For office use only	Team Control Number	For office use only
T1 ________________	1924649	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	B	F4 ________________

2019
MCM/ICM
Summary Sheet

A laconic model of transportable disaster response system

With the progress of industrialization, the global environmental pollution is becoming more and more serious, causing the frequency of extreme natural disasters to increase. The catastrophe happened in Puerto Rico in 2017 attracted worldwide attention, so it is essential to build a transportable disaster response system using rotor wing drones.

In order to design a most effective disaster emergency response system, we build several intuitively models which carry out different tasks.

Firstly, we design a drone fleet, set of medical packages and associated packing configuration for each ISO cargo container. We build two models to solve this problem. One is called **Drone-Billboard**, as the name suggests, it gives a rank list of those 7 drone types and top three are B,C,F. The other one is called **Three-dimensional 0-1 knapsack problem model**, this model applies knapsack method for three times to load the drones into the containers and the final result is: **Each cargo container should have 14 B drones, 9 C drones and 13 drones.**

Secondly, we determine the location of the three containers on the island to meet each hospital's demand and cover as many reconnaissance areas as possible. We have a model which is called **Three-center distributed model** to solve this problem. After doing some simplification and calculation, we get the three containers' coordinates as below: **(18.45, -66.45), (18.43, -65.85), (18.27, -65.93)**. (The previous number is latitude and the later number is longitude)

Finally, we design the drone payload packing configurations, delivery routes and schedule for each type of drone and provide a drone flight plan. We construct **Drone configuration model** to work out this problem, and the final result is given at the end of the passage.

Last but not least, we verified the robustness of the models and analyzed some strengths and weakness of our models to review our whole work.

Contents

1 Introduction

1.1 Problem Background

As the severity of global warming increases, the possibility and frequency of extreme natural disasters is getting bigger and bigger which means establishing a fast and effective disaster emergency response system is of great importance. With the development of technology, drones, such as the kind shown in **figure 1**, have been playing a significance role in modern rescue action because of its convenience and timeliness.

In this problem, we are required to consider the scenario of a hurricane hitting Puerto Rico in 2017 which caused a serious disaster, and helping the NGO HELP, Inc. design a set of rotor wing drones to deliver medical packages like the kind in **figure 2** below to proper place. Except delivering medical kits, how to design a drone video surveillance route is also a point we have to consider.

Figure 1: A widely used rotor wing drone

Figure 2: One kind of medical packages

1.2 Problem Restatement

Three major problems are discussed in this paper, which are:

(A) Sending enough medical packages and drones to Puerto Rico by up to three ISO cargo containers. This requires us to find the best optimal solution of distributing medical kits and drones.

(B) After sending those packages and drones to the Puerto Rico land, we need to find the best optimal location of those cargo containers in order to arrange route of drones which need to deliver medical packages to hospital or medical center.

(C) Finally, decide the configurations in each drone cargo bay, delivery routes and schedule. Then, design a drone flight plan to cover areas of land as more as possible.

1.3 Literature Review

One of the primary problems in this disaster response system design is "three-dimensional container problem". The container loading problems consists mainly three types, which are in one, two or three dimensional respectively. Three-dimensional packing problem is a common problem in the field of shipping container goods and enclosed truck goods. During the development of algorithms for this problem, only heuristic algorithm can provide pleasing solutions.

"Peng et al. (2009) present a hybrid simulated annealing algorithm for three-dimensional container loading problem. Firstly, a heuristic algorithm is sed for encoding feasible packing solutions, and then the simulated annealing algorithm is applied to search in the encoding neighborhood."[1] What stated above is one of the mature methods to solve container problem using simulated annealing algorithm. In addition, another way to solve this kind of question is similar to thoughts of Knapsack problem, which uses dynamic programming. In short, we solve knapsack problems three times to get the best columns, the best layers, the best cubic combinations of goods we have.

1.4 Our work

To solve this problem, we need to construct the three-dimensional container model to determine the optimal strategy which could achieve the following objectives:

1. Use drones as less as possible.
2. Use at most three ISO cargo containers like the kind shown in figure 3.
3. Find the best optimal position to place those cargo containers.

Figure 3: 20′ ISO cargo container

For the three different problem scenarios, we do the following things:

(A) We construct a **drone-billboard model** by comparing several aspects of each type of drones and this model will be clarified detailed in part 3. We use this model to pick 3 best drone types to carry out tasks and load these drones into the container using three-dimensional container loading algorithm.

(B) We construct a **three-center distributed model** and carry out cluster analysis on the five points with three centers to find the best optimal position of the three cargo containers.

(C) We allocate special mission for each container, which is not too difficult to solve. And we try our best to make the ratio of medical packages in the cargo bay approaches the real requirement in the scenario. After that, the route and schedule of droneC and droneF (two types drones we select to deliver the medical packages) are both clear.

2 Preparation of the Models

2.1 Assumptions

Due to the complex principles in real world, it is impossible to take all the circumstances into consideration, which means making appropriate assumptions to simplify the model is of great significance. In order to simplify the model and keep the correctness of results at the same time, we make several assumptions as below:

1. Each drone could only go to one destination.
Explain: This means we do not allow the situation that a drone delivers medical packages to another hospital after it has delivered some packages to one hospital. It is rational because delivering goods to only one hospital at a time can reduce costs and improve the utilization efficiency of drones.

2. All packages or drones must have a uniform orientation when they are placed into containers.
Explanation: For example, when a drone is placing into a cargo container, the long side of the drone is oriented along the long side of the container, the wide side of the drone is oriented along the wide side of the container, the high side of the drone is oriented along the high side of the container. So we do not allow rotation in the process of packing. It is rational because incorrect placement may result in damage to medicines and drones and specifying a uniform orientation can greatly simplify the complexity of the algorithm

3. Those ISO cargo containers can be transported to inland locations after they are transported to the port by sea.
Explanation: In real world, cargo containers can be transported by some trucks and inland locations can cover more disaster areas effectively.

2.2 Notations

The primary terminology used in this paper are listed in **Table 1**.

Table 1: Terminology

Concept	Explanation
Ratio of bay-volume to drone-size	the ratio of a drone's bay volume to its size, one indicator for detecting drone capability.
Drone-Capability radar chart	A radar chart which demonstrates multiple indicators for detecting drone capabilities.
Drone-Capability score	A final score to each type of drones after combining multiple indicators for detecting drone capabilities.

3 The Models And Results

3.1 Model 1: Drone-Billboard

By observing the radar chart, we can easily get the information that it is not necessary to use all A-H drones because some of them share similar advantages compared to other drones, and later in the "capability radar chart" the comparison will be shown clearly. Taken this into consideration, we make up 2 models to help us decide which types drones are more suitable for the scenario in the question stem.

3.1.1 Draw drone-capability radar chart of each drone

This model is designed to show the capabilities of all aspects of the drone intuitively, so we make radar chart for each type of drone to show five indicators of the type.

$$\textbf{Ratio of bay-volume to drone-size} = \frac{Volume\ \ of\ \ drone - bay}{drone\ \ size}$$

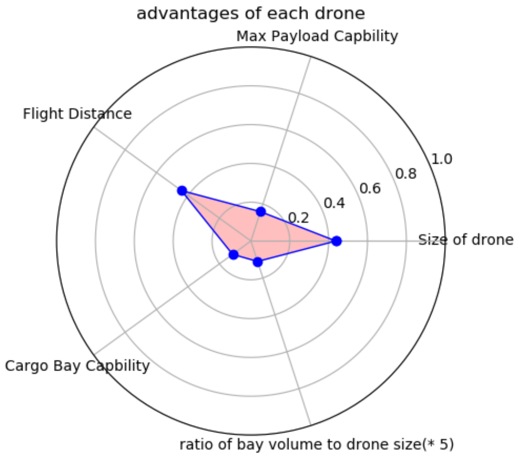

Figure 4: Capability radar chart of A

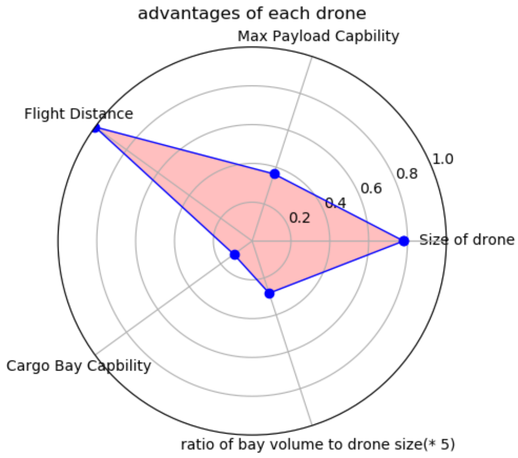

Figure 5: Capability radar chart of B

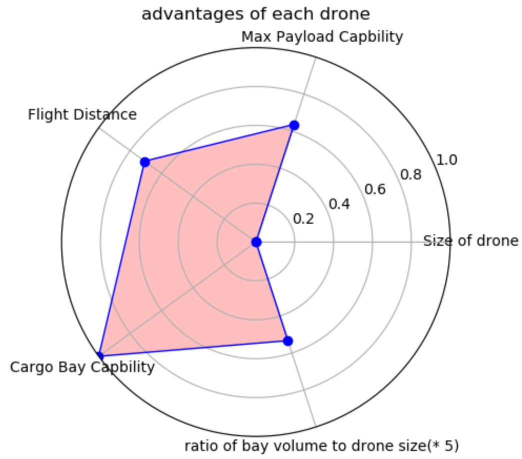

Figure 6: Capability radar chart of C

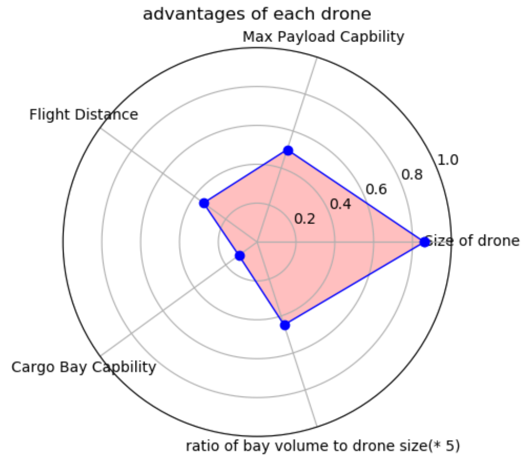

Figure 7: Capability radar chart of D

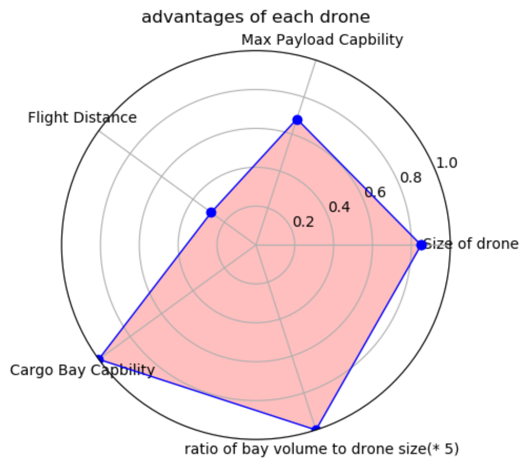

Figure 8: Capability radar chart of E

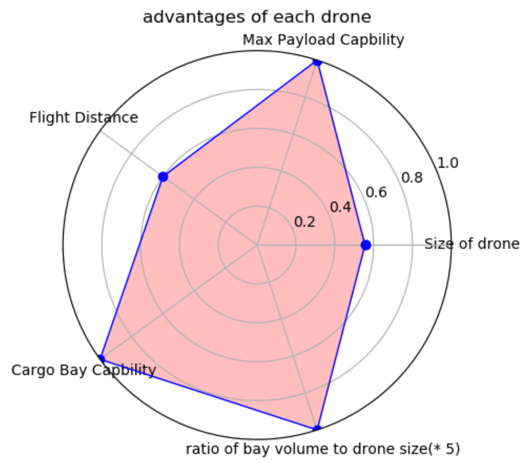

Figure 9: Capability radar chart of F

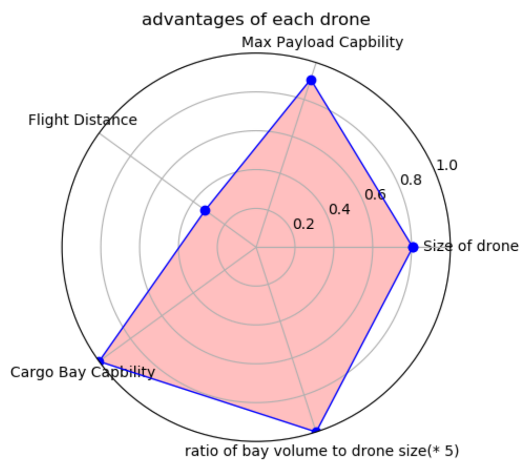

Figure 10: Capability radar chart of G

By observing the charts above, drone E, F and G almost have the same configuration but F does much better in continuation in the journey. Therefore, we can just take one drone among E, F and G who has the highest score on the billboard. To satisfy the requirement of video reconnaissance we need to consider the scope a drone can reach.

3.1.2 Calculate score of each type of drone

We set scores in 3 aspects, ratio of bay volume to drone size, max payload capability and max distance (speed×flight time). Note that for the "max payload capability" and "max distance" when calculate the total score of drone X, the max payload capability and max distance of drone X are divided by the largest number in that field. (22 means that drone F has the greatest ability of payload capability, and 52.7 means that drone B can fly the longest distance, 52.7 kilometer, among all drones)

Table 2: Weight distribution

Ratio	Payload Capacity	Flight Distance
30%	35%	35%

$$\textbf{Drone-Capability score} = \frac{Volume\ \ of\ \ dronebay}{drone\ \ size} \cdot 30 + \frac{payload\ \ cap}{22} \cdot 35 + \frac{distance}{52.7} \cdot 35$$

Reason for 30-35-35 proportion: after a roughly calculation, our group find that payload capacity of the drone is a bigger limitation when we try to add more MED to a cargo bay, so the weight of payload capacity is bigger than the ratio of bay volume to drone size. In addition, video reconnaissance is also a necessary function of drones so the weight of flying distance should be around the last two factors.

Table 3: Drone-Billboard

Drone Type	Score
A	21.71
B	49.42
C	50.25
D	32.14
E	55.16
F	63.19
G	59.72

Final choice : drone B,C,F.

3.2 Model 2: Three-dimensional 0-1 knapsack problem model

After selecting the three most powerful drones, the key-point is to design a scheme to place enough packages and drones into cargo containers. To solve this problem, we construct a three-dimensional 0-1 knapsack problem model inspired by the classic knapsack problem which involving dynamic programming.

Here is a brief explanation of classic knapsack problem: The knapsack problem arises whenever there is resource allocation with financial constraints. Given a fixed budget, how do you select what things you should buy? Everything has a cost and value, so we seek the most value for a given cost. The typical formulation in practice is the 0/1 knapsack problem, where each item must be put entirely in the knapsack or not included at all. Objects cannot be broken up arbitrarily, so it is not fair taking one can of coke from a six-pack or opening the can to take just a sip. It is this 0/1 property that makes the knapsack problem hard, for a simple greedy algorithm finds the optimal selection whenever we are allowed to subdivide objects arbitrarily. [2]

We improved the traditional knapsack problem and get this new model whose main idea to repeat the operation for three times because cargo container has three dimensions. Here is several steps in the three-dimensional 0-1 knapsack method:

First of all, establish a three-dimensional Cartesian coordinate system for the container like the figure below, define the lone side as x-axis, the wide side as y-axis, the high side as z-axis:

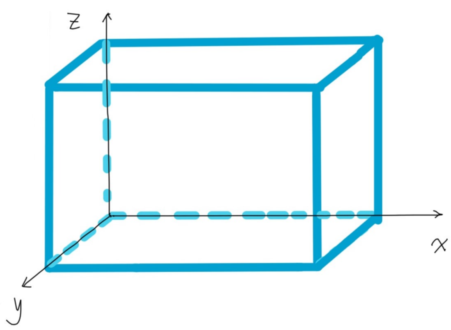

Figure 11: Three-dimensional Cartesian coordinate system

Then, execute the classic knapsack method for the z-axis:

$$\textbf{Goal: } maximize \sum_{i\in\{B,C,F\}} a_i v_i \qquad (inch)$$

$$\textbf{Condition: } \sum_{i\in\{B,C,F\}} a_i h_i \le 7'10'' = 94 \quad (inch)$$

In which a_i is an indicator variable:

$$a_i = \begin{cases} 0, & drone\ \ i\ \ is\ \ chosen \\ 1, & drone\ \ i\ \ is\ \ not\ \ chosen \end{cases}$$

And the recursive relations and optimal substructures of this dynamic programming is:

$$V(h) = max\{V(h-h_B)+v_B, V(h-h_C)+v_C, V(h-h_E)+v_E\}$$
$$V(k) = V(0) = 0\ \ for\ \ any\ \ k < min\{h_B, h_E, h_C\}$$

In which h_B, h_E, h_C are seperately B,C,E three types of drones' height:

$$h_B = 22 \quad h_C = 30 \quad h_F = 25$$

By using the conditions above, we can get two best optimal results, define them as α and β, which like a column along the z-axis in three-dimensional space intuitively. They represent two best combinations of drones to fill up the height of the container.

Next, execute this method for the y-axis:

$$\textbf{Goal: } maximize \sum_{i\in\{\alpha,\beta\}} a_i v_i \qquad (inch)$$

$$\textbf{Condition: } \sum_{i\in\{\alpha,\beta\}} a_i l_i \leq 19'3'' = 213 \quad (inch)$$

In which a_i is also an indicator variable:

$$a_i = \begin{cases} 0, & column\ \ i\ \ is\ \ chosen \\ 1, & column\ \ i\ \ is\ \ not\ \ chosen \end{cases}$$

And the recursive relations and optimal substructures of this dynamic programming is:

$$V(l) = max\{V(l-l_\alpha)+v_\alpha, V(l-l_\beta)+v_\beta\}$$
$$V(k) = V(0) = 0\ \ for\ \ any\ \ k < min\{l_\alpha, l_\beta\}$$

By using the conditions above, we can also get two best optimal results, define them as l_1 and l_2, which like a layer along the y-axis in three-dimensional space intuitively. They represent two best combinations of drones to fill up a two-dimensional plane of the container.

Finally, also execute this method for the x-axis:

$$\textbf{Goal: } maximize \sum_{i\in\{l_1,l_2\}} a_i v_i \qquad (inch)$$

$$\textbf{Condition: } \sum_{i\in\{l_1,l_2\}} a_i l_i \leq 7'8'' = 92 \quad (inch)$$

In which a_i is also an indicator variable:

$$a_i = \begin{cases} 0, & plane\ \ i\ \ is\ \ chosen \\ 1, & plane\ \ i\ \ is\ \ not\ \ chosen \end{cases}$$

And the recursive relations and optimal substructures of this dynamic programming is:

$$V(w) = max\{V(w-w_{l_1})+v_{l_1}, V(w-w_{l_2})+v_{l_2}\}$$
$$V(k) = V(0) = 0\ \ for\ \ any\ \ k < min\{w_{l_1}, w_{l_2}\}$$

By using the all conditions above, we can finally get the best optimal results, which could fill up the whole three-dimensional space. They represent the best combinations of drones to fill up a the container.

After solving the main problem for filling the containers with three kinds of drones in accordance with their values, there has to be some extra space unused (pink) that is close to door of container due to the setting of solution to knapsack problem. Besides, the vacant space is on the side where the door located. As the fact that the space left is quite limited and it does not affect the big picture, we can just design it by some simple calculation. And we do not make the last two columns here higher than door

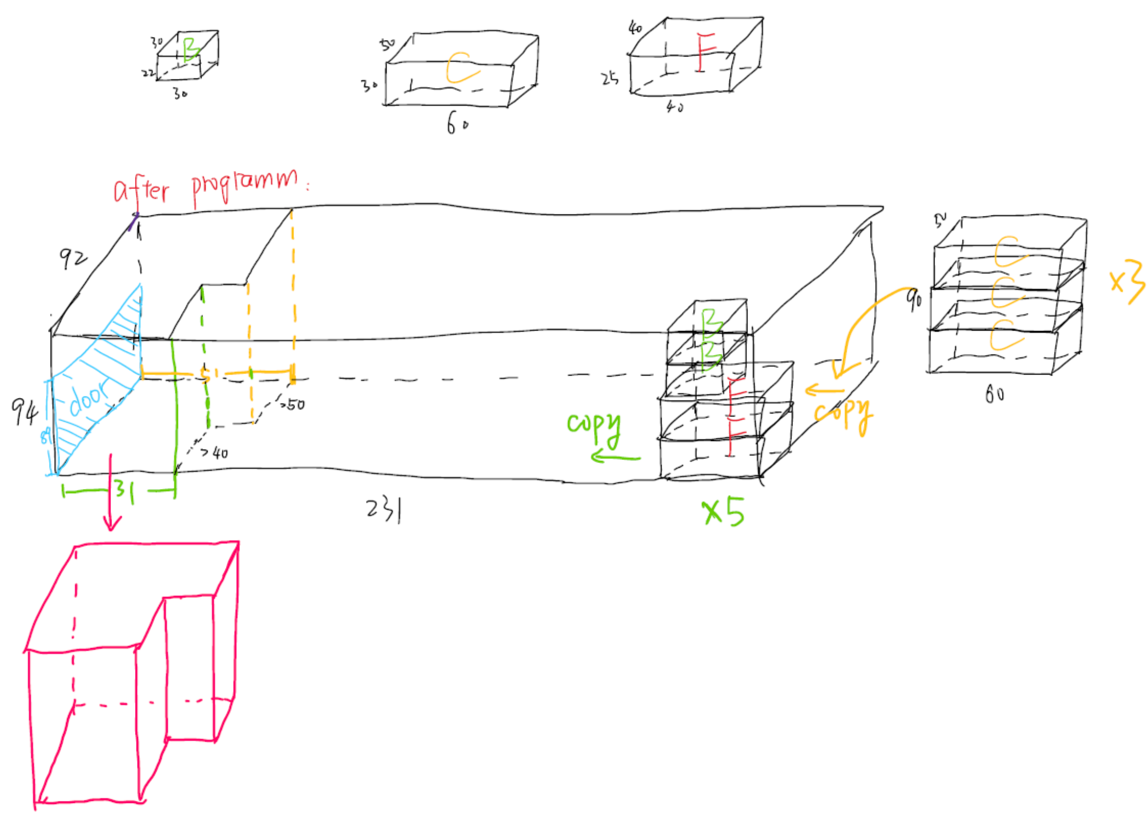

Figure 12: Concise illustration of the loading process(drawn by hand)

because if they are higher than door it will be hard to load and unload. Here we omit the details and give the final choices directly.

The figure below shows a concise illustration of the loading process:

And the final configuration of one cargo container is shown as below:

Table 4: Cargo container configuration

Drone Type	Number
B	14
C	9
F	13

This is the answer to problem A and drone C,F will carry out tasks of delivering medical packages while the drone of type B will carry out tasks of reconnaissance.

3.3 Model 3: Three-center distributed model

In problem B, we have 5 destinations but 3 centers(cargo containers). Inspired from the idea of clustering algorithm, we consider cargo container as the cluster center, consider demand at five disaster points and road network route planning as weighting factors, execute cluster analysis on the five points.

The five destinations is shown as below(the points were generated by MATLAB):

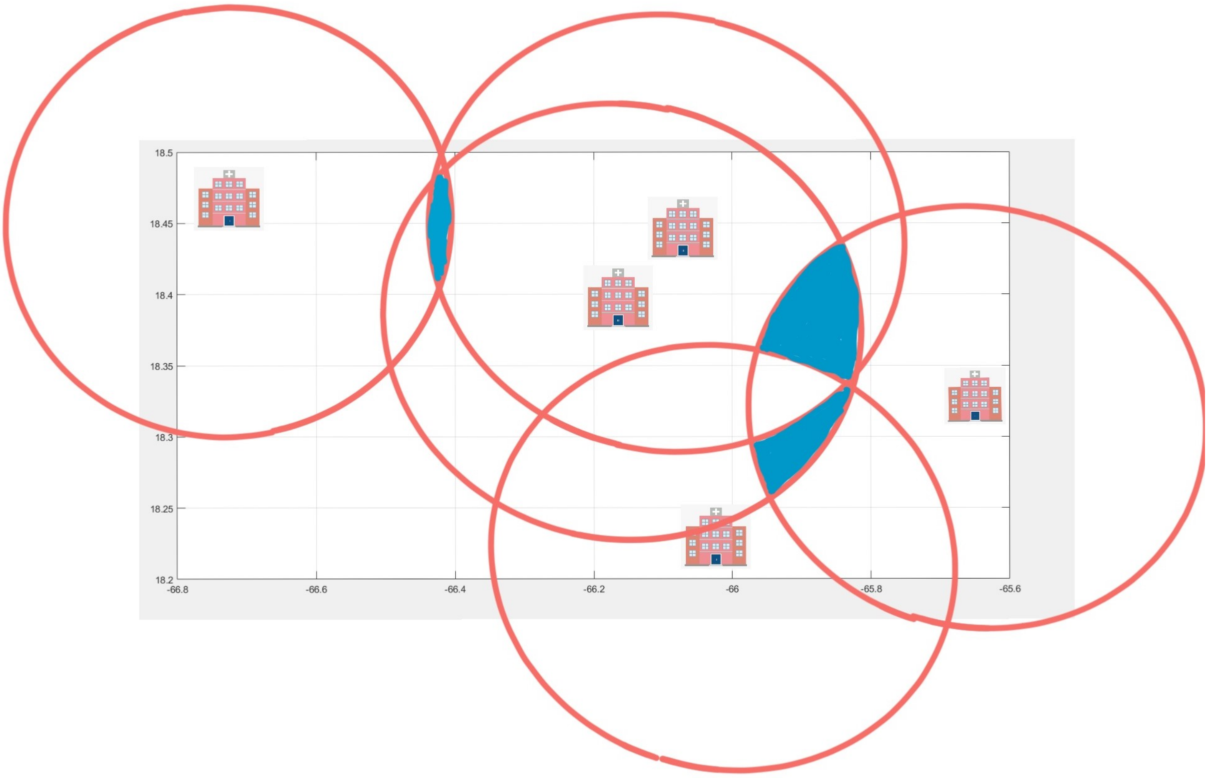

Figure 13: Five destination shown in the map

In our model, we consider the five medical center firstly and we need to meet the demand of medical packages. We draw a circle, whose radius is the flight distance of drone C(37 km). This is because we have chose drones of type C,F as the cargo drone and their fight distance C's flight distance. So as long as one container is located within the scope of the circle, this medical center's demand could be satisfied.

In figure 13, there are five circles, these five circles divide the entire map into multiple individual areas. We mark these areas as c_1 to c_n and define c_i represents the the number of circles this area belongs to:

$$c_i = \sum_{j=1}^{5} r_j$$

in which r_j is an indicator which shows whether this area is in circle j:

$$r_j = \begin{cases} 1 & if \;\; c_i \;\; is \;\; in \;\; circle \;\; j \\ 0 & if \;\; c_i \;\; is \;\; not \;\; in \;\; circle \;\; j \end{cases}$$

And we want to find the optimal solution of picking three areas to place containers, so our goal is:

$$\textbf{Goal:} \quad maximize(c_i + c_j + c_k)$$

In which c_i, c_j, c_k are three areas we chosen.

In order to maximize utilization of containers, it is not difficult to imagine that the three containers should be as far as possible. Without loss of generality, we may wish to assume that the three areas we choose should not be adjacent. With this restriction, we can finally decide the three areas to place containers which has been shown in figure 13.

After determining the areas, we can say we have met the requirements of medical packages. Then we need to judge the exact location by the constraint of video route destination. Base on the problem A, we have chosen drones of type B as the scout drones, so we can also draw the reconnaissance scope for each container, which is also a circle whose radius is drone B' flight distance. The figure 14 shows an abridged general view of containers:

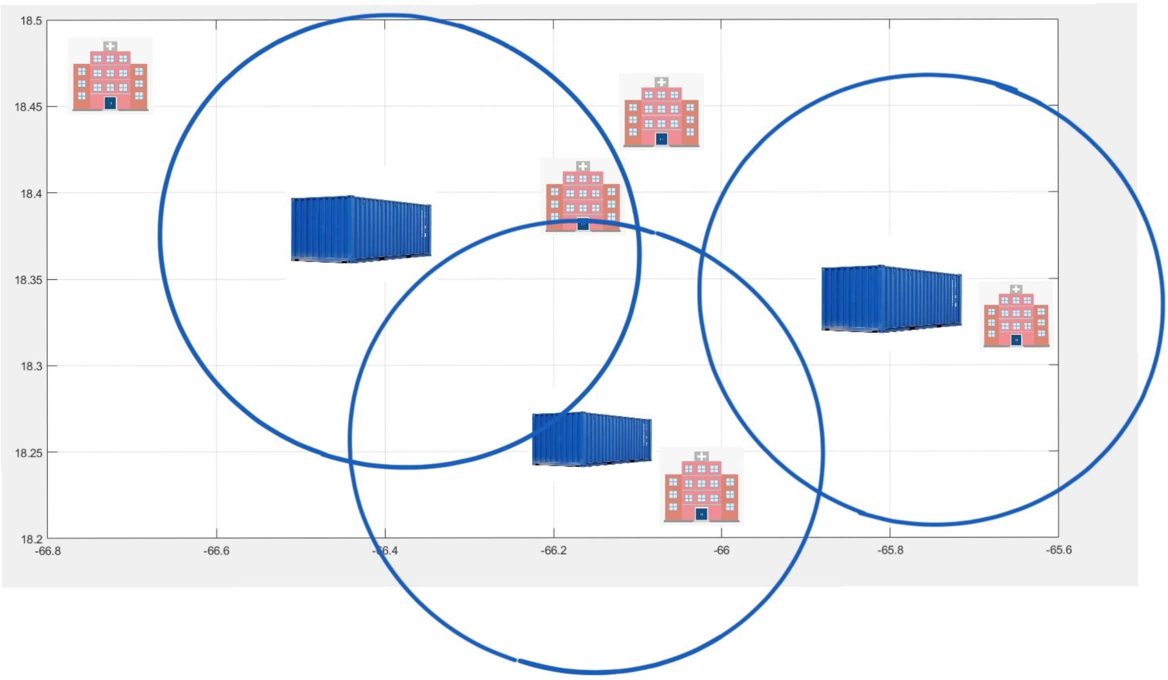

Figure 14: Abridged general view of containers

Now, we need to decide the exact position of the three containers and our goal is to scout more areas as much as possible which could be represented as:

$$\textbf{Goal:} \quad maximize\ the\ total\ area\ of\ three\ circles\ covering = A$$

In order to simplify the calculation and maintain the correctness of the result, we can make the following approximation:

$$A \propto the\ area\ of\ the\ triangle\ made\ up\ by\ the\ three\ containers$$

So we just need to calculate the area of the triangle, we take the steps as below:

1. Define three possible areas as A_1, A_2, A_3.

2. Assume latitude and longitude of three containers to be $(x_1, y_1) \in A_1, (x_2, y_2) \in A_2, (x_3, y_3) \in A_3$. Mark three vertices of this triangle as c_1, c_2, c_3

3. Use Helen formula to calculate the area:

$$S(\Delta c_1c_2c_3) = \sqrt{p(p-c_1c_2)(p-c_2c_3)(p-c_3c_1)}$$

$$p = \frac{1}{2}(c_1c_2 + c_2c_3 + c_3c_1)$$

$$c_1c_2 = 6370 \times \frac{\pi}{180} \times [\arccos(x_1 - x_2)\cos y_1 \cos y_2 + \sin y_1 \sin y_2]$$

$$c_2c_3 = 6370 \times \frac{\pi}{180} \times [\arccos(x_2 - x_3)\cos y_2 \cos y_3 + \sin y_2 \sin y_3]$$

$$c_3c_1 = 6370 \times \frac{\pi}{180} \times [\arccos(x_1 - x_3)\cos y_1 \cos y_3 + \sin y_1 \sin y_3]$$

4. Find the three points to maximize $S(\Delta c_1c_2c_3)$.

Using this model, we can decide the best optimal location of the three containers are:

Table 5: Cargo container location

Index	Latitude	Longitude
1	18.45	-66.45
2	18.43	-65.85
3	18.27	-65.93

3.4 Model 4: Drone configuration model

Finishing 2 problems above, we have 3 optimal locations for containers in our model. Roughly each container is responsible for 3 hospitals which is shown in **table 7** and **figure 15**:

Table 6: Container-Hospital relation

Container 1	Container 2	Container 3
Arecibo	Bayamon	Bayamon
San Juan	San Juan	Fajardo
Bayamon	Fajardo	San Pablo

To simplify the model, we decide to allocate assignments to each container in the following method. If we see MED1 as a unit along its volume, volume of MED2 is about the double of MED1 and volume of MED3 is about triple of MED1. We consider their weight the same way, and their weight will be 1, 1 and 1.5. here we definite a term named “cost” which measures the effort we will take to transport this medical package. The total cost of this scenario is:

$$Total \;\; cost = 7 \times 4 + 2 \times 2 + 4 \times 3.5 = 46.0$$

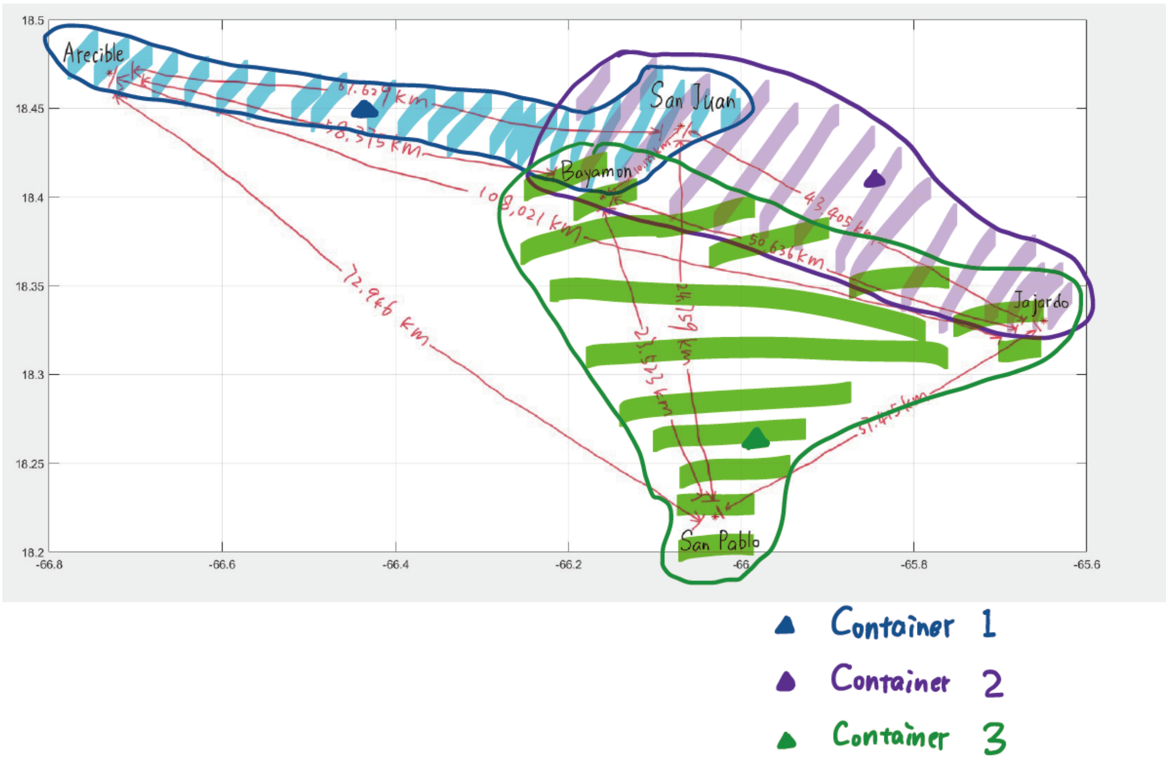

Figure 15: Container-Hospital relation diagram

$$\frac{Total\ \ cost}{3} = 15.333$$

Therefore if we allocate approximately 15 units cost to each container, the stress on three containers will be relatively balance.

Table 8 is one way of allocate balance stress on each container:

Table 7: Each container's mission

Container	Mission	Cost
1	MED1 in Arecibo MED1 in San Juan MED1 in San Bayamon	16
2	MED2 in San Juan MED2, MED3 in Bayamon MED2 in Fajardo	14.5
3	MED1 in Fajardo All MEDs in San Pablo	15.5

This method of distribution avoids the situation that one container needs to handle all three MEDs' combination, instead, there are most 2 types medical packages one container need to prepare. This dramatically reduce the difficulty of how to allocate medical packages to drones.

By some simple calculation, we can get the load capability of C,F types:

Table 8: Each container's mission

Type	Load Capability
C	7 MED1 or 7 MED2 or 4 MED3
F	8 MED1 or 11 MED2 or 7 MED3

Above all, the final result is:

- Container 1:
  Loading strategy: All drones are loaded with as many MED1 as possible.
  Maximum loading:
  $$7 \times 9 + 8 \times 13 = 167 \ \ \textbf{MED1}$$
  Lasting days :
  $$\frac{167}{4} \approx 41 \ \ days$$
- Container 2:
  Loading strategy: **We want the ratio of MED2 to MED3 approaches** $\frac{2}{3}$. All droneC are loaded with MED2, all droneF are loaded with MED3.
  Maximum loading: 63 MED2, 91 MED3
  Lasting days: min63/2, 91/3 ≈ 30 days
- Container 3:
  Loading strategy: **We want the ratio of MED1 to MED3 approaches 1/1.** All droneC and 3 droneF are loaded with MED1 =77 MED1. The left 9 droneF are loaded with MED3 = 77 MED3
  Maximum loading: 77 MED1, 77 MED3
  Lasting days: 77/2 = 33 days

As stated above, there are at most 2 types medical packages per container needs to handle, and filling each cargo bay with one type medical package is enough to provide a pleasing amount. Therefore, the type of medical packages a certain drone will be loaded is only decided by its location instead of its drone type.

The delivery routes are shown in figure 16 below:

All droneB in the fleet is used for video reconnaissance, each container has 14 droneB, so each droneB is responsible for a fan area whose central angle is roughly $25.71°$ and radius is 52.17 km.

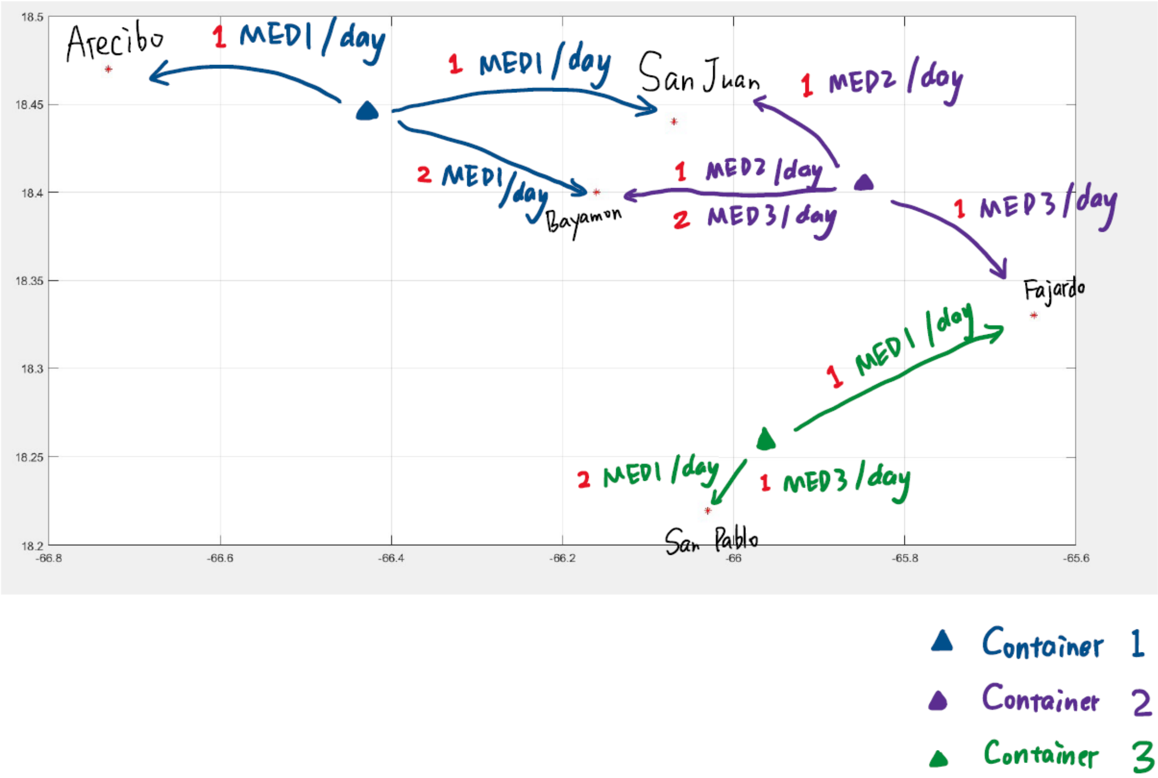

Figure 16

Above all, we give a final result of configurations of cargo containers and drones of the whole problem:

- Container 1:
  Place it to (18.45, -66.45)
  Load 14 droneB, 9 droneC, 13 drone F
  All drones load MED1, total 167 MED1.
  Supply for Arecibo, San Juan and Bayamon.
  Lasting days: 41 days.

- Container 2:
  Place it to (18.43, -65.85)
  Load 14 droneB, 9 droneC, 13 drone F
  All drones of type C load MED2, all drones of type F load MED3.
  Supply for Bayamon, Fajardo and San Juan.
  Lasting days: 30 days.

- Container 3:
  Place it to (18.27, -65.93)
  Load 14 droneB, 9 droneC, 13 drone F
  All droneC and 3 droneF are loaded with MED1. The left 9 droneF are loaded with MED3.
  Supply for Bayamon, Fajardo and San Pablo.
  Lasting days: 33 days.

4 Robustness Analysis

We take some easy examinations to check the robustness of the model:

Sensitivity: First, we choose drones according to their configurations quite comprehensively, therefore, if there are new type of drones come to market, we can still easily decide whether we should add them to the fleet. Second, the location of container is firstly determined by location of hospitals, so if there is some change in hospital location or new hospital appears, our model will response agilely. At last, if there is an increase or decrease for a certain MED in a certain hospital, we can change current method of allocating MEDs without making much sacrifice because most hospitals are not supported by one container, we can make a chain reaction to allocate resources to offset the outbursts.

Insensitivity: We selected the drone mostly according to their configurations, and requirement in reality is not considered importantly, therefore, if some situation do need many types of drones work together, our way of selecting drones may not that satisfying.

5 Strengths and Weaknesses

5.1 Strengths

1. According to our "drone billboard" model and "three-dimensional 0-1 knapsack problem" model, we reduce the types of drones to 3, which simplifies the problem of filling containers with drone, and this makes the problem solvable for computer and human brain. Note that human brain just needs to do quite simple jobs which are residual problems after the computing of computer. Also, these two models are combined to take all factors of a drone into consideration to assess its ability under this scenario.
2. When dealing with the problem of choosing location for containers, "three-center distributed" model settle the problem of both delivery of medical packages and support of video reconnaissance.
3. Each container is not responsible for one single hospital and most hospitals is not supported by one container. This also gives HELP Inc. more flexibility to change strategy in case of outbursts.

5.2 Weaknesses

1. The distribution of containers is more dominated by where hospitals are. Thus, it may result in the issue that some area where there are no hospitals may be unreachable for drones. In this scenario the southwest corner of the island is a blind spot of our design because we put more significance on delivery of medical packages.

2. When choosing the drones, we did not consider whether this drone in the fleet will increase the utilization of container. Therefore, the combination of drone B, C and F may not be the best combination to fill the containers up.

6 Memo to the CEO of HELP, Inc.

To: the Chief Executive Officer of HELP,Inc.

From: an MCM team

Date: January 28, 2019

Subject: Some suggestions on DroneGo:the transportable disaster response system

Mrs. CEO,

We are a MCM team who are dedicated in designing a transported disaster response system(DroneGo) which meets your company's demand, and we are going to share our investigation during recent research. We sincerely hope our work can make a little help to your company.

In order to make our research closer to reality world, we set out to simulate the situation of the Puerto Rico catastrophe in 2017. What we have known about your company's DroneGo plan before starting work are:

- A map of Puerto Rico.
- Three types of medical packages: MED1,MED2,MED3.
- Eight types of rotor wing drones: A,B,C,D,E,F,G,H.
- Five medical center's demand and location.
- Size of ISO cargo containers.

In order to design a most effective disaster emergency response system, we build several intuitively models which carry out different tasks. The mainly work we have done could be separated into three parts shown as below:

1. Design a drone fleet, set of medical packages and associated packing configuration for each ISO cargo container.
   We build two models to solve this problem. One is called **Drone-Billboard**, as the name suggests, it gives a rank list of those 7 drone types and top three are B,C,F. The other one is called **Three-dimensional 0-1 knapsack problem model**, this model helps us to load the drones into the containers and we directly give you the final result:
   Each cargo container should have 14 B drones, 9 C drones and 13 drones.
2. Determine the location of the three containers on the island to meet each hospital's demand and cover as many reconnaissance areas as possible.
   We have a model which is called **Three-center distributed model** to solve this problem. After doing some simplification and calculation, we get the three containers' coordinates as below:
   (18.45, -66.45), (18.43, -65.85), (18.27, -65.93). (The previous number is latitude and the later number is longitude)

3. Design the drone payload packing configurations, delivery routes and schedule for each type of drone and provide a drone flight plan.
   We construt **Drone configuration model** to work out this problem, and the final result is given at the end.

Above all, we give you a clear recommendation of configurations of cargo containers and drones:

- Container 1:
  Place it to (18.45, -66.45)
  Load 14 droneB, 9 droneC, 13 drone F
  All drones load MED1, total 167 MED1.
  Supply for Arecibo, San Juan and Bayamon.
  Lasting days: 41 days.
- Container 2:
  Place it to (18.43, -65.85)
  Load 14 droneB, 9 droneC, 13 drone F
  All drones of type C load MED2, all drones of type F load MED3.
  Supply for Bayamon, Fajardo and San Juan.
  Lasting days: 30 days.
- Container 3:
  Place it to (18.27, -65.93)
  Load 14 droneB, 9 droneC, 13 drone F
  All droneC and 3 droneF are loaded with MED1. The left 9 droneF are loaded with MED3.
  Supply for Bayamon, Fajardo and San Pablo.
  Lasting days: 33 days.

Please let us know if you have any questions.

Yours sincerely,

An MCM team

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