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Analysis and Optimization of DroneGo Disaster Response System

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Abstract: Natural disasters can be destructive and cause a wide range of attacks, thus emergent rescue can be crucial. DroneGo disaster response system play an important role in the rescue after disasters. DroneGo fleet is expected to provide both transportation of medical packages and video of damaged and serviceable transportation road networks. We take the hurricane happened in Puerto Rico in 2017 as an example to analyse the DroneGo system. Firstly we develop integer programming model to find the best packing configuration. Then, the selection of locations to position cargo containers can be variant. In order to find the optimal solution, we use level analytical method and develop multiple attribute decision-making model. Finally, the genetic algorithm plays a vital role in optimization of air routes. In addition, we combine the solution to the packing problem and optimal locations to position cargo containers, thus the packing configuration and flight plans are determined. Schedule can be the summary of the previous questions. We make the table for clear explanation.

1. Introduction

1.1 Problem Background

People are vulnerable to the insane tempers of the nature. Therefore American government has attached great significance to the response during or after the natural disaster. For the response, speed and abundance are important. "DroneGo" disaster response system is a good choice under the circumstance of terrible road condition and cellular communication networks.

The mission of "DroneGo" disaster response system is to "provide medical supply delivery and video reconnaissance". In order to reach this goal, "DroneGo" disaster response system need to overcome lots of difficulties such as terrible terrain and long distance of flying. Therefore these factors are all needed to take into consideration in order to get the comprehensive solution.

1.2 Supposing Conditions

Here are some supposing conditions of such problem:

The dimensions of an ISO standard dry cargo container are described in Table 1

Table 1. Standard ISO Container Dimensions

	Exterior			Interior			Door Opening	
	Length	Width	Height	Length	Width	Height	Width	Height
20' Standard Dry Container	20'	8'	8'6"	19'3"	7'8"	7' 10"	7'8"	7'5"

The general map of Peurto Rico is shown in Figure 1

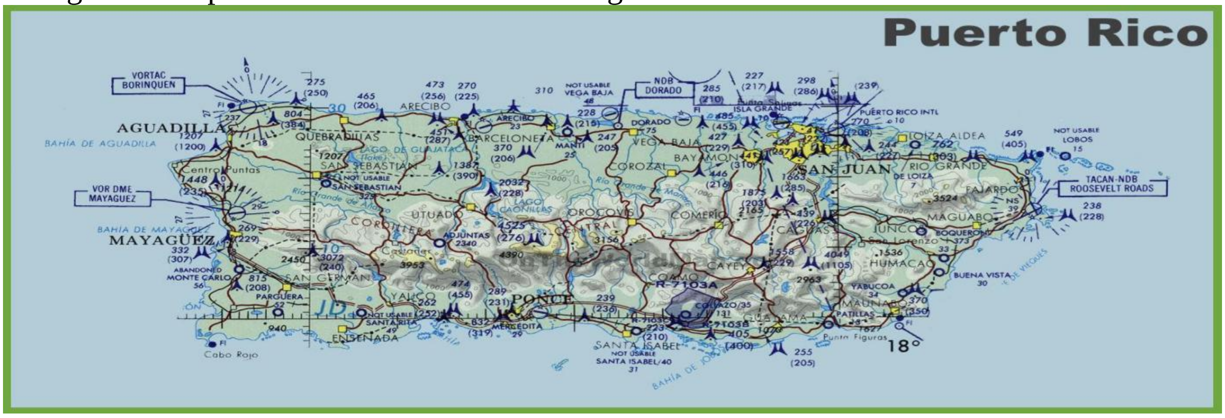

Figure 1. Map of Puerto Rico

Potential Candidate drones for DroneGo Fleet Consideration (with Drone *Payload Capability)* are illustrated in Table 2

Table 2. Candidate drones

	Shipping Container Dimensions			Performance Characteristics/Capabilities			Configurations Capabilities		
Drone	Length (in.)	Width (in.)	Height (in.)	Max Payload Capability (lbs.)	Speed (km/h)	Flight Time No Cargo (min)	Video Capable	Medical Package Capable	Drone Cargo Bay Type*
A	45	45	25	3.5	40	35	Y	Y	1
B	30	30	22	8	79	40	Y	Y	1
C	60	50	30	14	64	35	Y	Y	2
D	25	20	25	11	60	18	Y	Y	1
E	25	20	27	15	60	15	Y	Y	2
F	40	40	25	22	79	24	N	Y	2
G	32	32	17	20	64	16	Y	Y	2
H Tethered	65	75	41	N/A	N/A	Indefinite	N	N	N/A

*Note that cargo bays are affixed to the drone and that drone must be on the ground to offload cargo.

Drone Cargo Bay Packing Configuration/Dimensions by Type are shown in Table 3

Table 3. Drone Cargo Bay Packing Configuration/Dimensions

Drone Cargo Bay Type	Length (in)	Width (in)	Height (in)	
1	8	10	14	Top Loaded
2	24	20	20	Top Loaded

Emergency Medical Package Configuration/Dimensions are illustrated in Table 4

Table 4. Emergency Medical Package Configuration/Dimensions

Emergency Medical Package Configuration		
Package ID	Weight (lbs.)	Package Dimensions (in.) (L × W × H)
MED 1	2	14 × 7 × 5
MED 2	2	5 × 8 × 5
MED 3	3	12 × 7 × 4

Anticipated Medical Package Demand is described in Table 5

Table 5. Anticipated Medical Package Demand

Delivery Location			Emergency Medical Packages		
Location Name	Latitude	Longitude	Requirement	Quantity	Frequency
Caribbean Medical Center Jajardo	18.33	-65.65	MED 1 MED 3	1 1	Daily Daily
Hospital HIMA San Pablo	18.22	-66.03	MED 1 MED 3	2 1	Daily Daily
Hospital Pavia Santurce San Juan	18.44	-66.07	MED 1 MED 2	1 1	Daily Daily
Puerto Rico Children's Hospital Bayamon	18.40	-66.16	MED 1 MED 2 MED 3	2 1 2	Daily Daily Daily
Hospital Pavia Arecibo Arecibo	18.47	-66.73	MED 1	1	Daily

1.3 Literature Review

To simplify the problem and facilitate the implementation of computer language, researchers recommend level analytic method and multiple attribute decision-making model analytic method to work out optimal solution [1]. Total score of alternative locations can be worked out and the best location can be selected.

After that, some people use particle swarm optimization (**PSO**) and genetic algorithm to find the optimal solution through iteration [2][3]. Simulation results show that, unmanned aerial vehicle (**UAV**) route planning based on optimized **PSO** algorithm not only reduces the optimal route, but also improve search speed [4]. This problem is in the city environment. The city environment, including buildings, other obstacles and threatening areas with radar interference, is modeled. Then, the hybrid **PSO** algorithm with differential evolution operations and adaptive inertia weight strategies is used for path planning of multiple **UAV**s. Finally, the validity of algorithm is verified by simulations [5].

In addition, terrain and altitude can be quite important for solving the flight optimization problem. We obtain some data from maps online [6].

1.4 Our work

1) We need to contrast the mathematical model to determine the optimal strategy which could achieve the following objectives:

- Recommend a drone fleet and medical packages.
- Design the associated packing configuration

2) Identify the best locations on Puerto Rico to position cargo containers of the DroneGo disaster response system to achieve the following things:

- Provide medical supply delivery.
- Provide video reconnaissance.

3) Using genetic algorithm and particle swarm optimization to provide the most suitable plan for:

- Payload packing configurations
- Delivery routes
- Schedule

2. Preparation

2.1 Assumptions

It is difficult to figure out the accurate placement of medical packages on the drone and the placement of drones inside the cargo containers. In order to simplify the problem and hold the correctness of results at the same time, we make the assumptions as follows:

1) For security, medical packages and drones will not be placed vertically in transit. In other word, medical packages and drones are placed horizontally in ISO cargo containers in transit.

2) We set choosing drones or medical packages independent of each other because we select drones or medical packages randomly.

3) We use inch as the unit of measurement. Therefore there exists some unit conversion in our model.

4) We consider the circumstance where medical packages are put inside the drone cargo bay only.

This assumption will simplify the model and the precondition of the stationary transportation.

5) We do not take accidents into consideration for they are unpredictable and difficult to quantify.

This kind of varying factors can not be demonstrated in the model, such as unpredictable bad weather and varying airflow.

6) We assume that the drone will not be limited by flight time, for drones of type-H can be used for charging. The specific arrangement will be stated in the paper.

7) We do not take no-fly zone into consideration. The golden period after natural disasters can be valuable. Therefore it is reasonable that reasons for flying restriction such as affecting the normal flight and residents' quality of life are not considered.

8) We assume that drones use video cameras to assess the highways and roads after the transportation of medical packages. Because it is efficient and convenient to monitor roads when drones go back to Cargo containers.

9) When the distance is longer than the longest distance drones can reach without charging, we use H-type drones for charging in. It is reasonable for a larger monitoring scope.

10) In order to provide specific schedule, we assume the charging time is 30 minutes and the unloading time is 20 minutes.

11) We assume that the drone used for transportation can not be sent out until the previous drone has finished unloading medical packages.

2.2 Notations

The primary notations used in this paper are listed in Table 6

Table 6: Notations

Symbol	Definition
C_i	the number of drone or medical package
L_i	the length of drone or medical package
W_i	the width of drone or medical package
H_i	the height of drone or medical package
a	Caribbean Medical Center in Jajardo. (Destination 1)
b	Hospital HIMA in San Pablo (Destination 2)
c	Hospital Pavia Santurce in San Juan. (Destination 3)
d	Puerto Rico Children's Hospital in Bayamon. (Destination 4)
e	Hospital Pavia Arecibo in Arecibo. (Destination 5)
D_i	the alternative locations to position containers(Alternative i)
l_{min}	minimum length of air segments
l_{max}	maximum length of air segments
l_i	the length of air segments
t	the number of evolutionary generation
t_{max}	the max number of evolutionary generation
M	a location for monitoring only

3. Integer Programming Model

The integer programming is very useful in solving the question that we want to provide the most efficient response system. We can work out the best drone fleet and set of medical packages. In addition, the first limitation we need to consider about is volume.

3.1 Volume of Drones

It is obvious that the total volume of drones must be less than the volume of the standard ISO container:

$$\sum_{i=1}^{7} Ci \times Li \le 19 \times 12 + 3$$

$$\sum_{i=1}^{7} Ci \times Wi \le 7 \times 12 + 8$$

$$\sum_{i=1}^{7} Ci \times Hi \le 7 \times 12 + 10$$

3.2 Volume of Medical Packages

Apparently the total volume of medical packages must be less than the volume of the drone they are loaded into.

$$8 \times (C_a + C_b + C_d) + 24 \times (C_c + C_e + C_f + C_g) \geq 14 \times C_1 + 5 \times C_2 + 12 \times C_3$$

$$10 \times (C_a + C_b + C_d) + 20 \times (C_c + C_e + C_f + C_g) \geq 7 \times C_1 + 8 \times C_2 + 7 \times C_3$$

$$14 \times (C_a + C_b + C_d) + 20 \times (C_c + C_e + C_f + C_g) \geq 5 \times C_1 + 5 \times C_2 + 4 \times C_3$$

3.3 Packing Configuration

According to the two limitations above, we can calculate the outcome. And the packing configuration is shown in the Table 7

Table 7. Packing Configuration

Type of drone	E	G	
Number	4	4	
Type of medical packages	MED1	MED2	MED3
Number	8	2	4

4. The Choice of Best Location

In this section, we would like to select the best location to position cargo containers to acquire the ability to conduct both medical supply delivery and video reconnaissance of road networks. The valid tool to solve this problem is the multiple attribute decision-making model and level analytic method.

4.1 Data Reduction

To simplify this model and calculation, we convert the latitude and longitude to coordinates. In addition, the latitude and longitude in the given map can be relatively vague. Therefore we use the Miller Projection to realize the conversion. For comparison, we reduce data and keep three decimal places. The coordinates of delivery locations are shown in Figure 2

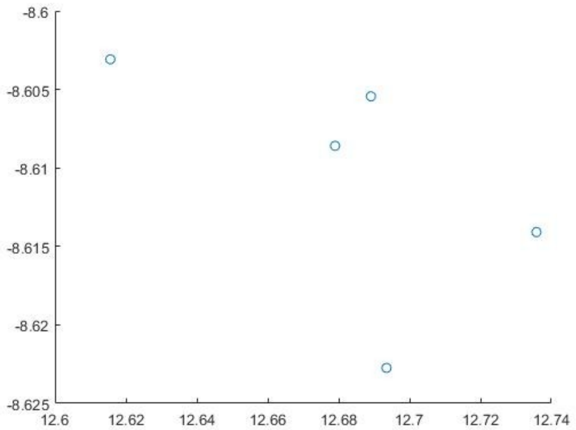

Figure 2. Coordinate of Delivery Locations

In addition, we also measure the distance from alternatives to delivery locations on the map online[6]. Therefore our data can be accurate.

4.2 Level analytic method

Firstly, we would like to select the candidate cities that meet the requirements by analyzing the map of Puerto Rico. Screening the city, as a first condition, a good coastal location for convenient transportation is better. Of course, terrain and the distance to delivery locations are considered. After the analyzing, roughly five candidate sites have been identified.

Then we use the Miller Conversion to convert the latitude and longitude into coordinate. Locations are shown in Figure 3

The green points are delivery locations, blue points are candidate sites and red points are both delivery locations and candidate sites.

Then we analyze the map more carefully. Terrain, the distance to delivery locations, the number of highways passed through can be three most influential factors.

- Terrain can be the most influential element because it sets limitation for the drone's landing.
- Roads are not only the components of cellular communication networks but alsothe target of video reconnaissance.
- Distance affect the transport efficiency which is not the key for transporting.

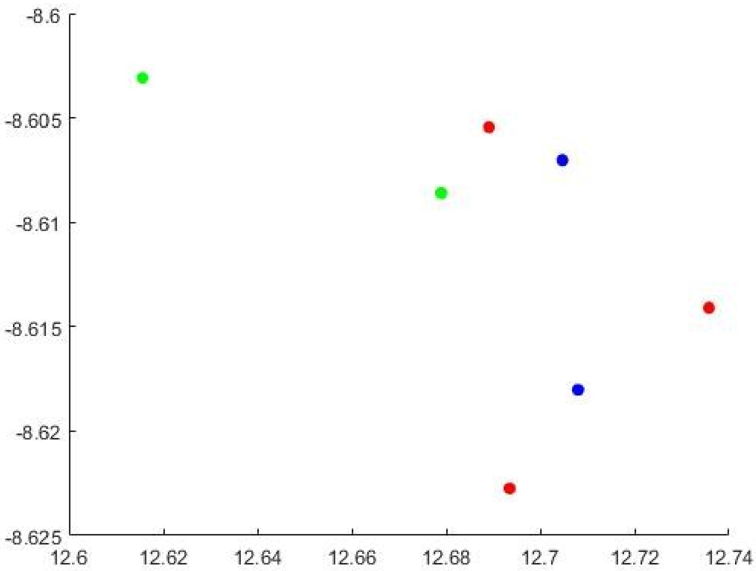

Figure 3.Coordinate of Candidate Locations

Table 8. Weights

	Terrain	Road	Distance
Terrain	1	2	3
Road	1/2	1	2
Distance	1/3	1/2	1

Table 8 shows the weights of pairwise comparison.

To determine weight coefficients of factors, the pairwise comparison matrix is established

$$\begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}$$

Then we can calculate the weights. 0.5396 for terrain, 0.2970 for roads and 0.1634 for distance.

4.3 Multiple attribute decision-making model

We build this model to calculate the total score of five candidate sites. And we will choose the two most suitable sites to position cargo containers. Weight arithmetic average operator(WAA) can be a useful tool in calculating the total score.

We would like to explain standard for evaluation at first.

1) Scoring of terrain will based on altitude difference. Minor altitude difference means relatively flat land condition. As a result it gets higher score.

2) Road score is based on the number of highways passed through. Effective road detection requires the intersection of highways. We draw a line between a candidate site and a delivery location. Then count the number of highways the line passes through.

3) The distance from the candidate sites to the delivery location can be calculated by using the coordinate. Short distance means effective transportation.

The score for every alternative is shown in the Figure 4

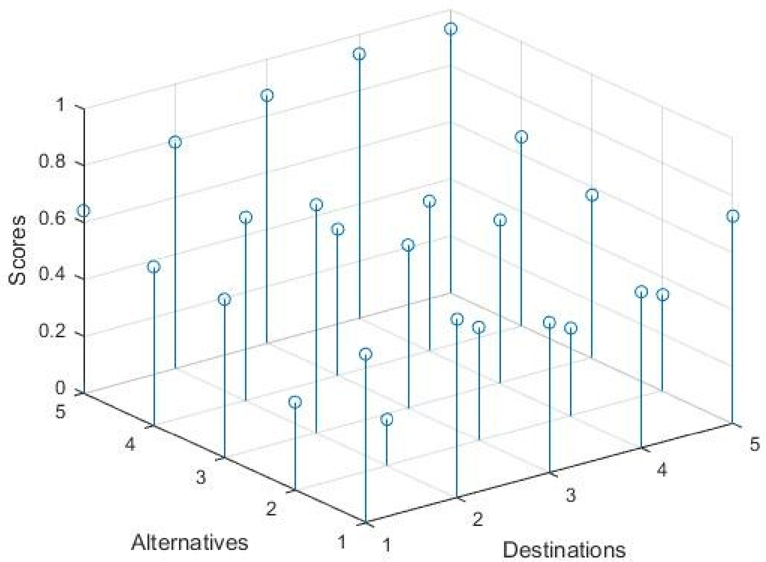

Figure 4. Score

It is obvious that the third alternative location D3 and the fifth alternative location D5 get the higher score than the other candidate sites.

D3 and D5 need to be compared in detail to determine the specific transportation plan.

Therefore we gain the Figure 5 and Figure 6 by fitting points in Figure 4

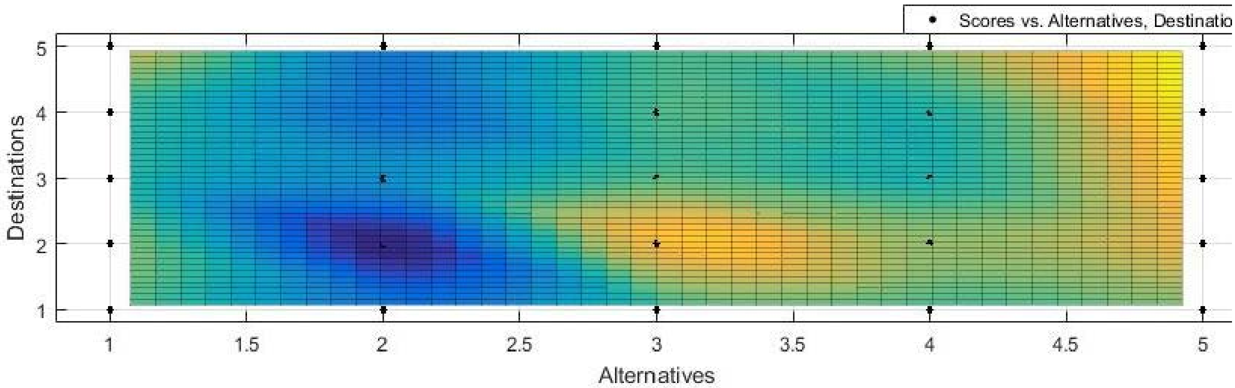

Figure 5. Total score of Candidate Locations

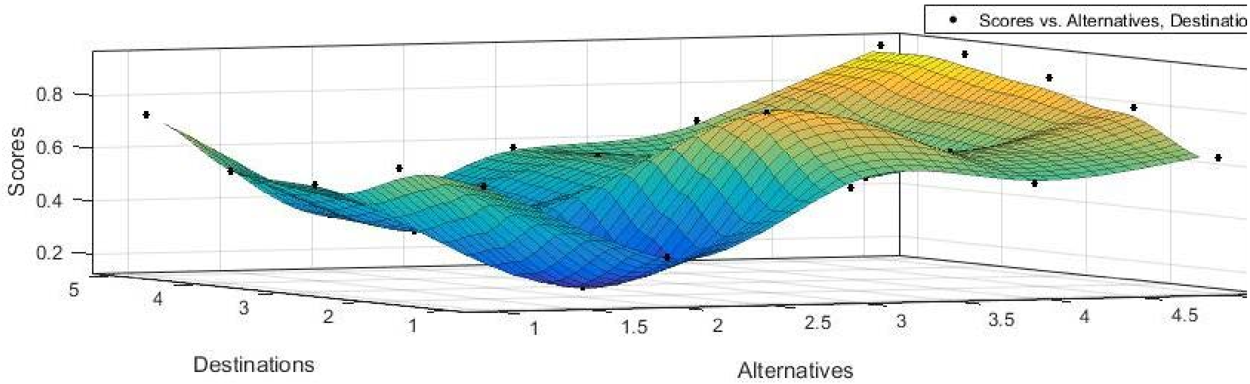

Figure 6. Total score of Candidate Locations

According to the Figure 5 and Figure 6, *D*3 and *D*5 are in the yellow region. It represents they have higher total scores.

In addition, the yellow region of *D*3 converges on a and b. It means they are suitable to place cargo containers and transport medical packages to delivery locations. Therefore we should position two cargo containers in *D*3. The drones in *D*3 are responsible for transporting medical packages to a and b.

Similarly, the yellow region of *D*5 converges on c, d and e. Therefore we should position three cargo containers in *D*5. The drones in *D5* are responsible for transportingmedical packages to c , d and e.

Configuration and other details are shown in the Table 9.

Table 9. Configuration of *D*3 and *D*5

Alternatives	Delivery Location	Distance/km	MED1	MED2	MED3
D5	A	28. 076	1	0	1
	B	15. 248	2	0	1
	C	22. 703	0	1	1
D3	D	10. 579	2	1	2
	E	73. 537	0	1	0

5. The Best Flight Plan

Genetic algorithm is the key for solving flight optimization problem

In the view of the multiple constraints of unmanned aerial vehicle (UAV), the genetic algorithm is combined with the specific route planning problem, and the constraints of UAV are fused into the algorithm, and the reasonable chromosome datastructure, genetic operator and route evaluation function are designed. Stimulation results show that the algorithm can plan flight routes for the UAV to meet the survival probability and penetration probability according to the mission requirements [7].

The flow of route planning is shown in the Figure 7

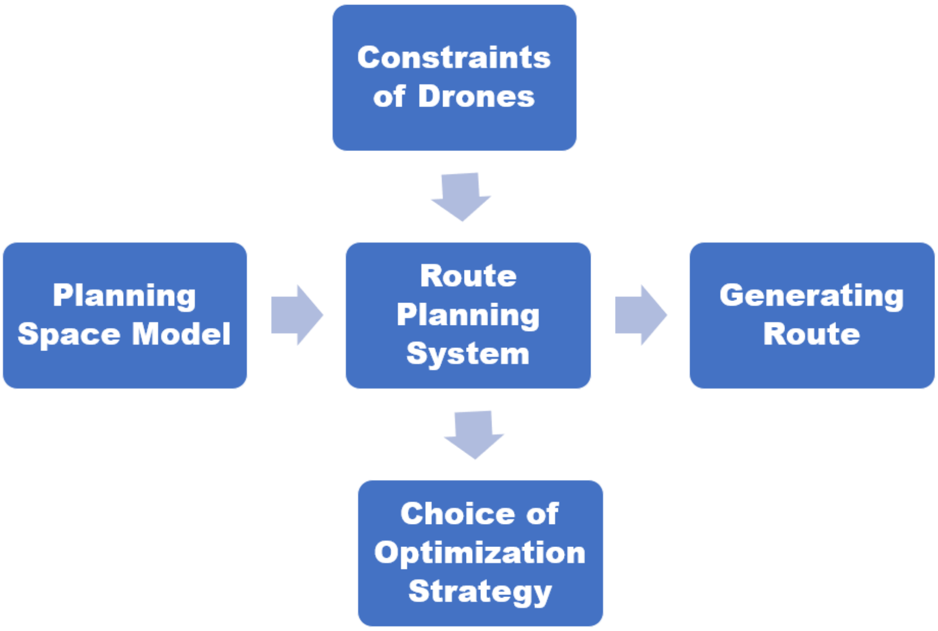

Figure 7. Flow of Route Planning

5.1 Route Planning Space

The purpose of route planning is to find the optimal trajectory by analyzing terrain, no-fly zone and objective function. The essence of the route planning space is to find the optimization under several constraints.

5.2 Constraints of Air Line

The air route can be divided by a series of points into segments. Therefore the constraints of the air route is the same as the constraints of the segments. Constraints we have considered about is listed as follow:

- Minimum length of air segments l_{min}.
  Minimum length of air segments means the minimum distance of flat flight before the next action is performed. And this constraints can be written as:

$$l_i \geq l_{min}$$

- Air routes constraints l_{max}. It means the constraints on the air routes by maximum length of air segments. And this constraint can be written as:

$$\Sigma l_i \leq l_{max}$$

5.3 Route Planning Based on the Genetic Algorithm

The genetic algorithm set a population which is consisted of a certain number of gene coding individuals. Every individual can be deemed as a chromosome with characteristic. The chromosome is consisted of gene sequences. In addition, every chromosome represents a possible solution to the problem. We choose individuals according to the fitness of the problem domain. With the help of genetic operators, the evolution happens. This process is the same as the natural evolution. Individuals with higher fitness are easier to be chosen, thus the fitness of the whole population will improve. And the chromosome with highest fitness is the optimal solution.

The genetic algorithm is consisted of selection, intersection and variation.

5.3.1 Selection

The probability of being selected and passing to the next generation is proportional to the fitness. Therefore we need to:

- Calculate the sum of fitness of each individual in the population.
- Calculate the probability of being selected of every individual. It means we need to calculate proportion relative to the sum.
- For every individual, the number of times of being selected can be determined by the random number.

5.3.2 Intersection

We cut two parent air routes into two parts randomly. Offspring air routes is consisted of the first half part of the first air routes and the latter half part of the second air routes. The sketch map is Figure 8

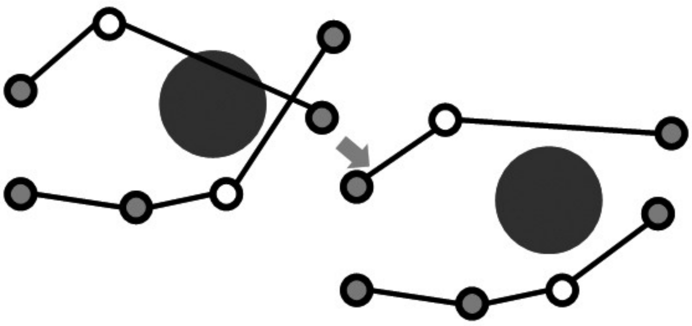

Figure 8. Crossover Operator

5.4 Specific Work

- Initialization of the population.
  Generating the initial population randomly which is consisted of n different air routes. Set t=0 and t_{max}.
- Evaluation of Individuals.
  Calculate every air routes in the population.
- Heredity.
  Find the next generation.
- Find the optimal solution and finish the evolution.

5.5 Transportation Plan and Monitoring Plan

In order to find the best plan, we download maps online. Then we obtain the route for transporting medical packages, and we mark the routes on the map. The route is shown in the Figure 9, Figure 10, Figure 11 and Figure 12

Figure 9. Distance to **a**

Figure 10. Distance to **b**

Figure 11. Distance to **d**

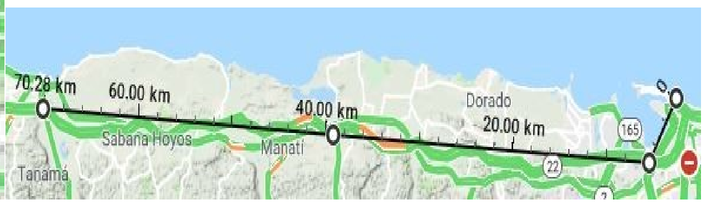

Figure 12. Distance to **e**

Then we can calculate time and number of drones we need. On the way back, drones can monitor the road condition, thus video of damaged and serviceable transportation road networks can be provided. Constraints and genetic algorithm are used to determine the return route. Air routes are shown in the Figure 13, Figure 14, Figure 15 and Figure 16

Pay attention to San Juan, for D_3 is at the same location as San Juan. Therefore the transport time required in San Juan is zero and drones can not monitor roads in San Juan as well.

In order to finish the monitoring tasks better, we also select a location M for monitoring only. For M, the number of major highways and routes is crucial. In order to choose the best location, we use the multiple attribute decision-making model to calculate the total score. Then make comparison between alternatives. We select Ad Juants as the best location for monitoring.

We draw the air routes for monitoring as well. The routes are shown in the Figure 17, Figure 18 and Figure 19

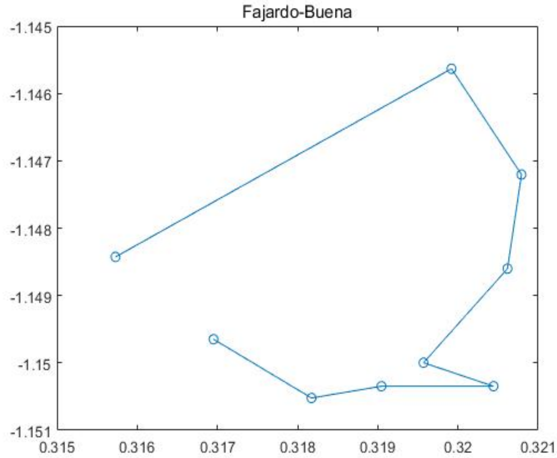

Figure 13. The route for drones to

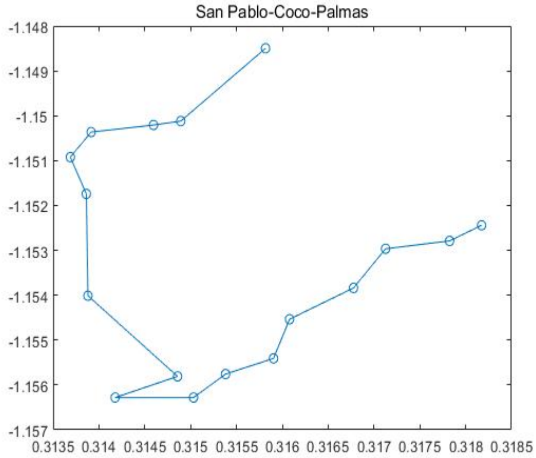

Figure 14. The route for drones to b

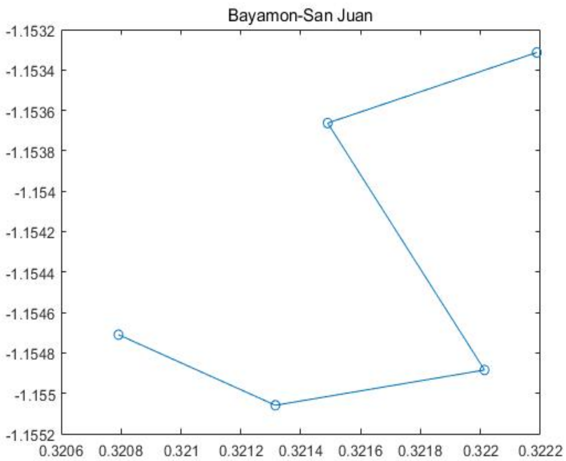

Figure 15. The route for drones to d

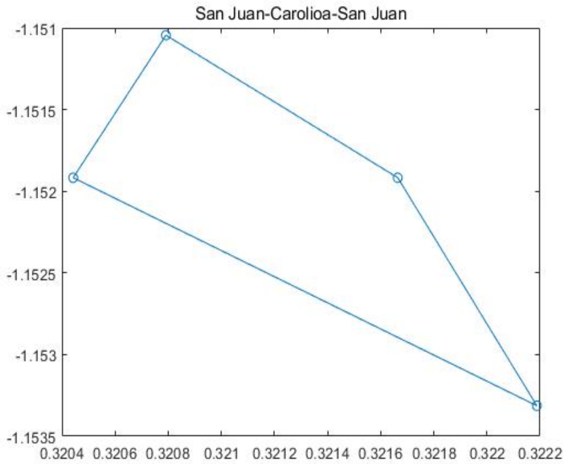

Figure 16. The route for drones to e

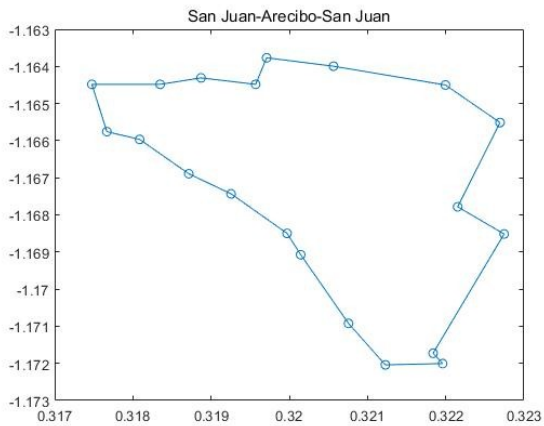

Figure 17. Monitoring Route 1

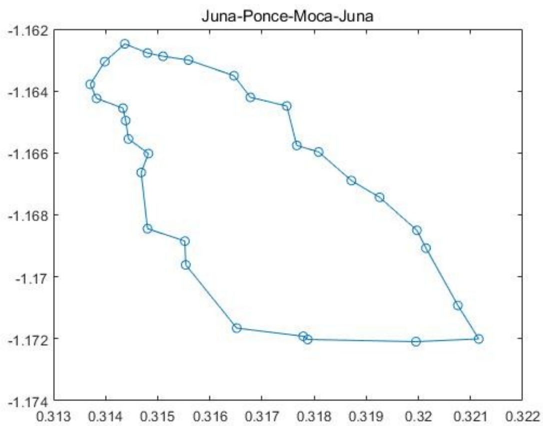

Figure 18. Monitoring Route 2

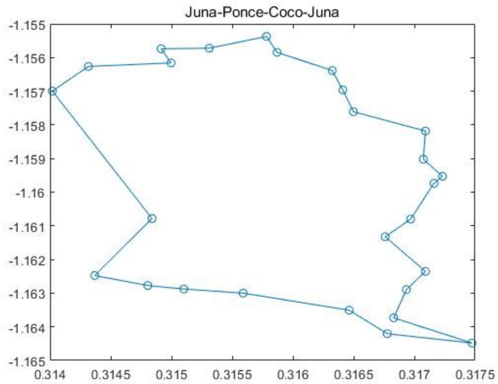

Figure 19. Monitoring Route 3

6. Conclusion

6.1 The Table for Conclusion

The flight plan is complicated and the final answer is not very clear. Therefore we make a table for conclusion in order to explain our plan clearly. The plan can be seenclearly in the Table 10

Table 10. Plan Conclusion

Locations	Delivery Location	Type and Number of Drones	Function	Distance/km	Time/min	Med1	Med2	Med3
D5:Buena	A	B+H	Transportation and Monitoring	28.076	23.21	1	0	1
	B	F+H	Transportation and Monitoring	15.248	23.19	2	0	1
D3: San Juan	C		Transportation and Monitoring	0.000	0.00	1	1	0
	D	E+H	Transportation and Monitoring	10.579	14.11	2	1	2
	E	B+H	Transportation and Monitoring	73.537	40+13.37	1	0	0
AD JUNTAS		3B+3H	Monitoring					

6.2 Schedule

Our solution is listed in the Table 11

Table 11. Schedule

Schedule					
The disaster warning has been activiated.					
Locations	Buena		San Juan		AD JUNTAS
Latitude and Longitude	(18.28,-65.90)		(18.44,-66.07)		(18.18,-66.74)
City	Fajardo		San Juan		Send drones for detecting.
	Action	Time/min	Action	Time/min	
	Flight	23.21	Unload	20	
	Unload	20			
City	San Pable		Bayamon		
	Action	Time/min	Action	Time/min	
	Flight	23.19	Flight	14.11	
	Unload	20	Unload	20	
City		Total:86.4	Arecibo		
	Continue to detect roads.		Action	Time/min	
			Flight	40	
			Charging	30	
			Flight	13.37	
			Unload	20	
				Total:157.48	
			Continue to detect roads.		

6.3 Strengths and Weaknesses

6.3.1 Strengths

- Our model is flexible for changing demand of medical packages.
  Though our integer programming model are based on the anticipated medical package demand and payload capability of potential candidate drones, we use volume as the most important limitation. Therefore our model can be adapted in the real world.
- Our plans can support the real-world scenarios
  Our data is obtained from maps online, thus our models and graphs can reflect the reality. It means our solutions are far practical.
- Our flight plan can provide a wide monitoring range.
  In our plan, H-type drones are widely used for charging, and it brings a greater flight range for other drones.

6.3.2 Weaknesses

- Our analysis for optimization ignore the probability of unpredictable accidents, thus our plan can only work in a peaceful environment.
- Our optimal answer to the locations to position cargo containers can not be adapted in other areas.
  Our analysis is based on the data in Puerto Rico, thus our plan is made for Puerto Rico and can not be used in other areas.
- The cost of flight can not be measured in our model, for the cost of electricity isunknown.

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