines, leading to power losses [2]. In addition, the storm damaged or destroyed most of the island's cellular communications network. In most parts of the island, power and battery service disruptions continued for several months [3]. Widespread flood blockages have damaged many roads and roads across the island, making it almost impossible for emergency services to plan and navigate routes [4]. Puerto Rico's demand for Medical supplies, life-saving equipment and treatment stretched the relief operations of clinics, hospital emergency rooms and non-governmental organizations. Demand for health care has continued to surge for some time as chronically ill people turn to hospitals and temporary shelters for care [5].

2. Symbolic descriptions

Table.1. Notations

Symbols	Definition	Unit
Day	Number of days of Medical packages that can be supported	Day
L	Total length of roads that drone can detect	km
L_i	Container to No.i Hospital distance (along highway)	km
N	Number of drone	

Where we define the main parameters while specific value of those parameters will be given later.

3. Model establishment

As you can see from the map, the Figure 1 shows the location of 5 hospitals (maned 1st, 2nd, 3rd, 4th, 5th hospital in title order).

Figure 1. Hospital distribution map

We see the hospital address roughly as a node on the main road and use tools to measure the length of the main traffic path in the Area between 5 nodes, as shown in Figure 2. Due to the complexity of the central city Road, we have simplified it by selecting the main road between several major road nodes [6].

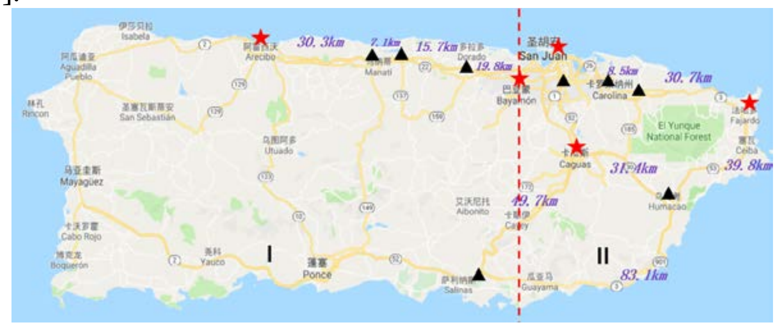

Figure 2. Length of major roads in the central Area

On this basis, we turn our goal into: finding as many roads as possible while successfully delivering emergency Medical kits. Therefore, in order to reduce the useless itinerary that cannot detect roads, we have arranged containers on the main roads that need to be investigated [7].

According to annex II, we are able to calculate the farthest flight distance of different drone, as shown in the following table 2.

Table.2. The farthest flight distance calculated of different drone

Drone	Speed (km/h)	Flight Time (min)	Farthest flight distance (km)
A	40	35	23.3
B	79	40	52.7
C	64	35	37.3
D	60	18	18.0

E	60	15	15.0
F	79	24	31.6
G	64	16	17.1

As can be seen from the table above, the farthest distance flown by drone is 52.33km. It is clear that if there is only one container, it is impossible to send Medical kits to 5th hospitals and 1st hospitals at the same time [8].

Therefore, in order to be able to meet the needs of all hospitals, a minimum of two containers are required. In order to reduce costs and improve efficiency, we assume that the number of containers is 2.

3.1 Sub-model 1: Determine drones combinations model

Prior to this, we had completed the division of the Area, so that we completed the model separately in each Area.

Suppose there is an I hospital in a certain Area, maned 1st--ith Hospital, respectively, L_i indicates the distance from the container to each hospital. max_i said the farthest flight distance of the drone, which was able to transport Medical kits from No.i hospital alone [9].

The following constraints are given:

$$L_i \leq max_i \text{ (i=1, 2, 3}\cdots\cdots)$$

A range of containers can be obtained by introducing data calculations to screen existing drones available to each hospital and selecting the smallest drone combination [10].

3.2 Sub-model 2: packing model

In order to maximize the number of days a Medical package is supplied, we need to maximize the filling of the container. So we loaded the cargo bay into containers and the Medical packaging into the cargo bay, so that when we packed the drones, we just had to consider the loading of different models of drones.

By 5.1, we have identified a combination of drones, and the problem has evolved into a three-dimensional packing problem of known container and cargo sizes.

3.3 Sub-model 3: determine container location model

Because the container placement in the AreaIis very simple, we focus on the location of the container in this case.

Because it is not a problem to transport Medical kits regardless of the location of the container. Therefore, the main basis for determining the location of the container is the largest video reconnaissance route.

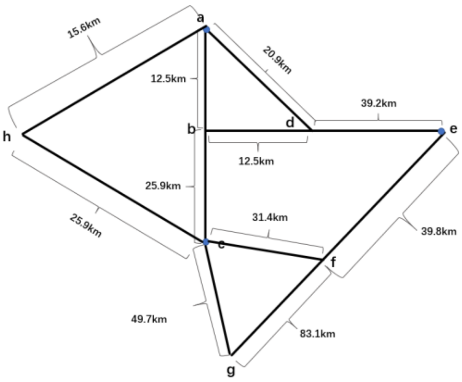

Figure 3. Simplified Figure 1 in urban Areas

By the method one known container location o possible position for road ad, ab, bc, bd and de.

Then, we calculate the maximum length l of the road that the drones can cover in the 2 Area, and compare several cases, select the position of the container corresponding to the maximum value of L, that is, the location of the container we are asking for.

4. Model solution

4.1 Result 1

Method one: considering that the Medical kits required by the hospital could be transported separately by a single drone to limit the type of drones, the results are as follows table 3.

Table.3. Result 1

Hospital	Types of drone available	Farthest flight distance (km)
5th	ABCDEFG	52.7
4th	CEFG	37.3
3rd	BD	52.7
2nd	CEFG	37.3
1st	BD	52.7

In AreaI, we can limit the location of containers by successfully delivering the Medical bags to 2 hospitals (4th 5th) through drones.

Figure 4. Simplified

The distance from the container to two hospitals (5th 4th) (along the motorway) is L_5, L_4.

According to the constraint conditions:

$$\begin{cases} L_5 \leq 52.7 \\ L_4 \leq 37.3 \\ L_4 + L_5 = 72.9 \end{cases}$$

Solution to $35.6 \leq L_5 \leq 52.6$,

In order to maximize the video reconnaissance Area, take $L_5 = 35.6$.

Therefore, the available drones for the delivery of Medical kits for 5th Hospital is BC;

The available drones for the delivery of Medical kits for 4th Hospital is CF;

Therefore, the choice of the smallest size drones combination is BF.

In Area 2, we can limit the location of containers by successfully delivering the Medical bags to 3 hospitals (1st 2nd 3rd) through drones.

For ease of calculation, we reduced the map to figure5.

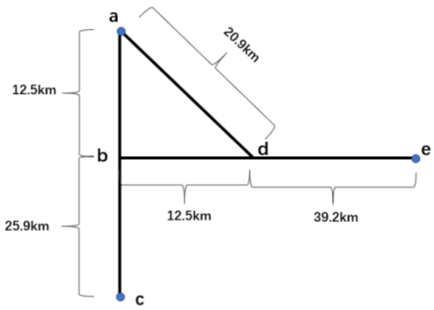

Figure 5. Simplified in urban Areas

The location of the container is O, which may be located in the road bc, ab, bd, ad and de.

According to the constraint conditions:

$$\begin{cases} L_3 \leq 52.7 \\ L_2 \leq 37.3 \\ L_1 \leq 52.7 \end{cases}$$

By solving the position range of the container on each road, the range of L_a, L_c *and* L_e is obtained, and the smallest drones combination is selected.

Take the container on ad as an example

Order ao=x

$$\begin{cases} x \le 52.67 \\ x + 12.5 + 22.1 \le 37.33 \\ (\text{or } 20.9 - x + 12.5 + 22.1 \le 37.33) \\ 20.9 - x + 39.2 \le 52.67 \end{cases}$$

Solution to $18.2 \le x \le 20.9$

Then

$L_a \in [18.2, 20.9]$, Available drone for BCF;

$L_c \in [34.6, 37.3]$, Available drone for C;

$L_e \in [30.7, 33.4]$, Available drone for BCF;

Therefore, the choice of the smallest size drones combination is BCB.

Using the same approach, we can get:

On the Road ad, bd and de, the choice of the smallest size drones combination is BCB;

On the Road ab and bc, the choice of the smallest size drones combination is DFB.

Method Two: Now, we think that multiple drone is responsible for hospital transportation at the same time. To ensure maximum supply days, we think the number of drone per day is 4.

After a comprehensive consideration, we found that the flight distance and relatively small size of drones of type B, so four drones of type B have a greater advantage in the combination of Medical package transportation and video reconnaissance.

4.2 Result 2

Through three-dimensional packaging simulation, the following conclusions are drawn.

In the container of the Area I, as shown in the right image:

Name of the goods	Color	Number
B		26
F		24
H		1

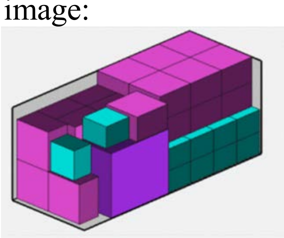

Figure 6. Model results

Volume utilization is 83.83%.

In the container of Area II, as shown in the right image:

Name of the goods	Color	Number
B		84
H		1

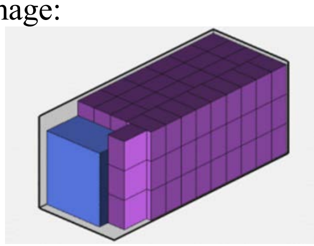

Figure 7. Model results

Volume utilization is 85.69%.

In this case, the container can achieve maximum utilization.

4.3 Result 3

Scenario One: Containers on road ad (Order $od = x \le 13.4$)

Known by geometric relationships

$$L = 198.1 - 3x \in [166.75, 198.1]$$

Scenario Two: Containers on road ab (Order $ob = x \le 0.9$)

Known by geometric relationships

$$L = 210.6 - 3x \in [207.9, 210.6]$$

Scenario Three: Containers on road bc (Order $ob = x \le 0.9$)

Known by geometric relationships

$$L = 210.6 + x \in [210.6, 211.5]$$

Scenario Four: Containers on road bd (Order $od = x \leq 12.5$)

Known by geometric relationships

$$L = 198.1 + x \in [198.1, 210.6]$$

Scenario Five: Containers on road de (Order $od = x \leq 2.7$)

Known by geometric relationships

$$L = 198.1 - x \in [195.4, 198.1]$$

Comparing the above 5 cases, we know that when the container is on BC and ob=0.9, L obtains the maximum value of 211.5km.

Therefore, the location of the container is determined.

4.4 Result 4

After determining the location of the drone combination and two containers, we determined the flight plan according to the graph theory knowledge to make the road effective coverage of the longest and the shortest time to achieve.

Drones Payload Packaging configuration:

The container in Area I has 26 drones of type B, 24 drones of type F, of which 24 drones of type B go to 5th hospital, loads MED1, 24 drones of type F to 4th hospital, loads 2*MED1+MED2+MED3.

The drones in the container in the Area II has 84 drones of type B, 24 of which go to 3rd hospital, loaded with MED1+MED2, 48 drones of type B go to 2nd hospitals, loaded 2*MED1 and MED3, 24 drones of type B go to 1st hospital, loaded MED1+MED3.

Forms will not be displayed here. The table above is a daily flight plan, and the flight route is determined by the road number (refer to Google Maps for details). As shown in the table, the Area I can support a 24-day delivery dose, and the Area II can support a 21-day delivery dose. Area I on the 2nd day to achieve the maximum scope of effective detection, Area II on the 7th day to achieve the maximum scope of effective investigation. The delivery route and schedule of the drone are also shown in the table above.

5. Model inspection

5.1 Stability

Because the algorithm uses simple geometric operation more, the algorithm is stable and not easy to be disturbed.

5.2 Accuracy

However, due to the completion of the algorithm, we have a series of simplification of the problem, and made a series of assumptions, at the same time, there may be some deviation in the measurement of the data, which will have a certain impact on the accuracy of the model.

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