For office use only	Team Control Number	For office use only
T1 ________	**1925006**	F1 ________
T2 ________		F2 ________
T3 ________	Problem Chosen	F3 ________
T4 ________	**B**	F4 ________

2019
MCM/ICM
Summary Sheet

Auto Life-Saver

Summary

As Artificial Intelligence develops, drones are helping to save lives. The application of drones in disaster response systems is very broad, and they could carry needed medical supplies and conduct video reconnaissance. Also, the advantages of using drones in disaster relief are obvious, drones could be deployed quickly, access to the area that is nearly impossible to reach, and are capable of executing several missions at the same time.

In a disaster response system containing drones, reasonable deployment and arrangement of drones could enhance the efficiency of disaster relief. Therefore, in this problem we will create a model to support a transportable disaster response system called "droneGo" to satisfy the requirements of medical supplies and video reconnaissance in Puerto Rico.

We create two models. k_2 Model has two different locations while k_3 model has three different locations to place ISO cargo containers. And in each model, we discuss normal sub-model and optimized sub-model, and provide plans of packing configurations and flight fleet.

There are three main problems in our modeling process. The first is locating ISO containers, we analyze it using the method k-mean clustering; the second part is scheduling delivery plan, we introduce some variables, make assumptions and compare the solutions considering many factors; the third one is solving packing configuration problems which is the same as bin packing problem, and we solve it by designing and running programs in java, PHP and R programming languages.

Contents

1 Overview

Background

The storm that hit Puerto Rico in 2017 produced damages not only to buildings, home and roads, but also to the island's cellular communication networks. Demands for medical supplies, video reconnaissance and other non-governmental organizations' (NGOs) relief operations.

Restatement of the problem

Transportable disaster response system is used to deliver medical supplies and provide high-resolution aerial video reconnaissance, and the system could be implemented during or after natural disasters. For designing such system, we use the data collected from the hurricane disaster that struck the US territory of Puerto Rico in 2017 to analyze the problem and create models.

This problem has 4 separate items to talk about:

- Standard ISO Container (i.e. droneGo transportable disaster response system)
- Candidate drones for droneGo Fleet
- drone Cargo Bay
- Emergency Medical Packages

The 3 main parts of the problem are:

- Identify the best location(s) of ISO cargo containers on Puerto Rico , i.e. the droneGo disaster response system, to provide sufficient medical supplies and video reconnaissance.
- Design the packing configuration of drones in each ISO cargo container and set of medical packages in each drone Cargo, that will meet the requirements of medical packages in different delivery locations after Puerto Rico hurricane.
- Provide the delivery routes, schedules and flight plans for drones to satisfy medical package requirements and enable the use of video cameras in each delivery location.

Overview of our work

- Analyze the problem. Talk about the quantity and type of the emergency medical packages required in distinct delivery location
- Find location(s) of Standard ISO Containers, build corresponding packing configurations for drones and containers, and recommend flight schedules of drones.

- Consider the external factors that may impact our decision on packing configuration and flight fleet.
- Summarize the modeling results, conclusions and recommendations about applying models in other similar disaster scenario.

2 Analysis of the Problem

On the United States territory of Puerto Rico, the five anticipated delivery locations are clustered close enough for using drones to accomplish the relief in hurricane disaster scenario.

In this problem, We are provided with three containers of transportable disaster response system and specific requirements of medical packages in the five delivery locations. Start from these two conditions, we could calculate and arrange packing configurations and flight fleet.

Figure 1 shows the procedures of our modeling. Since there are three containers that could be sent to the same or several different locations, we should consider the problem under 3 situations: All 3 containers in the same location, 3 containers in two different locations, and each container in a different location.

Then under each situation, we will solve packing configuration of medical packages in drones and that of drones in ISO container. After that, we could achieve the optimized plan in a given time, considering characteristics and capabilities of drones and other external factors.

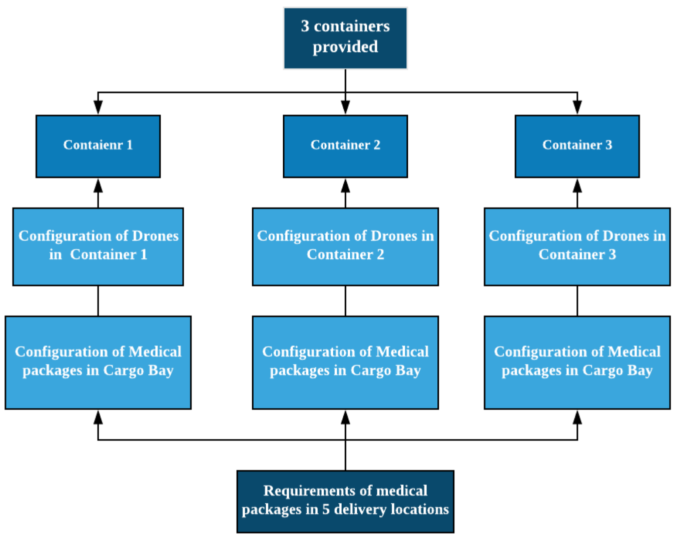

Figure 1: Analysis of the problem

3 Generalized Concept

Symbol	Definition
DIR	Demand Index Rate
FL_k	Flight-ability of the drone k
D_{ij}	Distance between a ISO container i and a delivery location j
K_m Model	The model with m locationsãĂĂ
n	Maintenance index (Number of maintenance period in each delivery)
t	Maintenance Multiplier (The number of days in each maintenance period)
Supply ratio	In every receipt, hospital receives different proportional of supply from different container.

Table 1: Generalized Concept in this Paper

In this model, we start from clustering the 5 anticipated delivery locations into several clusters considering both the geographical locations and the requirements of medical packages of each location.

3.1 Locations of ISO containers

First, the locations of ISO containers have to be inside a "rectangle", which covers all of the anticipated delivery locations.

Already have latitude and longitude of the five different delivery locations, the coordinates of expected containers' locations could be calculated and plotted on graphs.

We will use k-means cluster and compile some code in R programming language to compute the best locations. k-means clustering aims to partition n observations into k clusters, this problem has 5 observations and number of clusters between 1 and 3, in which each observation belongs to the cluster with the nearest mean.

Three containers could be sent to the same or several different locations. The three situations are:

1. All 3 containers are put in the center of the five delivery locations
2. Choose two locations, then one of the location has 1 container and the other has 2 containers
3. Choose three different locations and each location has exactly 1 container

After calculating the specific coordinates of containers' locations, we use python to plot the graphs.

In figure 2, the graphs plotted above, there are 5 pie charts which represent 5 different delivery locations and their requirements of medical packages. Red part represents Medical package 1, blue part represents Medical package 2, and green part represents Medical package 3. From the pie charts, we could see the proportion of requirement of

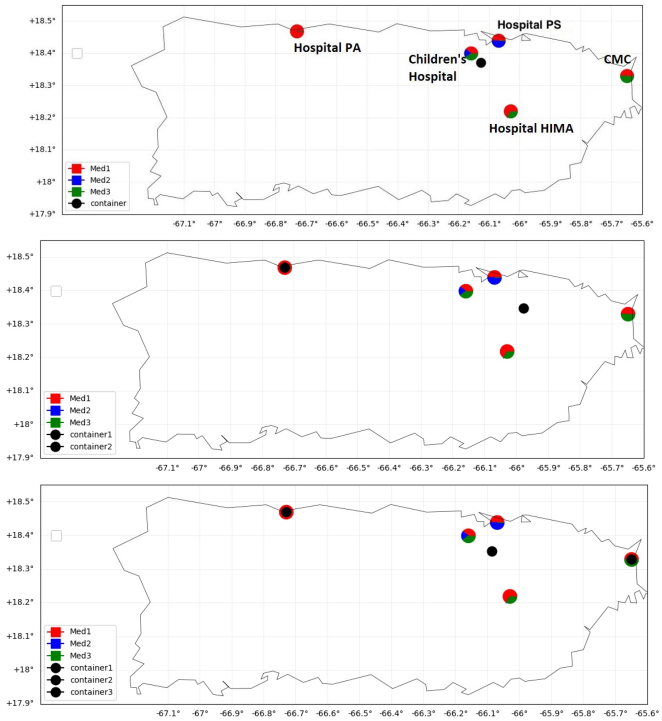

Figure 2: Containers' locations after geographical analysis

different type of medical packages directly. And the black points are expected locations of containers calculated based on coordinates and distance only.

However, this simplified calculation neglects many factors and limitations. The utilization of container will be limited if the container is located at the delivery locations that have extremum coordinates; the locations of containers could be set more reasonable if we consider the impact of the requirements of medical packages in distinct delivery locations; also, the relationship between containers' locations and the packing configuration of drones should not be ignored. These consideration will be used to improve the setting of containers' locations in the the parts below.

Therefore, the locations of ISO containers will be adapted after we consider the "importance" of each delivery location.

3.2 Demand index of each Delivery Location

In algorithm, "importance" of a node is represented by the nodes' weight. And in this problem, we use the similar idea. To describe the "importance" of each delivery location, we want to introduce a coefficient called DIR (Demand index rate) to each delivery location. The definition of DIR is

$$DIR_j = \sum_{i \in R_j} \frac{W_i}{V_i}$$

where R_j stands for the quantity of Medical package i required in location j, W_i stands for the weight of Medical package i, and V_i stands for the volume of Medical package i

which is calculated by $V_i = l_i \times w_i \times h_i$. (data of medical packages configuration is given in Attachment 5)

After computation, we can get

Delivery Locations	DIR
CMC	0.01301
Hospital HIMA	0.028929
Hospital PS	0.14082
Children's Hospital	0.03602
Hospital PA	0.00482

1

Table 2: The demand index rate of each hospital

3.3 The flight ability of each drone

For selecting the possible types of drones in each airline from potential candidate drones, We first compute the "Flight-ability" of each type of drone. "Flight-ability"(km) represents how far a single drone can fly. "Flight-ability" is defined as

$$FL_k = s_k \times t_k$$

where s_k is speed (km/min) of drone k , and t_k is the flight time (min) of drone k with no cargo. After computation, we could get

drones	Flight-ability(km)
A	23.33
B	52.67
C	37.33
D	18
E	15
F	31.60
G	17.07

Table 3: The flight-ability for each drone in ideal situation

3.4 Packing Configurations

So far, we are only talking about packing configuration theoretically. After all, the calculation and optimization are proceeded in the code.

In this problem, there are two sections require study of packing configuration. One of them is to find the best packing configuration of drones in ISO containers; the other is to find the packing configuration of medical packages in drones.[1, 2]

We use PHP[6] language to proceed the calculation. And the general algorithm is :

Algorithm 1: Fitness evaluation

```
P = {(0, 0, 0)};
```

```
for i = 1 to n:
    Get the height H_{i-1} of convex hull of currently packed cartons;
    for P_j ∈ P do
        Calculate the index I_{P_j} ;
    if no extreme point can be selected then
        P = P ∪ {(0, 0, H_{i-1})};
        Calculate the index I_{P_(0,0,H_{i-1})} ;
    Select the extreme point P_j with highest index;
    Put carton i at P_j and delete P_j from set P ;
    Squeeze the carton along X-axis, Y -axis and Z-axis as much as possible,
    denote the new location as {(x_i, y_i, z_i)};
    Put carton i at {(x_i, y_i, z_i)};
    Add the left-front-bottom, right-behind-bottom and left-behind-top points
    of carton i as extreme points into set P ;
```

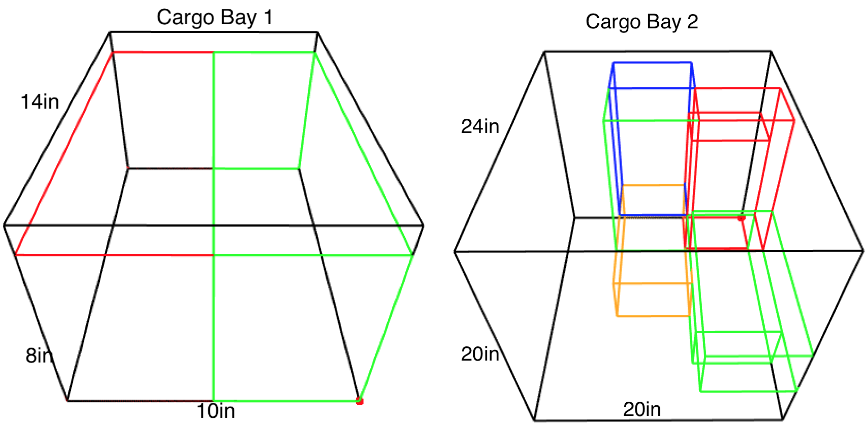

Figure 3: Both of figures show the max load of corresponding cargo bay. The left one is cargo bay 1, the right one is cargo bay 2. The madical material inside cargo bay is med3

Use above pseudo-code, the program can be implemented in most of programming language. Then input the size and max capabilities of cargo bay, weight and size of medical package. The program can simulate optimized solution for packing medical package. In simulation, two typical drones are chosen because of large capability and good flight-ability in their own category. For package inside drone, MED1 is chosen arbitrarily since the size and weight are similar among three package. The graph 3 shows cargo bay 1 can hold at most 2 MED1, and cargo bay 2 can hold at most 7 MED1. The packing constrain in cargo bay 1 is volume, in cargo bay 2 is weight. Similarly, using program can also calculate the drone packing configuration.

3.5 Key factors of drones selection on airlines

We use several different languages, including PHP[6], Java[7] and R[8] languages to find possible allocations of drones in airlines that could satisfy the requirements in delivery locations.

The flight-ability of each drone has been calculated in the previous section and it will help us to eliminate some candidate drones, because only the drones with sufficient flight-ability could take part in the flight fleet.

Given updated candidate drones and fixed requirements of medical packages in delivery locations, we run the code to output several possible allocations of drones.

Then, we need to choose the best allocation plan among all the possible plans. How to select the best allocation depends on the priority of drones.

- The ratio of the volume of medical package to the volume of the drone Cargo Bay

  To maximize the utilization of the bay's space, we want the maximum ratio of the volume to reduce any waste space. We are focusing on the volume of drone cargo bay, because each type of drone has only one corresponding type of Cargo bay.

- The total volume of drones

  In order to optimize our model, we want the ISO containers to load as many drones as possible, so we will choose the drones with less volume. Strictly speaking, data about dimensions of drones is not directly provided to us, but we could estimate the volume from the drones' shipping container dimensions.

- The total amount of drones

  We also want to minimize the cost of delivery and reduce complexity of system, which means we want to use the fewest number of drones. Fewer drones mean fewer operations are required, then HELP company can decrease the cost and time used in drone controlling and monitoring.

- The utilization of flight-ability

  As the drones fly with no return, we need the remaining flight-ability(i.e. original flight-ability - distance between the delivery location and container location) to be the least. But, this value can not be too small, because there are some factors require the drone flight-ability's extra tolerance. These factors include possible accident of drones, lower drones' flight-ability caused by weight of loads, and smaller speed because of dead wind. So, we introduce a variable $\gamma \in (0, 0.5]$, such that

  $$FL_k \geq (1+\gamma)D_{ij} \ \ \forall k, (i,j) \in S_k$$

  where FL_k stands for the ability of the drone k, D_{ij} stands for the distance between the container i and the demand point j, and S_k stands for the set of the airlines that drone k should accomplish.

- The video capability

  Since the requirements in the delivery locations include providing video reconnaissance, we have to make sure that the best packing configuration does not miss this goal. drone F is the only candidate drone that does not have the video capability. The only situation that may not satisfy the video requirement is that all of the drones fly to one delivery location are drone F. So when this situation happens, we will force a drone B to fly with drone F to ensure the provision of video.

From the factors we list above, we could even estimate the most popular drones. drone B will be very popular because of its smaller shipping container dimensions and the best flight-ability. drone C will also be used a lot because of its big max payload capability and the type of drone cargo bay. drone F is more complex, though it is lack of video capability, it has the best max payload capability, great flight-ability and middle shipping container dimensions.

The preparation for modeling is done, and it's time to start real model. We talked about the locations of ISO containers before, but we did not consider "importance" of each delivery location. Now, we could use DIR to relocate best locations of containers. Start from the situation that has all the three containers in the same location.

3.6 K_1 model

After identifying the the requirements of medical packages in each location, we can cluster the locations and divide them into three parts: right CMC node, middle three nodes, and left Hospital PA nodes.

Based on the physical locations, a.k.a latitude and longitude of anticipated delivery locations, together with their DIR, we can discover that When $k = 1$, the best location of the containers should simply be the weighted center (physical center with DIR consideration), which is located at: $(18.372, -66.128)$

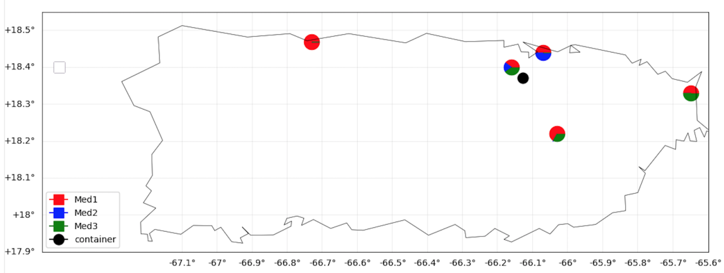

Figure 4: Containers' locations after DIS analysis of $k = 1$

Have gotten the best location of ISO container, we could proceed into figuring out the most suitable packing configurations of medical packages in drone cargo bay and those of drones in transportable ISO containers.

However, before executing the code, we should run the drone flight-ability check. Unfortunately, there are no drones have the sufficient flight-ability to deliver daily requirement of medical packages to left Hospital PA (Pavia Arecibo).

So, the K_1 model failed. This result is not surprising, because even if three transportable ISO containers locating in the same place could still ensure the medical requirements under some distribution of resources, it is still an extremely inefficient plan.

4 K_2 Model

4.1 Overview

When $k = 2$, our basic model will focus on fixed maintenance index n. And for each constant n, we will analyze the packing configurations of drones and containers after achieving the expected locations of ISO containers. Finally, we will try to maximize n that could fit the containers.

To remind the definition of maintenance index n, it is the number of maintenance period in each delivery. And maintenance multiplier t is the number of days in each maintenance period. The more intuitive meaning is that, the total number of days during which every delivery location could achieve its requirement of medical packages is $n \times t$.

The reason of introducing maintenance index in modeling is that when we are analyzing the problem, we realize that resources including containers, cargo bay, drones and medical packages provided are more than sufficient for each delivery location's daily requirement of medical supply.

So, we create two parts in one model. In the first part of the model, given a constant maintenance index n, we will provide a best plan of packing configuration of medical supplies in drone cargo bay, flight fleet and arrangement of drones in the containers. This part of the model will be useful for the decision makers. They could set the lasting time of disaster relief, and the model will give a specific plan of the whole disaster relief procedure.

While in the second part of the model, we will produce a plan that maximize the utilization of all the resources and output the largest possible value of n. This part of the model will be useful for the researchers. The total number of days during which every delivery location could achieve its requirement of medical packages is $n \times t$. The researchers of drones could compare our optimized number of maintenance days that we provide with the actual number of maintenance days, and work out the factors that reduce the efficiency, improve the performance of drones and Containers to advance the efficiency of droneGo's disaster relief.

4.2 Locations of the Containers

Considering the DIR of the delivery locations, it's reasonable to cluster the demands in such a way: regard the left 4 points and right 4 points as two cluster, since the middle three points have the greatest density and demand, so all of the three containers should be in charge of contributing the requirement of three middle points.

Under $k = 2$ situation, two containers are placed in one place, and the left one container is placed in another place. However, there could be two valid arrangements. If we claim the two places of containers' locations as location NO.1 and location NO.2, then one way of placement is two ISO containers are located in location NO.1 and one ISO container is located in location NO.2. And the left way of placement is obvious that two ISO containers are located in location NO.2 and one ISO container is located in location NO.1.

In this model, we will put two containers in location NO.1 which is on the right, and one in location NO.2 which is on the left. The reason of doing this supposition is that we notice that requirements of medical packages in delivery locations on the left cluster are much higher than those of delivery locations on the right.

Like we mentioned before, after rough estimate of the effect that could be brought from known resources, we realize that if we set the goal of the model as to satisfy only daily requirement in each delivery location, then the space of drones, drone cargo bay and container is wasted, and the utilization in this situation will be too low for the droneGo organization to accept.

One critical design of our model is that the medical packages sent to 5 delivery locations could all satisfy $3n$ days of locally requirements. Therefore, we make the assumption that each container will send n-day's medical supplies to each of the three middle delivery locations, and send $3n$-day's medical supplies to the 2 delivery locations that locate on the left and on the right of the map. Then, such arrangement will result in the situation that each delivery location will receive medical packages that satisfy its $3n$-days medical requirements.

4.3 Updated candidate drones and flight fleet

After comparing the Flight-ability of each drones and the distance of each airline, we can get the following table:

To simplify the problem, we will first set $\gamma = 0$. To remind the definition of the coefficientγ, $\gamma \in (0, 0.5]$, such that

$$FL_k \geq (1+\gamma)D_{ij} \ \ \forall k, (i,j) \in S_k$$

where FL_k is the ability of the drone k, D_{ij} is the distance between the container i and the demand point j, and S_k is the set of the airlines that drone k should accomplish.

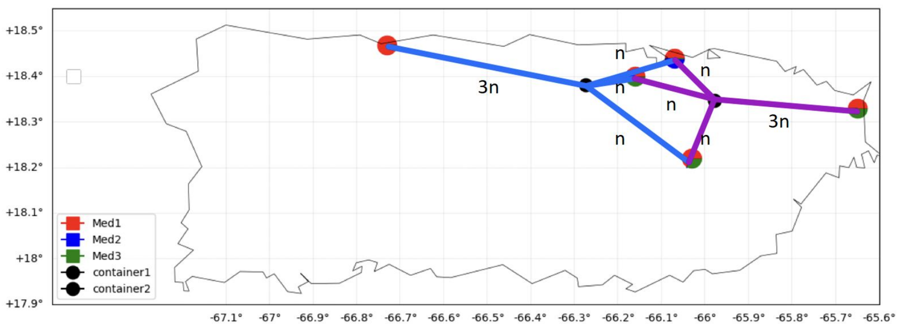

Figure 5: Containers' locations after DIS analysis of $k = 2$

Container	Demand Point	Distance(km)	drones that can reach
Container 1	Hospital HIMA	33.186	BC
	Hospital PS	23.717	BCF
	Children's Hospital	12.896	ABCDEFG
	Hospital PA	51.677	B
Container 2	CMC	36.474	BC
	Hospital HIMA	16.032	ABCDFG
	Hospital PS	14.943	ABCDEFG
	Children's Hospital	21.205	ABCF

Table 4: Distance from container1 and container2 to adjacent hospitals

And then, we can see from the figure that there are 8 possible routes from the ISO containers' locations to the anticipated delivery locations. If you have doubt about how do we decide these 8 routes as valid airlines and discard other possibilities, please check the table above again. If the distance between the delivery location and the ISO container's location overruns flight-ability of any drones, this airline is discarded.

4.4 Allocation of drones

And according to the requirements of medical packages on each delivery location, we will find the best allocation of the drones to accomplish the daily requirement of medical supplies.

Algorithm 2: Packing Algorithm

```
pack_med_into_drone(supplied_drone, required_med, dist_to_all_hospital):
    useful_drone = use_distance_to_remove_drone();
    add_med_into_Templist()
    drone_number = pack_item_in_Templist()
    return pack_info

main_function (constant, proportion_ratio_for_all_hospital ):
    for n = 1, ... k:
        break_flag = True
        for container in all containers:
            for hosp in container:
                # ration depends on the distribution strategy
                add required med into list
            pack_med_into_drone(supplied_drone, med_list, Dij)
            # similar with pack_med_into_drone function
            pack_drone_into_container(drone_number)
            if (required container > given container):
                break_flag = False
        if (break_flag == False):
            break
    The maintenance day is n * constant
```

For completing the first part of the mode, we set the value of n as a constant from integer 1. And the code similar to the pseudo-code above gives us a best packing configuration of drones in ISO containers each time. We plot the detailed arrangement of drones in the figure below. The graph is reasonable since we can see the increasing trend of number of drones as the total maintenance days increases.

4.5 Video Reconnaissance

We have talked a little about this point before. In order to meet the demand for video reconnaissance, although the drone F has absolute advantage in carrying large amount of cargo and maintain good flight-ability, it cannot accomplish its duty of bringing video singly. So if there exists a plan of airline that only consists of drone F, we will add a drone B to that line. drone B is chosen because according to the volume of the drones,drone B is the one with minimum volume. To clarify, even add another drone, we will still

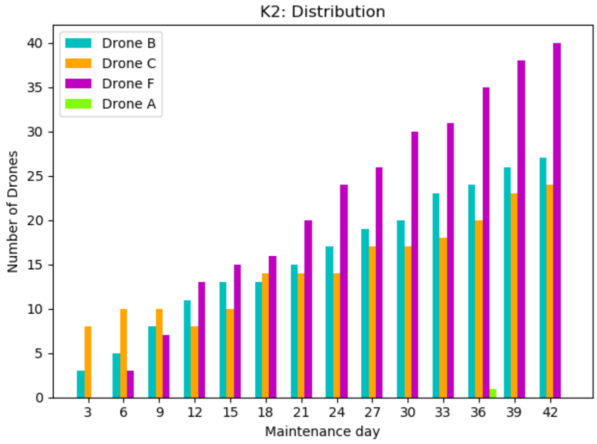

Figure 6: Number of each drones for different Maintenance Days

check whether such packing configuration is valid before output this set, so this design adaption will not alter validity of the result.

4.6 Maximize the efficiency of each delivery

To maximize the efficiency, we simply convert the goal of the model from providing arrange packing configurations and schedules of flight fleet to finding the maximum n period given the fixed amount of medical packages. And in our program, the program stops at $n = 15$, which implies that $n_{max} = 14$.

Therefore, when $n = 14$, we have the optimized solution under the situation $k = 2$, which means we can provide the amount of medical packages to meet at most $3 \cdot n = 42$ days demand of each delivery location.

When $n = 14$ and $k = 2$, in each container we have the following packing configuration. From the graph, we can see that the demand of each type of drones are distributed evenly in the three containers, and the space of the container is used in optimized plans. The number of drone B in Container 2 and Container 3 have little amount. Although drone B has the longest flight-ability, the graph implies that drone B is not very useful in container 2 or Container 3. So, the existence of drone B in these two containers may be because drone B is used to fly together with drone F. Remember we mentioned before that drone F could not provide video by itself, but with a helper drone, the group could carry not only much more amount of medical packages but also video for communication.

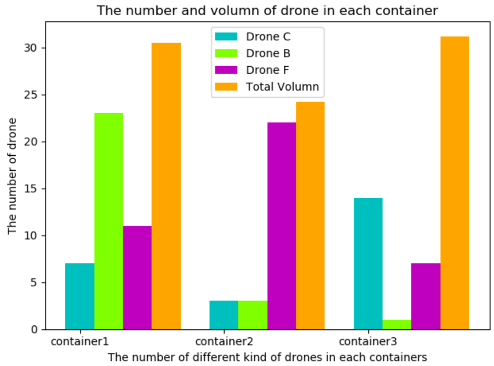

Figure 7: Number of each drones in different containers

4.7 Sensitivity Analysis

Now, some constant values setting in previously need to be considered as variable, The program will run the whole model again to provide new optimized packing configuration. For example, the flight-ability in table 3 only consider the ideal situation. In real situation, many factors such as the weather condition, weight of on-loading packages will affect(mostly decrease) the flight-ability of drones.

The flight-ability has direct relationship with γ, in above calculation, the γ is set to 1. In this section, the γ will be tuning. Finally, the program output a relationship between γ and maintenance day. In the simulation, only drone B can accomplish the requirements in Hospital PA, but the distance difference from Container 1 to Hospital PA and the flight-ability of drone B is pretty small.

$$\begin{aligned}\delta d &= |\text{flight-abiliity of drone B} - \text{distance from container1 to PA}| \\ &= 52.67 - 51.667 = 1.00\end{aligned}$$

Since the weight of cargo or bad weather could affect the flight-ability of drones, we may overestimate the actual flight-ability of drone B. So, we should alter the location of Container 1 to ensure there exists drone can reach hospital PA and the arrangement of drones will meet the demand in that hospital. Consider both flight-ability and value of γ, the revised model will ensure drone B can reach hospital and output optimized configuration.

From graph 8, the relationship is a little surprised, the decreasing flight-ability leads to longer maintenance day. After reviewing the data of different types of cargo bay, using the cargo bay1 is more efficient than using the cargo bay2. In following analysis, choosing method is same as above, drone B with cargo bay1 and drone C with cargo bay2.

$$\text{Volume ratio} = \frac{V_{\text{drone B}}}{V_{\text{drone C}}} = \frac{30 \times 30 \times 22}{60 \times 50 \times 30} = \frac{1}{4.54}$$

$$\text{Mean capacity ratio} = \frac{1}{3} \times \sum_{i=1}^{3} \left(\frac{C_{i,\text{drone B}}}{C_{i,\text{drone C}}}\right) = \frac{1}{3}\left(\frac{2}{7} + \frac{2}{4} + \frac{4}{7}\right) = \frac{1}{2.21}$$

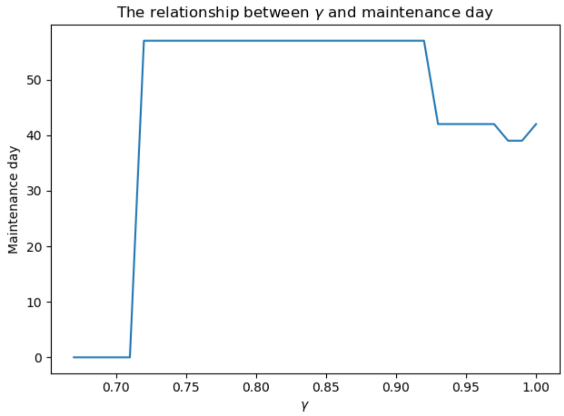

Figure 8: The relationship between γ and maintenance day

where i represents the type of medical packages, $C_{i,\text{drone B}}$ represents the max number of medical i which drone can take. These two ratios show a situation of both types of drones delivering max capacity of medical package. Suppose cargo bay1 can deliver 1 unit of medical package by using 1 unit of container volume, then cargo bay2 needs 4 units of container volume to deliver 2 units of medical package. The efficiency of cargo bay 1 is higher than cargo bay 2. However, the program chooses drone C instead of drone B. This is due to the big volume capacity of drone C. The program tries to minimize the total number of drones. Under this constrain, choosing drone C is better than drone B.

From the figure 8, the maintenance day is increasing when $\gamma <= 0.92$, which means after flight-ability of drone C decrease 8%, the drone C cannot reach any of the hospitals. Then the program must choose drone B to deliver packages to hospital PA. Then much more free space can be used to store more drones in container 1. From figure **??**, the location 2(including container 2 and 3) has more space to store medical packages. Since both locations have more space to store packages, the whole system can maintain a longer time than before.

5 K_3 Model

5.1 Overview

Similar as $k = 2$, the program we write will take three input locations (of the ISO containers). The only difference is that here, three nodes are in three different locations. Two locations from k_2 model will still be used as locations in k_3 model. One more location will be at the k-mean cluster center of three hospitals at the center of disaster area. The third container will only provide medical packages to three adjacent delivery locations.

5.2 Locations of Container

The middle ISO container provides medical supplies only to the middle three delivery locations, and the container (on the left) provides medical packages to Hospital PA and the three center delivery locations, while the container (on the right) provides medical packages to Hospital CMC and the three center delivery locations.

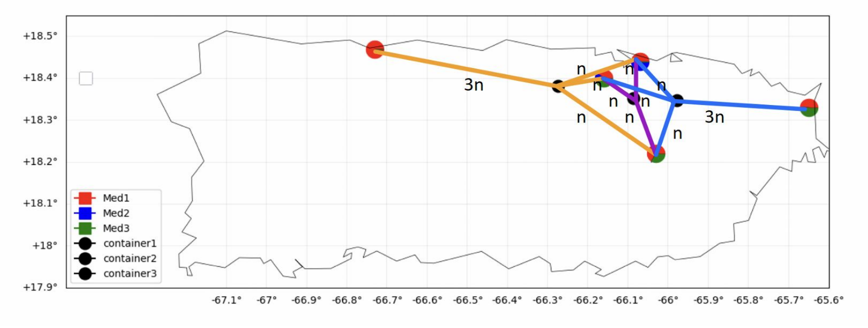

Figure 9: Containers' locations after DIS analysis of $k = 3$

After comparing the distance of each airline and the flight-ability of drones, we could decide current possible candidate drones. Since the data of airlines from Container1 and 2 are the same as that in $k = 2$ model, we will only show the data of airline from container 3 here, which is

5.3 Delivery and Packing Configuration

The main procedure of $k = 3$ modeling will be the same as that in $k = 2$ modeling. The only difference is that the location of one container is moved to the center of three hospitals in the middle of map. The reason is that large requirement of medical packages coming from middle three hospital, approximately 77%. Put one container at the center of these three hospitals can hugely increase the efficiency of the HELP system. The distribution proportion also changed. The below table 7 shows the how to change the supply ratio. For simplicity, one container need to provide one unit of medical package to neighbourhood hospitals at one time. The left and right containers need provide two extra units of packages to hospital PA and CMC. So that at one time, all of five hospital can receive 3 unit of medical packages.

Figure 10 shows packing configuration of drones in different day and the usage information of containers at the condition of longest maintenance day.

We can observe from figure 10 that the supply of medical packages could support for requirement of delivery locations for at most 27 days. This value is much smaller than the optimized maintenance day in k_2 modeling.

The above figure 10 also shows the details of packing configuration of drones in

Container	Demand Point	Distance(km)	drones that can fly
Container 3	Hospital HIMA	16.717	ABCDFG
	Hospital PS	10.452	ABCDEFG
	Children's Hospital	9.890	ABCDEFG

Table 5: Distance from container3 to adjacent hospitals

Model	Container ID	Location	Supply ratio
K_2 model	Container1	Left	1
	Container2/Container3	Right	2
K_3 model	Container1	Left	1
	Container2	Right	1
	Container3	Middle	1

Table 6: Adjust supply ratio from different location

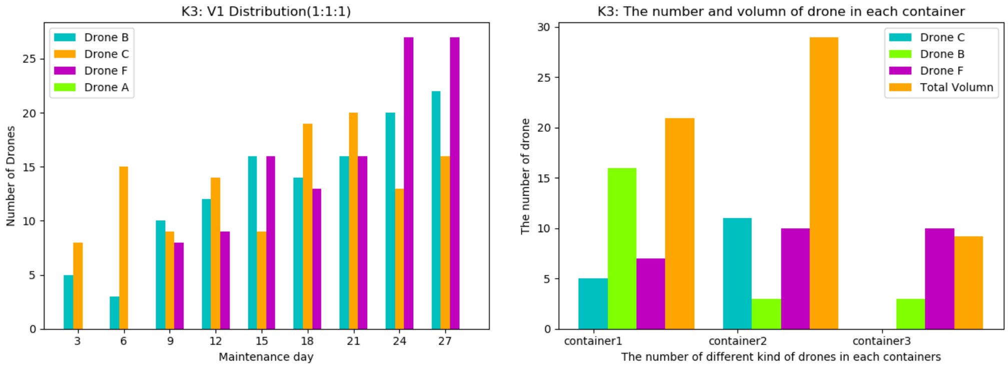

Figure 10: k_3 model, the left figure is drone number in different maintenance day. The right figure is the drone number in three containers at the longest maintenance day

each container as n is a constant input. Obviously this distribution is not optimized, the container 1 and container 3 is not meeting its maximum capability. The workload of container 2 is too large.

5.4 Sensitivity Analysis

From the result of above k_3 model, we need to do another workload distribution, to use more free space in container 1 and container 3. The variable directly relates with the workload is supply ratio. In order to optimize above situation, move more workload from container 2 to container 1 and 3.

The table 7 above represents two attempts to redistribute the workload. The version 2 is as symmetric as version 1. And version 3 is asymmetric comparing with version 1 and 2. The result shows more asymmetric distribution leads more efficient. Since different hospital has different requirement. In some situations, container only needs to take a few kinds of medical package, fewer kind of medical package simplifies the whole system and increase the deliver efficiency. For version 3 situation, container 2 only needs to take med1 and med2 medical package. What's more, this version has longest maintenance day.

The below figure 11 shows the package configuration of drones in containers. Now the workload is more balanced than k_3 version model.

Model	Container ID	Supply ratio	maintenance day
K_3 version1 model	C1(left)	HIMA : PS : CH : PA 1:1:1:3	27
	C2(right)	HIMA : PS : CH : CMC 1:1:1:3	
	C3(middle)	HIMA : PS : CH 1:1:1	
K_3 version2 model	C1(left)	HIMA : PS : CH : PA 0:0:2:4	32
	C2(right)	HIMA : PS : CH : CMC 4:4:0	
	C3(middle)	HIMA : PS : CH 1:1:1	
K_3 version3 model	C1(left)	HIMA : PS : CH : PA 0:1:2:4	40
	C2(right)	HIMA : PS : CH : CMC 0:0:0:4	
	C3(middle)	HIMA : PS : CH 4:3:2	

Table 7: Adjust supply ratio from different location

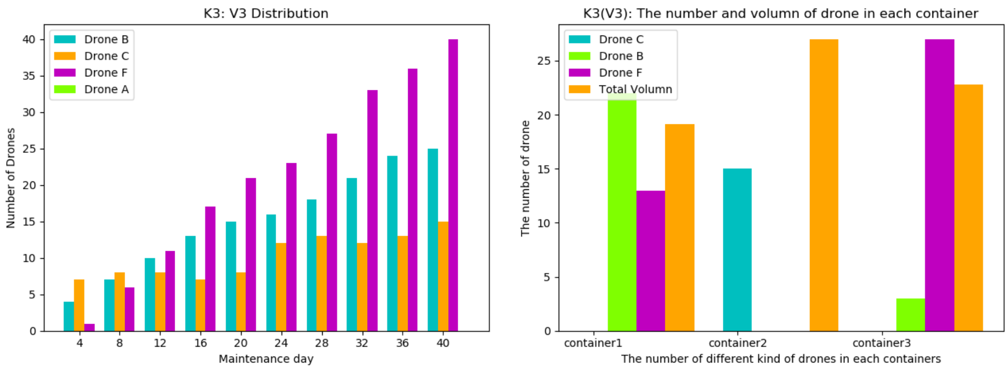

Figure 11: Revised k_3 model (version 3)

At the beginning of model construction, the key criterion to evaluate model is number of maintenance day. From data in table 7, the version 3 of k_3 model is the well performed solution in this stage. However, this model is not the best one, there still exists imbalanced workload among different containers.

6 Final Result

After compared the optimized version of k_3 model and the k_2 model, we can conclude that k_2 model is the optimized model for setting ISO containers. Because k_2 model has the largest maintenance index. Here we do not consider k_2 model appeared in sensitivity analysis since we need to do verification of new hypothesis. In this case, the detailed configuration of each drones in different airline is shown as below table 8:

Container	Demand Point	drones	Insider of each drone	Number
Container 1	Hospital HIMA	C	4MED 1 2MED 2	7
	Hospital PS	F	3MED 1 7MED 2	1
			9MED 1	1
			3MED 1 6MED 2	1
	Children's Hospital	F	3MED 1 7MED 2	1
			4MED 1 1MED 2 4MED 3	7
	Hospital PA	B	2MED 1	21
Container 2/3 (At location 2)	CMC	C	4MED 1 2MED 3	10
			2MED 1 3MED 3	1
			4 MED 3	4
			3MED 3	1
	Hospital HIMA	F	11MED 1	2
			5MED 1 4MED 3	7
	Hospital PS	F	11MED 2	2
			5MED 1 5MED 2	1
			9MED 1	2
		C	6 MED1 1MED 2	1
	Children's Hospital	F	11MED 2	1
			4MED 1 1MED 2 4MED 3	14
		B	3MED 2	1

Table 8: drones in each airlines in k_2 model

7 Conclusion

7.1 Strengths

- **Optimization of Packing Configuration**

  Our packing consideration is comprehensive. When we pack the medical packages, we take the flight-ability as our primary gist, and choose the plan with the least number of drones. When we pack the drones, we pack the large drones first, and this can help us to maximize the utility of space in containers.

- **Applied Widely**

  The whole system is simple. If more containers or more container locations are provided, it'll be easy to extend model by calculating one more set of data. This can be revealed in our $k = 2$ and $k = 3$ models. And if we have more anticipated delivery locations, we just need to add airlines from the containers to new delivery locations. What's more, adding more constrains is also easily to add more constraints.

7.2 Weakness

- **Single Destination**

  We assume that one drone can only have one destination in the beginning of our analysis to simplify our model. But in reality, the drones with high flight-ability can have multiple destination to maximize the utility and cover more video reconnaissance.

- **Idealized Model and unused conditions**

  We ignore the factor of wind, altitude and the load weight in our model, and these factors may influence the flight-ability of our drones. And it is also possible for the drones to crash at some point.

  Besides, the height of the door of containers is not taken into our consideration as well.

8 Future Expectation

The models we create for this problem are meaningful, because in other similar disaster scenario, the models could be reused and improved considering the specific situation.

Suppose that the amount of medical packages and the number of drones available are infinite, which means that the possible limitation of resources is out of our consideration. Under this assumption, as long as we know enough data about the geography, anticipated delivery locations, SIO containers, drones, drone cargo bay and medical packages, we could create models to schedule flight fleet for drones, provide reasonable packing configuration in drones and transportable containers.

However, in reality, resources will not be available forever. There has to be some limitation on some items. Then in such situation, we could improve the program by adding new limitations and conditions.

The finally expected models for the droneGo transportable disaster relief system in the future will be able to achieve such a status: users provide the data of disaster situations, delivery locations, requirements in each location and their priority of plan, i.e. the users could pick the property of plans that they care most, like shortest time, least cost, lowest risk etc. Then, the model could consider all these items and factors, and create a most suitable and reasonable plan for the disaster relief.

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TO: CEO of HELP, Inc

FROM: LovePeace

DATE: January 28, 2019

SUBJECT: Launch Plan of droneGo

Hi Mr./Mrs. CEO of HELP, Inc,

We're here to help you design the transportable disaster response system – "droneGo". Apparently, this system will be very popular and useful in the future, because the advantages of launching drones in disaster relief system are apparent. droneGo could protect human-beings in the rescue teams and improve the efficiency speed of disaster relief. And we, as LovePeace, promise that you will have our full support.

The model we recently created could allocate the resources of drones when disaster comes, and optimize the time period each delivery can maintain. We will explain our optimized model and give some recommendations for HELP's droneGo project.

Firstly, before proposing our solution, we make some general assumption that one drone can only fly to one destination and the medical packages are packed and delivered together within a period of maintenance time.

Secondly, we use an algorithm to pack our packages and an algorithm to deliver the drones, and build an evaluation model to optimize our result.

Finally, we analyze the influence of different number of container's location to our model and try to find the optimized plan.

And the result comes, we find that separating 3 containers into 2 locations is the best way that can maintain 42-day supply for the medical requirement, we think our model can be optimized further, but at this time, 42 is optimized.

Among the 3 containers, we put one at the location at latitude of 18.3825 and longitude of -66.2475 with 7 drone C, 11 drone F, and 23 drone B in it. As for other two, we will locate them at latitude of 18.3475 and longitude of -65.9775, and put 3 drone C, 22 drone F, and 3 drone B in one of them, and 14 Done C, 7 drone F, and one drone B in another. We also have the detailed plan, if you interested in our model, we can provide it to you.

While analyzing our data, we can find that drone C used in high frequency, since it is the one with moderately flight-ability and large volume, which means it can carry a lot of package with less amount, so it has a higher priority in our algorithm, but the ratio of maximum payload capacity to its volume is small, which means the efficiency of drone C is less than others, such as drone B, so in our future work, we will improve our algorithm including consideration of deliver efficiency, avoiding space waste.

During the process of modeling, we find some shortage of existing drones and Bays that

- drone with large load capacity but not support video reconnaissance

  As we can observe that the only drone without video function is the drone with the largest load capacity, we may enable video reconnaissance to work on that drone.

- The matching of volume of cargo bay and the maximum weight capacity of the drone

During our modeling, we find that the type 2 of Cargo Bay has big capacity for packing, but the drones that can carry this kind of cargo bay have small maximum weight capacity. So, many space is wasted in the cargo bays. If this can be improved, the maintenance time will increase a lot. So, when you purchase the new drones, you need to use some medical packages to test the wasted volume in the Bays, and make wasted volume as small as possible.

In summary, our model is feasible and reasonable, and it can fit in various conditions. If you want to add or remove some containers, our model can still work. Although our model is suitable under our assumption, we suggest your company to evaluate the realistic factors such as wind and altitude that we may affect the flight-ability of drones.

Hope that our model will help you to relive the disaster area and save more people in the future. We're eager to hear back from you.

Your Sincerely, Love and Peace