DroneGo disaster response system based on genetic algorithm

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Abstract: This paper firstly we established an integer programming optimization model according to the type and quantity of medical packages required by each hospital, and obtained the type of the drone cargo bay required to transport the medical packages, and then determined the types of drones (C, E, F, G) that transport the medical packages. Combined with the actual situation of drone flight range, the option to use one or two standard containers was excluded. Finally, we established the DroneGo disaster response system with three ISO cargo containers drone to enhance Puerto Rico's ability to respond to hurricane disasters.

1. Introduction

Puerto Rico was hit by the worst hurricane in its history in 2017, causing a severe humanitarian disaster for local residents. The hurricane damaged nearly 80 percent of the island's electrical and communications equipment and destroyed most of the island's roads, which left many parts of the region with limited power supplies and transportation and communication problems. Meanwhile, the island's residents have seen a surge in demand for health care as a result of the disaster. In this crisis American NGOs often face the challenge of providing appropriate and timely assistance to affected areas.

2. Our work

2.1 Restatement of Question

The problems we need to solve in the paper are:

- To establish an ISO cargo container assembly model to determine the quantities of containers needed, how many drones and medical packages are assembled in each container and how the articles are arranged in the container.
- Find the best place in Puerto Rico to place the ISO cargo containers of the DroneGo disaster response system so that medical packages can be delivered and video reconnaissance can be performed.
- To schedule the transport drone in the DroneGo disaster response system, and to assign the video reconnaissance drone formation in the DroneGo disaster response system.
- Write a memo to the HELP, Inc. CEO summarizing our modeling results, conclusions, and recommendations.

2.2 General Assumption

- The current climate in Puerto Rico has a negligible impact on drone flights so that we could ignore it.
- There are no obstacles in the height of the disaster area, which will not hinder the flight of the drones.
- All locations are suitable for ISO cargo containers landing.
- Uneven container assembly will not affect the container, the container in the transport process will not appear uneven force problem.

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2.3 Symbols

Table 1. Symbols

Symbols	Definition
Lat	Latitude
Lon	Longitude
n_i	Usage count of type i allocation option
N	The quantities of drone cargo bays
x	Cartesian coordinate system abscissa
y	Cartesian coordinate system ordinate
D_i	The i-th area
D_{ij}	The j-th point of the major roads in the i-th area
O_i	The i-th ISO cargo containers location for landing
S_t	The flight range of transport drone
S_v	The flight range of video reconnaissance drone
d_{ij}	The distance between the j-th point of the major roads in the i-th area and the i-th ISO cargo containers location for landing

3. The Model for Selecting Drone Cargo Bay Type

We listed all possible medical packages arrangement in No.1 and No.2 cargo bay, combined with the total demand for medical packages, established an integer programming model to determine the types of required drone cargo bay. According to the quantities and type of medical packages needed by each hospital, we determined the quantities and sorts of the drone cargo bays that were needed.

3.1 Drone Cargo Bay Loading Condition

According to the carrying capacity of each drone cargo bays and the size of medical packages, we have listed the following eight situations:

Table 2. The situations

Sorts	Drone Cargo Bay Type	Medical Package ID		
		MED1	MED2	MED3
①	1	0	1	0
②	2	1	1	0
③	2	0	1	1
④	2	0	2	0
⑤	2	0	0	2
⑥	2	1	0	0
⑦	2	0	1	0
⑧	2	0	0	1

3.2 Integer programming model

In the above table, n_i represents usage count of type i allocation option. Five hospitals need a total of seven MED1, two MED2 and four MED3. Under the premise of meeting the needs of various hospitals, it is necessary to minimize the use of drone cargo bays to reduce waste of resources. The objective function of the total demand for the drone cargo bays of the drone is as follows:

$$N = \min \sum_{i=1}^{8} n_i \tag{1}$$

Use integer programming to solve for the minimum number of cargo bays required. List the following relationships:

$$\begin{cases} n_2 + n_6 \ge 7 \\ n_1 + n_2 + n_3 + 2n_4 + n_7 \ge 2 \\ n_3 + 2n_5 + n_8 \ge 4 \\ n_1, n_2, n_3, n_4, n_5, n_6, n_7, n_8 \ge 0 \end{cases} \quad (2)$$

3.3 Determine the type and quantity of cargo bays

Using MATLAB to write a program to solve the model, the solution is:

Table 3. The solutions of drone cargo bay choosing

Sorts	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
Quantities	0	2	0	0	2	5	0	0

As can be seen from the table 3, we need to use the second assembly scheme 2 times, the fifth assembly scheme 2 times and the sixth assembly method 5 times, a total of 9 cargo compartments.

Taking the demand of each hospital into account, we found that the assembly plan we chose did not meet the medical package needs of individual hospitals. Therefore, on the basis of the existing situation, we carried out the adjustment of the plan and finally determined that there were 0 No. 1 cargo bay and 10 No. 2 cargo bays, for a total of 10 cargo bays. There are only four types of drones that can carry the No. 2 cargo bay: C, E, F, and G. Therefore, we can only choose from these four types of drones to carry out the mission of transporting medical packages.

4. Establish an ISO cargo containers allocation model

We determine the quantity of ISO cargo containers and the location of the landing based on the drone's flight range. In order to determine the optimal location of the container and the type of drone selection, we established the ISO cargo containers allocation model. In the model, we applied the genetic algorithm, and finally released the optimal location of the ISO cargo container landing point and the best range for transporting the drones and video reconnaissance drones according to the drone's flight range.

In order to facilitate the study of drone delivery problems, we assumed that the speed and flight time of the drone are not affected by the load.

4.1 Determine the quantity of ISO cargo containers

To determine the quantity of ISO cargo containers, we measured the distance between adjacent hospitals as shown:

Figure 1 The distance between adjacent hospitals

4.1.1 Use only one ISO cargo container

If there is only one container, the transport drones in the container need to send the medical packages to five hospitals. However, the drone’s flight range is limited, the maximum range in C, E, F, G is 37km. After finishing the transportation mission, the drones need to return to the location where the container is located. As shown in the figure, we used the half of the maximum range of the drone as the radius, and draw the circle with the container drop as the center. This circle is the maximum range that can be achieved by transporting drones. We tried to make more hospitals included in the scope of the aircraft voyage, make the following picture:

Figure 2 The circle of flight range (1)

As can be seen from the figure, the maximum quantity of hospitals a container can meet is only three, which can't meet the supply demand, so it is impossible to use only one container.

4.1.2 Use two ISO cargo containers

When there are two containers, we took the same approach and once again took the radius of half of the maximum range of the aircraft, and draw the circle with the radius of the drop position of the two containers. Also, make more hospitals be included in the scope of the flight range inside, make the following picture:

Figure 3 The circle of flight range (2)

As the picture shows from the figure 3, the maximum number of hospitals that can be meet by two containers is four, which still cannot meet the supply demand, so we can't use only two containers.

In summary, we can meet the supply requirements of all hospital medical packages only when we use three containers.

4.2 Establish a Cartesian coordinate system

The coordinates we know are latitude and longitude coordinates, it is not easy to calculate and process data. Therefore, we establish a Cartesian coordinate system to convert latitude and longitude coordinates into Cartesian coordinate system coordinates.

- If the latitude and longitude coordinates of the target location are known, then the Cartesian coordinate system of the target is calculated as:

$$\begin{cases} x = 2\arcsin\left(\sqrt{\cos^2\left(\frac{Lat}{180}\bullet\pi\right)\bullet\sin^2\left(\frac{66.73-Lon}{360}\bullet\pi\right)}\right)\bullet 6378.137 \\ y = 2\arcsin\left(\sqrt{\sin^2\left(\frac{Lat-18.22}{360}\bullet\pi\right)}\right)\bullet 6378.137 \end{cases} \quad (3)$$

- If the Cartesian coordinates of the target ground are known, the formula for calculating the latitude and longitude of the target ground is:

$$\begin{cases} \mathrm{Lat} = \dfrac{360\bullet\arcsin\left(\frac{y}{2\bullet 6378.137}\right)}{\pi} + 18.22 \\ Lon = 66.73 - \dfrac{360\bullet\arcsin\left(\dfrac{\sin\left(\frac{x}{2\bullet 6378.137}\right)}{\cos\left(\frac{Lat}{180}\bullet\pi\right)}\right)}{\pi} \end{cases} \quad (4)$$

We converted the latitude and longitude of the five hospitals into Cartesian coordinate system coordinates, as shown in the following figure 4:

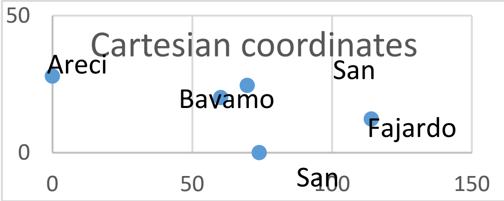

Figure 4 Cartesian coordinate system

4.3 The drone flight range limit

H Tethered is a mooring drone. According to the references, the mooring drone requires a high-voltage power supply system, a drive motor and a tethered cable. The conditions are not given in the question. Therefore, we do not consider using H Tethered.

Based on the data, we calculated the maximum flight range of each drone (regardless of the impact of the aircraft load). The results are as follows:

Table 4. The maximum flight range

Drone	Range(km)
A	23.3
B	52.6
C	37.3
D	18.0
E	15.0
F	31.6
G	17.1

The flight range of the drone that can carry the No. 2 cargo bay is $(15.0, 37.3)km$, The flight range of the drone that can perform the reconnaissance mission is $(15.0, 52.6)km$.

4.4 Genetic algorithm solving model

We used Google Maps to mark the major highways and roads between the five hospitals in Puerto Rico. As shown in the figure, in order to detect the roads on the island as much as possible, we will divide the following picture into three areas. The first area is the scope of road investigation for the reconnaissance drone carried by the first container. The second area is the scope of road investigation for the reconnaissance drone carried by the second container. The third area is the scope of road investigation for the reconnaissance drone carried by the third container. We take a number of points on the main roads in the three regions, record the latitude and longitude of each point, and use the formula (3) to convert their latitude and longitude into points in the Cartesian coordinate system we created, and store them in an array.

Figure 5 Area division

D_1 represents the main road in the area of the first area, the coordinates is $D_{1j}(x,y)$. D_2 represents the main road in the area of the second area, the coordinates are $D_{2j}(x,y)$. And D_3 represents the point on the main road in the third area, whose coordinates are $D_{3j}(x,y)$. We assume that the coordinates of the position of the first container in the established Cartesian coordinate system is $O_1(x,y)$, the coordinates established by the position of the second container is $O_2(x,y)$, and the position coordinates of the third container is $O_3(x,y)$. The flight range of the reconnaissance drone is represented by S_v and his range is (15.0, 52.6) km.

d_{ij} represents the distance between the j-th point of the major roads in the i-th area and the i-th ISO cargo containers location for landing.

$$d_{ij}=|\overrightarrow{D_{ij}O_i}| \qquad i=1,2,3\ j=1,2,3,...$$

If d_{ij} is less than half of the reconnaissance drone S_v, it means that the location of the point on the road is within the flight range of the reconnaissance drone, that is, the reconnaissance drone can fly to the point and conduct road detection. The location and number of points on the road we take in different areas are determined. If the container is in a certain position, the number of points on the road that its reconnaissance drone can detect is more, the more detailed the road information that the position reconnaissance drone can detect. Based on this, we have established the following model:

$$\begin{cases} \varphi(O_i(x,y))=\sum_{j=1}\omega_{ij} \\ \omega_{ij}=\begin{cases} 1, d_{ij}\le S_v \\ 0, d_{ij}>S_v \end{cases} \end{cases} \tag{5}$$

ω_{ij} is 0 or 1. When the distance from the j-th point to the i-th container on the i-th area is less than or equal to the range, ω_{ij} is 1. When the distance from the j-th point to the i-th container on the i-th area is more than or equal to the range, ω_{ij} is 0. $\varphi(O_i(x,y))$ represents the number of points that the i-th container can detect on the i-th area.

4.5 Container drop location and drone voyage determination

4.5.1 Introduction of the genetic algorithms

Genetic algorithm is a kind of self-organizing and adaptive artificial intelligence technology that simulates the evolution process and mechanism of natural organisms to solve the extreme value problem. The basic idea is to simulate an algorithm of optimal search for process search by simulating natural genetic mechanism and biological evolution theory and has a solid biological foundation. Genetic algorithm provides a general framework for solving complex system optimization problems and has wide application value.

In this paper, we mainly use it to solve the complex nonlinear and multi-dimensional space optimization problems, combined with the objective function, seek container's coordinates and several sets of possible optimal values for transporting drones and reconnaissance drones.

4.5.2 Genetic algorithm execution process

As an adaptive global optimization search algorithm, genetic algorithm uses binary genetic coding, which is the same as allele Γ={0,1}, individual space HL={0,1}L, and reproduction is divided into two independents of cross and mutation. The steps are carried out. The basic implementation process is as follows:

Initialization. Determine the population size as 80, cross probability P_c, mutation probability P_m and set termination evolution criteria -- 500 times of iterations; set the number of variables (8 variables, horizontal and vertical coordinates of three container positions and the best range for transporting drones and reconnaissance drones); 80 individuals are randomly generated as the initial population; the evolution algebra counter t→0 is set.

Individual evaluation. Calculate or estimate the fitness of each individual. The fitness function is:

$$Fit(f(x))=\begin{cases} f(x)-C_{\min}, f(x)>C_{\min} \\ 0, others \end{cases} \tag{6}$$

f(x) is the target value of the genetic algorithm, $C_{\min}$ is the smallest estimate of f(x)

1) Population evolution.

Select (parent). The selection operator is used to select the M/2 pair mother (M ≥ C) from X(t).

Cross. For the selected M/2 parent, the intersection of the probability P_c forms M intermediate individuals.

Variation. The M intermediate individuals are independently mutated according to the probability P_m to form M candidate individuals.

Select (child). From the above-mentioned M candidate individuals, N individuals are selected according to the fitness to form a new generation population X(t+1).

2) Termination of inspection. If the termination criterion has been met, the individual with the greatest fitness in X(t+1) is output as the optimal solution, and the calculation is terminated.

4.5.3 Model results and analysis

Using MATLAB to write a program to solve the model, the solution is:

Table 5. The location of the first ISO cargo container landing

Longitude	Latitude
-66.6655	18.5280
-66.6001	18.3643
-66.6063	18.4838
-66.6323	18.4987
-66.6495	18.4394
-66.6187	18.5314
-66.6523	18.4787
-66.5863	18.3471
-66.6006	18.4981
-66.5950	18.4926
-66.6619	18.4961
-66.6608	18.4526
-66.5941	18.4656
-66.6346	18.4928
-66.6073	18.4560
-66.5660	18.4183

Table 6. The location of the second ISO cargo container landing

Longitude	Latitude
-66.1811	18.3453
-66.1592	18.3669
-66.1750	18.3627
-66.1442	18.3703
-66.1549	18.3682
-66.1609	18.3262
-66.1933	18.3445
-66.1671	18.3371
-66.1853	18.3458
-66.1707	18.3783
-66.1794	18.3392
-66.1382	18.3348
-66.1396	18.3448
-66.1719	18.3748
-66.0372	18.3180
-66.1553	18.3099
-66.1641	18.3045
-66.1707	18.3783

Table 7. The location of the third ISO cargo container landing

Longitude	Latitude
-65.7638	18.3065
-65.6366	18.2628
-65.8272	18.3443
-65.7476	18.2777
-65.8217	18.3407
-65.6798	18.2557
-65.8054	18.4526
-65.7529	18.3120
-65.6986	18.3722
-65.6774	18.3382
-65.7054	18.2390
-65.6889	18.3508
-65.7687	18.2462
-65.7119	18.2333
-65.7988	18.3419
-65.6300	18.3760
-65.7964	18.3798

We made the genetic algorithm run 17 times. From the data in the above table, we can see that most of the locations are concentrated in (18.4656°,-66.5941°)、(18.3180°, -66.0372°)、(18.2333°, -65.7119°) and its vicinity, so we judged that the best location for the three container landings probably located is :

$$O_1(18.4656,-66.5941), O_2(18.3180,-66.0372), O_3(18.2333,-65.719).$$

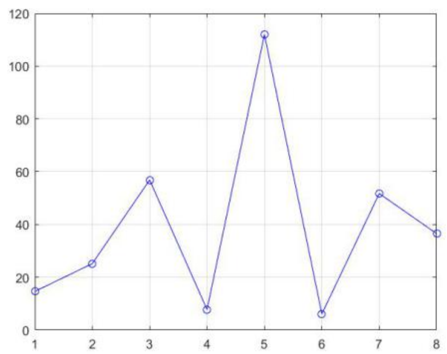

Figure 6 Iterative calculation result

The last two points in the figure represent the best flight range selection for the transport drone and the best flight range selection for the reconnaissance drone. The best flight range for the transport drone is 37.3km (S_t=37.3km), and the best flight range for the reconnaissance drone is 52.6km (S_r=52.6km).

5. Develop the DroneGo Disaster Response System

5.1 CLP_Spreadsheet_Solver solve ISO cargo container assembly

In the drone disaster response system, we used 3 ISO containers for loading transport drones and video reconnaissance drones. Based on the location of each container, in order to enable the reconnaissance drone to reconcile the main highways and roads as much as possible, and at the same time make each drone works, we finally arranged the following carrying plan, details are as following:

Table 8. The load of each ISO cargo container

The number of ISO	B-Type Drone	C-Type Drone	Drone Cargo Bay
1	7	1	1
2	14	7	7
3	6	2	2

After the number of drones is determined, we use CLP_Spreadsheet_Solver to solve the assembly problem of each ISO container. According to the length information given by the table, we solve the assembly as followings:

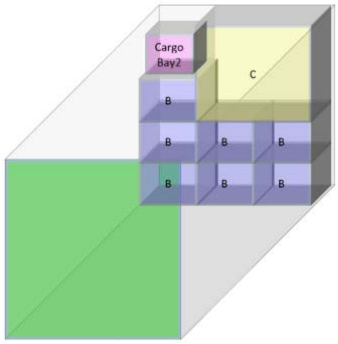

Figure 7 The assembly of the first ISO cargo container

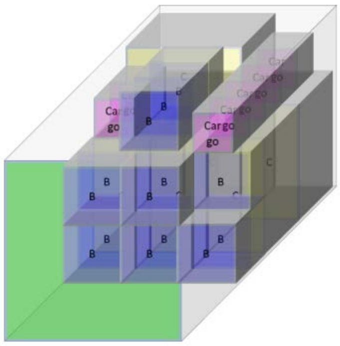

Figure 8 The assembly of the second ISO cargo container

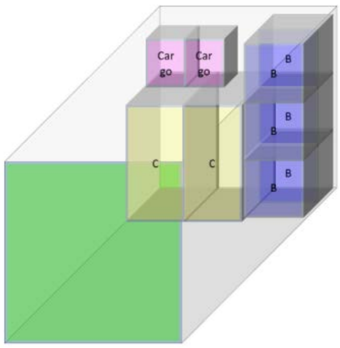

Figure 9 The assembly of the third ISO cargo container

5.2 Drone payload packing configurations

We used 10 C-Type drones to transport medical packages. The configuration of each drone is as follows:

Table 9. The configuration of each drone

Number	The number of ISO	Destination	MED1	MED2	MED3
1	1	Arecibo	1	0	0
2	2	San Pablo	1	0	0
3	2	San Pablo	1	0	0
4	2	San Pablo	0	0	1
5	2	San Juan	1	1	0
6	2	Bayamon	1	1	0
7	2	Bayamon	0	0	2
8	2	Bayamon	1	0	0
9	3	Fajardo	1	0	0
10	3	Fajardo	0	0	1

5.3 Delivery routes and schedule

The daily arrival time and location of the container are fixed, and the drones start missions from the container. As long as the time to transport the drone from the container location to the destination is calculated, we can schedule a daily flight schedule for the drones. Now we assume that the daily arrival time of the container is 8:00, then the daily flight schedule of the transport drone is shown in the following table:

Table 10. The routes and distances of the drones

	Shortest transit time(min)	Shortest distance(km)
$O_1 -$ *Arecibo*	14	14.36
$O_2 -$ *Bayamon*	15	15.90
$O_2 -$ *San Juan*	14	14.03
$O_2 -$ *San Pablo*	11	10.94
$O_3 -$ *Fajardo*	12	12.57

Table 11. The schedule of the drones

	Preparation time(min)	Starting time	Uploading time(min)	Returning time
$O_1 -$ *Arecibo*	10	8:00	5	8:43
$O_2 -$ *Bayamon*	10	8:00	5	8:45
$O_2 -$ *San Juan*	10	8:00	5	8:43
$O_2 -$ *San Pablo*	10	8:00	5	8:37
$O_3 -$ *Fajardo*	10	8:00	5	8:39

In order to shorten the transportation time, the drones direction of the delivery drone is defined as the straight line along the destination hospital.

5.4 Drone flight plan

We divided the reconnaissance drones into three teams to detect the D_1, D_2, and D_3 regional road conditions. The reconnaissance drones in each container are compiled into a team to conduct reconnaissance operations on an area. Different drones in the same formation try to detect different paths as much as possible, taking into account the limitations of the flight capacity of each drone and ensuring that the main roads can be reconnaissance by drones. We made each drone's flight plan, figure 11 shows the most detailed information on major highways and roads that can be obtained by three reconnaissance drone formations.

Figure 10 Drone flight plan

As can be seen from the figure, the reconnaissance drones we designed can detect most of the information connecting the main roads of the five hospitals. From this point of view, the three formations have a nice strong detection capabilities.

6. Model Evaluation

6.1 Advantages

- We have established a DroneGo disaster response system consisting of three containers, and solved the assembly problem of each container.
- We have established a container location model and solved the optimal placement position of three standard containers by genetic algorithm.
- Determine the types and quantities of transport medical kit drones that need to be carried in three containers to meet the medical package needs of each hospital.
- Construct a drone road detection system that can obtain more detailed road information within the range allowed by the drone flight.
- Provide drone payload packaging configurations, shipping routes and schedules, and drone flight plans to meet identified emergency medical packaging requirements for the hurricane scenario in Puerto Rico, and enables the DroneGo team to use the onboard camera to support Help, Inc. conducts reconnaissance missions on major highways and roads

6.2 Disadvantages

- There are subjective factors in the manually select points on the road and highways. Although we deliberately avoid this problem, it will still affect the location of the container to some extent.
- The genetic algorithm has its own insufficiency, such as poor local search ability, immature convergence and random walk, which leads to poor convergence performance of the algorithm, and it takes a long time to find the optimal solution.
- We did not consider the impact of weather conditions, high-altitude obstacles and load on the flight performance of the drone, but these factors are often not negligible, so there will be some degree of difference between the theoretical situation and the actual situation.

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