A study on the DroneGo disaster response system

Long Qian, Keyi Wang, Qi Zhang

North China University of Science and Technology, Hebei, Tangshan, 064000

Email: 1224148443@qq.com

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Abstract: In this paper,we design a DroneGo disaster response system to support the hurricane catastrophe in Puerto Rico.We set the medicine demand of five hospitals a day as a medical package. We use the three-dimensional boxing model to list the maximum objective function,and we introduce the new constraints of the center of gravity, sequencing rules, and use the greedy algorithm to determine the number of drone fleets and medicines in the container.We determine the location of the three ports by the population density and the distance limit of the drones. Then, we calculate the coverage of the drone, and compared the number of roads covered with the total number of roads to obtain the coverage probability of the road by aerial photography.

1. Introduction

In 2017, the worst hurricane to ever hit the United States territory of Puerto Rico left the island with severe damage and caused over 2900 fatalities. The combined destructive power of the hurricane's storm surge and wave action produced extensive damage to buildings, homes, and roads, particularly along the east and southeast coast of Puerto Rico. The storm, with its fierce winds and heavy rain, knocked down 80 percent of Puerto Rico's utility poles and all transmission lines, resulting in loss of power to essentially all of the island's 3.4 million residents. In addition, the storm damaged or destroyed the majority of the island's cellular communication networks. The electrical power and cell service outages lasted for months across much of the island, and longer in some locations. The full extent of the damage in Puerto Rico remained unclear for some time; dozens of areas were isolated and without communication. Demands for medical supplies, lifesaving equipment, and treatment strained health-care clinics, hospital emergency rooms, and non-governmental organizations' (NGOs) relief operations.

2. Problem Analysis

1) Recommend a drone fleet and set of medical packages for the HELP, Inc. DroneGo disaster response system that will meet the requirements of the Puerto Rico hurricane scenario. Design the associated packing configuration for each of up to three ISO cargo containers to transport the system to Puerto Rico.

2) Identify the best location or locations on Puerto Rico to position one, two, or three cargo containers of the DroneGo disaster response system to be able to conduct both medical supply delivery and video reconnaissance of road networks.

3) For each type of drone included in the DroneGo fleet:

a) Provide the drone payload packing configurations (i.e. the medical packages packed into the drone cargo bay), delivery routes and schedule to meet the identified emergency medical package requirements of the Puerto Rico hurricane scenario.

b) Provide a drone flight plan that will enable the DroneGo fleet to use onboard video cameras to assess the major highways and roads in support of the Help, Inc. mission.

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3. Symbol Description

Table 1. Symbol Description

Symbol	Description
α_1	The maximum payload of a drone
α_2	The weight of a package
Lon	Accuracy
Lat	Latitude
C	The Coefficient of wind force
k_h	The variation' coefficient of wind height
q	The pressure of wind
b	The windward area of the drone
F_h	The power of wind
P	Rated power
F	The Resultant of force
u	The Speed of drone flight
h	The Light of drone flight
T_d	Days of road detection
γ	The number of roads covered
σ	The total number of highway
ρ	The coverage of a highway

4. Establishment of Model

4.1 Solve of the Problem A

In order to improve the space efficiency, we can do our best to maximize the volume of the load in a certain constraint. Therefore, the maximization function of medicine task is

$$\max V = \left[\frac{\sum_{i=1}^{N} (l_i \times w_i \times h_i)}{\sum_{j=1}^{K} (L_j \times W_j \times H_j)} \right]$$

N is the types of drugs, l_i is length of the goods, w_i is width of the goods, h_i is height of the goods, m_i is weight of the goods, and the weight is denoted by $i(i = 1,2,\ldots,N)$, K is the number of loading containers, L_j is the length of the drone's loading box, W_j is the width of the drone's loading box, H_j is the height of the drone's loading box, V is the volume of the container.

Step 1:Processing of Constraint Conditions

Loading capacity constraint: the total volume loaded into the drug must be within the loading capacity:

$$\sum_{i=1}^{N} (l_i \times w_i \times h_i) \le V$$

Loading quantity constraint: the number of loading containers meet the demand of the hospital, $K \ge 5$.

Table 2. the Drone Cargo Bay Type of each hospital

Location Name	Drone Cargo Bay Type	Weight (lbs.)	Daily quantity(package)
Caribbean Medical Center	2	5	1
Hospital HIMA	2	7	1
Hospital Pavia Santurce	1	4	1
Puerto Rico Children's Hospital	2	12	1
Hospital Pavia Arecibo	1	2	1

It can be seen from the table that the package IDs are two drone cargo bay type 1 and three drone cargo bay type 2.

Step 2:.The Introduction of Comprehensive Performance

We get the drone parameter comparison diagram, as is shown in figure 1.

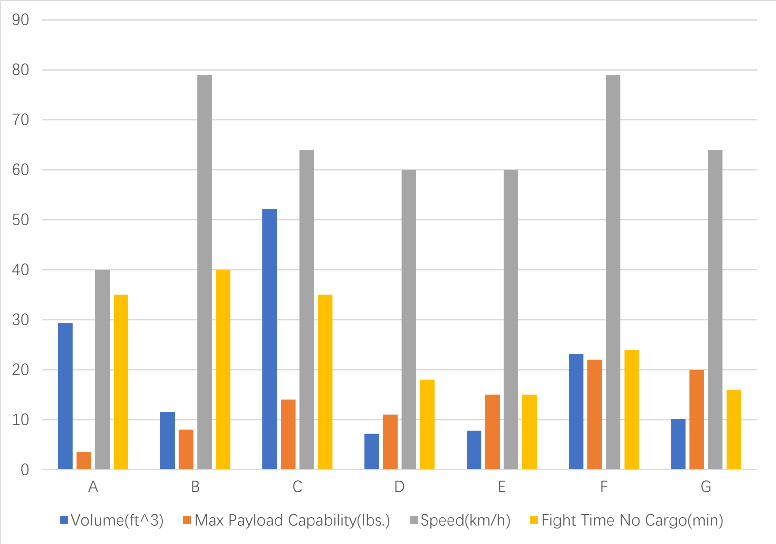

Figure 1: Comparison of Drone Parameters

$$s = vt$$

Where: s is the flight distance of the drone, v is the flight speed, t is the flight time.

The drone flight distance comparison diagram, as shown in figure 2:

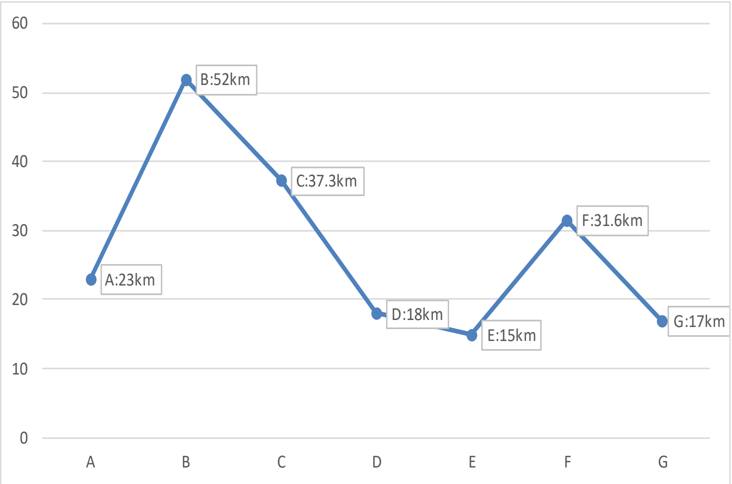

Figure 2: Comparison of Drone Flight Path

We introduce an equation to evaluate the comprehensive performance of drone to determine our drone fleet:

$$\omega = 0.3\omega_1 + 0.4\omega_2 + 0.3\omega_3$$

ω is the comprehensive performance, ω_1 is maximum effective load of the drone, ω_2 is the flight speed.

Step 3:.Selection of the Drone

• Options for drones with Drone Cargo Bay Type 1

Relationship between drone load and weight of the package IDs is shown as follow:

$$\alpha_2 \geq \alpha_1$$

α_1 is load of the drone, α_2 is weight of the package IDs.

As the load of the A - type drone (it is 3.5 pounds) is less than the weight of package IDs (it is 4 pounds), Drones, flying to Hospital Pavia Arecibo ,are type B or type D. As the weight of the package- sending to Hospital Pavia Arecibo less than the load of all the type 1 drone, it can be selected as A, B or D.

According to the above comprehensive performance equation of drone:

$$\omega = 0.3\omega_1 + 0.4\omega_2 + 0.3\omega_3,$$

We get the following result:

$$\omega_a = 22.3 \quad \omega_b = 46.9 \quad \omega_d = 28.5$$

ω_a is the Comprehensive performance of the B- type drone, ω_b is the Comprehensive performance of the B- type drone, ω_c is the comprehensive performance of the C-type drone.

Considering that performance comparison of multiple drone requires a standard, we set the reference index of comprehensive performance as $\omega = 30.0$, while only the B-type drone exceeds the performance index, so we chose two B-type drones to deliver medical packages to Hospital Pavia Arecibo and Hospital Pavia Santurce.

- Options for drones with Drone Cargo Bay Type 2

According to the relationship between the load of the drone and the weight of the package IDs, the weight of three drones with Drone Cargo Bay Type 2 – sending to the hospital ,are all less than the load of drones that they are C-type drone ,F-type drone and G-type drone. That means all four types of drones can be selected.

According to the above comprehensive performance equation of drones:

$$\omega = 0.3\omega_1 + 0.4\omega_2 + 0.3\omega_3,$$

We have the following result:

$$\omega_c = 38.3 \quad \omega_e = 28.5 \quad \omega_f = 42.9 \quad \omega_g = 32.0$$

Because the reference index of comprehensive performance (ω) is 30.0, t the drones that exceed the performance index are C-type drone, F-type drone and G-type drone, and $\omega_f > \omega_c > \omega_g > 30.0$. The F-type drone doesn't have the function of video shooting. Considering that only one drone is sent to the target hospital, we replaced the f-type with c-type with better comprehensive performance. Finally, we used two C-type drone and one G-type drone to deliver medicine for Caribbean Medical Center, HIMA Hospital and Puerto Rico Children's Hospital.

To sum up, our drone fleet is made up of two B-type drones, two C-type drones and one G- type drone, and our medical package is made up of the daily drug requirements of five target hospitals.

Step 4:. Optimization of the Model

- Loading weight constraint:

The total weight of the goods loaded is within the carrying weight of the container, the equation is shown below:

$$\sum_{i=1}^{N} m_i \le G$$

- Barycenter constraint of cargo:

The center of gravity of the goods needs to be within the allowable range to ensure the stability of container transportation. We stipulate that [0,cx] represents the safe range of the center of gravity along the X axis of the container. Similarly, [0,cy] and [0,cz] respectively represent the safe range of center of gravity on Y-axis and z-axis, the equation is shown below:

$$
\begin{cases}
0 \le \dfrac{\sum_{i=1}^{N}(m_i \times x_i)}{\sum_{i=1}^{N} m_i} \le cx \\
0 \le \dfrac{\sum_{i=1}^{N}(m_i \times y_i)}{\sum_{i=1}^{N} m_i} \le cy \\
0 \le \dfrac{\sum_{i=1}^{N}(m_i \times z_i)}{\sum_{i=1}^{N} m_i} \le cz
\end{cases}
$$

- Cargo sequencing rules:

When placing the goods, we give priority to placing the drone at the bottom, and the medicine will be stacked on the top of the drone, so as to ensure that the medicine will not be affected by the weight of the drone and avoid the damage of the medicine. After considering these new constraints, we use the greedy algorithm to solve the boxing model again, and the solution results are shown in figure 3:

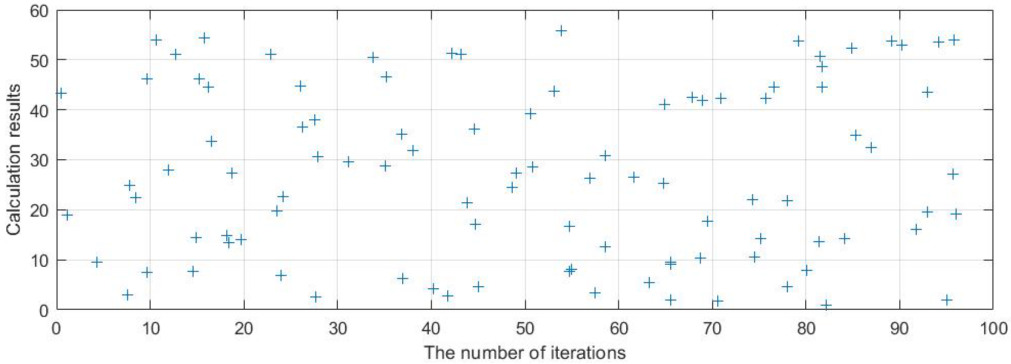

Figure 3: the New Packing Results

As shown in figure 3, we carry out 100 iterative calculations, and the blue scatter represents 100 results. Considering that the entire shipping container should be filled as much as possible, the 74th calculation result is selected, and the corresponding value is 56. Each container can hold up to 56 medical packages with just one drone.

4.2 Solve of the Problem B- The best choice of container location

We calculated the shortest distance between two pairs of five target cities and marked it on the map. As shown in the figure 4.

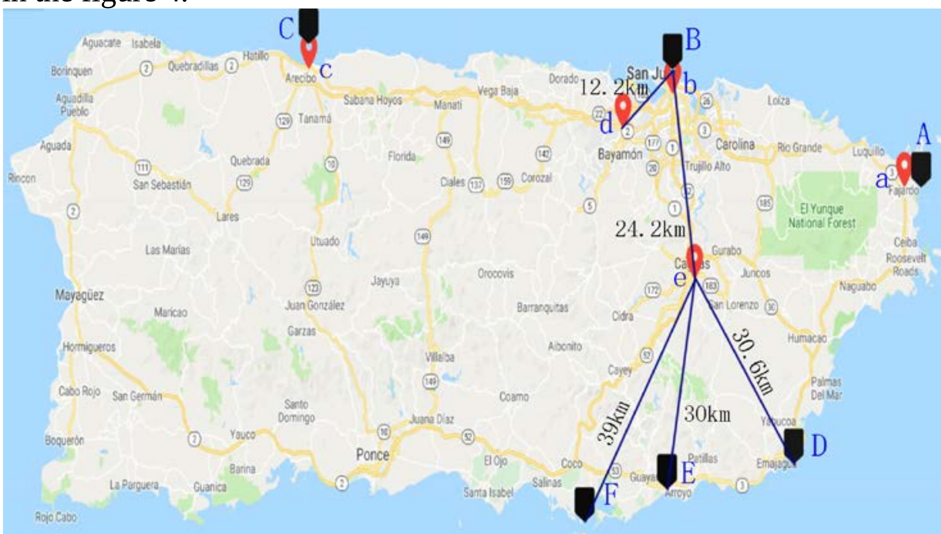

Figure 4 : the Distance between Port and Hospital

The red icon indicates the location of the hospital, The black icon indicates the location of the port, Since the distance between A port and A hospital, B port and B hospital, and C port and C hospital is very close, we ignore the distance between them.

Step 1:Calculate the Distance between Five Hospitals

According to the triangle derivation, we get two points distance equation:

$$C = \sin(MLatA)\times\sin(MLatB)\times\cos(MLonA - MLonB)+\cos(MLatA)\times\cos(MLatB) \quad Dis\tan ce = R\times Acorss(C)\times\frac{Pi}{180}$$

We put the coordinate values of the six ports into the formula to obtain the distance between them:

$$C_{Bd} = 12.2$$
$$C_{Be} = 24.2$$
$$C_{Fe} = 39$$
$$C_{Ee} = 30$$
$$C_{De} = 30.6$$

The distance between A port and A hospital can be ignored, it is very convenient to transport drugs. We chose port A (San Juan) as the second location, and port C as the third location.

Step 2: The Flight Status of the Drone

• The calculation of wind resistance

Since the main resistance of drones in flight comes from wind force, we need to consider the value of wind resistance, the equation for the wind resistance values is given below:

$$F_h = Ck_n q b^2$$

$$\text{b} = \text{DroneLength} \times \text{DroneHeight}$$

C is the coefficient of wind force, k_h is the variation coefficient of wind height, q is wind pressure, b is the windward area of the drone, F_h is the wind resistance.

• The changes of Drone flight time

When the drone flies, the power of the output device has been as the rated power, engine provides a part of energy to produce thrust forward, another part of the lift up, the formula is shown below:

$$P = F_1 u_1 = F_2 u_2$$

$$F = f(F_h)$$

We obtained the ratio of the drone's no-load flight time t1 to the load flight time t2:

$$\frac{t_1}{t_2} = \frac{u_2}{u_1} = \frac{F_1}{F_2}$$

4.3 Solve of the Problem C

Step 1: The detection of drone and the delivery arrangements of the drone

Considering that the distance of the B-type drone is the longest, we have sent the B-type drone to perform this task in the road network video detection of the three ports. In the process of the C-type drone - going to the hospital E, we sent the B – type drone to cooperate with it and the hospital B itself is a B-type drone to complete the delivery task, and there is no need to change it. The results of our final arrangements are as follows:

Table 3. the Arrangement of Results

Hospital	Drone(Medical)	Drone(Video)
a	C	B
b	B	B
c	B	B
d	G	C
e	C	B

Step 2: Make a timetable

Relationship of time and distance:

$$t = \frac{s}{v}$$

According to the required time, we can get the drone flight schedule is as follows:

Table 4. Schedule

Time	The event
6:00	Drones take off from the port.
6:02	Drones called CA, BB ,BC arrive at hospital.
6:04	Drones called CA,BB ,BC take off
6:06	Drones called CA,BB,BC arrive at their ports
6:11	Drone called GB arrives at hospital.
6:13	Drone called GB takes off.
6:17	Drone called CB arrives at hospital.
6:24	Drone called GB arrives at its port.
8:19	Drone called CB takes off.
8:36	Drone called CB arrives at its port.

Step 3: Range of shooting range

When the drone's camera shoots video, it creates a range of film that has a boundary, as is shown in the figure 5:

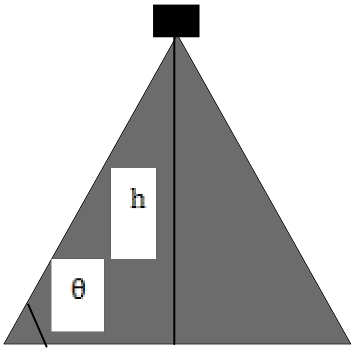

Figure 4: Range of shooting range

h is the altitude of the drone's flight, θ is the boundary angle.

According to the tangent formula:

$$\tan\theta = \frac{h}{x},$$

We can get: $x = 231$

Step 4: Choosing the ways of flight for drones

Straight-line flight of arriving and depart means that the drone flies out and returns in the same route, in other words, the drone can only shoot the road condition of one path video, as is shown in figure 6.

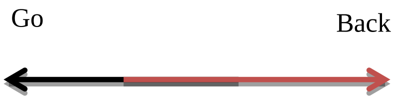

Figure 5 : Straight-Line Flight of Arriving and Depart

Turning flight of arriving and depart means that the drone flies out and returns in different routes. In other words, the drone can shoot the road condition of two path videos, as is shown in figure 7. And when l is equal to 2x, that's the best way to turn.l is the turning diameter, x is the width of the shooting range.

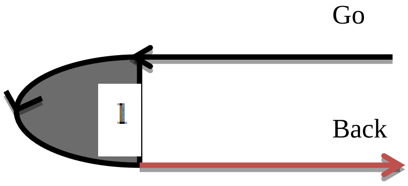

Figure 6: Turning Flight of Arriving and Depart

Step 5: Shooting area of the drone

Taking the B-type drone with the longest flight distance as a reference, we plotted the maximum range that can be covered by the drone shooting, as is shown in figure 8:

Considering the geographical location of Caribbean Medical Center and Hospital Pavia Arecibo is close to the sea, we take $\frac{1}{3}L$ and $\frac{1}{2}L$ respectively, and the rest hospitals will have cross coverage. We take the length of the boundary of Hospital Pavia Santurce as $\frac{1}{4}C$, and the calculated circumference of Puerto Rico Children's Hospital as $\frac{1}{2}L'$, and the HIMA of Hospital will not be processed, the formula is as follows:

$$\begin{cases} L = 2\pi R_b \\ L' = 2\pi R_c \\ T = \dfrac{l_i}{p} \end{cases}$$

Figure 7: Shooting area of the drone

L is the complete circumference (coverage in the map), l_i is the perimeter of each hospital ($i = a, b, c, d, e$), T is the flight cycle required to complete the mission.The solving result is as follows:

Table 5. the Solving Result

Hospital	Length of the boundary(km)	Cycle
a	54.43	59
b	40.82	44
c	81.64	88
d	58.56	63
e	163.28	177

By comparing the data , The charging time of the drone is two hours, and the round-trip time of the type B drone is 40min, so the interval between two consecutive takeoffs is t=160min. We stipulate that all hospitals release the drone at 8:00am, and each drone returns to the port at 6:00 PM. The task time is h=10

$$\begin{cases} C_d = \dfrac{h}{\sum_{i=1}^{N} t_i} \\ N \le 4 \\ T_d = \dfrac{T}{C_d} \end{cases}.$$

We used MATLAB to solve the problem, and the result is shown in figure 9:

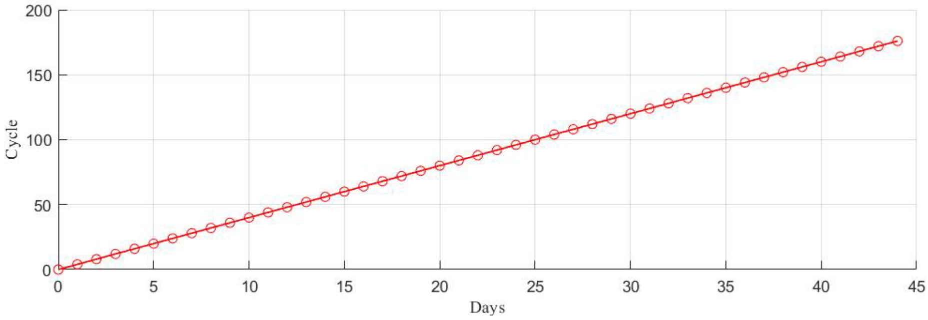

Figure 8 : Number of days to complete the task

As can be seen from the figure, it takes 44 days to deliver the medicines, As the furthest distance of the drone is known, we can get the area of the circle with five hospitals as the center and the furthest distance of the drone as the radius, so as to accurately get the coverage. By comparing the number of roads in the coverage with the total number of roads on the island, we can get the highway coverage:

$$\rho = \frac{\gamma}{\sigma},$$

σ takes the total number of roads in Puerto Rico in 2012 in the national highway odometer (27316) .

$$\gamma = 14477, \rho = 0.53$$

It can shoot two road conditions back and forth. It takes 44 days to shoot the maximum coverage, and the maximum coverage can reach 53%.

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