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

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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.

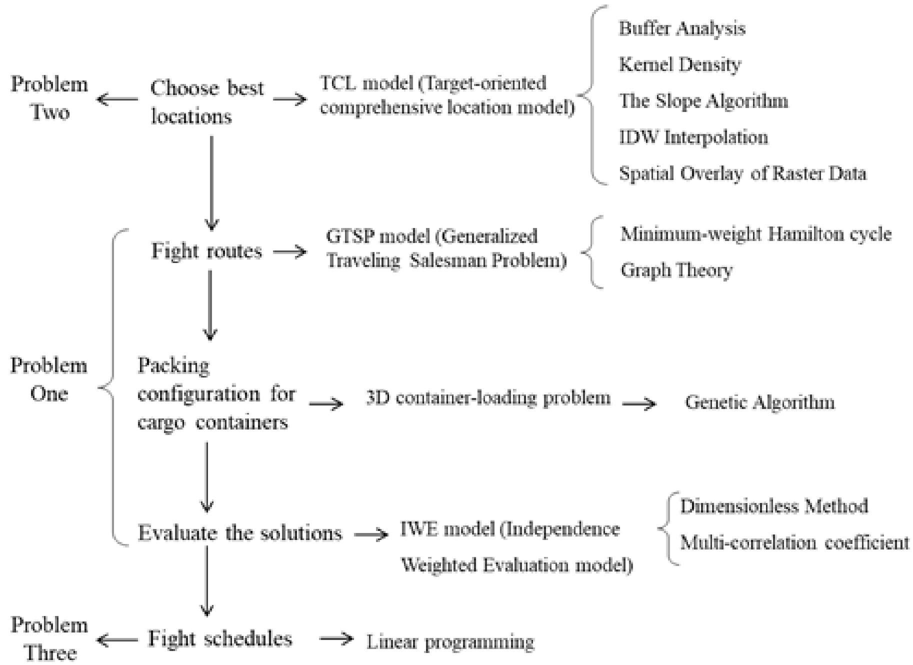

Figure. 1 Analyzing process

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.

Table. 1 Rank of Candidates Potential Drones

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

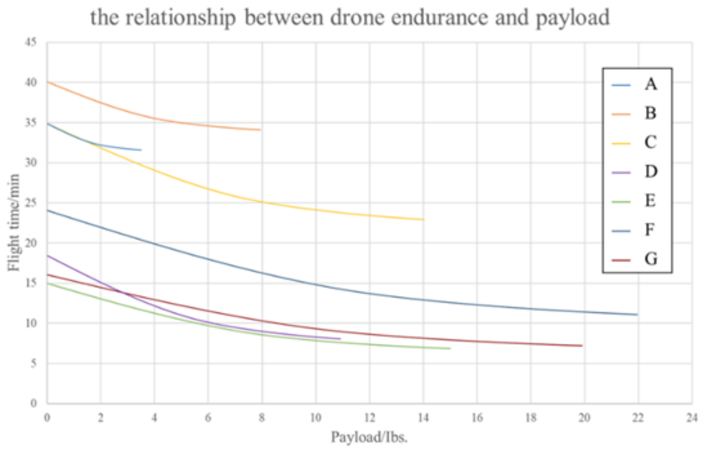

Figure. 2 The Relationship between Drone Endurance and Payload

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

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:

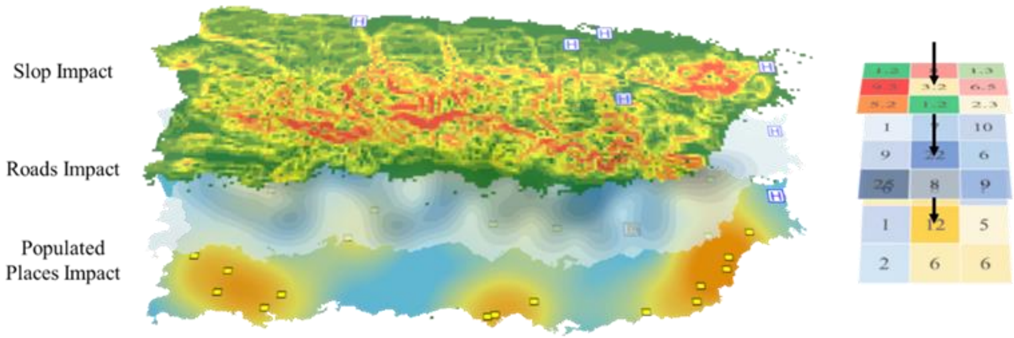

Figure. 4 Spatial Overlay of Raster Data

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.

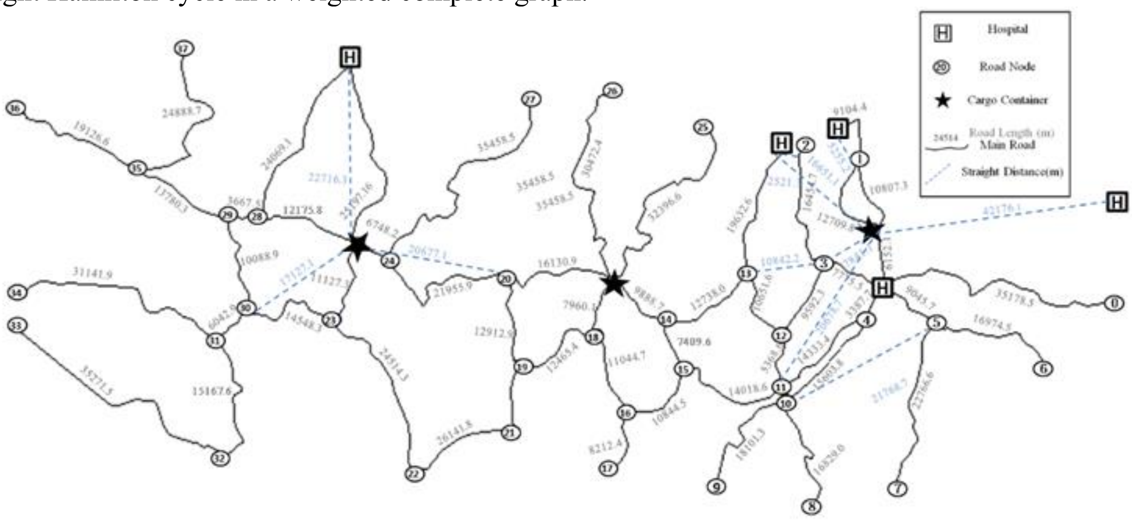

Figure. 5 The Road Net Drawing

4.3. Design Packing Configurations for Each Cargo Container
The basic calculating process of GA (genetic algorithm) is as following:

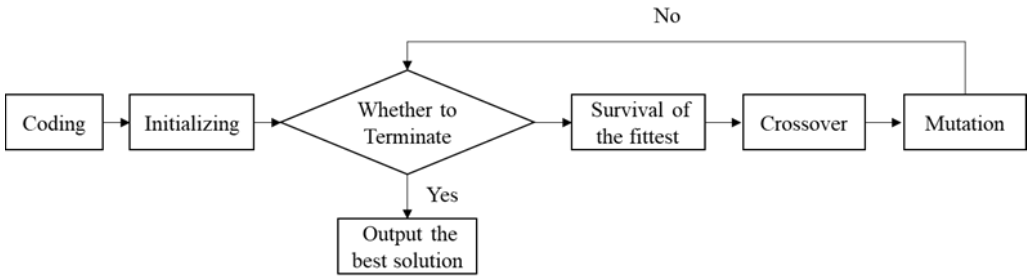

Figure. 6 Calculating Process of GA

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

$$\text{Score} = \sum_i R_i \times \eta_{\mathrm{i}}, i \in \{M_a, M_m, N, T, \tau, \gamma, CR\}.$$

Table. 4 Evaluation Indicators

Indicator	*Definition*	*Symbol*	*Formula*
Benefit index	The information acquisition rate	γ	$\gamma_i = \frac{D_A \times (\mathrm{T}_i/l_i) + D_M \times (1 - \mathrm{T}_i/l_i)}{D_A \times \mathrm{T}}$
	The duration of medical supply	T	The value is provided in part 4.3
	The utilization efficiency of drones	τ	$\tau_i = (N_{Ri} + N_{CDi} \times \mathrm{T}_i)/N_i$
Cost index	The cost of drones (the amount of drones)	N_i	$N_i = N_{Ri} + N_{Di} \times (\mathrm{T}_i - \mathrm{T}_i/l_i) + N_{CAi} \times \mathrm{T}_i$
	The video time (for the whole island)	M_a	$M_a = \max_j\{\mathrm{T}_{Aj}\}$
	The video time (for main roads)	M_m	$M_a = \max_j\{\mathrm{T}_{Mj}\}$
Fixed index	The container's space utilization ratio	CR(i)	$\mathrm{CR}(i) = \frac{\sum_{i=1}^{m} BV_i}{CV} \times 100$

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
l	4		
Total time of video reconnaissance/min		M_a	193.38
		M_m	198.84
T	19		
N_i	142		
τ	0.6338		
γ	0.543		
CR	0.8291		
Score	79.06682		

Table. 6 Packing Configuration for Each Cargo Container

			L1	L2	L3
Packing Configuration for Each Cargo Container	Drone	B	60	47	10
		F	2	12	6
		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:

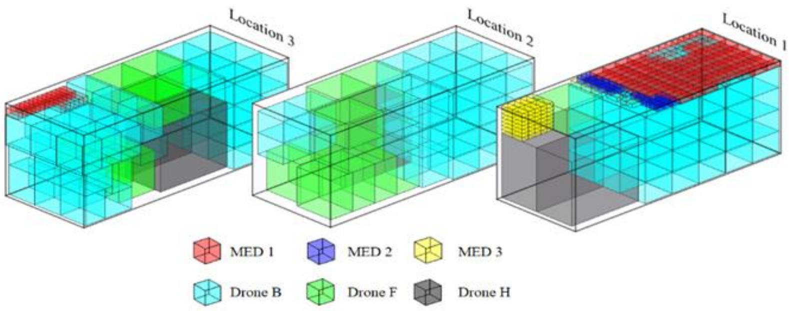

Figure 7. The packing configuration for each cargo container

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)

Schedule and Routes (Under the Situation of Reconnaissance of the Whole Island)						
Drone	Path	Route	Task	Starting time	Arriving at the hospital	Flying back to the location
L1-b1	A1	L1-1-H3→1-L1	V&M	7:00	7:14	7:28
L1-b2	A2	L1→3-12-13-14-L2	V	7:00		7:39
L1-b3	A4	L1-H2-4-11-12-3-H2-L1	V	7:00		7:40
L1-B	B1	L1-H2-0	V	7:00		7:31
	B2	L1→H1	M	7:00	7:32	8:04
	B4	L1-H2-5-6	V	7:00		7:40
	B5	L1-H2-5-7	V	7:00		7:35
	B6	L1-H2-4-10-9	V	7:00		7:37
	B7	L1-3-2→H4-13	V	7:00		7:37
L1-f1	A3	L1→H2→L1	M	7:00	7:06	7:12
L1-F	B3	L1→H4	M	7:00	7:31	7:31
L2-b1	A5	L2-14-15-16-18-L2	V	7:00		7:36
L2-b2	A6	L2-18-19-20-L2	V	7:00		7:37
L2-B	B8	L2-25	V	7:00		7:25
	B9	L2-26	V	7:00		7:23
L3-b1	A7	L3-24-20→L3	V	7:00		7:38
L3-b2	A8	L3-23-30-29-28-L3	V	7:00		7:40
L3-b3	A9	L3→H5→L3	M	7:00	7:17	7:34
L3-B	B10	L3-23-22-21	V	7:00		7:40
	B11	L3-24-27	V	7:00		7:32
	B12	L3-H5-28	V	7:00		7:37
	B13	L3-28-29-35-37	V	7:00		7:41
	B14	L3-28-29-35-36	V	7:00		7:37
	B15	L3→30-31-34	V	7:00		7:41
	B16	L3-23-30-31-32-33	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)

Schedule and Routes (Under the Situation of Reconnaissance of the Main Roads)						
Drone	Path	Route	Task	Starting time	Arriving at the hospital	Flying back to the location
L1-b1	C1	L1-1-H3-1-L1	V&M	7:00	7:18	7:37
L1-b2	C2	L1-H2-4-11-12-3-H2-L1	V	7:00		7:52
L1-b3	C4	L1->3-12-13-14-L2	V	7:00		7:51
L1-B	D3	L1->H1	M	7:00	7:21	7:42
L1-f1	C3	L1->H2->L1	M	7:00	7:06	7:12
L1-F	D2	L1->H4	M	7:00	7:16	7:16
L2-b1	C5	L2-14-15-11-L1	V	7:00		7:52
	C6	L2-18-16-15-14-L2	V	10:00		10:47
L2-b2	C7	L2-18-19-20-L2	V	7:00		7:49
L3-b1	D1	L1->H1	M	7:00	7:21	7:42
L3-b2	D2	L1->H4	M	7:00	7:16	7:33
L3-b3	D3	L1-3-2-H4-13	V	7:00		7:52

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References

[1] Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) https://topotools.cr.usgs.gov/gmted_viewer/
[2] "The World Factbook – Puerto Rico#Geography". Cia.gov. Retrieved October 30, 2011.
[3] Charles E. Noon & James C. Bean (1993) An Efficient Transformation Of The Generalized Traveling Salesman Problem, INFOR: Information Systems and Operational Research, 31:1, 39-44, DOI: 10.1080/03155986.1993.11732212
[4] Bondy J A, Murty U S R. Graph theory with applications[M]. London: Macmillan, 1976.
[5] Silverman, B. W. Density Estimation for Statistics and Data Analysis. New York: Chapman and Hall, 1986.
[6] Burrough, P. A., and McDonell, R. A., 1998. Principles of Geographical Information Systems (Oxford University Press, New York), 190 pp.
[7] Awange J.L., Kyalo Kiema J.B. (2013) Spatial Analysis. In: Environmental Geoinformatics. Environmental Science and Engineering. Springer, Berlin, Heidelberg