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Problem Chosen

B

2019

MCM/ICM

An Optimal strategy of Aerial Disaster Relief Response System

Summary

Analyzing the influence of the hurricane in Puerto Rico, we recommend a transportable disaster response system to the HELP, Inc., including number and locations of Cargo containers. And we make strategy for medical packages delivery and video reconnaissance of road networks.

We cluster cities on the island and select three areas according to the limitation of the number of containers and the level of urgency. Then we establish a relief utility-cost model, which can measure the profitability according to the severity of the disaster in different areas and the population density of the area. Optimizing the utility-cost model, we determine the number of the containers in each area.

In order to determine the locations of containers from many ports around each area, we establish a multi-objective optimization model with two objectives: minimizing the cost of medical packages delivery and the cost of video reconnaissance of road networks. We determine the best locations of containers by optimizing the multi-objective program.

Aiming at two missions in relief, we select drones according to their medical packages delivery ability and video reconnaissance ability. By means of the AHP method, we select type B drone and type F drone as the best types in road reconnaissance and medical delivery respectively. And with the constraints of the demand in each area and the limitation capacity of containers and cargo bays, we determine the number of drones and medical packages.

Constructing the graph of main roads in each area, we define the value of each edge measured by the length of corresponding road. Applying genetic algorithm to maximize the value of roads to be videoed, we design the best flight route of video reconnaissance.

The sensitivity analysis shows the strong robustness of our model. Variation of key parameters cause moderate changes to the computing result.

Keywords: relief utility-cost model; multi-objective optimization; AHP method; graph; Genetic Algorithm

Memo

To: Chief Operating Office of HELP

Subject: Designation of An Aerial Disaster Response System

A. Areas to be Rescued

Fig. 1 Areas to be rescued

B. Number and Locations of Containers

Area A: One container located in Port of Arecibo

Area B: Two Containers， container 1 places in Port of San Juan, container 2 places in Port of Fajardo.

C. Number of Drones and Medical in each Container

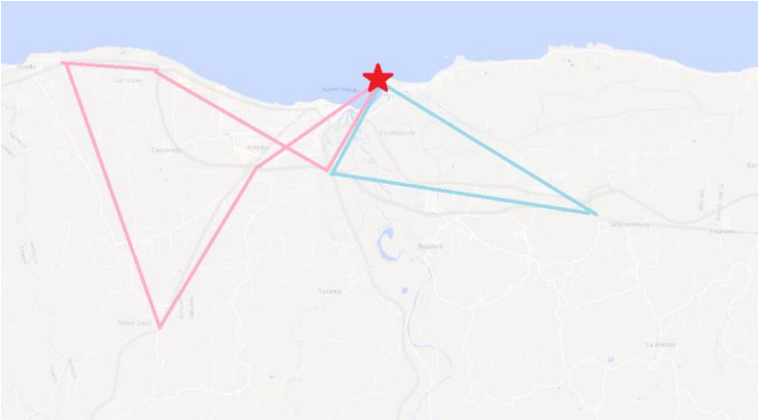
The container in area A:
Drones: One H-type drone, one F-type drone, two B-type drone
Medical:90 MED1
The container 1 in area B:
Drones: One Drone H,two Drone F,six Drone B
Medical:450 MED1,180 MED2,270 MED3
The container 2 in area B:
Drone: One Drone H,one Drone F,one Drone B
Medical:90 MED1,90 MED3

D. Schedule for Medical Delivery

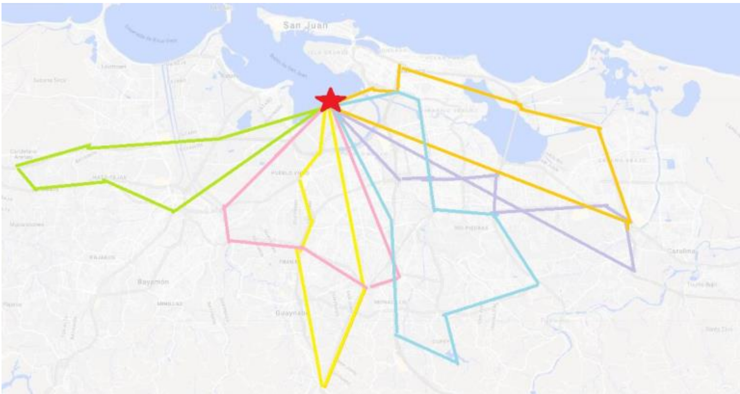
Jarjado: Once every 4 days
San Pablo: Once a day
San Juan: Once every 5 days
Bayamon: Once a day
Arecibo: Once every 11 days

E. Route for Reconnaissance

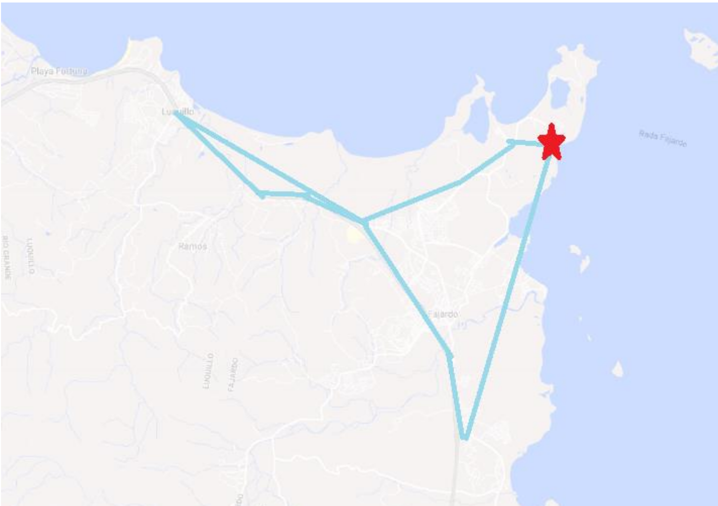
Area A:



Area B with container 1:



Area B with container 2:



Contents

1 Introduction

1.1 Background

Hurricane Maria in 2017was the worst natural disaster in history, which directly smashed into Puerto Rico as a Category 5 storm near peak intensity. It was the deadliest Atlantic hurricane since Jeanne in 2004 and left the island with severe damage and approximate 2900 deaths. Most of Puerto Rico's utility poles, transmission lines, and cellular communication networks were severely destroyed. Moreover, lots of highways and roads were blocked or damaged because of the following severe flood. The residents living in the island faced the unprecedented terrible situation. Therefore, the demand for medical supplies, lifesaving equipment and treatment in the disaster area etc. were indeed urgent.

1.2 Restatement of the Problem

The challenge for non-government organizations (NGOs). is to provide relief response in time for natural disasters. HELP, Inc., one of the NGOs, is planning to develop an aerial transportable disaster response system called "DroneGo". DroneGo is supposed to complete two tasks, specifically, medical supply delivery and video reconnaissance of road networks by using rotor wing drones. Since the function of drones are different and the space of the cargo containers are limited, the choice of drones for the GroneGo fleet and the packing configuration are of importance for the response capabilities.

In accordance with the HELP, Inc.'s requirements, our team is tasked to design a DroneGO disaster response system meeting with the situation in Puerto Rico. We are supposed to solve the following tasks.

Task 1: We first figure out the DroneGo fleet and the set of medical packages in terms of Puerto Rico disaster scenario. Then we design the packing configuration such that the DroneGo system fits in at most three International Standards Organization (ISO) standard fry cargo containers.

Task 2: We determine the optimal locations for cargo containers in order to facilitate delivering medical packages as well as providing video reconnaissance of road networks.

Task 3: Considering the emergency medical package requirements, we design the drone payload packing configuration; determine the delivery routes and flight schedule for each type of drone in the fleet. Moreover, we make flight plan for each type of drone such that the fleet can conduct video reconnaissance of major highways and roads using airborne cameras.

Task 4: We write a memo that summarize our modeling results, conclusions, and recommendations, making it easy for the Chief Operating Officer (CEO) of Help, Inc. to discuss with her Board of Directors.

1.3 Overview of Our Work

In order to recommend to HELP, Inc. a transportable disaster response system to rescue the Puerto Rico island in disaster, we establish an optimization model through the following steps:

- We cluster the cities on the island depending on the size of the population, the level of destruction in disaster, and whether medical packages are needed. And we find the areas in most need of help for container delivery.

- We define the level of urgency in each area and build a relief utility-cost model. By optimizing the net utility of relief in each area, we determine the number of containers to be placed in each area.
- We analyze the maximum flight distance of the drones. And we determine the locations of containers with the objective that all of the hospitals can receive the medical packages.
- We determine the type and quantity of drones and medical packages in each Cargo container according to the demand of medical packages and video reconnaissance of road networks in each area. aiming at the lowest cost and the shortest rescue time.
- We arrange delivery schedule for the drones provided that the demand of medical packages for each hospital is met and the weight of medical packages do not exceed the drones' loading capability.
- We define the value of each road before and after the reconnaissance. We maximize the length of the road of reconnaissance and select the road with respect to the higher profit of the road. Appling the genetic algorithm, we obtain the optimal reconnaissance path.

2 Assumptions and Notations

2.1 Assumptions

- There are enough drones. If not, drones can be bought from the market.
- Ignore the variation of the medical demand of each hospital.
- The weight of the medical packages effects the duration of the drone slightly, we can ignore it.
- The drones in the fleet have good autonomous navigation performance, so they can fly accurately according to the previously setting route.
- The selected data is true and available.

2.2 Notations

Tab. 1 Symbols and their meanings

Symbol	Meaning
b_i	Level of urgency of the area i
N_i	Number of containers in area i
C	Cost
U	Utility of relief

U^*	Net utility of relief
d_{ij}	Distance between port and hospital
l_{ik}	Distance between port and city
e_{kij}	0-1 variables
LD_k	The maximum range of drone k

3 Determine the Number of Containers

3.1 Net Utility of Relief

We define the net utility of relief as

net utility of relief = total utility of relief – cost of the relief,

where the total utility of relief varies in terms of the number of Cargo containers. Obviously, the total utility of relief is increasing in the number of containers. The number of Cargo containers and the total utility of relief correspond to the relation between input and output. According to the law of decline of marginal output in microeconomics, as the number of Cargo containers increases, the overall rate of increase in total utility of relief will decrease. Thus, the net utility of relief must be a concave ($\partial^2 y / \partial x^2 < 0$) function. Therefore, the typical logarithmic function is chosen to describe the variation of the total utility with the number of containers. In addition, if the number of containers is given, the total utility of relief is also related to the **basic condition of the rescued area**. The worse the **basic condition** in the area is, the more potential it has to enhance the situation after the disaster. In other words, it will have more potential to bring a greater disaster relief benefit in those areas. Thus, we define the total utility of the relief U as,

$$U = b \times \log(A + N) - b \times \log(A), \tag{1}$$

where N is the number of Cargo containers, A is positively related to the basic condition of the rescued area, and the coefficient b presents the **level of urgency.** The higher level of urgency is, the greater rescue the area needs. It means that there is more potential to bring higher utility of relief for that kind of area.

The total cost of relief is related to the cost of the stuff packed (DroneGo response system) in the Cargo containers. To simplify the calculation, we assume that each Cargo container has the same cost of the stuff. It follows that

$$C = c \cdot N, \tag{2}$$

where C is the total cost of relief and c is the cost of the stuff packed in each container.

Now we get the net utility of relief

$$U^* = U - C = b \times \log(A+N) - b \times \log(A) - a \cdot N\,. \tag{3}$$

We can determine the assembly plan such as the number of containers, the type and the corresponding number of drones and medical packages for each container by optimizing the net utility of relief.

3.2 Number of Cargo Containers

The different demand for rescue in different areas of the island results in the different demand for containers. The requirement of at most three containers can be supplied implies that we can provide at most three DroneGo disaster relief systems for three parts. T Therefore, we need to cluster cities on the island so that each container serves the cities included in one class. To provide maximum relief to the whole island, we select three areas with the first three emergency levels from all categories to deliver containers. Since taking all the cities on the island into consideration is difficult, for simplification, we only those cities with large population. We find the top 20 cities with large population in Puerto Rico Island, as shown in Fig. 1.

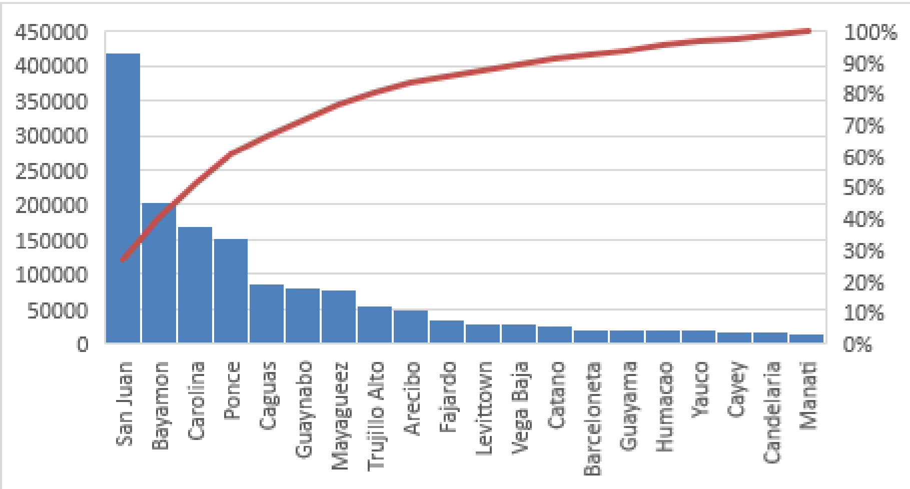


Fig. 1 The population of the top 20 cities.

Each blue bar in Figure 1 presents the single city population and the red curve represents the proportion of the cities' cumulative population to the total population of 20 cities. By Figure 1, we find that the cumulative population of the top 7 cities occupies the 80 percent of the total population of the 20 cities. Hence, it is reasonable that we choose the first seven cities for clustering. Then we get the center points of the three clusters, and mark the geographical location of the three centers as 1 \ 2 \ 3 on Google Map as shown in Fig. 2.

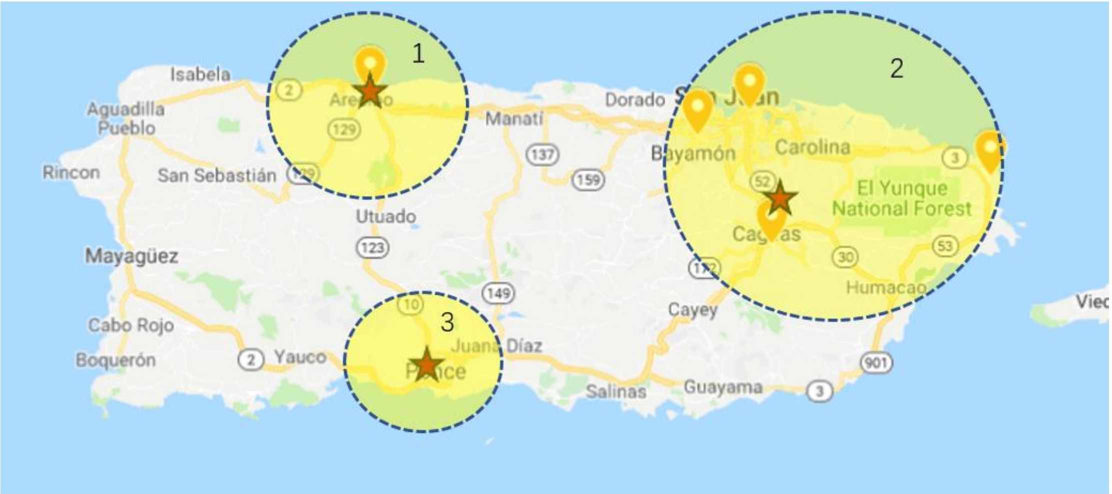


Fig.2 Three areas to be rescued

3.2.1 Definition of Urgency Level

To maximize the relief to the whole island, we optimize the net utility of relief for each area (i.e. each class by clustering) to determine how many containers need to be supplied to that area. Before that, we need to define the urgency level of each area.

There are mainly two kinds of demands for relief: medical packages delivery and video reconnaissance of road networks. We measure a area's urgency level of relief by daily demand in medical packages delivery and the demand in video reconnaissance.

- For daily demand in medical delivery, according to Attachment 4, only five given hospitals require medical packages. For each area, the daily medical demand is the sum of the daily medical demand of the hospitals located in that area. We define the rate of daily medical demand in each area as

$$m_i = M_i / M, \quad i = 1,2,3 \tag{4}$$

where M_i is the daily medical demand in the ith area and M is the total daily demand of the five hospitals. For other areas where there are no daily demand for medical, then $m_i = 0$.

- For the demand for video reconnaissance, according to hypothesis 2, the demand for video reconnaissance in a certain area has positive correlation with the population of that area. In addition, there is a lower demand for video reconnaissance in those areas with large populations but less affected by disasters. Therefore, the demand in video reconnaissance should also have positive correlation with the level of destruction.

  We first consider the factor of population. The population in one area is defined as the sum of the population of the cities among the first seven densely populated cities located in that area. We define the population rate of each area as

$$p_i = P_i / P, \quad i = 1,2,3 \tag{5}$$

where P_i is the population of the ith area and P is the total population of the seven cities.

Now we analyze the level of destruction in the disaster. We find the distribution of destruction in the hurricane, which is shown in Fig.3[3]. And we define the level of destruction for these three areas, as is shown in Tab.2.

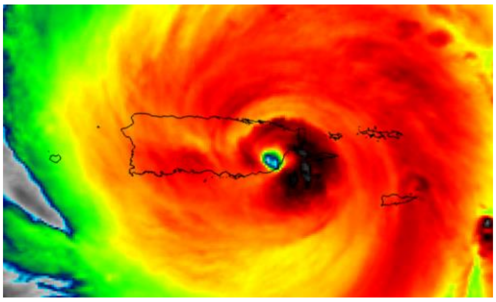


Fig.3 Distribution of the destruction.

Tab.2 Level of destruction.

Level of Serious	Value
especially serious	0.9
generally serious	0.7
not serious	0.5

Then we define the level of urgency as

$$b_i = \alpha \cdot m_i + (1-\alpha)\cdot(p_i + d_i). \qquad i = 1,2,3 \tag{6}$$

Setting $\alpha = 0.5$, we obtain the level of urgency in each area shown in Tab.3.

Tab.3 Level of urgency in each area

Area	Level of Urgency
1	0.046
2	0.677
3	0.025

3.2.2 Optimizing Net Utility of Relief

We determine the number of cargo containers for each area in the sequel.

Objective:

Based on the previous analysis, we need to determine the number of containers in each area in order to maximize the net utility of relief. We have

$$\max\ U^*_{total} = \sum_{i=1}^{3} U_i^* = \sum_{i=1}^{3} \frac{b_i \times \log(A_i + N_i) - b_i \times \log(A_i)}{U_{\max}} - \sum_{i-1}^{3} \frac{c \cdot N_i}{C_{\max}}$$

where $U^*_{\max} = b_i \cdot \log(\mathrm{A}_i + 3)$ and $C_{\max} = 3c$. In order to ensure the feasibility of calculation, we make A_i and N_i on the same dimension. The condition before rescue in each area varies from 1 (the worst) to 10 (the best). The conditions in the three areas are all very poor once the disaster occurs, so we set

$$A_1 = A_2 = A_3 = 1\,.$$

Then the objective is

$$\max \quad U^*_{total} = \sum_{i=1}^{3}\left(\frac{b_i \cdot \log(1+\mathrm{N}_i)}{b_{\max}\cdot \log(1+3)} - \frac{N_i}{3}\right).$$

Constraints:

- Since up to three containers are available, we get

$$\sum_{i=1}^{3} N_i \le 3\,.$$

- There are hospitals demanding medical packages in area 1 and area 3. Therefore, both area 1 and area 3 need containers. Hence

$$N_1 \ge 1,\quad N_2 \ge 1\,.$$

Then the optimization model of the number of containers is

$$\max \quad U^*_{total} = \sum_{i=1}^{3}\left(\frac{b_i \cdot \log(1+\mathrm{N}_i)}{b_{\max}\cdot \log(1+3)} - \frac{N_i}{3}\right)$$

$$s.t.\ \begin{cases} \sum_{i=1}^{3} N_i \le 3 \\ 1 \le N_1 \le 3 \\ 1 \le N_2 \le 3 \\ 0 \le N_3 \le 3 \\ N_i \in N^+, i \in 1,2,3 \end{cases} \tag{7}$$

Solving (7), we get $N_1 = 1, N_2 = 2, N_3 = 0$.

As shown in Fig. 3, though area 1 is relatively less affected by hurricane and contains one densely populated city. However, area 1 still needs medical package delivery because it contains a hospital. Area 2 is most affected by the disaster and contains five cities with large population and four hospitals, so it needs the largest number of containers to be delivered. For area 3, it is slightly affected by disasters, contains only one densely populated city, and there are no hospitals, so the demand for containers is small.

4 Locations Determination

4.1 Multi-objective Optimization

We decide to position the container at the port, because we could only land from the port. Furthermore, the damage was serious and the traffic was blocked, it would be very costly to ship the container out of the port. By consulting the relevant information, we find that there are many ports around the island, as is shown in Fig, 4. How to select the best ports to place the containers?

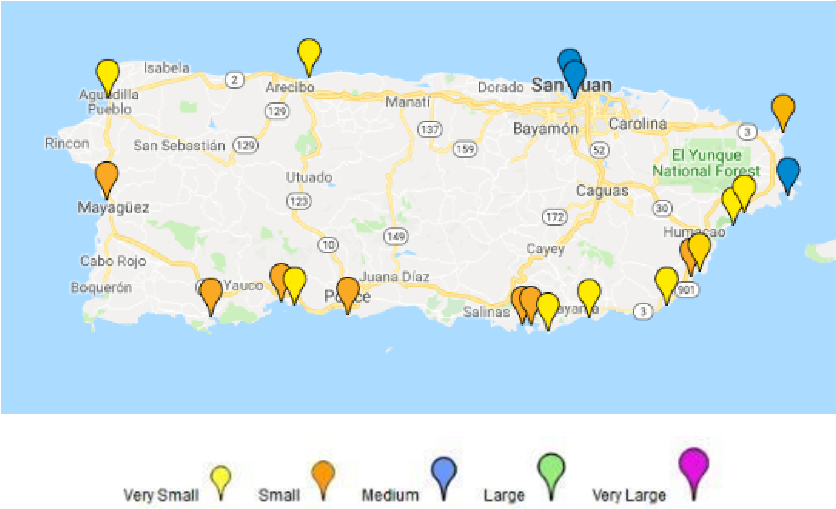


Fig. 4 The ports' distribution on Puerto Rico

Since there is no container in region 3, we do not analyze it any more. For the container in area 1, we placed it at the port of Arecibo, nearest to the hospital. For area 2, there are two containers. After analyzing the candidate drones in Annex 2, we find that the B-type drone flies fastest with the longest flying time, and its maximum flight distance is 52.7 km. In order to ensure round-trip, all drones can only travel within 26.35 km away from the container planning to be delivered. In other words, the distance between each hospital and the container should not exceed 26.35 km, otherwise the delivery will not be completed. We found that two containers parked in the same port could not satisfy the medical delivery of four hospitals in the region at the same time. Therefore, we place these two containers on different ports in the region. Now we set out on determining the best docking locations for the containers by optimization model.

4.1.1 Objectives of Optimization

The DroneGo disaster response system has two rescue missions, medical delivery and video reconnaissance. In order to conduct the disaster relief mission better, we need to take into account both of these requirements at the same time.

- For the medical delivery, it is necessary to consider the cost of transport. For each port, the cost on delivery is positively proportional to the product of the distance to the target hospital (j) and the weight of the medical for the hospital, thus defining the cost M as

$$M = \sum_{j=1}^{n} d_j * w_j ,$$

where d_j is the distance to the j th hospital and w_j is the weight of the medical for the j th hospital.

Thus, we get the first objective

$$\min\ M=\sum_{j=1}^{n}d_j\cdot w_j$$

- For video reconnaissance, we need to choose a port closer to the trunk speed, which can reduce the distance that drones fly away from their docking position (port) each time they cruise. This optimization objective is necessary in the case of limited endurance of drones. It follows that

$$\min\ L_j=\sum_{k=1}^{m}l_k\ \mathrm{c},$$

  where l_k is the distance to the densely populated city k.

4.1.2 Constraints

After analyzing the candidate drones in Attachment 2, we find that the B-type drone flies fastest with the longest flying time, and its maximum flight distance is 52.7 km. In order to ensure round-trip, all drones can only travel within 26.35 km away from the container planning to be delivered. In other words, there is at least one container port within 26.35km away from the hospital. We have

$$x_j\geq 1.$$

Combining the objectives and the constraint, we proposed the multi-objectives optimization model as following,

$$\min\ M=\sum_{j=1}^{n}d_j*w_j$$

$$\min\ L_j=\sum_{k=1}^{m}l_k$$

$$\text{s. t.}\quad x_j\geq 1$$

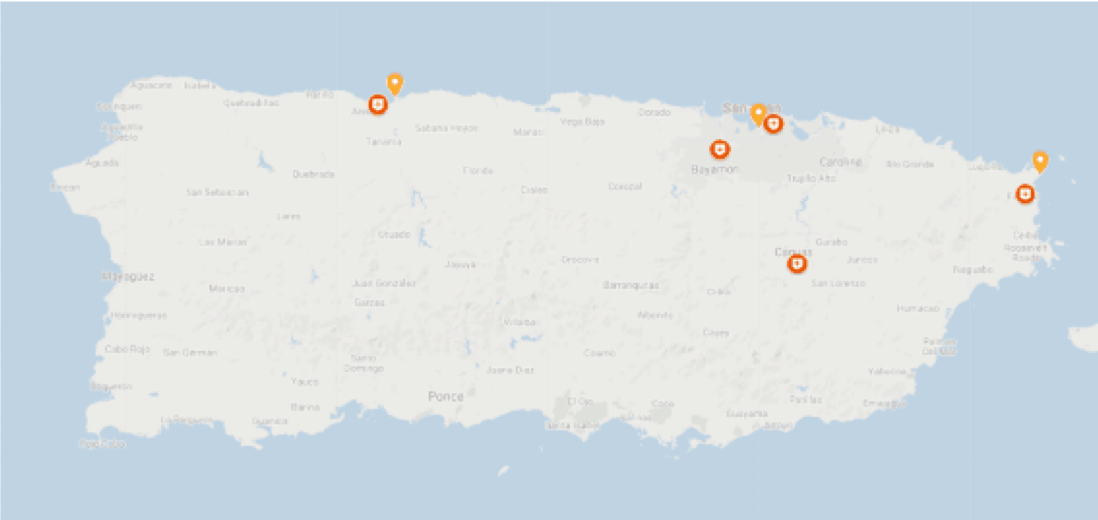
4.2 Decision

Dealing with such a multi-objective optimization programming model, we normalize each objective to transform it into single objective programming. So, we get

$$\min\quad \alpha M^*+(1-\alpha)L^*$$

$$\text{s. t.}\quad x_j\geq 1,$$

where $M^*=\dfrac{M}{M_{\max}}$, $L^*=\dfrac{L}{L_{\max}}$. And then, we get three best positions of the containers as is shown in Fig. 5 and the basic information of the three ports is shown in Tab. 3.



Delivery Location Ports Location

Fig. 5 Best positions of the containers

Tab. 3 Basic information of ports

Number	Name	Position
1	Port of Arecibo	18.48198, -66.70131
2	Port of San Juan	18.43451, -66.09517
3	Port of Fajardo	18.36016, -65.62486

5 DroneGo Fleet Composition

5.1 Selection of Drones

Drone H-Tethered: For the majority of the communication network was damaged by hurricane, we must select the H-Tethered Drone with the function to provide communication to meet the requirements of video transmissions and other network transmissions. Thus, one H-Tethered drone is necessary in each area.

For each area, there are two missions for each drone in the disaster response system For these two types of tasks, we decide to select several drones that perform best in the two missions respectively. So how to measure the performance of these types of drones in different aspects? We use the AHP (Analytic Hierarchy Process) to evaluate the performance of drones quantitatively.

5.2 AHP Evaluation

The parameters of various drones are given in Attachment 2. Applying the AHP on evaluating the drones, we assign different weights to different indexes, as is shown in Tab. 4.

Tab. 4 Weights for different indexes

index	capability	speed	flight time	video capable	package capable
Medical delivery	0.4	0.2	0.1	0	0.3
Road reconnaissance	0	0.3	0.4	0.3	0

According to the weights above, we get the scores of two aspects of each type of drone, as is shown in Fig. 5

Tab. 5 Reconnaissance score and delivery scores

Type	Reconnaissance score	Delivery score
A	5.20	17.35
B	9.84	34.30
C	9.90	30.10
D	8.50	27.60
E	9.31	28.50
F	12.74	32.50
G	10.73	31.60

According to the result in the table above, we select B-type drone and F-type drone for road reconnaissance and medical delivery respectively.

6 Strategy for Medical Delivery

There is a constraint relationship between the quantity of medicine delivery and the numbers of drone. The medical packages and the corresponding drones need to be transported in the same container. On the other hand, the total volume can't exceed the limited volume of the container. Therefore, the following constraint is obtained:

$$N_m \cdot V_m + N_d \cdot V_d \leq V_C$$

where N_m, V_m are the number and volume of the medical packages, respectively, N_d, V_d are the number and volume of the drone, respectively, and V_C is the the volume of Cargo container.

Furthermore, with the limited capability of the container, we get

$$N_m \leq Capability * N_d$$

where, N_m is number of drug packs， N_d is the number of drone.

7 Route of Reconnaissance

For better reconnaissance, we are supposed to plan the route of the drone fleet to maximize the length of road to be videoed.

We define the reconnaissance gains as the new situations on roads obtained. For the reconnaissance mission, there is no gains to repeat the path taken by other drones or travel along the flight lines which is not along the roads (such as returning to the port from a point in a straight line or flying straightly between two points). We can measure the gains by the length of the load.

$$\begin{cases} \text{Roads which have been videoed} \Longrightarrow w_{ij} = 0 \\ \text{Filght lines with no roads recovered} \Longrightarrow w_{ij} = 0 \\ \text{Roads which haven't been videoed} \Longrightarrow w_{ij} = d_{ij} \end{cases}$$

7.1 Road Network Graph

For conveniently search the best reconnaissance, we need to draw the graph of main roads, for example, around the Port of San Juan, as is shown in Fig. 6.

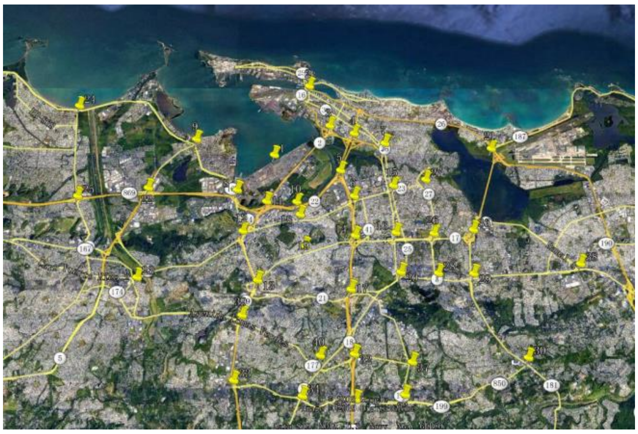


Fig. 6 Graph of main roads around Port of San Juan.

Regarding the position of Port of San Juan (location of the cargo container) as origin, the road intersections as the vertexes of the graph, and the length of the corresponding road as the weight of the edge of the graph, an undirected weighted graph G is constructed. To simplify the calculation, we assume that once a drone selects one road, it will travel until the intersection.

7.2 Multi-Objective Programming

For drone k, the distance from point i to the point j is w_{kij} and e_{kij} is a zero-one variable and

$$e_{kij} = \begin{cases} 0 \text{ , no direct connection} \\ 1 \text{ , direct connection} \end{cases} .$$

Objectives:

- Minimizing the length of flight route, we get

$$max \sum_{k=1}^{N_v} \sum_{i=0}^{N_c} \sum_{j=0, j \neq i}^{N_c} w_{kij}$$

- Maximizing the utility od drones, we get

$$min \sum_{k=1}^{N_v} \sum_{i=0}^{N_c} \sum_{j=0, j \neq i}^{N_c} e_{kij} \cdot w_{kij}$$

Constraints:

- Drone starts from the origin, and we get

$$\sum_{j=1}^{N_c} x_{kOj} = 1 , \quad \forall \mathrm{k}=1,2...N_c$$

- Drone return to the origin at the end, and get

$$\sum_{i=1}^{N_c} x_{kiO} = 1 , \quad \forall i=1,2...N_c$$

- With limitation of the duration, we have

$$\sum_{i=0}^{N_c} \sum_{j=0, j\neq i}^{N_c} x_{kij} \leq LD_k$$

7.3 NSGA-II Algorithm

This optimization problem is a NP-Hard problem, and we can't solve it in polynomial time. Therefore, we can only use heuristic algorithms such as artificial neural networks, genetic algorithms, simulated annealing to obtain approximate solutions.

The general method of solving multi-objective optimization problem is, according to the importance of multiple objectives, to give certain weight to different objectives, so as to transform the multi-objective problem into a single-objective optimization problem. However, when some objective functions have noise or variable space discontinuity, the classical multi-objective optimization methods have poor results, and it is difficult to determine the importance of each objective. As a multi-objective evolutionary algorithm based on pareto, NSGA-IIalgorithm does not need to normalize multiple targets. It has the advantages of fast, diverse and uniform. [9]

In addition, with the increase of reconnaissance targets, the number of alternative path schemes for unmanned aerial vehicles will increase dramatically, which makes it difficult for common accurate algorithms to deal with them effectively. We draw lessons from the idea of NSGA-II algorithm to solve multi-objective optimization problems. And a path planning algorithm for unmanned aerial vehicles is constructed.

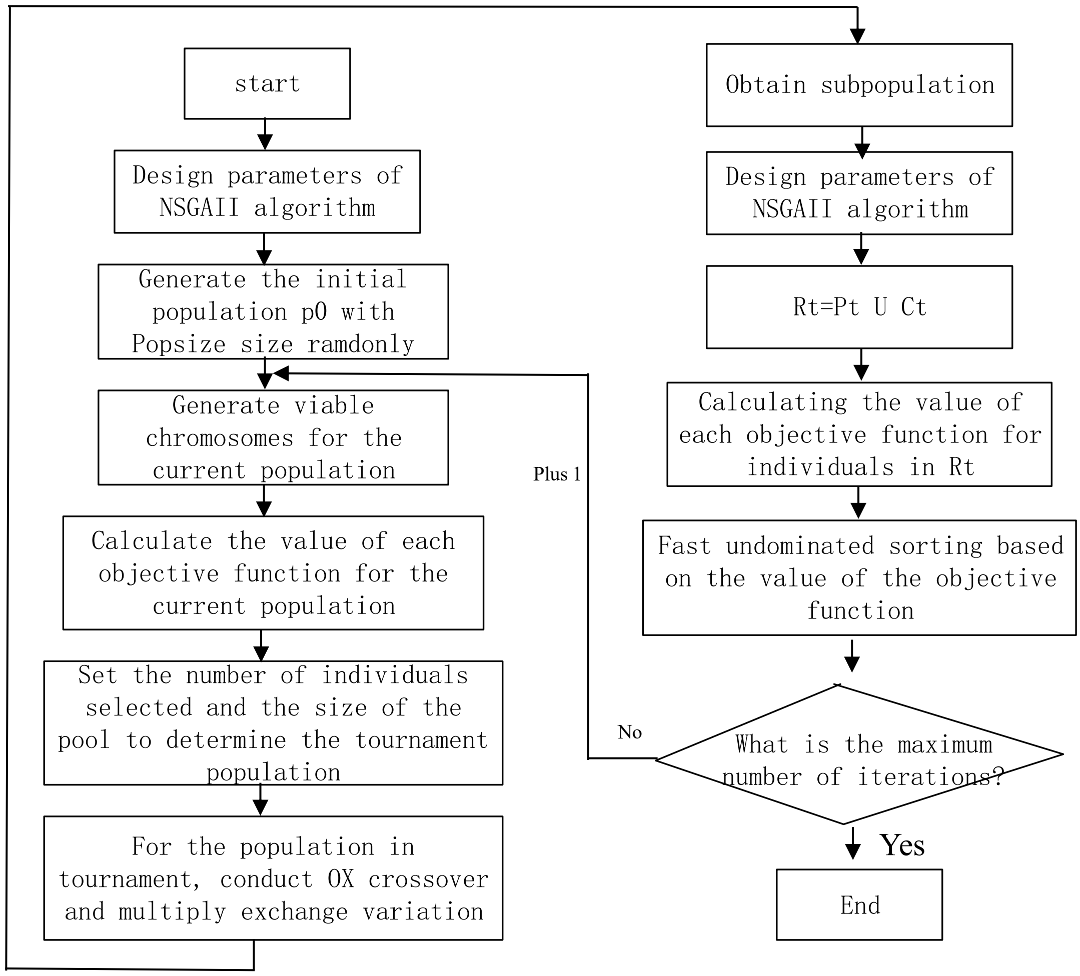


Fig.7 Algorithm flow chart

8 Sensitivity Analysis

8.1 Coefficient b_i and Base A_i of Utility Function

In the Utility Function, considering that the degree of demand for relief varies from in terms of different areas, we define the level of urgency b_i, which represents the potential of bringing utility of relief.

The effect of parameter based on the return model is shown in the Fig.8 .

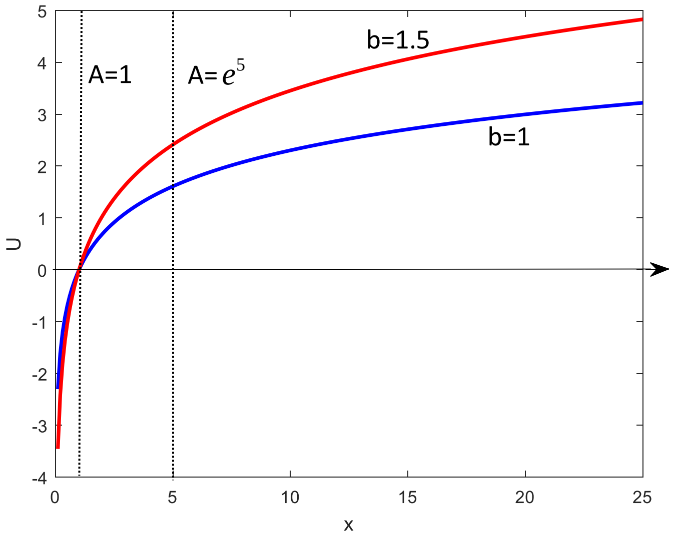


Fig. 8 Utility Function

To test the sensitivity of the Utility Model, We need to analyze the effect on the results with the slight variation of the level of urgency and the basic condition before relief. The results of sensitivity with the variation of level of urgency is shown in the Tab. 6.

Tab.6 The result of the sensitivity with the variation of level of urgency

b_i	$1.1b_i$	$0.9b_i$	$1.2b_i$	$0.8b_i$
N_1	1	1	1	1
N_2	2	2	2	2

9 Conclusion Discussion

9.1 Conclusion

This paper managed to recommend a transportable disaster response system to the HELP, Inc. including number and locations of Cargo containers. And we made strategy for medical delivery and video reconnaissance.

We first clustered the cities on the islands and analyze the urgency of the relief. And two areas were selected with one container located in one area and two containers located in another area. And we determined the position with the limitation of the duration of drones.

We determined the type of drones with the feature of drones and we obtain the schedule for medical delivery.

At last, we optimize the length of roads and get the best path of reconnaissance.

9.2 Discussion

Limitation and extensions:

Although our model is instructive to actual disaster relief assistance, it can be improved in two ways:

● Our model is based on the idealized environment, however, a slight change in the environment will have a big impact on our results. To make more accurate plan, it is very necessary for us to consider the difference of the different environment.

●We only consider short-term disaster relief condition where the factors in our model will not have obvious changes. Actually, disaster relief is a long-term mission, so we need to enrich the model further and discuss the adjustment of disaster relief plan with the changes of the condition of disaster

10 Strengths and Weaknesses

10.1 Strengths

- Our model is available for conducting relief even without knowing the exact situation of disaster areas. The designation of our fleet based on the features of the disaster area (such as population, road density, etc.) and the approximate severity of the disaster can result in the best relief plan.
- Our model provides decision-making for disaster relief areas and rescue scales. Moreover, the model maximizes rescue benefits with limited rescue capabilities.
- The model can be applied to other similar disaster relief situations.
- The model has good stability and the results are reliable.

10.2 Weaknesses

- Lacking the consideration of all kinds of conditions in the disaster ereas might cause some deviation to the strategy
- Ignoring the impact of drones on flight distance after loading might affect the location of delivering cargo containers.
- Analyzing the calculation results, we found that each container has a lot of unused space which may cause the waste of buffer materials.

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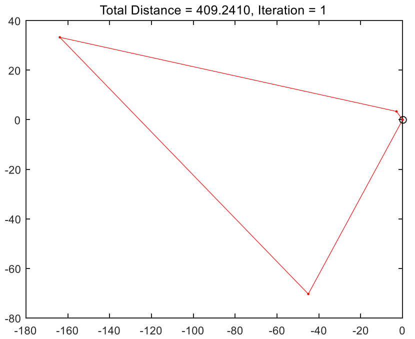
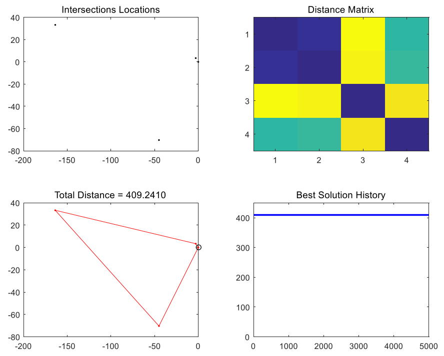
Appendices

Appendix A Cruising Map and Computing

1.Port of Fajardo (18.36016, -65.62486)





2.Port of Arecibo (18.48198, -66.70131)