Recovering from A Disaster: A Study of The Relief and Response System

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Abstract. Mass natural disasters cause severe damage. Aiming at the multi-supply and multi-demand point problem of routes scheduling and packing configurations, we are ready to provide adequate and timely response to the emergencies.

1. Summary
Mass natural disasters cause severe damage. Aiming at the multi-supply and multi-demand point problem of routes scheduling and packing configurations, we are ready to provide adequate and timely response to the emergencies.

First, we identify the best locations of cargo containers to conduct the two required missions. We use ArcGIS software and create TCL model (Target-oriented comprehensive location model) to assist. TCL model aims to find the best location under restrictions with comprehensive methods. TCL model includes buffer analysis, Kernel Density Analysis, the Slope Algorithm and IDW Interpolation.

Then we design the flight routes with transferring it into a generalized TSP (GTSP) and solving it via the minimum-weight Hamilton cycle. We discuss two situations: the video reconnaissance is of the whole island or only the main roads. Besides, to maximize task completion with the limited flight distance, we consider two kinds of flight trips: the round trip and the one-way trip. After comparing the characteristics of different drones, we are supposed to choose 2 or 3 kinds of drones to implement the transport tasks.

Since the flight routes raise requirements for the amounts of drones and the medical packages, we design packing configurations for each cargo container. We employ the genetic algorithm to solve this 3D container-loading problem. Then we can find the best plan with the relatively largest space utilization.

Once we have depicted the flight routes and packing configurations meticulously, our IWE (Independence Weighted Evaluation) Model calculates how effective the candidate solutions are and provides the best drone fleet. Thinking about the real situation of a disaster area, the road condition may change even in a few days. So, we creatively design a kind of plan called loop, which means we send drones to finish a video reconnaissance once l days. After making a drone schedule with linear regression, we get all the details of the drone fleet and its schedule.

Next, we will take the worst hurricane which hit the United States territory of Puerto Rico in 2017 as an example. We are going to recommend a drone fleet and set of medical of the response system, identify the best location on Puerto Rico to position cargo containers to transport the system then provide the drone payload packing configurations and a drone flight plan eventually.
2. Assumptions
1) Assume that a drone’s flight speed remains unchanged during flying.
2) If the drone needs to obtain videos, it will only fly along the road. (The reason is shown in to Appendix.)
3) If the drone needs to deliver medicine, it can fly directly between two places.

3. Preparation for the System Design

3.1. Select a Drone
The relationship between drone endurance and payload is shown in the following figure.

According to the data, we figure out that type B, C and F have the highest ranks among the seven candidates with flight capability. B is especially suitable for long distance flight. C and F have high payload capability. Thus, to simplifying the model and maximize the utility of the drones, we will choose type B, C and F for further design.

| Type | Video | Length | Width | Height | Capacity | Velocity |
|------|-------|--------|-------|--------|----------|----------|
| A    | Y     | 45     | 45    | 25     | 3.5      | 40       |
| B    | Y     | 30     | 30    | 22     | 8        | 79       |
| C    | Y     | 60     | 50    | 30     | 14       | 64       |
| D    | Y     | 25     | 20    | 25     | 11       | 60       |
| E    | Y     | 25     | 20    | 27     | 15       | 60       |
| F    | N     | 40     | 40    | 25     | 22       | 79       |
| G    | Y     | 32     | 32    | 17     | 20       | 64       |
Table. 2 Rank of Candidates Potential Drones (continued)

| Type | Time | Corr | Rank | Volume | Max_d | Ave_w |
|------|------|------|------|--------|-------|-------|
| A    | 35   | 0.4303 | 7    | 0.64815 | 23.33 | 0.19  |
| B    | 40   | 0.7427 | 1    | 0.64815 | 52.67 | 0.08  |
| C    | 35   | 0.6382 | 3    | 5.55556 | 37.33 | 0.4   |
| D    | 18   | 0.5618 | 6    | 0.64815 | 18    | 0.06  |
| E    | 15   | 0.5625 | 5    | 5.55556 | 15    | 0.37  |
| F    | 24   | 0.6481 | 2    | 5.55556 | 31.6  | 0.25  |
| G    | 16   | 0.594  | 4    | 5.55556 | 17.07 | 0.28  |

![Figure 2: The Relationship between Drone Endurance and Payload](image)

4. Develop a DroneGo Disaster Response System

4.1. Identify the Best Locations for the Cargo Containers with TCL Model

We introduce TCL model (Target-oriented comprehensive location model) to assist. TCL model aims to find the best location under restrictions with comprehensive methods. The model includes buffer analysis, Kernel Density Analysis, the Slope Algorithm and IDW Interpolation.

![Figure 3: Locations of the hospitals](image)

For this problem, we use the kernel density analysis to get the probability density of the island to the highway and present in a thermodynamic chart. Then, we use the DEM data to calculate the slope. The flatter the area, the more suitable it is to locate the cargo container. Rarely will only one factor or one layer be sufficient in ordinary spatial analysis involving typical GIS analysis. So we choose the weighted overlay tool and raster data for a solution. The overlay result is as following:
Finally, we identify the best locations of the cargo containers as below (the brightest nodes). The geographic coordinates are as follows:

**Table. 3** The Geographic Coordinates of the Best Locations of Cargo Containers

| Latitude       | Longitude     |
|----------------|---------------|
| 18.295366      | -66.047012    |
| 18.228495      | -66.382278    |
| 18.266216      | -66.707382    |

### 4.2. Design the Flight Routes

We regard the endpoints of each road as the vertices set. We regard the roads as the arcs between two vertices. We also regard the length or the flight time of each road as the weight of the arc, respectively. Then the problem is transferred into a Generalized Traveling Salesman Problem (GTSP). That is, given a set of target vertices and three set of drones located at distinct depots, find a Hamiltonian path for each drone such that each vertice is visited at least by one drone, the drone–target constraints are satisfied and the sum of the costs of the paths traveled by all the drones is minimized [3].

We employ graph theory to solve this problem. In graphical terms, the aim is to find a minimum-weight Hamilton cycle in a weighted complete graph.
4.3. **Design Packing Configurations for Each Cargo Container**

The basic calculating process of GA (genetic algorithm) is as following:

![Figure 6 Calculating Process of GA](image)

4.4. **Evaluate Solutions**

To build the evaluation model, the first step is to select evaluation indicators and then do the dimensionless method. Moreover, it is supposed to determine the weighted vector of evaluated index with multi-correlation coefficient. Eventually, IWE model is

\[
\text{Score} = \sum_{i} R_i \times \eta_i, i \in \{M_a, M_m, N, T, \tau, \gamma, CR\}
\]

**Table. 4 Evaluation Indicators**

| Indicator      | Definition                                    | Symbol | Formula |
|----------------|-----------------------------------------------|--------|---------|
| Benefit index  | The information acquisition rate              | \( \gamma \) | \( \gamma_i = \frac{D_A \times (T_i/l_i) + D_M \times (1 - T_i/l_i)}{D_A \times T} \) |
|                | The duration of medical supply                | \( T \) | The value is provided in part 4.3 |
|                | The utilization efficiency of drones          | \( \tau \) | \( \tau_i = (N_{RI} + N_{CDI} \times T_i) / N_i \) |
| Cost index     | The cost of drones (the amount of drones)    | \( N_i \) | \( N_i = N_{RI} + N_{DI} \times (T_i - T_i/l_i) + N_{CAI} \times T_i \) |
|                | The video time (for the whole island)         | \( M_a \) | \( M_a = \max\{T_{hj}\} \) |
|                | The video time (for main roads)               | \( M_m \) | \( M_m = \max\{T_{mj}\} \) |
| Fixed index    | The container’s space utilization ratio       | CR(i)  | \( \text{CR}(i) = \frac{\sum_{i=1}^{m} BV_i}{CV} \times 100 \) |

5. **Conclusion**

5.1. **The Solution to Problem One**

Use the IWE model and filter some obviously inefficient solutions, we get the score of each solution.
Table 5 the score of each solution

| No. | 46 |
|-----|----|
| Round trip drone | B |
|   | L1 | 3 |
|   | L2 | 2 |
|   | L3 | 3 |
| I | 4 |
| Total time of video reconnaissance/min | $M_a$ | 193.38 |
|   | $M_m$ | 198.84 |
| $T$ | 19 |
| $N_l$ | 142 |
| $r$ | 0.6338 |
| $γ$ | 0.543 |
| CR | 0.8291 |
| Score | 79.06682 |

Table 6 Packing Configuration for Each Cargo Container

| Packing Configuration for Each Cargo Container | L1 | L2 | L3 |
|-----------------------------------------------|----|----|----|
| Drone B | 60 | 47 | 10 |
| Drone F | 2 | 12 | 6 |
| Drone H | 2 | 1 | 2 |
| Medical Package | MED 1 | 114 | - | 19 |
|                  | MED 2 | 38 | - | - |
|                  | MED 3 | 76 | - | - |
| The Ratio of Space Utilization | 84.40% | 79.85% | 84.49% |

Using the GA model in part 4.3, the packing configuration for each cargo container is as below:

Figure 7. The packing configuration for each cargo container

Table 7 schedule and routes (WHOLE ISLAND)

| Details of the Drone Fleet | Drone | B | 117 |
|---------------------------|-------|---|-----|
|                           | F     | 20|
|                           | H     | 5 |
| Loop of video reconnaissance | $l=4$, i.e. once four days |
| The duration of medical supply | 19 days |
| The utilization efficiency of drones | 63.38% |
| The information acquisition rate | 54.30% |
5.2. Routes of the response system

Table. 8 schedule and routes (WHOLE ISLAND)

| Drone | Path | Route | Task | Starting time | Arriving at the hospital | Flying back to the location |
|-------|------|-------|------|---------------|--------------------------|-----------------------------|
| L1-b1 | A    | 1-1-3 | H2-3 | Y&M          | 7:00                     | 7:14                        | 7:28                        |
| L1-b2 | A    | 1-1-3 | 12-5 | V            | 7:00                     | 7:39                        |
| L1-b3 | A    | 1-1-3 | 12-5 | V            | 7:00                     | 7:40                        |

Notes: “→” refers to flying directly from one node to another. “-” refers to flying along the road. “V” refers to video reconnaissance. “M” refers to medical delivery.

Table. 9 schedule and routes (MAIN ROADS)

| Drone | Path | Route | Task | Starting time | Arriving at the hospital | Flying back to the location |
|-------|------|-------|------|---------------|--------------------------|-----------------------------|
| L1-b1 | C    | 1-1-3 | H3-1 | V&M          | 7:00                     | 7:18                        | 7:37                        |
| L1-b2 | C    | 1-1-3 | 12-5 | V            | 7:00                     | 7:37                        |
| L1-b3 | C    | 1-1-3 | 12-5 | V            | 7:00                     | 7:51                        |
| L1-b3 | D    | 1-1-3 | H1   | M            | 7:00                     | 7:21                        | 7:44                        |
| L1-b3 | C    | 1-1-3 | H2   | M            | 7:00                     | 7:06                        | 7:12                        |
| L1-F  | D    | 1-1-3 | H4   | M            | 7:00                     | 7:16                        | 7:16                        |
| L2-b1 | C    | 2-1-3 | 14-1 | V            | 7:00                     | 7:18                        | 7:32                        |
| L2-b2 | C    | 2-1-3 | 14-1 | V            | 7:00                     | 7:37                        |
| L2-b3 | C    | 2-1-3 | 14-1 | V            | 7:00                     | 7:42                        |
| L2-b3 | C    | 2-1-3 | 14-1 | V            | 7:00                     | 7:45                        |
| L2-b3 | C    | 2-1-3 | 14-1 | V            | 7:00                     | 7:57                        |

Notes: “→” refers to flying directly from one node to another. “-” refers to flying along the road. “V” refers to video reconnaissance. “M” refers to medical delivery.
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