Drone transports medical supplies to Puerto Rico based on shortest path

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Abstract: Puerto Rico suffered the worst hurricane which caused devastating damage in 2017. In order to deliver medical supplies in time and patrol the lines, NGOs try to improve the response capabilities of its by designing a portable disaster response system called DroneGo. DroneGo needs to find the optimal delivery path and the optimal equipment utilization rate for delivery according to the disaster relief conditions and schedule. In this paper, the integration of integer programming algorithm and Dijkstra algorithm is used to construct the shortest distribution path model for medical supplies transported by rescue drones in disaster areas. Using integer programming method, 7 kinds of drones and 3 kinds of medical packages are distributed, and then the Dijkstra algorithm is used to obtain the optimal distribution plan. San Juan Port is equipped with medical kits and three C-type drones, Arecibo Port allocates B-type drone patrol lines and medical kits for rescue, and Guayama Port only allocates drones for patrol lines. Using this distribution scheme greatly improves the efficiency of rescue, and distributes rescue materials reasonably and effectively, achieving the goals of optimal delivery path and optimal equipment utilization.

1. Introduction
Puerto Rico[1] is one of the four largest islands in the Greater Antilles, located in the eastern Dominican Republic and northwest of the Lesser Antilles. Countless trees were scrapped, cut off branches, and uprooted and died in 2017. In addition to destroying local transmission lines and power generation facilities, the local vegetation must also be devastated. Hurricane Maria's damage[2] was severe and lasting. Hurricane Maria damaged[3] 95% of cell phone towers and cut off almost all cell phone communications in the area. At the same time, the operation of the Puerto Rican power grid was severely destroyed, leaving all residents on the island completely without electricity. Now, medical rescue work must be organized for the residents of the island. As a result, NGOs tend to improve their response capabilities through a mobile disaster response system called DroneGo. Compared with traditional modes of transportation, drones have the ability to overcome the difficulty of accessing remote locations. In these cases, drones have the ability to traverse rugged terrain, closed streets and destroyed bridges. Therefore, drones can play an indispensable role in disaster relief. The disaster response system will use the rotorcraft drone system to transport medical supplies and survey road conditions. Therefore, it is now necessary to plan the unmanned crew of the disaster response system to carry medical supplies and packages.

According to Table 1: Among the potential candidate drones considered by the DroneGo fleet, we observed the drone H, although its largest size, the drone H cannot load weight, no video function, no ability of load medical packages, while the flight time is uncertain. It can be seen from the above that...
the availability of the drone H is too low and cannot meet our needs. Based on this idea, we do not consider the drone H in the following considerations.

Table 1. Potential Candidate Drones for DroneGo Fleet Consideration .

| Drone   | Shipping Container Dimensions | Performance Characteristics/Capabilities | Configurations Capabilities |
|---------|-------------------------------|------------------------------------------|-----------------------------|
|         | Length (in.) | Width (in.) | Height (in.) | Max Payload Capability (lbs.) | Speed (km/h) | Flight Time No Cargo (min) | Video Capable | Medical Package Capable | Drone Cargo Bay Type* |
| A       | 45             | 45             | 25            | 3.5                      | 40            | 35                          | Y             | Y                       | 1                           |
| B       | 30             | 30             | 22            | 8                        | 79            | 40                          | Y             | Y                       | 1                           |
| C       | 60             | 50             | 30            | 14                       | 64            | 35                          | Y             | Y                       | 2                           |
| D       | 25             | 20             | 25            | 11                       | 60            | 18                          | Y             | Y                       | 1                           |
| E       | 25             | 20             | 27            | 15                       | 60            | 15                          | Y             | Y                       | 2                           |
| F       | 40             | 40             | 25            | 22                       | 79            | 24                          | N             | Y                       | 2                           |
| G       | 32             | 32             | 17            | 20                       | 64            | 16                          | Y             | Y                       | 2                           |
| H Tethered | 65             | 75             | 41            | N/A                      | N/A           | Indefinite                  | N             | N                       | N/A                         |

2. Research method

2.1 Drone cargo bay medical package allocation problem

Since the medical items[4][5] are packaged into the cargo bay of the different types of drones[6]. There are three different types of medical packages and two different models of cargo bay. According to the actual situation, the number of medical packages must be an integer. Thus, we use the integer programming method[7][8] to solve the allocation of medical packages in the warehouse.

Let the volume of the medical packages be expressed as \( v_i \) \((i = 1,2,...,7)\), the quality of the medical package is expressed as \( m_i \) \((i = 1,2,...,7)\), the load bearing capacity of the drone cargo bay is expressed as \( d_j \) \((j = 1,2,...,7)\), the volume of the cargo bay is expressed as \( c_j \) \((j = 1,2,...,7)\), the number of the medical package \( i \) th in the \( j \) type drone cargo bay is denoted as \( x(i,j) \).

When space utilization reaches its maximum, the objective function is

\[
\max z = \sum_{j=1}^{7} \sum_{i=1}^{3} \frac{x(i,j) \cdot v_i}{c_j} \tag{1}
\]

the constraint is

\[
\left\{ \begin{array}{l}
\sum_{i=1}^{3} x(i,j) \cdot m_i < d_j \quad (j = 1,2,...,7) \\
\sum_{i=1}^{3} x(i,j) \cdot v_i < c_j \quad (j = 1,2,...,7)
\end{array} \right. \tag{2}
\]

Since formula (1) and (2) belong to a single-objective programming model, Lingo software[9] was used to solve the single-objective model. The specific results are shown in Table 2.

Table 2. Drone cargo bay with medical packages

| Medical/Drone | A | B | C | D | E | F | G |
|---------------|---|---|---|---|---|---|---|
| MED1          | 1 | 2 | 3 | 1 | 7 | 11| 10|
| MED2          | 0 | 1 | 3 | 0 | 0 | 0 | 0 |
| MED3          | 0 | 1 | 2 | 0 | 0 | 0 | 0 |

According to Table 2, the optimal transportation scheme for the four types of A, E, F and G drones is: just transport MED1. According to the demand for medical packages at the five delivery locations in Table 3, we selected three types of drones, B, C, and D, as alternative drones for transportation.
Results from the known, indicate that the ports where medical packages need to be transported by drones are San Juan\textsuperscript{10} and Arecibo ports.

| Table 3. Anticipated Medical Package Demand |
|-------------------------------------------|
| Delivery Location | Emergency Medical Packages ** |
| Location Name | Latitude | Longitude | Requirement | Quantity | Frequency |
| Caribbean Medical Center | 18.33 | -65.65 | MED 1 | 1 | Daily |
| Jajardo | - | - | MED 3 | 1 | Daily |
| Hospital HIMA | 18.22 | -66.03 | MED 1 | 2 | Daily |
| San Pablo | - | - | MED 3 | 1 | Daily |
| Hospital Pavia Santurce | 18.44 | -66.07 | MED 1 | 1 | Daily |
| San Juan | - | - | MED 2 | 1 | Daily |
| Puerto Rico Children's Hospital | 18.40 | -66.16 | MED 1 | 2 | Daily |
| Bayamon | - | - | MED 2 | 1 | Daily |
| - | - | MED 3 | 2 | Daily |
| Hospital Pavia Arecibo | 18.47 | -66.73 | MED 1 | 1 | Daily |
| Arecibo | - | - | - | - | - |

2.2 Port medical package distribution problem

In the process of transporting medical packages, we use the Dijkstra algorithm\textsuperscript{11} and the shortest distance from the harbor of San Juan to the Caribbean Medical Center, HIMA Hospital, Pavia Santurce Hospital and Puerto Rico Children's Hospital. The shortest route is shown in Figure 1.

Figure 1. Schematic diagram of the shortest route at the port and delivery location

As can be seen from Figure 1, in order to meet the medical package needs of each delivery location, three transport drones should be placed in the container at the harbor of San Juan to transport medical packages to San Juan and Fajardo, Bayamon and San Pablo. The requirements for medical packages in various regions are shown in Table 4.

| Table 4. Medical package demand |
|-------------------------------|
| Location Name | MED1 | MED2 | MED3 | total weight | total capacity |
| San Juan and Fajardo | 2 | 1 | 1 | 9 | 1510 |
| Bayamon San | 2 | 1 | 2 | 12 | 1852 |
| Pablo | 2 | 0 | 1 | 7 | 1316 |

According to Table 4, the model of the drone used to transport the medical package is C. Therefore, the container packaging at San Juan\textsuperscript{9} Port is configured with three C-type drones, six MED1s, two MED2s, and four MED3s.

2.3 Patrolling drone and port allocation problem

The drone used for road detection requires strong endurance. According to the data in Table 1, we find that the B-type drone has the strongest endurance, so the B-type drone is selected for road detection. The packaging configuration of the container at the harbor of Arecibo should be responsible for the distribution of medical packages at the Pavia Arecibo Hospital, and the monitoring of nearby roads; the
containers at the harbor of Guayama are only responsible for road monitoring nearby roads. According to the map, it can be seen that there are six roads that can be surveyed by drones from the port of Arecibo, so six drones can be dispatched to monitor the roads, of which no one is responsible for monitoring Highway 129. The machine can also transport medical packages from Pavia Arecibo Hospital, so the container at the harbor of Arecibo is configured with 6 B-type drones and 1 MED1. It can be concluded by the same method that the container packaging of the harbor of Guayama is configured as three B-type drones. The final result is shown in Table 5.

|                  | MED1 | MED2 | MED3 | Drone's type | Number | Number of cargo bay | Total capacity |
|------------------|------|------|------|--------------|--------|---------------------|----------------|
| San Juan         | 6    | 2    | 4    | C            | 3      | 3                   | 298800         |
| Arecibo          | 1    | 0    | 0    | B            | 6      | 1                   | 119920         |
| Guayama          | 0    | 0    | 0    | B            | 3      | 0                   | 59400          |

3. Conclusion
In response to the impact of Hurricane Maria on the island of Puerto Rico, which caused serious disasters and huge casualties, non-governmental organizations tended to use the DroneGo mobile disaster response system and winged drone system to transport medical materials and survey road conditions. In this case, this article plans for the 7 categories of drones in the disaster response system to carry medical supplies packages.

(1) According to the size of the medical package and the endurance of the drone, this article uses the integer programming method to obtain the four drones A, E, F and G for transporting MED1, and the three unmanned B, C and D MED2 and MED3 are the best configuration scheme;

(2) For the six MED1s, two MED2s and four MED3s medical supplies in the San Juan port, this article uses the Dijkstra algorithm to conclude that three C-type drones should be deployed at the San Juan port to transport the medical package to San Juan, Fajardo, Bayamon and San Pablo.

(3) Since the B-type drone has the strongest endurance, the B-type drone is selected for road detection. Six B-type drones and one MED1 are deployed in the Arecibo port. Using the same method as container packaging, Guayama Port is configured with three B-type drones.

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References
[1] Van der Geer, J., Hanraads, J.A.J., Lupton, R.A. (2010) The art of writing a scientific article. J. Sci. Commun., 163: 51–59.
[2] George, M., David, A., Charles, Himali, W. (2019) Hurricanes and healthcare: a case report on the influences of Hurricane Maria and managed Medicare in treating a Puerto Rican resident. BMC health services research.
[3] Jessica M, G., Deidre, O., Mary, U., Frederico, G., Rodriguez, V. Y. E. (2019) Lessons Learned from a Medical Response Team 45 Days Post Hurricane Maria in Puerto Rico. J.1-6.
[4] Sarke, P., Lester, H. D. (2019) Post-Disaster Recovery Associations of Power Systems Dependent Critical Infrastructures. J. Infrastructures, 4.
[5] Song Qiyou. Research on Multi-voyage Dynamic Container Allocation.[D]. Dalian: Dalian Maritime University, 2013.
[6] Song Jin. Research on empty container dispatch based on customer value classification[D]. Dalian: Dalian Maritime University, 2015.
[7] Peng, X.Y., Chen, C., Rao, Z.Q., Yang, B.S., Mai X.M., Wang, K.(2015)Drone power line safety inspection and intelligent diagnosis based on drone multi-sensor data collection. J. 01:159-166.

[8] Du, H.K., Zhao, Y.K. (2010) A Survey of Intelligent Solving Algorithms for Integer Programming Problems. J. Application Research of Computers., 02.

[9] Sun, X.L., Li, R. (2014) New progress in integer programming. J. 01: 39-68.

[10] Qiyuan. Jiang Xie, Jun Ye. Mathematical Mode[M]. Higher Education Press. 2011.1.

[11] Flores, D., Ocaña, E., Rodríguez, A.I. (2019) Relationships between landform properties and vegetation patterns in the Cerro Zonda Mt., Central Precordillera of San Juan, Argentina. J. Journal of South American Earth Sciences.

[12] Zhang, Z.N., Wang, T. (2018) Research on Taxing Optimization Dijkstra Algorithm. J. Aeronautical Computing Technique. 06.