Optimal planning for UAV disaster response based on mathematical modeling

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Abstract. For the case of natural disasters in island countries with incomplete conditions that lead to the destruction of basic services, we analyze a real example of the island of Puerto Rico and propose a response plan using mathematical modeling methods. We compute the optimal path for the delivery of medical kits using the UAV dynamic response mechanism. We consider it as a multi-objective path problem and work to achieve cost reduction, transportation time saving, and efficiency, and build an optimization model for the calculation. The results show that our model calculation outperforms other solutions.

Keywords: Mathematical Modeling, UAV Response, Optimization Problem.

1. Introduction

Puerto Rico is an island in North America. It has a tropical rainforest climate with abundant rainfall. the average temperature is 24°C in January and 27°C in July, making it vulnerable to hurricanes. Puerto Rico was hit by an unprecedented hurricane in 2017. The hurricane caused severe damage to Puerto Rico's infrastructure such as buildings and roads, as well as basic services such as communications and electricity. Dozens of areas were isolated, there was no communication, medical needs were strained, and many patients were moved to hospitals and temporary shelters for treatment. There is a question of how to effectively rescue Puerto Rico, deliver various relief supplies and save as many lives as possible.

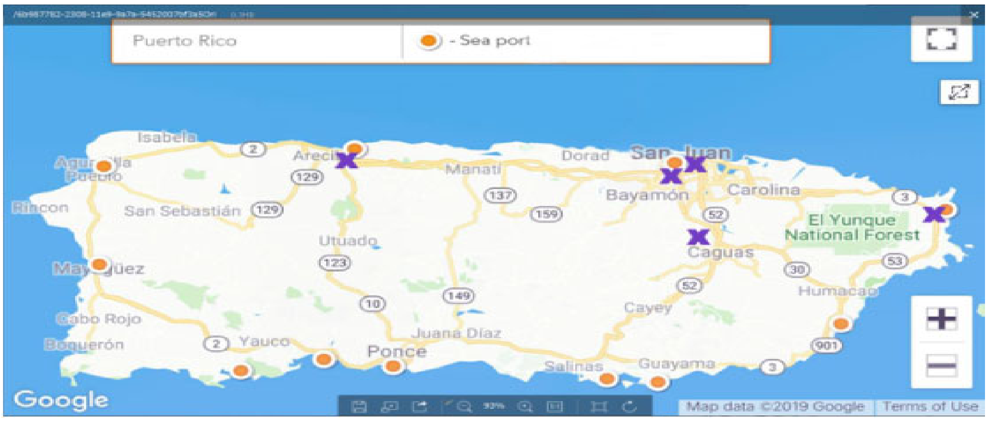

Fig. 1 Puerto Rico Map

2. Model Overview

First, we considered where the medical package should be placed, as the hurricane made it impossible to properly place the container inland. Based on this, we had to build a model to balance the transport time of the medical package and the difficulty of placing the container with the economic costs and benefits; the first model was about determining the location. Based on the transport time and the difficulty of placing the container, we use multivariate analysis to determine the goals we need to achieve. We consider the problem as a set of problems covering the problem and then build a multivariate model based on the calculations to satisfy the optimal demand. After selecting the type of parking location, we were asked to choose several specific locations to place the ISO containers. Influenced by many factors, we used hierarchical analysis to first conduct the analysis and arrive at the three factors that have the greatest impact on the objective. Unlike previous models, we used a combination of dynamic programming, fitting of these factors, and other methods. The results of the analysis selected the three ports that best meet the ISO container delivery conditions. Then we use dynamic programming, fitting and other methods to analyze these factors, and finally select the three ports that best meet the ISO container placement conditions for the fleet matching and medical package, we divide the container into several small parts according to the container, and place different types of medical packages and drones in each part, and then use greedy algorithm [1] to find feasible solutions for each part. In turn, we get the optimal assembly solution for the container. After that, we use loadmaster [2] to validate our ideas and make sure they work. For the video reconnaissance mission of the drones, we think that any port in the country that is not destroyed by the hurricane can provide charging for the drones. We used the drone in charge of the filming task as input and the port providing charging service as output, and based on the requirements, using neural network algorithms [3], we came up with the idea that the drone could achieve video reconnaissance work on roads other than the island highway [4].

3. Model Theory

The purpose of building smaller dams instead of larger dams is to manage water resources better, Inland roads and houses were damaged because the area was affected by the hurricane disaster, and the hurricane make it difficult for containers to be dropped inland. In order to reduce the impact of disasters on containers, we should avoid the excessive distance of containers to be dropped inland. So we get that:

$$minL_{ij}$$

For the purpose of saving time and increasing delivery efficiency, We have to choose some docking locations which are closer to the destination, and we also have to take into account the impact of conditions during the flight such as wind and rainfall on transport time. so we get that:

$$min\sum_{i=1}^{n_1} f * y * d(x_i)$$

We considered that dropping containers should reduce the cost of the container, enhance security, convenience and other factors. Because it is a small island, we assume that all three iso containers are transported by ship or aircraft. And we have to consider the issue of the docking of the ship and the location of the landing of the aircraft. so we get that:

$$max\sum_{i=1}^{n_2} o * m(i)$$

We analyzed the performance of each type of drone and chose the fastest drones, B and F, for delivery, while meeting the delivery requirements and minimizing delivery time.

◯ Caribbean Medical Center This hospital has a small demand for medical kits and is close to the port, so we could meet the demand while minimizing the cost of the drones. Based on an analysis of the drone's performance, we dispatched UAV B, which can drop med1 and med3 at once, and perform video reconnaissance of the road network at cruising range.

◯ HIMA Hospital This hospital is located far from the port of San Juan, which is very densely populated along its shores. Only the most capable UAV B could meet the requirements. We also took into account the smaller load of UAV B. In order to deliver efficiently to the affected area, we could send two UAV Bs to deliver medical packages to the Puerto Rico Children's Hospital.

The specific plan is: UAV B1 transports 2 med1 and UAV B2 transports 1 med3. UAV B has a video capture function to capture the main traffic arteries on the way to transport and return.

◯ Pavia Santurce Hospital, Puerto Rico Children's Hospital both hospitals are not more than 4 miles from San Juan port, we think San Juan port should provide medical packages for three hospitals, so we need to put a large amount of medical packages into containers. Then we can choose UAV F with large load, small package size and low range requirement to deliver medical parcels to these two hospitals. UAV F can provide the daily needs of these two hospitals (UAV F can hold 3 med1, 2 med2, 2 med3, and the load capacity.

◯ Hospital Pavia Arecibo9 Considering that the Hospital Pavia Arecibo9 has a small demand for Medical Packages and is close to the port. So we can reduce the cost of UAVs as much as possible while meeting demand.

we chose the drone B to send Medical Packages to the Hospital Pavia Arecibo because according to the analysis of drone performance, drone B have strong endurance and poor load capacity which is satisfied the demands. And it can also be used after delivery to take pictures of the main roads in the area and feedback the disaster information. In order to save the space inside the container, the drone warehouse can be loaded into two medical containers med1, and the remaining space in the container is used to install the medical box med1.

All marked above, in order to meet the delivery requirements, sanjuan port container (at least) need to install two B drones, one F drone, several medical containers. In order to transport the goods to the corresponding hospital, one B-type drone (at least) must be installed in the container of the port of fajardo and arecibo. To save space, the medical box can be installed in the bin of the drone.

4. Model Implementation and Results

We combine the operating range of each drone with the length of the road that can be taken within its operating range, based on the actual conditions of the island. Then using the fitting algorithm to obtain the fitting equation of the operating range and the length of the road have photographed by each of the three ports. (figure n), Combine it with the percentage of the population in the operating range, then the location of the three ports was determined.

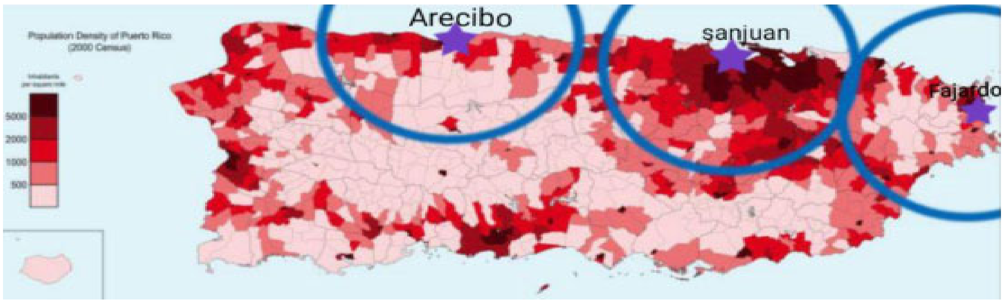

Fig. 2 Diagram of the port where the drone was dropped

According to the calculation, this three ports, and the range to be photographed by these three port drones corresponds to the proportion of the population of Puerto Rico as shown in the following table:

Table 1. The range of drone photography in relation to the number of people in each port

Port	Percent%
Arecibo	16.06
San Juan	41.21
Fajardo	13.62

Our model can provide emergency response scenarios for future unexpected disasters on the island and reduce the number of casualties caused by disasters. For the ports, roads and hospitals on the island, we have obtained enough data and integrated various algorithms to build a model to analyze the most suitable locations for containers. Our model is robust when the parameters are varied. That is, small changes in the parameters do not cause significant changes in the results.

References

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