| For office use only | Team Control Number | For office use only |
|---|---|---|
| T1 ________ | **1920684** | F1 ________ |
| T2 ________ | | F2 ________ |
| T3 ________ | Problem Chosen | F3 ________ |
| T4 ________ | **B** | F4 ________ |

**2019**

**MCM/ICM**

**Summary Sheet**

# The establishment of disaster response system

## Summary


“A powerful hurricane devastated Puerto Rico!” The island needs medical supplies, the outside world needs to understand the situation on the island. So the NGO Help, inc. who often challenged to provide adequate and timely response during or after natural disasters needs to design a disaster response system to address the problem[7].

In this work, multiple drones are compared and selected to address both medical supplies delivery and video reconnaissance missions. In a deepening model on the simulated annealing algorithm, a drone flight plan is given.

First of all, an assembly model is established, with annealing algorithm, the most suitable cargo assembly scheme for each drone and warehouse is obtained, which is convenient for determining the type and quantity of the drone and the optimal configuration of the cargo in warehouses.

Second, in order to determine the location of the warehouse to meet the needs of shipping cargo and video reconnaissance, a location model is established. Convert the latitude and longitude of the five medical points into coordinates in a three-dimensional rectangular coordinate system. Then through constantly adjusting the position of the three containers, we try to capture video data of the whole island under the premise of providing medical products for more than half a year for all hospitals. Finally, the longitude and latitude of the three containers are respectively A (18.18, -66.97), B. (18.20, -66.57) and C. (18.15, -65.88).

Third,, after determining the optimal configuration of the drone loading cargo and warehouse location, we extract the main roads for more complex areas, and the Dijkstra algorithm is used to maximize efficiency while meeting the needs of video reconnaissance and delivery of goods.

Finally, consider the assembly methods of drones and warehouses and mission need, the overall system configuration scheme, including the configuration plan of container cargo as well as the location of the warehouse and the flight plan of the drone is proposed.

To sum up, we have weighed the need of video detection and the number of days sustained. The final number of days the system sustained is 158 days, and can take video shots on most parts of the island.



**Key words**: **simulated annealing    integer programming    graph theory    optimization**

# Content

# 1. Introduction

## 1.1 Background

During natural disasters, how to make a timely and adequate rescue strategy is a tough problem. In 2017, Puerto Rico was destroyed terribly by a strong hurricane. Due to powerful hurricanes, storm
surge and waves damaged 80 percent of communications network and power. Most of the island lacked of electricity or batteries for months. So, dozens of areas were isolated and unable to use communications. The floods caused landslides and blocked major highways and roads. As a result, NGOs did not know the specific disaster situation in Puerto Rico. Especially, they were unable to plan and apply navigate routes for emergency services ground vehicles using
existing maps. In addition, 2900 people were killed and the number of injured increased significantly and the demand for medical supplies continued for quite some time.

## 1.2 Existing Achievement

The NGO HELP, Inc wants to aim at the situation in Puerto Rico in 2017, using drones to deliver pre-packaged medical supplies and filming video of the transportation network. It would use dry cargo containers of the international standards organization (ISO) standard so that convey the rapid delivery of a complete Drone Go disaster response system containing drones and medical packages to specific disaster areas. The list of candidates for drones and medical packages has been ensured. Their kinds are eight and three respectively. The drone must land on the ground to unload medical supplies from the drone cargo bays.

## 1.3 Restatement of the Problem

In the work, there are four requirements for this problem. First of all, we should find out the associated packing configuration for ISO cargo containers and drones. Second, the kinds of drones and schedule are ensured basing on delivery routes and the need of video detection. In addition, we should confirm different best locations for one, two, there cargo containers. Finally, in order to deal with similar disaster scenario, our strategy should include stability test and make solution.

# 2. Model 1 Simple Assembly Model

## 2.1 Model Analysis

The assembly problem of drones and containers is not only determined by the size and weight capacity of the loaded goods, but also affected by the need of delivery routes and road detection. Therefore, if taking all aspects into account, all aspects, this problem cannot can be regarded as a simple three-dimensional packing problem. As a result, we merely consider various ways in which medical packages are assembled according to the size and weight in each drone. Since the type and number of bags per day are constant, the combination of the minimum number of drone can be determined and the additional space can be used for increase medical packages to meet the medical needs for as many days as possible. There is no property that limits either side of a medical bag, so all three sides of a medical bag can be used as length, width or height. Each medical bag should be in a stable state during transportation and the use of cushioning materials should be minimized, so medical bags are merely placed at the bottom of the drone cargo bay or on the other medical bags.

## 2.2 Symbols

The primary symbols used in this paper are listed in Table 2.1.

**Table 2.1 The symbols and explanations**

| Symbols | Explanations |
|---|---|
| $V$ | Container volume |
| $V_k$ | The volume of the $kth$ drone or medicine |
| $\delta(r)$ | Residual rate increment |
| E(r) | Probability function |
| $rand()$ | Generate a random value |
| $exp()$ | Exponential function |
| $x_k$ | Demand for the Kth drone |
| G | weighted graph |
| $S$ | set of node |
| $V_i$ | The ith node |
| $e=(V_i, V_j)$ | The path from node i to node j |
| $W(e)$ | The e path weights |
| $dist()$ | Path weight sum |
| $Min()$ | minimum value |

## 2.2 Model Assumptions

1. We assume that the medical kits and drone shipping containers would not be damaged by the placements that any face is at the top.
2. Don’t consider the medical bags and the drone shipping containers being tilted.
3. Any side of the medical bag can be considered as length, width or high.
4. The medical bag must be supported by the bottom of the drone cargo bay or the top of other medical bags.
5. Each operation is a single object first in the horizontal direction, then in the vertical direction, and then in the vertical direction.

6. Object placement is limited by the volume of the internal space of the drone and the total mass of the cargo loaded, which cannot exceed the two constraints

## 2.4 Model Establishment

Due to the need of making full use of the volume of cargo drone cargo bay of drones, the priority should be given to the volume of drones, and then the capability of drones should be considered. There is priority: $MED\ \text{I} > MED\ \text{II} > MED\text{III}$ . Therefore, the total volume V1 of medical package, in the drone should be sufficiently large. That is, the filling rate inside the drone (the filling rate refers to (V1/V*100%)) should be as large as possible to increase the transportation efficiency for the medical package. In addition, for the same type of medical package with the same orientation, a larger medical package can be directly synthesized. If the case is not the above situation, the two medical packages can also be viewed as a larger cuboid. However, the cuboid has internal space, and the supporting area of the top of the cuboid is smaller than that of the bottom of the cuboid.

In a certain volume of drone (its volume is V), there are three kinds of drugs, $MED\ \text{I}$ , $MED\ \text{II}$ , $MED\text{III}$ to be loaded, and both the drone and the drugs are cuboids. When disaster relief is carried out, time is of the utmost importance, so the total amount of drugs in the drone the volume V1 needs to be as high as possible, that is, the filling rate inside the drone (filling rate means (V1/V*100%)) is large enough to increase transportation efficiency.

First, there are seven different drones in total, but in the drone loading, the cargo is loaded with cargo. The main limiting effect of the drone loading is the cargo type (type 1 and type 2) and the maximum load weight of the drone. Find the optimal loading cargo and its load for each drone, and then optimize the overall loading of goods by local optimization.

Using the simulated annealing algorithm, it is assumed that each operation of the packing process is independent. In this process, each operation is a single object first in the horizontal direction, then in the vertical direction, and then in the vertical direction. It is limited by the volume of the internal space of the drone and the total mass of the loaded cargo, that is, the two constraints cannot be exceeded.

The three drug types are numbered separately. The system is initially in a certain sorting state, and a certain constant $N_k$ is set as the packing order when the number of iterations is k, The system free volume is gradually reduced by iteration until a certain equilibrium state is reached. The specific operation is as follows:

(1) Initialization: Set an original packing sequence and define the volume at this time as V0. The ratio of the remaining volume to the total volume in the space (remaining rate) is R0.

(2) According to the number of iterations set before, when iteration is less than the number of iterations, it will generate a residual rate R1 after iteration at the current time, and record this state.

In the process of total cooling, the function of controlling parameter attenuation is:

$$V_{k+1} = aV_k, k > 0 \quad \text{(A is a constant, 0<a<1)}$$

(3) Comparing the two time states and calculating the increment of the residual rate, the increment is $\delta(r) = \delta E(r)$ . If $K(r) < 0$ is satisfied, the space utilization requirement is met, indicating that V1 is A new solution, if σ(r)>0, then set a certain probability function E(s) to accept V1 as a new solution according to a certain probability.

Probability function:

$$E(r) = \exp((f(i) - f(j) / \mathrm{N})$$

If it satisfies $E(\mathrm{r}) < \mathrm{rand}[0,1]$, accept it as a new solution.

$Rand[0,1]$ : Generate a random value on $[0,1]$

(4) When the number of iterations reaches the number of iterations of the termination setting, the running program ends, and the current solution satisfying the termination condition is the optimal solution. However since the wrong solution also has a certain probability to be accepted, several consecutive new solutions can also be used as Termination condition

Second, by this method, the best solution for loading drugs in a certain drone can be found. In this problem, there are seven types of drone, and seven types of drone can be obtained by seven simulated annealing algorithms. For the best solution for loading drugs, the loading scheme is as follows:

**Table 2.2 Drone loading scheme**

| | MED Ⅰ | MED Ⅱ | MED Ⅲ |
|---|---|---|---|
| Drone A | 1 | 0 | 0 |
| Drone B | 2 | 1 | 0 |
| Drone C | 2 | 1 | 1 |
| Drone D | 1 | 1 | 1 |
| Drone E | 2 | 1 | 1 |
| Drone F | 3 | 1 | 3 |
| Drone G | 3 | 2 | 2 |

Third, the maximum load per drone is known when transporting drugs to the disaster area. you need to know the quantity required by each drone to ensure that the total amount of drugs delivered meets the demand of the disaster area. At this time, when all the drone cargo volume is optimal, the following equations can be derived from the relationship between the quantity and demand of various drones through the daily demand of drugs:

$$\begin{cases} \text{MED I} \geq 7 \\ \text{MED II} \geq 2 \\ \text{MED III} \geq 4 \end{cases} \tag{2,3,1}$$

Forth, among them, since all the drone need to be transported to the disaster area through containers, the container not only needs to load the drone, but also needs to load medicines. The medicine supply to the disaster area requires as much as possible. At this time, the drone needs to be occupied in the container. The space is as small as possible, so the target equation can be established:

$$\begin{aligned} Z = {} & 50625x_A + 19800x_B + 90000x_C + 12500x_D + 13500x_E \\ & + 40000x_F + 17408x_G \end{aligned} \tag{2,3,2}$$

At this point, you can get the number of drone required and the configuration of the drugs installed in each drone. The configuration of the drone and the drugs installed is as followed

$$\begin{cases} -(x_A + 2x_B + 2x_C + x_D + 2x_E + 3x_F + 3x_G) \leq -7 \\ -(x_B + x_C + x_D + x_E + x_F + 2x_G) \leq -2 \\ -(x_C + x_D + x_E + 3x_F + 2x_G) \leq -4 \end{cases} \tag{2,3,3}$$

Through the volume formula, calculate the volume occupied by different drone. Drones loading scheme can be concluded,

The total daily delivery volume is selected as the basic unit to minimize the volume occupied by the drone by limiting conditions [1]

$Z$ is the space occupied by drones. $X_i$ is type of drones. i is from A to G.

By solving the inequality (2,3,3), the model number and cargo type of the drones can be obtained by minimizing .

**Table 2.3 Drone assembly scheme**

| | MED 1 | MED 2 | MED 3 |
|---|---|---|---|
| Drone B | 2 | 1 | 0 |
| Drone F | 3 | 1 | 1 |
| Drone F | 2 | 0 | 3 |

Thus, the daily cargo load of the drone can be obtained.

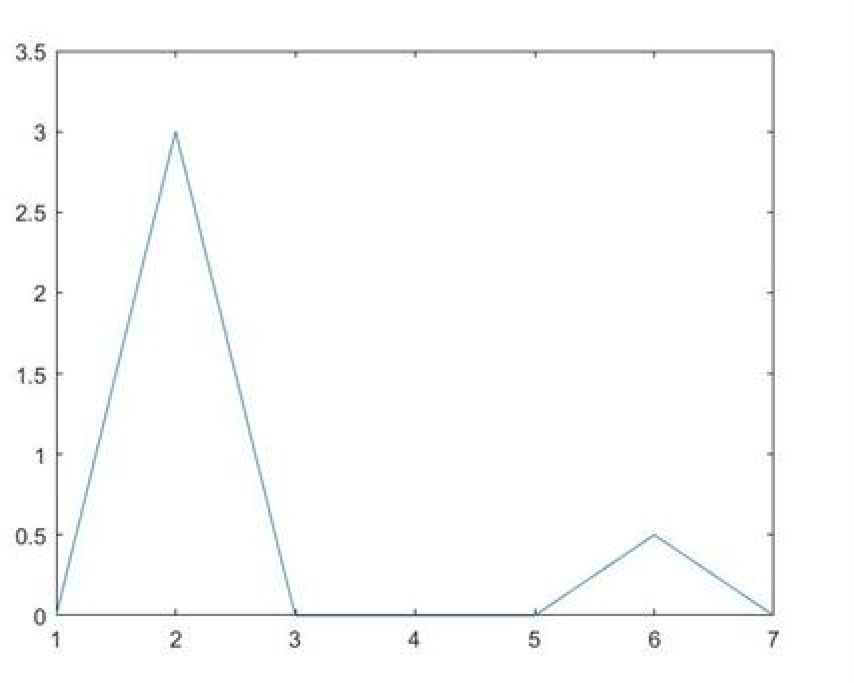


**Figure 2.1 The weight of goods daily for drones**

The horizontal axis is the drone type the vertical axis is the weight of goods.

# 3. Model 2 Container Location Problem

## 3.1 Model Analysis

Because of the observation of the main highway and roads of the whole island by drones, it is not enough to throw a container for the limited flight time. In order to observe the situation of the whole island as comprehensively as possible, we first consider the situation of throwing three containers. For the width of the river and the lake is much smaller than the accuracy of the longitude and latitude lines, the positioning of the container can be considered to have no effect. In other words, the containers can be placed anywhere on the island of Puerto Rico. The drone is flying in the air, so the altitude of each point will not affect the flight distance of the drone. Therefore, the terrain coordinate system can be converted into a rectangular coordinate system so as to obtain the distance between two points. Although the earth is an irregular ellipsoid, any two points on the island of Puerto Rico do not exceed 2 degrees in longitude and 1 degree in latitude. The distance for any point on the island and the line of the center of the ball is not different.

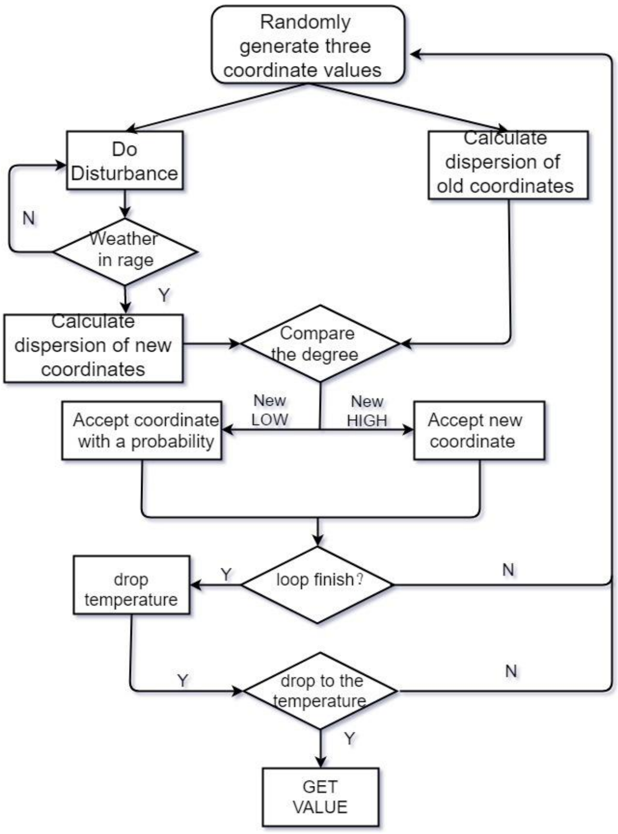


**Figure 3.1 Model2 structure**

## 3.2 Model Assumptions

1. Don't consider the influence of rivers and lakes for the location of containers.
2. Suppose the maximum amount of work that a drone can do in a single flight is fixed.
3. The earth may be thought of as a regular sphere.
4. The shipping container and the medical station are both powered.
5. Medical packages must not overlap.

## 3.3 Model Establishment

Mark the medical point on the island according to its latitude and longitude.

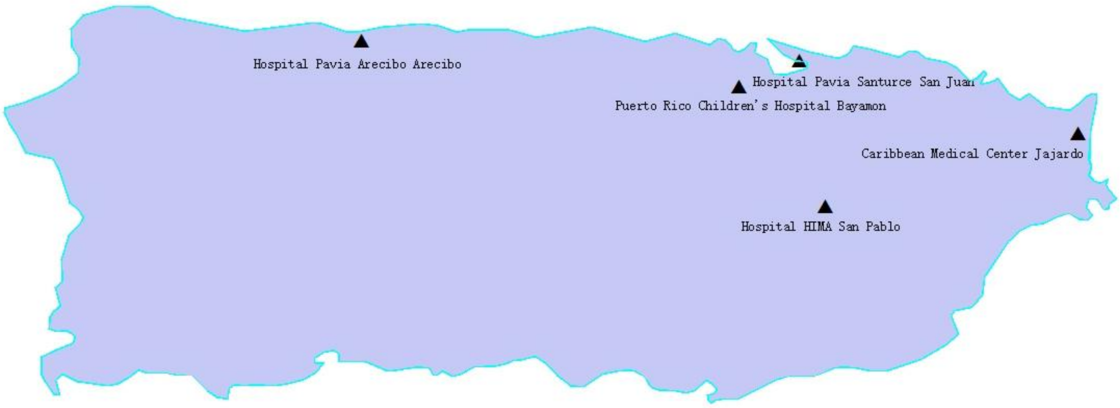


**Figure 3.2 Medical point location**

Endurance is represented by flight distance that each drone can fly without load is calculated,

$$X_1 = Vt_1 \ , \tag{3.3.1}$$

$X_1$ is the longest distance a drone can fly when there is no load. $V$ is the maximum flying speed of a drone. $t_1$ is the flight time of a drone at its maximum speed under no load.

As the weight of the drone increases after loading, resistance increases and endurance time decreases when the maximum speed is maintained. The dead weight of the drone is not known, an empirical coefficient of 0.75 is multiplied to obtain a conservative maximum load flight distance,

$$X_2 = Vt_2 = 0.75Vt_1 \ , \tag{3.3.2}$$

$X_2$ is the longest distance a drone can fly when there is loaded.

According to Formula (2.3.2) and Formula (2.3.3), the maximum flight distance could be obtained under different conditions of no-load and loading.

**Table 3.1 Flight distances in different situation**

| | Flight Distance No Cargo(km) | Flight Distance with Cargo(km) |
|---|---|---|
| Drone A | 23.33 | 17.50 |
| Drone B | 52.67 | 39.50 |
| Drone C | 37.33 | 28.00 |
| Drone D | 18.00 | 15.50 |
| Drone E | 15.00 | 11.25 |
| Drone F | 31.60 | 23.70 |
| Drone G | 17.07 | 12.80 |

The latitude and longitude of each point are given, the spherical coordinate system needs to be replaced with a rectangular coordinate system. Therefore, the XOY plane can be taken as the equator and the XOZ plane can be taken as the 0-degree longitude coil. Then the corresponding three-dimensional rectangular coordinate system can be established. The origin in the rectangular coordinate system is the point where the longitude and latitude are zero, and the distance between the points remains unchanged,

$$\begin{cases} x = R\cos u \cos v \\ y = R\sin u \cos v \ , \\ z = R\sin v \end{cases} \tag{3.3.3}$$

$u$ is longitude. $v$ is latitude. $R = 6371km$ and it is radius of the earth. $x, y$ and $z$ are coordinates of the coordinate axes.

Any two points of the sphere can be connected along the surface of the earth to form an arc. Both the three-dimensional rectangular coordinate system and the spherical coordinate system are orthogonal coordinate systems. Therefore, by using the nature of coordinate transformation in the tensor analysis, the longitude and latitude coordinates of points are transformed into the coordinates under the rectangular coordinate system (since the earth is regarded as a regular sphere, the radius of the earth corresponding to different longitude and latitude is fixed, which can be omitted),

$$d = R\arccos(\frac{OM \cdot ON}{|OM||ON|}), \tag{3.3.4}$$

$d$ is the distance between any two points on the surface of the earth. $OM$ and $ON$ are points to the origin of the rectangular coordinate system. $M = (x_m, x_m)$. $N = (x_n, \mathrm{y}_n)$.

Formula (2.3.3) is substituted into Formula (2.3.4). This is,

$$d = R\arccos[\cos(x_m - x_n)\cos y_m \cos y_n + \sin y_m \sin y_n \ . \tag{3.3.5}$$

According to Formula (2.3.3) and (2,3,5), The latitude and longitude of the five hospitals are converted into rectangular coordinates.

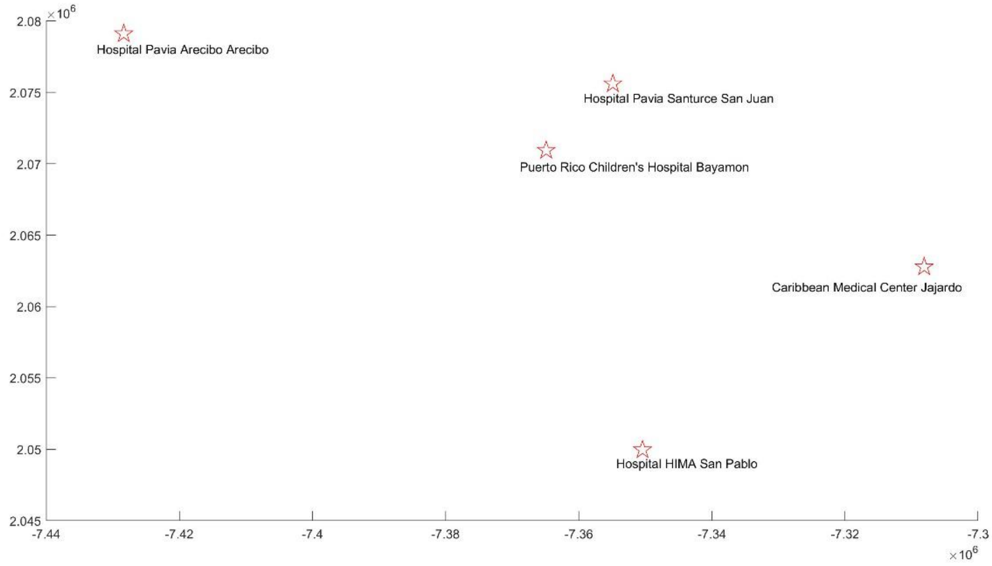


**Figure 3.3 The coordinates of each hospital in a rectangular coordinate system**

The absolute values of horizontal and vertical axis coordinates are horizontal and numerical distance from the origin. Coordinate units are meter.

Without regarding to weight, MED1=3*MED2 MED3=2*MED2, MED2 is as a unit volume. For the needs of different hospitals, we can convert the space size of all the needs into unit size.

**Table 3.2 Daily volume of cargo required by different hospitals**

| Delivery Location | Daily volume |
|---|---|
| Caribbean Medical Center | 9 |
| Hospital HIMA San | 8 |
| Hospital Pavia Santurce | 4 |
| Puerto Rico Children's Hospital | 11 |
| Hospital Pavia Arecibo | 3 |

According to Table 2, each medical location takes medicine from a container less than 47.4km away from itself. According to the maximum number of days that the drone supply can be maintained rather than the demand of video detection for the time being, the strategy of delivering goods at the medical point is formulated and the container place is selected. In addition, the scope of the drone is constantly narrow until there is little overlap between the circles[2]

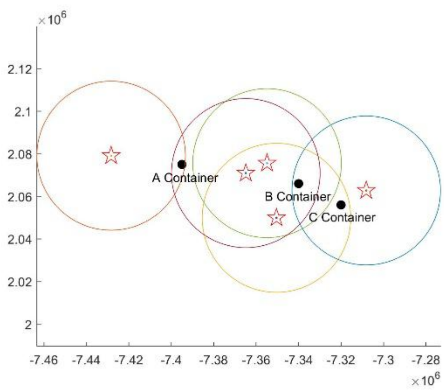


**Figure 3.4 Container location range map**

Medical point delivery strategy: select the warehouse with the most drugs that can be delivered by plane and request delivery of drugs to ensure the maximum number of days that all stores support drugs. Recording each hospital that from each container receive the number and frequency of the medical package, the needs of hospital medical bag type conversion take hypothesis'MD2 into the actual number of medical kits. The need of each container about number and type of medical insurance could be determined. Through the delivery of the frequency and the distribution of the hospital, the required number of drones is ensured. Finally boxing and for drone configuration in the first model need further adjustment. Though determining the distribution of the container takes the overall number of days supported as the optimization target, when the medical requirements of any hospital cannot be obtained from the container within the range that can be reached by the drone, the number of days to be recorded and a Monte Carlo model is completed. Then repeating experiments to obtain the stable value and the location of the container is obtained.

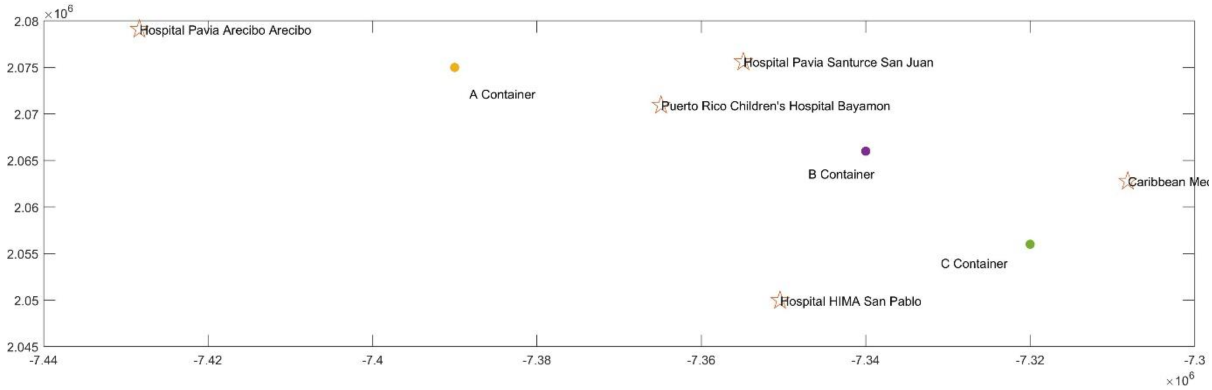


**Figure 3.5 Container location map in Three-dimensional rectangular coordinate system**

Substitute the coordinates of the three containers in the figure in the rectangular coordinate system into the Formula (2.3.3). Latitude and longitude of containers can be obtained [3]


**Figure 3.6 Container location map in geocentric coordinate system**

Taking the volume of MED as a unit, the container can be converted into 9,108[4], the drone H into 1,170, the drone B into 75, the drone F into 200[5], the medical package 1 into 6, and the medical package 3 into 4. The table is followed.

**Table 3.3 Container assembly**

| | Drone | MED 1 | MED 1 | MED 1 | days of supply |
|---|---|---|---|---|---|
| A container | H and B | 1310 | 0 | 0 | 1310 |
| B container | H and F | 858 | 286 | 572 | 143 |
| C container | empty | 1008 | 336 | 672 | 168 |

A container supplies for hospital Pavia Arecibo. B and C container supply four medical stations on the right of Figure 7. The total duration of maintenance requirements is 311 days. The location of containers cannot be arbitrarily selected. The distance between containers and the disaster area will not only affect the efficiency of transportation, but also make it impossible for some drones to reach the disaster area if the arrangement is not reasonable. The configuration of the container, when the location of the container changes, and at the same time, different needs of drugs in different disaster areas, will inevitably make the container for the supply of drugs in different disaster areas to load different drugs. To sum up: in the above mentioned restrictions on container configuration, the restrictions on container location must also be added. At this time, the position of the container changes, and it is necessary to ensure the relative optimization between the drone and drugs under the condition of meeting the requirements of the container position.

# 4. Model 3 Route Model

## 4.1 Model Analysis

The most of the island is without power and the affected area is not known to the outside world, it can be considered that only container and hospital can provide charging as the charging place of the drone. For hospitals as a disaster shelter, the general power will not be interrupted. We do not know the charging time, we try to shorten the delivery time and video detection time. From the picture, we can see that the hospital on the far right (the name of the hospital) is far away from other hospitals, and there is a large area to the west of this hospital, so containers need to be dropped on the southeast side of this hospital. When transporting goods, the drone can be charged at both the container and the medical point. Therefore, since the drone would not be charged during the landing in video reconnaissance, the maximum distance of flight is greater than the distance from the drone to the container so that the drone can land and continue to fly after the container is charged. The length of the island is so long that a type B drone is required for each container to patrol the island's roads. Each container carries a drone H so that the video of the drone can be transmitted to the outside world.

## 4.2 Model Assumptions

1. Drones are not damaged during flight.
2. We suppose the drone takes half an hour to recharge.

## 4.3 **Model Establishment**

A map of Puerto Rico could be found on the Google map. Because the road and the surrounding color is highly differentiated[8]. By limiting the value of RGB, extracting the road pixel points and process the image, we can get the main road. its main nodes and their coordinates, and then proceed to the next step. We can figure out all the routes[9].

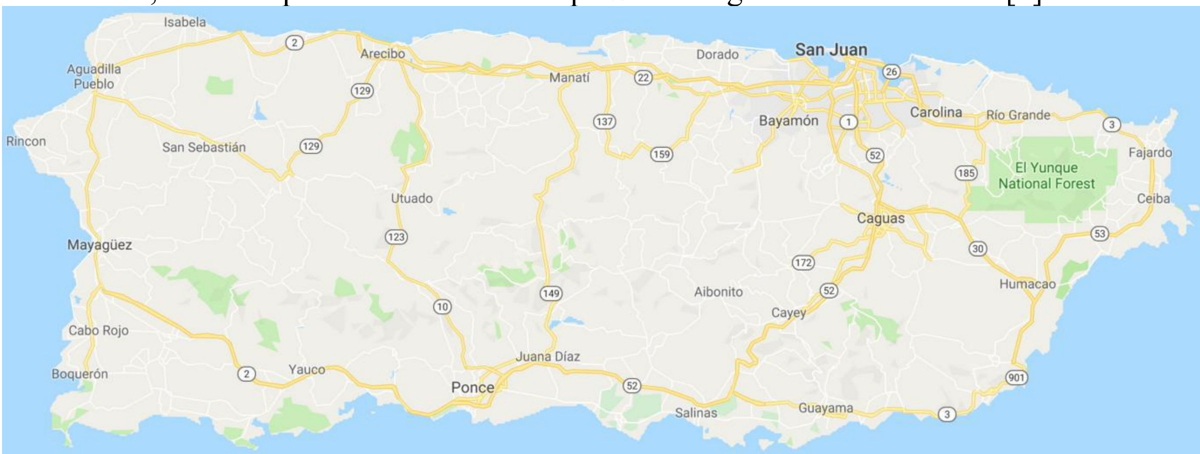


**Figure 4.1 Origin map from google**

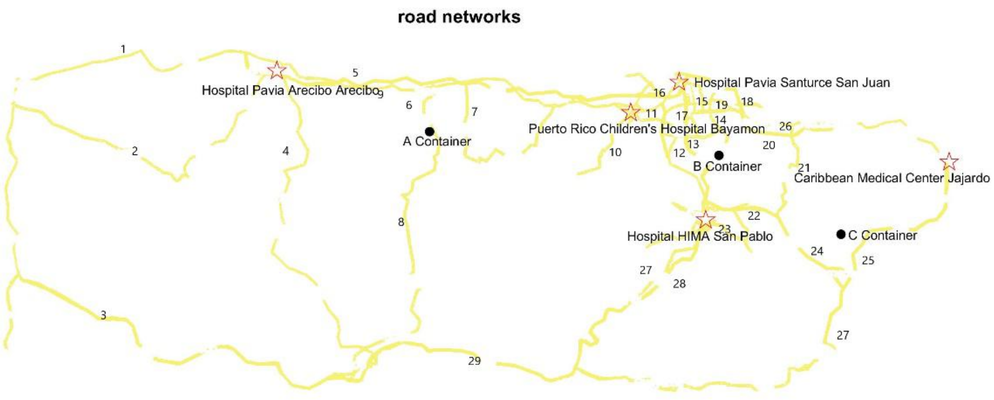


**Figure 4.2 Main roads in previous location map**

When the airplane is transporting medicine to the disaster area, the transportation efficiency is very important[10]. When the airplane transporting medicine is determined, Dijkstra algorithm is adopted to make the flight route optimal while traversing all the disaster areas, and ensure the traversing all the paths that need to be observed, so as to improve the efficiency[11]. F'medical delivery are as follows:

1) convert the flight route diagram of the drone into weighted graph $G=<V,E,W>, V$ is the point needed to be reached by the drone F, where $V_0$ is C container, Vi is the node to be traversed $E = \left(V_i, V_j\right)$, that is, the path from node $V_i$ to $V_j$; $W\left(V_i,V_j\right) = W\left(e\right)$ is the weight of each path, when $V_i$ is adjacent to $V_j$, $e = \left(V_i,V_j\right)$, $W\left(V_i,V_j\right) = W\left(e\right)$, when $V_i$ is not adjacent to $V_j$, $W(V_i,V_j) =$ infinity, that is, the time needed to traverse the path. The vertex set in the graph is divided into two parts, one is the vertex of the shortest path (set $T$), which is the C container at the beginning, and the other is the set of undetermined vertex (set S), P (I, j) is defined as $\left\{V_i, V_{i+1} ..., V_j\right\}$ is the shortest time path from vertex $V_i$ to vertex $V_j$, where I

is in set $T$ and j is in set S. When all known vertices are put into set $T$ , the shortest path is determined.

2) At the beginning, $T$ only contains $C$ containers. Select a point from set $S$ to ensure that $dist(\mathrm{k}) = \min\{\mathrm{dist(k)} \mid \mathrm{k} \text{ in } S\}$, that is the shortest time from $C$ container to $k$ . At the same time, delete $k$ from $S$ set and add $k$ to $T$ set to find the shortest time from $C$ container to $k$ .

3) Take $k$ as the reference point to modify the time when each vertex arrives at the disaster area $k$ and container $C$ . at this time, the operation in step 2 is carried out until all the points in the final $S$ are moved to $T$ .

Model considering the container location before the plane can't video was carried out on the road around the island, and the whole system can continue to supply time is greater than the disaster system for insisting on the number of days, so the previous model, modified sacrifice adhere to the maximum number of days to keep the container distribution in most areas around the island makes the island can be video shooting, under the hypothesis that can be recharged in the hospital, the hospital and container can be shot in video as an drone landing and charging stations for drone.

Constraint conditions: the position of five hospital base stations does not move; the coordinates of all base stations are within the range of the island; Five hospital base-stations within the drone's maximum payload range have a warehouse that can provide medical package; The three points are selected from left to right to avoid the effect of duplicate conditions.

Optimization objective: take the standard deviation of all base station coordinates as the expression form of coordinate dispersion degree, and obtain a base station distribution with a large dispersion degree through constant cooling, so as to spread over the whole island as far as possible to complete the reconnaissance of the whole island.

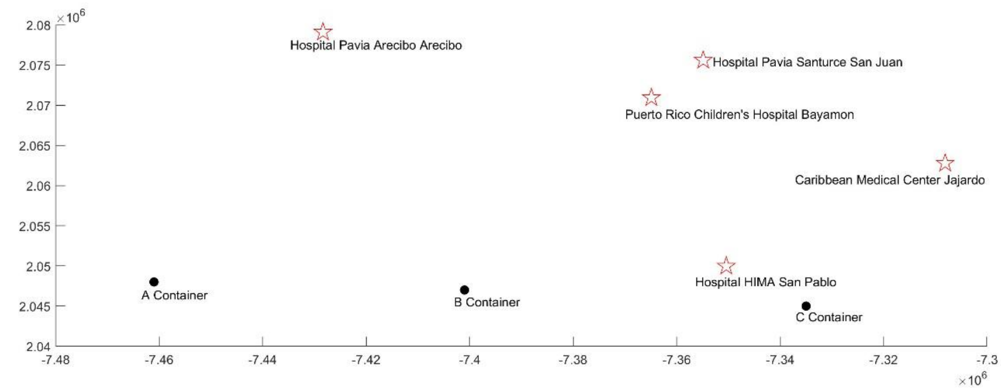


**Figure 4.3 New container location in Three-dimensional rectangular coordinate system**

Analyzing the coordinates of the distribution, we find that a container supply by C container quantities of demand, as much as possible in order to extend the system supports the largest number of days so as much as possible in the C container reserving medical package. So, put the drone needed for C container in B container and drone from B container transferred to C for medical delivery. Therefore, adding constraints, B container's drone of no-load distance has C or one of the four hospitals about C container supplies, so drones can be transferred from the B container to C container. The final warehouse location model is given

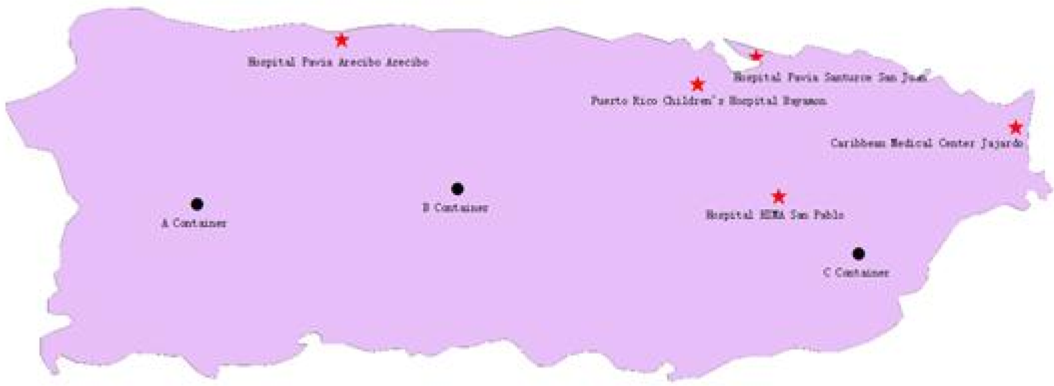


**Figure 4.4 New container location in geocentric coordinate system**

Considering all the constraints, the container assembly scheme can be determined: A Container : B Drone（1）*1 , H Tethered*1. B Container： B Drone（1， 2）*2 , H Tethered*1. C Container： H Tethered*1 ， MD1*1008， MD2*336， MD3*672. The total duration of maintenance requirements is 168 days.

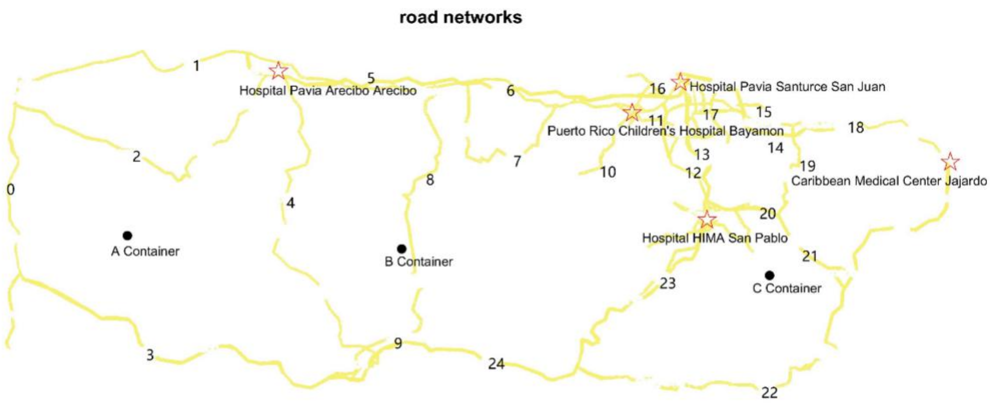


**Figure 4.5 Main roads in previous location map**

According to Figure 11, the drone B's video detection route and delivery route in container A are shown in the following schedule[6],

**Table 4.1 Route near container A**

| B Drone（1） | | | | | | | |
|---|---|---|---|---|---|---|---|
| No. | Flight route | flight duration | Carrier | No. | Flight route | flight duration | Carrier |
| 1* | To Arecibo | 30min | MD1*2 | 5 | Along 0 To 3 | 40min | N/A |
| 2 | To A Container | 30min | N/A | 6 | Along 3 To B Container | 40min | N/A |
| 3 | Along 2 | 40min | N/A | 7 | To A Container | 37min | N/A |
| 4 | Along 0 | 40min | N/A | | | | |

1*：Executed every two days

Since container A can fully meet the supply demand of the nearby medical point, one drone in container B flies to container C through the hospital, and another conducts video reconnaissance nearby. There's the drone for video reconnaissance,

**Table 4.2 Route near container B line**

| B Drone（2） | | | | | | | |
|---|---|---|---|---|---|---|---|
| No. | Flight route | flight duration | Carrier | No. | Flight route | flight duration | Carrier |
| 1 | Along 8 To 9 | 40min | MED1*2 | 4 | Along 8 | 40min | N/A |
| 2 | Along 4 To 9 | 40min | N/A | 5 | Along 6 To Puerto | 40min | N/A |
| 3 | Along 4 To 5 | 40min | N/A | 6 | Along 10 To 7 To B Container | 40min | N/A |

After the drone arrives at container C, it needs to take care of both delivery figures and video reconnaissance. Its schedule is as follow

**Table 4.3 Route near container C line**

| No. | Flight route | flight duration | Carrier | No. | Flight route | flight duration | Carrier |
|---|---|---|---|---|---|---|---|
| 1* | To Puerto | 40min | N/A | 9 | To C Container | 40min | N/A |
| 2* | To C Container | 30min | N/A | 10* | To Bayamon | 30min | MED2*3 |
| 3 | Along 13 To San Juan | 30min | MED1*1 MED2*1 | 11 | To C Container | 30min | N/A |
| 4 | Along 17 To C Container | 30min | N/A | 12 | Along 23 To San Pablo | 35min | MED1*2 |
| 5 | Along 11,12 To Bayamon | 30min | MED1*2 | 13 | Along 25 To C Container | 25min | N/A |
| 6 | Along 16,15,19 To C Container | 30min | N/A | 14* | Along 26 To San Pablo | 35min | MED3*2 |
| 7 | To Bayamon | 30min | MED3*2 | 15 | Along 23， 22 To C Container | 40min | N/A |
| 8 | Along 11,17,14,18 To Jajardo | 30min | N/A | 16 | Along 21， 18 To Jajardo | 40min | MED1*1 MED3*1 |

1*、2*：Execute only once when the system is initially placed.10*: Executed every three days. 14*: Executed every two days. N/A is without medical package.

# 5. Advantages and disadvantages of models

## 5.1 Advantage

1. Simulated Annealing jumps out of the circle that can only calculate the local optimum. The order of random generation is the order of the overall target arrangement. By comparing the remaining amount of space each time, the overall optimal spatial residual amount is gradually found out, and the optimal within the space is calculated.

2. Taking into account the different placement direction of the same item, reducing the waste of space.
3. Ensure that each operation is the optimal path (that is, the shortest time)

## 5.2 disadvantage

1.In the Simulated Annealing, the setting of iteration in the implementation process should not be too low. Otherwise, it may end when the balance state is not reached. However, when iteration is too high, the time complexity of the algorithm itself is very high. If iteration is increased, it will be make the program run longer.
2. In the Simulated Annealing, the probability function in the experiment is only an empirical function. If the condition is not met, the result will be biased to some extent.
3.the optimal path considered for each operation is only from the current position rather than the whole, it is easy to fall into the local trap.

# 6. Conclusion

In the disaster response system, there are three type B drone and three type H drone. In container A, there is one B drone, one H drone, and the rest are MD1. In container B, there are two type B drone, one type H drone, and the rest are MED1. The longitude and latitude of the container are A (18.18, -66.97), B (18.20, -66.57) and C (18.15, -65.88). The flight plan of the drone and the packaging configuration of the delivery are as follows,

**Table 6.1 Routes**

| No. | Flight route | flight duration(min) | Carrier | No. | Flight route | flight duration(min) | Carrier |
|---|---|---|---|---|---|---|---|
| 1 | To Arecibo | 30 | 2*MED1 | 16 | To C Container | 30 | N/A |
| 2 | To A Container | 30 | N/A | 17 | Along 13 To San Juan | 30 | 1*MED |
| 3 | Along 2 | 40 | N/A | 18 | Along 17 To C Container | 30 | N/A |
| 4 | Along 0 | 40 | N/A | 19 | Along 11,12 To Bayamon | 30 | 2*MED1 |
| 5 | Along 0 To 3 | 40 | N/A | 20 | Along 16,15,19 To C Container | 30 | N/A |
| 6 | Along 3 To B Container | 40 | N/A | 21 | To Bayamon | 30 | 2*MED3 |
| 7 | To A Container | 37 | N/A | 22 | Along 11,17,14,18 To Jajardo | 30 | N/A |
| 8 | Along 8 To 9 | 40 | 2*MED1 | 23 | To C Container | 40 | N/A |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 9 | Along 4 To 9 | 40 | N/A | 24 | To Bayamon | 30 | 3*MED2 |
| 10 | Along 4 To 5 | 40 | N/A | 25 | Along 23 To San Pablo | 35 | 2*MED1 |
| 11 | Along 8 | 40 | N/A | 26 | Along 23 To San Pablo | 25 | N/A |
| 12 | Along 6 To Puerto | 40 | N/A | 27 | Along 26 To San Pablo | 35 | 2*MED3 |
| 13 | Along 10 To 7 To B Container | 40 | N/A | 28 | Along 23，22 To C Container | 40 | N/A |
| 14 | To Puerto | 40 | N/A | 29 | Along 21，18 To Jajardo | 40 | 1*MED 1*MED3 |
| 15 | To C Container | 30 | N/A | | | | |

# References:

[1]. Pataki, G., Teaching integer programming formulations using the traveling salesman problem. SIAM Review, 2003. 45(1): p. 116-23.
[2] .Bianchi, L., L.M. Gambardella and M. Dorigo. An ant colony optimization approach to the probabilistic traveling salesman problem. 2002. Granada, Spain: Springer Verlag.
[3]. Xi, L., et al., Application of Ant Colony Algorithm Based on Optimization Parameters in Equipment Material Transport. Advanced Materials Research, 2013. 756-759: p. 3487-91.
[4]. Lodi, A., S. Martello and D. Vigo, Heuristic algorithms for the three-dimensional bin packing problem. European Journal of Operational Research, 2002. 141(2): p. 410-20.
[5]. Boschetti, M.A., New lower bounds for the three-dimensional finite bin packing problem. Discrete Applied Mathematics, 2004. 140(1-3): p. 241-58.
[6]. Yan, K. A model for fleet assignment in the city-pair route network. 2008. Three Gorges, China: IEEE Computer Society.
[7]. Aboukheir, M.K, et al., Notes from the Field: Tuberculosis Control in the Aftermath of Hurricane Maria - Puerto Rico, 2017, in MMWR. Morbidity and mortality weekly report. 2019. p. 46-47.
[8]. Cormen T.H., Leiserson C.E., Rivest R.L., Stein C.Introduction to Algorithms
(third ed.), The MIT Press, Cambridge, MA (2009)
[9]. S. Cotton, E. Asarin, O. Maler, P. Niebert, Some progress in satisfiability checking for difference logic, in: FORMATS/FTRTFT, 2004, pp. 263–276.
[10]. P. Cousot, R. Cousot, Abstract interpretation: A unified lattice model for static analysis of programs by construction or approximation of fixpoints, in: POPL, 1977, pp. 238–252.
[11]. Concepción-Acevedo J, Patel A, Luna-Pinto C, et al. Initial public health laboratory response after Hurricane Maria—Puerto Rico, 2017. MMWR Morb Mortal Wkly Rep 2018;67:333–6.

# Memo

**To: The chief executive officer of HELP, Inc.**
**From: Team #1920684**
**Subject: the DroneGo disaster response system**

After we got the problem, we conducted a comprehensive analysis of the problem. Under the various constraints, we found that the video surveillance needs and the number of days supported by the system have certain limits on each other, So we weigh the need for video detection and the number of days of persistence, in order to detect as many roads as possible, there was a certain waste of container space, and finally, in our program, our system adhered to 158 days, and can shoot video for most of the island. The specific analysis and solution are as follows.

First of all, we have comprehensively considered the cargo capacity of the drone and the volume occupied by the drone. Through the algorithm, the drone loading and container loading are continuously optimized, and finally a good result is obtained through a computer program. After implementing the algorithm, we obtain the type and quantity of medical kits carried by each type of drone and the most suitable cargo assembly plan for the warehouse, so as to determine the type and number of drones and the optimal configuration of the warehouse cargo. Then, since the transport cargo and video reconnaissance are all defined by the location of the container, we have established a location model. We converted the latitude and longitude of five medical points into coordinates in a three-dimensional Cartesian coordinate system. The location of the container is optimized by a computer program, so that the drone from the container can meet the medical package requirements of each hospital, and also can reach the largest possible range for video shooting to provide video information for HELP, inc. to understand the local road condition information. In the process of making adjustments and determining the drone flight plan, we found that the system detected a large area and insisted on more restrictions between the days, we must make a trade-off between them. After consulting the relevant information, considering that the disaster duration is only about two months, we believed that the system supports half a year to meet the actual system support time requirements. Thus, we sacrificed part of the container volume so that the drone can detect a larger range.

For the 2017 Puerto Rico hurricane scenario, medical kits and drone shipping containers are not considered as any face up internal cargo is damaged. Do not consider the medical bag with the drone's loading container tilted. Any edge of a medical bag can be considered length, width, or height. Suppose the maximum amount of work that a drone can do in a single flight is fixed

Three containers are required, and their longitude and latitude are A (18.18, -66.97), B (18.20, -66.57) and C (18.15, -65.88). For our determined container location and delivery requirements, B drones best meet our requirements. In container A: one B drone, one H drone, and the rest are MED1. In container B: two drones us, one H drones, and the rest are MED1: one H drone, 1008 MED1, 336 MED2, and 672 MED3. The B Drone is used for video detection and transportation of goods, and the H-Tethered is used as a communication base station to contact the entire system and provide certain communication services for the local area.For Arecibo, there is only a two-day delivery to meet the hospital's daily needs. Other time is used for video reconnaissance: before charging and take-off and landing time are considered, it takes 257min to complete the route near container A at one time; A patrol of the route near container B takes 260min. It takes 495min for a circle of route reconnaissance around container C.

In our model for this incident, due to the small number of containers and the large area required for video shooting, as well as the short time that the disasters required for disaster response systems, we sacrificed the number of days the system persisted to shoot as many roads as possible, and there is a large margin left in the container to carry the excess drone as a backup. When using our model in other similar disasters, It should be considered that the number of days that the disaster requires the system to adhere to, as well as the necessary range of video shooting, to weigh the system layout, so that the optimal configuration for a particular disaster can be achieved.

Sincerely,
Team #1920684