

## The area selection of drones disaster response system based on AHP and GIS technology: a case study of Puerto Rico

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**Abstract:** In 2017, the worst hurricane to ever hit the United States territory of Puerto Rico left the island. One NGO in particular – HELP, Inc. - is attempting to improve its response capabilities by designing a transportable disaster response system called “DroneGo”. DroneGo will use rotor wing drones to deliver pre-packaged medical supplies and provide high-resolution aerial video reconnaissance. The model is established to provide the best launch area for the DroneGo disaster response system. The study determined the selected indicators are “the distance from the Delivery Location to the best location or locations”, “the distance from the road to the best location or locations”, “the slopes in the Puerto Rico”, “the land types in Puerto Rico”. The corresponding weights are determined by Analytic Hierarchy Process (AHP). Finally, the corresponding values of each index are extracted from ArcGIS software and superimposed to get the highest score area, namely, the best area.

**Keywords:** DroneGo disaster response system; Puerto Rico; APH; ArcGIS

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### I. Introduction

In 2017, the worst hurricane to ever hit the United States territory of Puerto Rico left the island with severe damage and caused over 2900 fatalities. Widespread flooding blocked and damaged many highways and roads across the island, making it nearly impossible for emergency services ground vehicles to plan and navigate their routes. The full extent of the damage in Puerto Rico remained unclear for some time; dozens of areas were isolated and without communication. Demands for medical supplies, lifesaving equipment, and treatment strained health-care clinics, hospital emergency rooms, and non-governmental organizations’ (NGOs) relief operations[1]. Caribbean Medical Center, Hospital HIMA, Hospital Pavia Santurce, Puerto Rico Children's Hospital and Hospital Pavia Arecibo were in urgent need of medical supplies. HELP, Inc. will use International Standards Organization (ISO) standard dry cargo containers to quickly transport a complete DroneGo disaster response system to a particular disaster area.

The model is established to provide the optimal delivery area for the response system, so that the drones can quickly complete both medical supply delivery and video reconnaissance of road networks. After reading a lot of literature and combined with the requirements of the topic. The study selected four indicators: “Delivery Location to the distance of the best location or locations”, “Distance from the road to the best location or locations”, “Slope on the Puerto Rico”, and “Land type on Puerto Rico”. The corresponding weights are determined by Analytic Hierarchy Process (AHP) to be 0.43, 0.27, 0.07, and 0.2, respectively. Finally, the corresponding values of each index are extracted from ArcGIS software and superimposed to get the highest score area, namely, the best area.

### II. Preparation For Our Tasks

The study obtained Google Images and Google Maps from Puerto Rico from LocaSpace Viewer. LocaSpace Viewer is a free 3D digital earth product independently developed by 3D Vision Technology Co., Ltd., which can provide functions such as browsing and downloading data.

The study obtained the DEM image of the Puerto Rico 30m resolution from the National Geospatial Data Cloud website of the Computer Network Information Center of the Chinese Academy of Sciences. DEM is the abbreviation of Digital Elevation Model. It is a digital simulation of ground terrain by terrain elevation data. It is a kind of raster data. The gray value of each pixel represents the elevation of the position[2].

The study uses the ENVI software to supervise and classify Google images for land use types. ENVI (The Environment for Visualizing Images) is a complete remote sensing image processing platform. The software has functions such as enhancement, mosaic, transformation and information extraction of remote sensing images[3].

As a new generation of geographic information processing platform, ArcGIS software has more powerful functions such as data management, compilation, display and analysis[4].The study first uses ArcMap software, combined with the map of the study area given in the title, to obtain a vector map of the boundary of the Puerto Rico and a linear map of the main road through visual interpretation, taking the boundary of Puerto Rico as the study area According to the latitude and longitude information of the delivery locations, five delivery locations converts to a vector dot plot at the point location and marks it in the map. The coordinate system used is consistent with Google Maps. The projected coordinate system is: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere, and the geographic coordinate system is GCS\_WGS\_1984. The results are shown in Figure 1:



Figure 1 The Research Scope Maps

### III. Model building and solving

The study first determines the evaluation indicators and the indicators weights, then convert the vector point data and line data to a raster using the "Polyline to Raster" tool and the "Point to Raster" tool, and calculate each point and line using the Euclidean Distance tool. Distances to various locations in the study area, Point Distance and Road Distance. At the same time, the Google Image image is supervised and classified by ENVI to obtain the Land Use Map, and the slope of the DEM data is extracted to obtain the Slope. The Point Distance, Road Distance, Land Use Map and Slope are reclassified to each pixel to give corresponding values. Finally, according to the weight of each indicators, the "Raster Calculator" tool is used to superimpose and get the evaluation. Finally, the study selects the highest score range, and determine the best location or locations in the range. The specific process is shown inFigure 2:

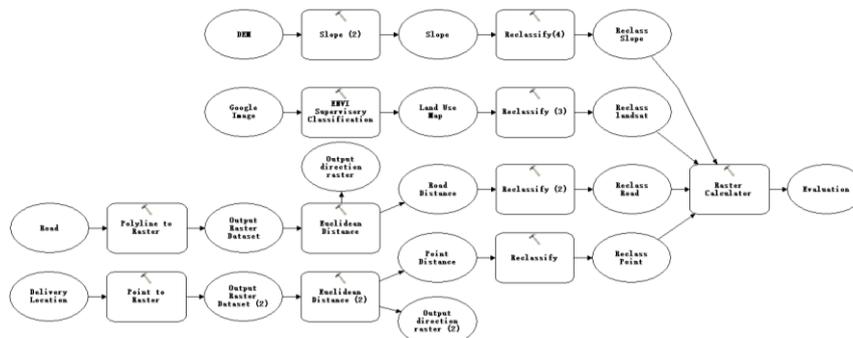


Figure 2The Flow Chart

#### A. Model Indicators selection and weight determination

After reading a lot of literature and combined with the requirements of the topic, the study selected four indicators: "Delivery Location to the distance of the best location or locations", "Distance from the road to the best location or locations", "Slope on the Puerto Rico", and "Land type on Puerto Rico" and they are labeled as "I", "II", "III", and "IV". Then, the weight of each indicators is analyzed by analytic hierarchy process.

- Establishment of AHP model
- Construct a pairwise comparison matrix

The ratio of the importance of the four indicators, the establishment of the comparison matrix:

$$A = (a_{ij})_{n \times n}, \quad a_{ij} > 0, \quad a_{ji} = 1 / a_{ij} \quad (1)$$

The diagonal element:  $a_{ii} = 1 (i = 1, 2, \dots, n)$

➤ Calculated eigenvector

When determining the weights of the four indicators, according to the comparison matrix A, the corresponding normalized feature vectors are obtained, that is, the weights of the indicators.

➤ Consistency indicator and consistency test

For matrix A, find its maximum eigenvalue and eigenvector (normalization). This paper uses the consistency indicator defined by Satty:

$$CI = \frac{\lambda - n}{n - 1} \quad (2)$$

Where: n is the level of A, which is the largest eigenvalue of A. When CI = 0, A is a uniform array. The larger the CI, the more inconsistent A[5]. In this paper, the value of the random consistency index RI introduced by Satty is shown in Table 1

**Table 1**

n	3	4	5	6	7	8	9	10
RI	0.5	0.9	1.1	1.2	1.3	1.4	1.4	1.4
	8	0	2	4	2	1	5	9

The way the study calculated the degree of inconsistency of A: After calculating the consistency index CI of the n-order pairwise comparison matrix A, compare it with the same-order random consistency index RI, when the ratio satisfies:

Then it is considered that the inconsistency range of A is within the allowable range.

● Pairs of analytic hierarchy process

Establish a pairwise comparison matrix that reflects the importance of each indicator. As shown in Table 2:

**Table 2**

	X1	X2	X3	X4
X1	1	2	5	5/3
X2	1/2	1	4	4/3
X3	1/5	1/4	1	1/3
X4	3/5	3/4	3	1

Establish a comparison matrix.

$$A = \begin{pmatrix} 1 & 2 & 5 & \frac{5}{3} \\ \frac{1}{2} & 1 & 4 & \frac{4}{3} \\ \frac{1}{5} & \frac{1}{4} & 1 & \frac{1}{3} \\ \frac{3}{5} & \frac{3}{4} & 3 & 3 \end{pmatrix} \quad (3)$$

Calculate the maximum eigenvector for the matrix using MATLAB:

$$\omega = (0.4278, 0.2702, 0.0755, 0.2265)^T \quad (4)$$

The CI is 0.0092, the RI is 0.8846, and the CR is 0.0104 < 0.1. The consistency test is satisfied, and the normalized eigenvector can be used as the weight vector. The weights of the four indicators are 0.43, 0.27, 0.07, and 0.23, respectively.

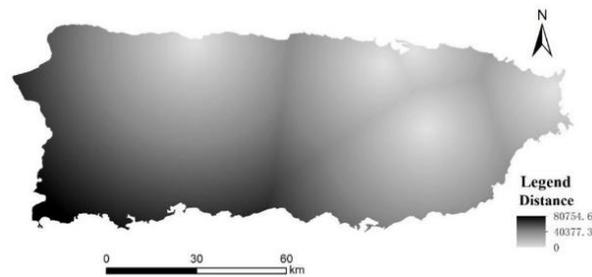
**B. The Calculation of the Distance from the Best Location or Locations to the Delivery Location and the Main Road**

The "Euclidean distance analysis" tool in the ArcMap Software Toolbox was used to calculate the distance from each pixel on the map to the delivery location and the main road.

● "Euclidean Distance Analysis" Tool Principle

The "Euclidean distance Analysis" describes each cell's relationship to a source or a set of sources based on the straight-line distance. The principle is to calculate the length of the hypotenuse for each pixel in the raster data with its maximum value in the x and y directions as the two right angle sides of the triangle. Therefore, the actual distance between the actual objects can be obtained instead of the distance between the pixels. The study first specified one or more cells as the source. If the minimum distance between the source and a cell was less than the maximum distance specified between them, the value would be assigned to the cell at that location in the output raster image. If the distance between the cell and the multiple sources was equal, the distance between it and the first source is assigned to the cell. This tool traversed all pixels in the graph to calculate the value of each cell as a gray value, combining all the pixels to produce a resulting image[6].

- The Calculation Process of the Distance
- Use the multiple tools under the "Conversion Tools" in the ArcMap Toolbox to convert the vector maps into raster maps with resolutions set to 100.
- Use the "Euclidean Distance Tools" tool in the ArcMap toolbox to calculate the distance between the delivery location and the road to each pixel in the research scope. Specify the boundary of the output image to be the same as the boundary of the research scope.



**Figure 3** All Raster Distance from the Delivery Location to the Research Scope

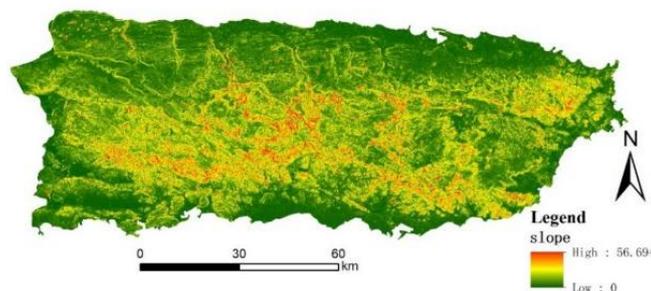
*C. The Calculation of the Slope on the Puerto Rico*

- The "Slope" Tool Principle

The Slope tool in the Arc Map Toolbox can identify the slope of each pixel in the raster. In DEM data, the value of each grid represents the actual altitude of the location. The Slope tool calculates the rate of altitude changes of pixels in eight directions by analyzing the horizontal, vertical increments between pixel at a certain location and its adjacent eight pixels[7]. The slope calculation formula of a raster is:

$$Slope = ATAN\left(\sqrt{\left[\frac{dz}{dx}\right]^2 + \left[\frac{dz}{dy}\right]^2}\right) \quad (5)$$

- Slope calculation uses the "Slope" tool in the ArcMap Toolbox and the DEM in the research scope as the input data to carry out the boundary of the designated output image which is the same as the boundary of the research scope.



**Figure 4** The Slope Map of the Research Scope

*D. The Land Type Division in Puerto Rico*

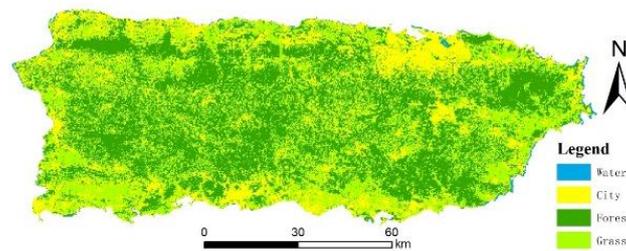
- Maximum Likelihood Method Principle

The land type division mainly uses the Supervised Classification in the ENVI app, its basic principle is Maximum Likelihood Method. As the Maximum Likelihood Method firstly needed to select certain training samples, the study mainly divided the research scope into four types of land use: forest, grassland, water and city, then selecting the training samples from Google images for each type of land by visual interpretation. It is

assumed that the spectral characteristics of ground objects in the training sample are similar to most random phenomena in nature and approximately obey normal distribution. By using the training sample, the characteristic parameters such as the mean value, the variance and the co-variance of each local class can be obtained, so that the prior probability density function of the general can be figured out. On this basis, for any pixel, the probability that it belongs to each category can be obtained in reverse so that the land type corresponding to the maximum probability can be taken as the classification result[8].

- The Classification Process

The Google images in the research scope are supervised and classified in ENVI software, and then the classification results are imported into ArcMap. The classification results are shown in Figure 5:



**Figure 5**The Land Use Map of the Research Scope

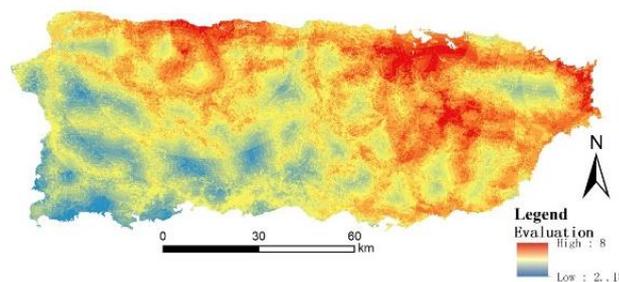
*E. Indicators Synthesis*

- Assign Values to Each Index

"The distance from the Delivery Location to the best location or locations" and "Distance from the road to the best location or locations" are divided into 8 categories on average. The closer it is to the Delivery Location or The Road, the higher its value is, with the maximum value of 8 and the minimum value of 1. Terrain Slope Classification Standard specified  $0^{\circ} \sim 5^{\circ}$  for flat slopes,  $6^{\circ} \sim 15^{\circ}$  for gentle slopes,  $16^{\circ} \sim 25^{\circ}$  for slopes,  $26^{\circ} \sim 35^{\circ}$  for steep slopes,  $36^{\circ} \sim 40^{\circ}$  for very steep slopes,  $41^{\circ}$  to  $45^{\circ}$  for sharp slopes, more than  $46^{\circ}$  slopes for risk[9]. The slower the slope is, the more favorable it is for the landing of Standard ISO Containers. Therefore, the slopes are divided from the flat slopes to risk slopes, and the value is assigned from 8 to 2. In terms of land use types, the study has read a lot of relevant materials and come to the conclusion that cities and towns are most conducive to the landing of Standard ISO Containers, followed by grassland, while Standard ISO Containers cannot land in water bodies. So the study assigns 8 for urban land, 6 for grassland, 4 for forest, and 0 for water. Use the Reclassify tool in the ArcMap Toolbox to assign values to each raster of each metric.

- The Synthesis Index Calculation

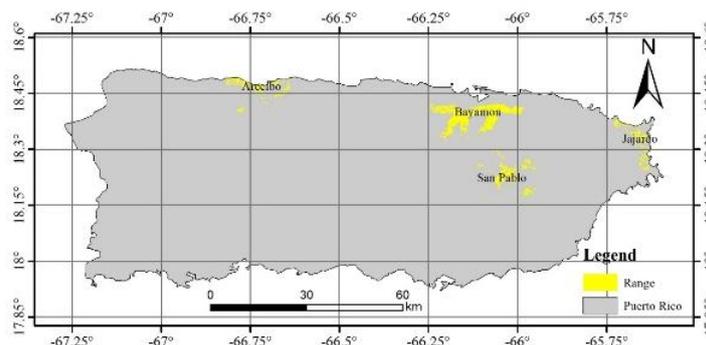
Use the Raster Calculator from ArcMap toolbox, and calculate the overall score of all the raster based on the weight of each index. The calculation results are shown in Figure 6:



**Figure 6**The Evaluation Chart

- The Determination of the Optimal Range

According to the figure above, the maximum value of the evaluation result is 8, so the study selected the range of the corresponding raster as the optimal region. Then the study used the Raster Calculator in the ArcMap Toolbox to select the range with a value of 8 and converted it into a Vector map. The results are shown in Figure 7:



**Figure 7**The Optimal Range Distribution

The study combined the blocks of adjacent locations and name them after the county or district of the area, and end up with four optimal ranges. The details are shown in Table 3:

**Table 3**The Table of the Best Latitude and the Longitude

Name	Longitude Range	Longitude Range	Area (square miles)
Arecibo	18.39 ~ 18.49	-66.82 ~ -66.64	10.40
Bayamon	18.32 ~ 18.42	-66.25 ~ -65.98	37.92
San Pablo	18.15 ~ 18.30	-66.11 ~ -65.94	13.49
Jajardo	18.24 ~ 18.38	-65.73 ~ -65.62	8.18

(Note: The ranges of the latitude and the longitude are the latitude and the longitude of the place where the optimal regional boundary is located.)

#### IV. Evaluation And Improvement Of The Model

##### A. Advantages

The assessment system fully integrated the factors such as distance, slope and land use type. The Locations provided to conduct both medical supply delivery and video reconnaissance of road networks were used to ensure the safety of Standard ISO Containers, which was considered comprehensively. Using systematic analysis method to determine the index weight is convenient and fast[10].

##### B. Disadvantages

When dividing the land use types, question B fails to verify the measured data, so the classification accuracy cannot be determined. And the evaluation system is limited by the collected data. When determining the weight of each index, the evaluation system uses the analytic hierarchy process (APH), which uses data with large qualitative factors, large subjective factors and small convincing force[11].

##### C. Improvements

If conditions permit, more factors can be selected to participate in the construction of the evaluation system, and expert opinions can be comprehensively considered to make the evaluation criteria more objective. And The study will try to use higher resolution images and more accurate ground object classification methods to get more accurate land use types.

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