Messengers of Hope

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Summary

A 2017 hurricane brought many casualties and substantial economic and property losses to Puerto Rico. We design a disaster response system that uses drones to deliver medical packages and do video inspection of roads.

We convert the problem of fitting the specified ratios of three types of medical supply packages into ISO containers into a combinatorial optimization problem in three-dimensional packing. To maintain stability of the contents, each loaded item must be fully supported; to facilitate loading and unloading, each item should be entirely separated by a vertical or a horizontal plane. We establish a single objective programming model and use the improved 3D-RSO algorithm to solve the model.

To determine the number and location of ISO containers, we establish a two-objective programming model aimed at achieving the shortest transportation time and the longest total reconnaissance of roads. We find that to meet the daily demand of five hospitals, at least three containers are needed.

For medical supply delivery and video reconnaissance, we first determine the number of drones, and then use the loading model to fit them into the ISO containers. The routes and schedules of the drones are calculated by traversal calculation of all roads. Finally, we give the transportation plan and determine the length of roads that can be surveyed.

The optimal locations (in latitude and longitude coordinates) for the containers are $(18.3805, -66.5109)$, $(18.3490, -66.2830)$, and $(18.2191, -65.8241)$. We give a detailed daily transportation plan. The daily medical supply delivery can be completed in 39 min; the total length of road that can be inspected is 722 km, over 12 h. Container 1 contains 53 drones of type B, 1 Tether H, and 700 MED1, 350 MED2, and 350 MED3 packages, with space utilization 89%. Container 2 contains 54 drones B, 1 Tether H, 684 MED1, 342 MED2, and 342 MED3, with space utilization 89%. Container 3 contains 53 drones B, 1 Tether H, 809 MED1, 0 MED2, and 539 MED3, with space utilization 91%.

Finally, we do sensitivity analysis and extend the model.

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Introduction

Background

The U.S. territory of Puerto Rico was hit by its worst hurricane in 2017, wreaking havoc on the island and killing more than 2,900 people. The hurricane damaged about 80% of Puerto Rico's utility poles and all transmission lines, so that the entire island lost power. The storm also damaged much of the island's cellular communications network. As time went on, hospitals and NGOs were running short of lifesaving equipment and medical supplies.

HELP, Inc., an NGO, is trying to use a transportable disaster response system called "DroneGo" to deliver medical supplies and provide high-resolution aerial video reconnaissance in disaster areas.

Restatement of the Problem

- A fleet of drones and a set of medical packages are to be sent to Puerto Rico: Design packaging configurations for up to three ISO cargo containers to ship the cargo to Puerto Rico.
- Determine location(s) to deliver one to three containers so as best to enable medical supply delivery and video reconnaissance of the road network.
- For each type of drone:
  - Provide payload packaging configurations (that is, medical packages packed into the drone cargo bay), delivery routes, and schedules to meet the emergency medical package delivery requirements.
  - Provide a flight plan that enables the drone fleet to use onboard cameras to evaluate the condition of roads and highways.

Analysis of the Problem

Developing the DroneGo disaster response system can be divided into three subproblems (see **Figure 1**):

Problem 1:

Optimal load the ISO containers. Using the specified dimensions of drones, medical packages, and ISO containers, determine loads for the ISO containers. The goal is not only space-efficiency but also ease of loading and unloading.

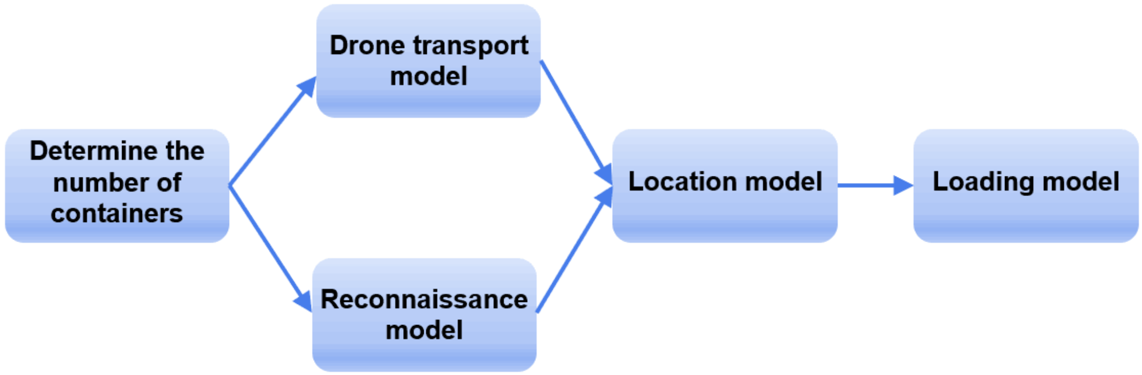

Figure 1. Solution planning chart.

Problem 2:

Determine

- the number and location of ISO containers to minimize delivery times and maximize road reconnaissance. Doing that requires taking into account the locations of the five hospitals, as well as the performance of each kind of drone, and assigning the five hospitals to containers.
- the specific loading scheme of each ISO container, considering the types and quantities of medical packages required by different hospitals.

Problem 3:

Determine the routes and schedules of the drone deliveries. Then find the best way for drones to monitor the roads, determine all the roads that can be inspected, and calculate their total length.

Simplifying Assumptions

- Maximum flight time of a drone will decrease due to the weight of the medical supplies, and it is inversely linearly related to the weight.
- We ignore the effects of wind and weather on drone flight and road conditions.
- The ISO containers should be located close to a city, highway, or road.
- The drone must be recharged at the location of an ISO container.
- Containers are transported to a port or airport in Puerto Rico.
- Medical supply delivery and video reconnaissance should be completed on a daily basis.

Table 1.
Symbols used.

Symbol	Description
α	Longitude
β	Latitude
θ	Angle between two places and the center of the Earth
Dis	The straight distance between two places
R_{Earth}	Radius of the Earth
C	A rectangular container
L	Length of container C
W	Width of container C
H	Height of container C
B	Set of different kinds of boxes
i	Type index variable
b_i	The ith type of box
l_i	Length of the ith box
w_i	Width of the ith box
h_i	Height of the ith box
r	Whether the ith box can be fitted in (boolean)
Q	Number of each kind of box
f	Number of layers of boxes in a container
k	Position occupied by the kth box, which is called a *region*
$S^{(f,k)}$	The top area of the kth box
$A^{(f,k)}$	The total bottom area of the boxes stacked on the f-layer k region
q_i	Number of boxes of type i

Data Processing

Calculate the distance between any two places on the Earth according to the longitude and latitude coordinates [Liu and Wei 2018]. Let (α_1, β_1) be the coordinates of place 1 and (α_2, β_2) the coordinates of place 2. Let the angle between them and the center of the Earth be θ, measured in degrees. Then

$$\theta = \arccos[\cos(90^\circ - \alpha_1) \cdot \cos(90^\circ - \alpha_2) \\ + \sin(90^\circ - \alpha_1) \cdot \sin(90^\circ - \alpha_2) \cdot \cos(\beta_1 - \beta_2)].$$

and the distance between the two places can be calculated by using the arclength formula:

$$Dis = \pi \cdot \frac{\theta}{180^\circ} \cdot R_{\text{Earth}}.$$

Three-Dimensional Loading Model

Loading as many drones and emergency medical packages as possible into a cargo container is a typical three-dimensional packing problem as

Table 1, cont'd.
Symbols used.

Symbol	Description
$q_i^{(f,k)}$	Number of boxes of type i on the f-layer in region k
F	Set of all boxes that have been put into container C
V_F	Total volume of all boxes that have been put into container C
n	Number of the cargo container, $n = 1, 2, 3$
d	Serial number of cargo container, $d = 1, 2, 3$
C_d	The location of the dth cargo container
j	Hospital index variable, $j = 1, 2, \ldots, 5$
D_j	Location of jth hospital
$N_d^{(i_1)}$	The dth container contains this many type i_1 medical packages
$N_j^{(i_1)}$	Number of type i_1 packages required for the j hospital
$N_d^{(i_2)}$	The dth container contains this number of type i_2 drone
$N_j^{(i_2)}$	Number of type i_2 drone to the j hospital
$N^{(i_2,i_1)}$	Number of type i_1 medical packages carried by type i_2 drone
$x_{dj}^{(i_2)}$	Number of i_2 droned from container dt to hospital j
$V^{(i_1)}$	Volume of type i_1 medical packages
$V^{(i_2)}$	Limited volume of type i_2 drone
$G^{(i_1)}$	Weight of type i_1 medical packages
$G^{(i_2)}$	Limited weight of type i_2 drone
μ	Ratio of the drone flight time to the time without load
$t^{(i_2)}$	No-load limit flight time of type i_2 drone
$v^{(i_2)}$	Flight speed of type i_2 drone
$L^{(i_2)}$	No-load limit flight distance of type i_2 drone
ϕ_1, ϕ_2	Relative importance weights for medical supply vs. reconnaissance

well as a combinatorial optimization problem. We have small rectangular solids of different sizes to put into a large rectangular solid (cargo container), aiming to maximize the total volume of items put in [Shang et al. 2018] (see **Figure 2**).

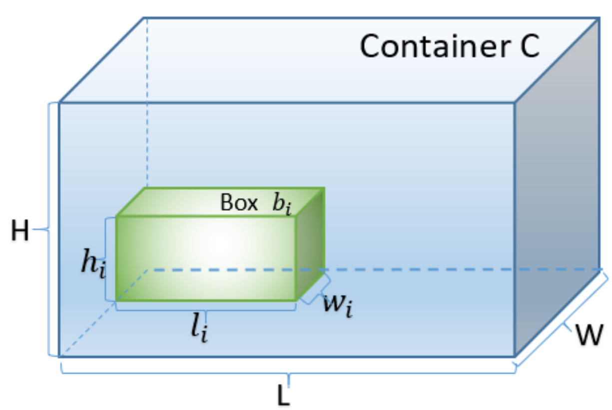

Figure 2. Schematic diagram of loading relationship.

Let a rectangular container C have length, width, and height L, W, and H, and let B be a set of different kinds of boxes:

$$\begin{aligned} B &= \{b_i\}\,, \qquad i = 1, 2, \ldots, n; \\ b_i &= (l_i, w_i, h_i, rl_i, rw_i, rh_i)\,, \end{aligned}$$

where l_i , w_i and h_i are the length, width, and height box i, and rl_i , rw_i, and rh_i are 0–1 variables that represent whether the ith box can be rotated around its length, width, and height so as to be placed in the container. For example, $rl_i = 0$ means that box i cannot be placed into the container no matter how it is rotated around its length. This situation would happen when the remaining space in the container is limited or the way that is used for the ith box's placement does not fit the limitations shown in **Figure 3**.

The total volume of a set F of boxes put into container C is

$$V_F = \sum_{b_i \in F} l_i \cdot w_i \cdot h_i.$$

The numbers of each kind of box is represented by a set Q:

$$Q = \{q_1, \ldots, q_n\}\,.$$

We let

- $S^{(f,k)}$ be the top area of the kth box,
- f be the number of layers of boxes in a container,
- k be the position occupied by the kth box, which we call a *region*. In the same layer of boxes, the top area of each box is the region.
- $A^{(f,k)}$ be the total bottom area of the boxes stacked on the f-layer of region k.

$$A^{(f,k)} = \sum_{i=1}^{n} q_i^{(f,k)} \cdot S_i^{(f,k)}$$

We take $q_i^{(f,k)}$, the number of boxes of type i on the f-layer of region k, as the decision variable.

The constraints are as follows:

- The total area of the bottoms of the boxes stacked on top of the k region in the fth-layer should be less than or equal to the area of the layer (the bottom layer is the bottom of the container). This restriction allows boxes to be loaded and unloaded in batches by forklifts. **Figure 3** shows two loading modes that do not meet our constraint conditions.

$$\begin{cases} A^{(1,k)} \le L \cdot W, & f = 1; \\ A^{(f,k)} \le S_i^{(f,k)}, & f \ge 2. \end{cases}$$

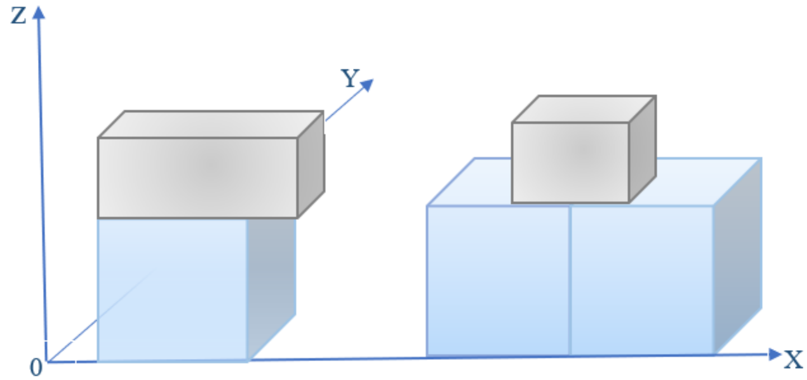

Figure 3. Two loading modes that do not meet the constraint conditions.

- The total of all boxes of type i in all layers and all regions is at least as many as the total number required:

$$\sum_f \sum_k q_i^{(f,k)} \geq q_i.$$

- We have three kinds of medical packages ($i = 1, 2, 3$) and eight kinds of drone A through H ($i = 4, \ldots, 11$). Consequently, $n = 11$ for our situation.
- According to the specified medical package demands, the daily demand for MED1, MED2, and MED3 packages for the five hospitals is 7, 2, and 4. So, the ratios of the number of medical kits required should be 7:2:4:

$$q_1 : q_2 : q_3 = 7 : 2 : 4.$$

To make the most of the space in the container and load more boxes, we maximize the space utilization Z of the container, subject to the constraints:

$$\max Z = \frac{V_F}{L \cdot W \cdot H}$$

$$\text{s.t.} \begin{cases} A^{(f,k)} = \sum_{i=1}^{11} q_i^{(f,k)} \cdot S_i^{(f,k)}; \\ A^{(1,k)} \leq L \cdot W, \qquad f = 1; \\ A^{(f,k)} \leq S_i^{(f,k)}, \qquad f \geq 2; \\ \sum_f \sum_k q_i^{(f,k)} = q_i; \\ q_1 : q_2 : q_3 = 7 : 2 : 4. \end{cases}$$

The Algorithm for the Loading Model

The 3D-RSO algorithm is a heuristic residual space optimization algorithm with advantages in solving efficiency [Shang et al. 2018] (see **Figure 4**).

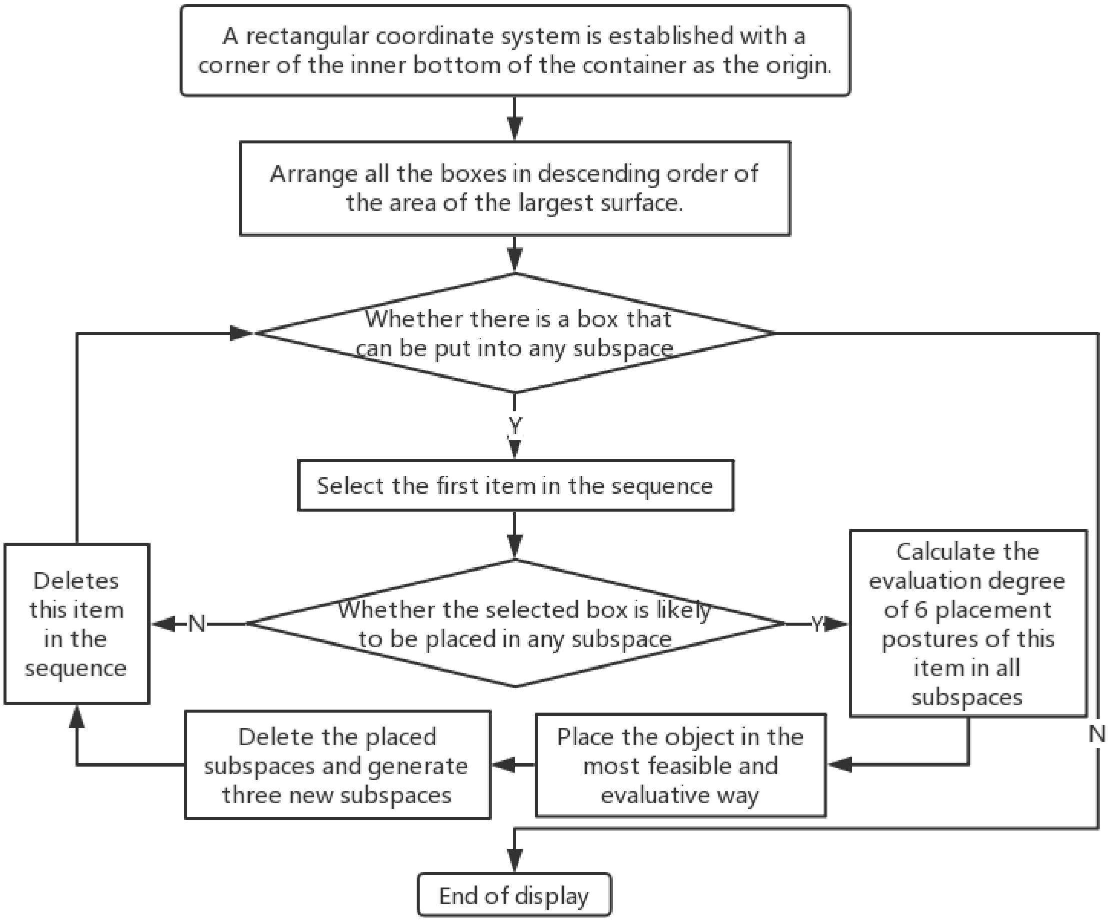

Figure 4. Flowchart of 3D-RSO algorithm [Shang et al. 2018].

Container's Location and Reconnaissance of Road Networks

Determine the Number of Cargo Containers

1. **How about one container?** The distance between Puerto Rico Children's Hospital and Hospital Pavia Arecibo is 61 km. The type B drone is the longest single-flight drone, but it can fly only up to 53 km at a time. Because the drone has to return, it is impossible to transport medical packages even if the containers are placed halfway between the two hospitals. As a result, the drones used to transport medicines for Puerto Rico Children's Hospital and for Hospital Pavia Arecibo must have come from two different cargo container locations.

2. **Will two containers be enough?** Puerto Rico Children's Hospital is the closest Hospital to Hospital Pavia Arecibo. As a result, for two cargo containers, one must supply medicine only for Hospital Pavia Arecibo and the other for the other four hospitals.

   Take these four hospitals as vertices and construct a quadrilateral. Traverse each coordinate point in the quadrilateral and calculate the distance between each point and the four hospitals. However, there is no point that satisfies the conditions. In other words, two containers cannot complete the transport task.

3. **Three containers is the best choice.** Because Puerto Rico Children's Hospital and Hospital Pavia Arecibo must be supplied with medicines from two different locations, containers 1 and 2 should be placed between Puerto Rico Children's Hospital and Hospital Pavia Arecibo. The HIMA Hospital is surrounded by the Cordillera Central mountains and the El Yunque mountains, and drones cannot cross them; so container 3 needs to be placed on the road between the Caribbean Medical Center and the HIMA Hospital. The remaining Hospital Pavia Santurce is serviced by container 2.

Drone Transport Model

In practice, containers can be transported to Puerto Rico only by port or airport and then transported by vehicles on undamaged roads. So containers can be placed only near roads, and due to the complex situation in the disaster area, as close as possible to the port or airport to avoid long-distance transport.

Drones cannot transport medical packages directly across mountainous areas because of limited climbing capacity. The containers that supply medicine to Hospital Pavia Arecibo are not able to supply other hospitals directly. Hospital Pavia Arecibo, however, has very low demand for medicines (only 1 MED1 per day). But since secondary disasters may result in a temporary surge in medicine demand, containers of medicines should be balanced to the extent possible so as to cope with such a situation, though we also want to avoid a large medicine stockpile. So we consider transferring some of the medicines in the container supplying Hospital Pavia Arecibo to other containers to avoid storing large quantities of medicine for a long time.

The constraints are as follows:

- The number of medical packages in all containers equals the most reasonable loading capacity:

$$\sum_{d=1}^{n} N_d^{(i_1)} = q_{i_1}.$$

- The number of drones in all containers equal to the most reasonable loading capacity:

$$\sum_{d=1}^{n} N_d^{(i_2)} = q_{i_2}.$$

- The various medical packages should meet the daily number of medical packages required by each hospital:

$$\sum_{d=1}^{n} x_{dj}^{(i_2)} = N_j^{(i_2)}.$$

$$\sum_{d=1}^{n} \sum_{i_2=4}^{11} N_j^{(i_2)} \cdot N^{(i_2,i_1)} \geq N_j^{(i_1)}.$$

- A drone has a limited amount of cargo space for medical packaging. The cargo volume must be no more than the capacity:

$$\sum_{i_1=1}^{3} N^{(i_2,i_1)} \cdot V^{(i_1)} \leq V^{(i_2)}.$$

- Similarly, there is a constraint on weight:

$$\sum_{i_1=1}^{3} N^{(i_2,i_1)} \cdot G^{(i_1)} \leq G^{(i_2)}.$$

- We let μ be the ratio of a loaded drone's flight time to its maximum flight time with no load. With no load, $\mu = 1$ (the load has no influence on the flight duration); with a full load, $\mu = \varepsilon$. In general, we have:

$$\mu = 1 - (1 - \varepsilon) \frac{\sum_{i_1=1}^{3} N^{(i_2,i_1)} \cdot G^{(i_1)}}{G^{(i_2)}}.$$

  The maximum distance that the drone can travel is:

$$L^{(i_2)} = v^{(i_2)} \cdot \mu \cdot t^{(i_2)}.$$

  The drone's range is also limited by needing to return after a delivery: The left side of the formula (22) represents

$$v^{(i_2)} \cdot \frac{\mu - 1}{2} \cdot t^{i_2} \geq 2Dis\left(C_d, D_j\right).$$

The objective function is to minimize the longest transport time:

$$\min\ T = \max_{d,j,i_2} \frac{Dis\left(C_d, D_j\right) \cdot x_{dj}^{(i_2)}}{v^{(i_2)}}. \tag{1}$$

Reconnaissance Model

Let the reconnaissance area covered by the drone be $S\left(C_d, \frac{L^{(i_2)}}{2}\right)$, which refers to the circle with C_d as the center and radius $L^{(i_2)}/2$ (half of the maximum flying distance of the drone). So the area covered is

$$S\left(C_d, \frac{L^{(i_2)}}{2}\right) = \pi \cdot \left(\frac{L^{(i_2)}}{2}\right)^2 .$$

The total length of road in the monitored area is $L\left(C_d, \frac{L^{(i_2)}}{2}\right)$.

We wish to optimize the length of road inspected:

$$\max\ P = L\left(C_d, \frac{L^{(i_2)}}{2}\right).$$

Location Model

The Location Model is the combination of the Drone Transport Model and the Reconnaissance Model.

Taking into account the shortest transport time and the longest total length of the road inspected, the objective planning function for selecting the optimal container locations is as follows, where φ_1 and φ_2 are the weights for the importance of medical supply vs. reconnaissance:

$$\max\ Z = \varphi_1 \frac{\min\ T}{T} + \varphi_2 \frac{P}{\max\ P}$$

$$\text{s.t.} \begin{cases} \sum_{d=1}^{n} N_d^{(i_1)} = q_{i_1}, \\ \sum_{d=1}^{n} N_d^{(i_2)} = q_{i_2}, \\ \sum_{d=1}^{n} x_{dj}^{(i_2)} = N_j^{(i_2)}, \\ \sum_{d=1}^{n} \sum_{i_2=4}^{11} N_j^{(i_2)} \cdot N^{(i_2,i_1)} \geq N_j^{(i_1)} \quad \sum_{i_1=1}^{3} N^{(i_2,i_1)} \cdot V^{(i_1)} \leq V^{(i_2)}, \\ \sum_{i_1=1}^{3} N^{(i_2,i_1)} \cdot G^{(i_1)} \leq G^{(i_2)}, \\ L^{(i_2)} = v^{(i_2)} \cdot \mu \cdot t^{(i_2)}, \\ v^{(i_2)} \cdot \frac{\mu-1}{2} \cdot t^{i_2} \geq 2Dis\left(C_d, D_j\right). \end{cases}$$

Algorithm for the Location Model

We extracted road information from the map of Puerto Rico available at Googlemaps. Under the condition that the constraint conditions are satisfied, all the points on the road in the map are traversed, and the corresponding objective function is calculated, and then the optimization results under the current preset parameters are selected.

The Flight Plan

To monitor as long a road length as possible, we choose the type-B drone. Its reconnaissance scope $L^{(5)}/2$ is 26 km, it flies at altitude $F_h = 300$ m, and the camera angle is 74° (in the range of a normal wide-angle lens) [Li 2009]. **Figure 5** shows a schematic diagram for its reconnaissance.

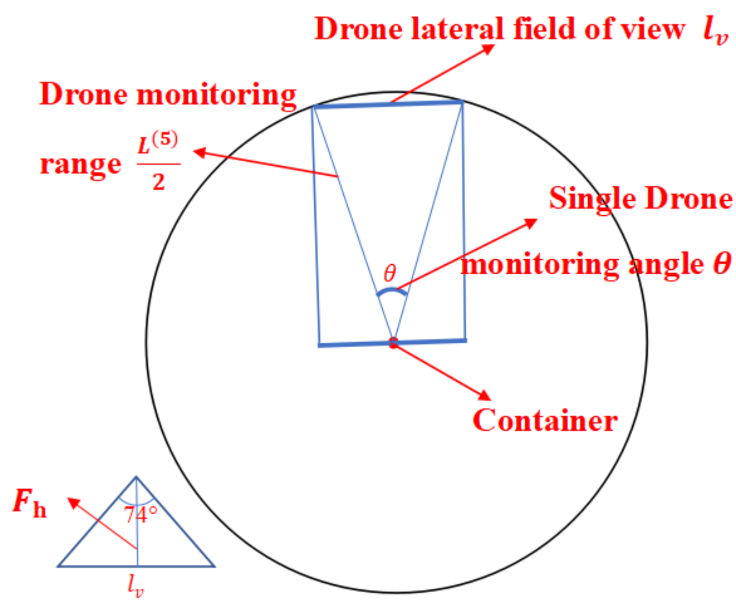

Figure 5. Reconnaissance schematic diagram of drone.

$$l_v = 2F_h \cdot \tan(37°) = 0.452 \text{ km}.$$

$$\theta = \arccos\left[\frac{\left(\frac{L^{(5)}}{2}\right)^2 + \left(\frac{L^{(5)}}{2}\right)^2 - l_v^2}{2\left(\frac{L^{(5)}}{2}\right)^2}\right] = 1°.$$

A single drone can do reconnaissance over 1°. The reconnaissance should be done during the day, so we suppose a total time limit for one day of 12 h. A completed 1° reconnaissance needs 40 min. We need to do 360° of reconnaissance. Using a type-B drone and ignoring recharging time, the total flight time required is 360×40 min and the total daylight available is 12×60 min, so the number of drones required is

$$N_d^5 = \frac{360 \times 40}{12 \times 60} = 20 \text{ drones}.$$

Considering that a drone must return to the container location for charging and maintenance, the number of drones for reconnaisance should be doubled to 40, so that pairs of drones can work alternately. This pairing not only takes into account the inevitable charging situation, but also reduces the work burden and use frequency of each drone.

Since breakdown of drones is inevitable, the number of drones for reconnaissance should be augmented by 10 more standby drones, for a total of 50 at each container location.

Additional drones are needed for delivering medical supplies. We find that the numbers needed are 3, 4, and 3 at container locations 1, 2, and 3.

Hence the total numbers of drones in each ISO container should be 53, 54, and 53.

Solution of the Location Model

The locations for the containers are affected by the configuration of the numbers and types of drones and medical packages in a container, the rules for packing, the performance capabilities of the drones, the number of medical packages required by each hospital, and other factors. We give the best result for the locations in **Table 2**. With a 2.6 GHz CPU on a Windows10 platform, it takes 5.5 s to run this calculation.

Table 2.
Solution of Location Model

Container	Latitude	Longitude	min T (min)	max P (km)
1	18.3805	−66.5109	39	313
2	18.3490	−66.2830	38	362
3	18.2191	−65.8241	34	252

Take container 1 as an example: It takes up to 39 min for a drone from container 1 to transport the medical packages to the hospital farthest from container 1 in a straight line, and return. Within the supply range of container 1, the total road length that can be inspected by drone is 313 km.

The reconnaissance coverage of the entire island road is 44%.

In **Figure 6**, the centers of the circles are the locations for the containers. Overlapping hospital or road segments can be supplied with medical packages or reconnaissance by drones from two different containers. In particular, the supply scopes of containers 1 and container 2 overlap, which means that hospitals and road segments in the overlap area can be supplied from either location and there can be transfer of medical packages between them.

We recommend that containers be shipped to:

- container 1: Port of Arecibo or to Antonio (Nery) Juarbe Pol Airport,
- container 2: Port of San Juan or else Fernando Ribas Dominicci Airport, and
- container 3: Port of Ceiba or else José Aponte de la Torre Airport.

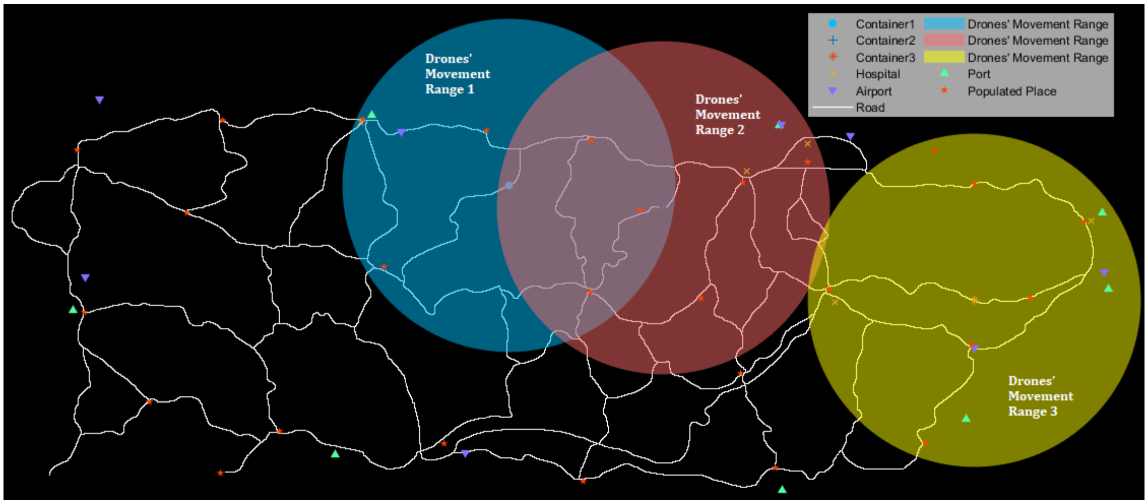

Figure 6. Locations for containers.

The containers are then transported by vehicle to the designated locations.

The greatest length of the section where the ranges of container 1 and container 2 overlap is 177 km, and the same for containers 2 and 3 is 28 km.

Table 3.
Results of the Loading Model.

Container	Drone B	Drone H	MED1	MED2	MED3	Space Utilization	Days
1	43+10	1	700	350	350	89%	350
2	44+10	1	684	342	342	89%	342
3	43+10	1	809	0	539	91%	269

Table 3 shows the results of the Loading Model. We take container 3 as an example to explain:

- It is loaded with 43+10 type-B drones, among which 43 are operational drones and 10 are standby drones.
- It is equipped with a type-H tether drone, which serves as a signal base station.
- It contains 809 MED1, 0 MED2, and 539 MED3 packages.
- It can support the medicine demand of the hospitals that it serves for 269 days, which is a very good result.

With a 2.6 GHz CPU on a Windows10 platform, it takes only 0.35 s to run the 3D-RSO algorithm, producing the results of **Figure 7**.

Figure 11 shows the daily transport and transshipment plan.

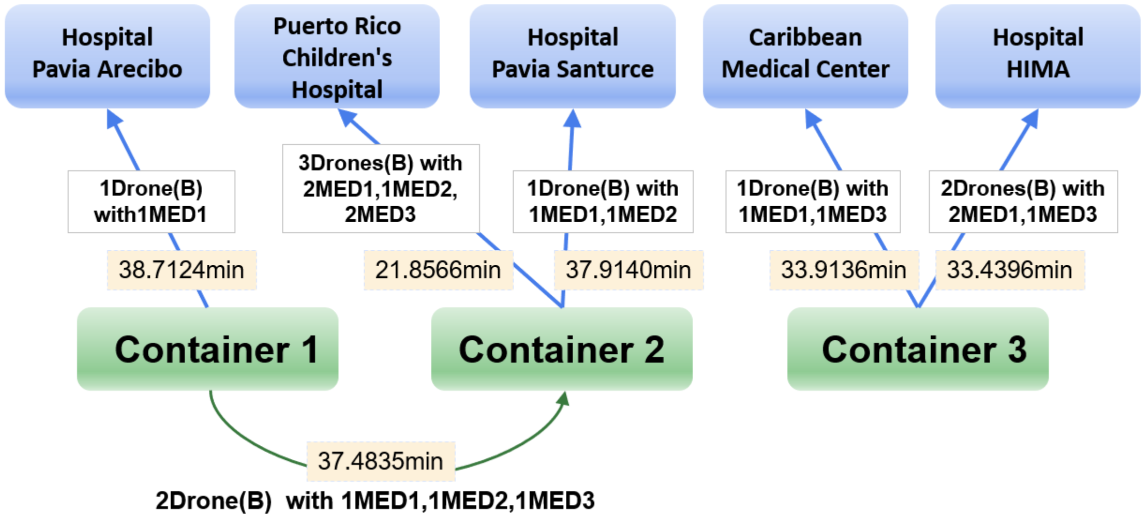

Figure 7. Daily transport and transshipment plan.

Sensitivity Analysis

Since the impacts of a hurricane on Puerto Rico may vary, the weights φ_1 and $\varphi_2 = 1 - \varphi_1$ in the model for the two target activities—medical supply and reconnaissance—should be changed in the face of different circumstances and actual situations. Therefore, we calculate 10 sets of results for $\varphi_1 = 0.1, 0.2, \ldots, 1.0$ to test the sensitivity and feasibility of the model.

We find that the influence of φ_1 on the results is not gradual; there is a big jump between $\varphi_1 = 0.1$ and $\varphi_1 = 0.2$ for container 1's time and range, and between $\varphi_1 = 0.3$ and $\varphi_1 = 0.4$ for that of container 2. When the value of φ_1 is close to these thresholds, the sensitivity is very high. However, when the value is far from the threshold, the calculation results are almost unaffected. Therefore, φ_1 should be carefully determined according to the actual situation, especially when the value is close to the threshold.

Model Extension

The following scheme improves road inspection capability by sacrificing part of the medical rescue capability, that is, $\varphi_1 = 0, \varphi_2 = 1$. Transshipment between containers is no longer considered; in addition, as many drones as possible are packed into a container to improve the efficiency and broaden the scope of reconnaissance.

Figure 8 shows the locations for the containers under this plan. There is no intersection of the supply scopes of container 1 and 2, but there is still intersection of the scopes of containers 2 and 3. The total length of the road at the intersection is 137 km. At this time, the reconnaissance coverage rate of the drone on the road of the whole island reaches 60%, which is higher than that of the previous scheme's 44%.

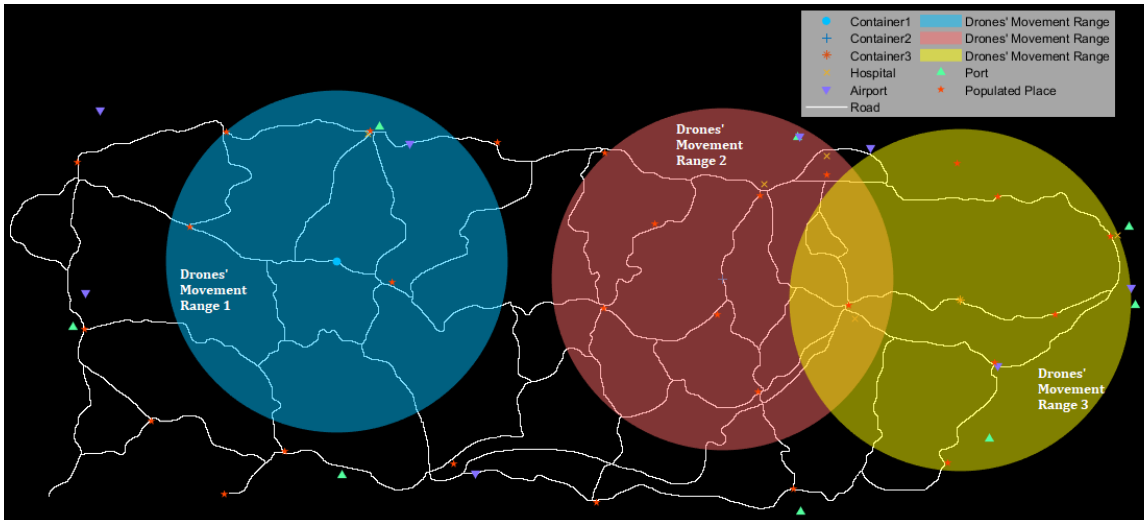

Figure 8. Locations for containers to favor reconnaissance.

With the increase of the number of drones, the number of medical packages in the container decreases correspondingly (**Table 4**). The supply time for materials in containers 2 and 3 to the hospitals is obviously shortened. Moreover, since containers cannot transfer supplies, the medical packages last for widely varying amounts of time. The detailed daily transport plan for this scheme is shown in **Figure 9**.

Table 4.

Results of the Loading Model for the scheme favoring reconnaissance.

Container	Drone B	Drone H	MED1	MED2	MED3	Space Utilization	Days
1	68	1	630	0	350	93%	630
2	68	1	321	212	213	91%	106
3	68	1	396	0	263	92%	131

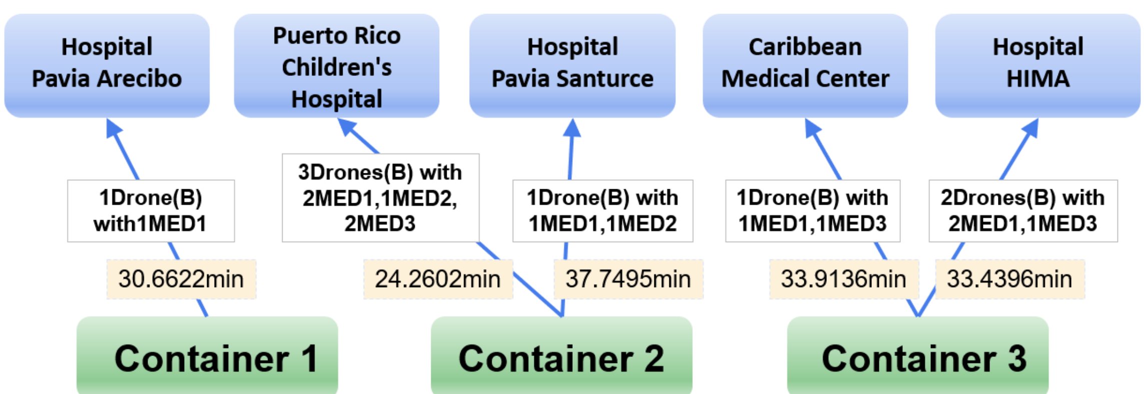

Figure 9. Delivery scheme for the scheme favoring reconnaissance.

Strengths and Weaknesses

Strengths

- In loading containers, we adopt an orderly stacking method, so that the boxes have overall stability and are convenient for loading and unloading.
- Considering the difficulty of transportation of containers in disaster-hit areas, we transport containers to ports or airports and then place them along highways, which improves the real-world feasibility of the model.
- The improved 3D-RSO algorithm is convenient and effective in solving the 3D loading model, can deliver results in a very short time, is very suitable for the allocation of materials in emergency, and gives a very high space utilization rate.
- The distribution of medical packages is balanced, which improves the system's ability to withstand possible secondary disasters and extends the time of disaster relief.
- In addition, we present a plan that focuses on road reconnaissance.

Weaknesses

- The influence of load on a drone is modeled relatively simply.
- Without considering the influence of altitude, wind, weather and other factors on drone flight, the model lacks practicality.
- The plan meets only the daily needs of each hospital, resulting in low utilization efficiency of the drones.

References

Liu, Lirong, and Li Wei. 2018. Derivation of calculation formula for mutual conversion of GPS coordinates and direction and distance [in Chinese]. *China Southern Agricultural Machinery* 49 (14): 106. http://kns.cnki.net/KCMS/detail/detail.aspx?dbcode=CJFQ&dbname=CJFDLAST2018&filename=NFLJ201814096&v=MTU2NDBGckNVUkxPZmJ1WnVGeUhuVUxySkt5dkhaTEc0SDluTnE0OU1Zb1I4ZVgxTHV4WVM3RGgxVDNxVHJXTTE=.

Shang, Zhengyang, Jinan Gu, Shixi Tang, and Xiaohong Sun. 2019. Efficient residual-space-optimization algorithm for three-dimensional container loading problem [in Chinese]. *Computer Engineering and Applications* 55 (5): 44–50. http://kns.cnki.net/KCMS/detail/detail.

aspx?dbcode=CJFQ&dbname=CJFDLAST2019&filename=JSGG201905007&v=MDE4NzZZNFI4ZVgxTHV4WVM3RGgxVDNxVHJXTTFGckNVUkxPZmJ1WnVGeUhnVjd2SUx6N01hYkc0SDlqTXFvOUY=.

Li, Ke. 2009. A brief discussion on the wide angle lens of the camera [in Chinese]. *Journal of Taiyuan Urban Vocational College* 4: 122–123. http://kns.cnki.net/KCMS/detail/detail.aspx?dbcode=CJFQ&dbname=CJFD2009&filename=CSZY200904064&v=MDAyNDBKajdSZDdHNEh0ak1xNDlEWUlSOGVYMUx1eFlTN0RoMVQzcVRyV00xRnJDVVJMT2ZidVp1RnlIZ1c3dkE=.

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