# *A GIS Based Analysis of Vulnerable Areas and Communities in the Event of a Medical Emergency*

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***Abstract*** *— This investigation focuses on determining areas that are underserviced by emergency response hospital in Puerto Rico. Using drive time distances from hospitals of 5, 10, and 15-minutes, perimeters are created. Once these areas are created, the investigation analyzes the areas found outside of these regions. Further investigation is done on these areas of lower accessibility to determining their demographic profiles. The results of the analysis found that 14.07 of block groups in Puerto Rico are outside of the service areas totaling to 13.82 of the population. The demographic profiles found areas of potentially high health risks within these underserviced areas.*

***Key Terms*** *—Geographic Information Systems, Network Analysis, Z scores, Public Health.*

## INTRODUCTION

Emergency preparedness is a crucial aspect of any society and it is important for the safety of the population to understand their geographic proximity to health centers. In the case of an unforeseen emergency event occurring, being able to identify the nearest facility could make a difference in the outcome of the event. This research is focused on the island of Puerto Rico and will use Geographic Information Systems (GIS) as a tool to analyze distances between communities and the nearest emergency response hospital. The goal of this investigation is to highlight communities that are at higher risk based on service areas created using isochrone driving distances from hospital geolocations.

Further analyses will be done on the areas deemed high risk. Using census data, demographic profiles will be created to monitor key aspects of the populations. This investigation is crucial because based on the profile of the communities outside of a hospital's service area there could be serious implications for the people living in those areas.

### Research Description

This research investigates the average distance of communities to the nearest emergency response hospital by mapping service areas around hospitals. The method chosen to create the service areas is using driving time distances. Further analyses will be done on areas outside of the service areas to determine the demographics of the communities deemed at higher risk due to being outside of service areas.

### Research Objectives

The objective of this research is to highlight vulnerable communities that should be monitored closely to ensure that they are being properly served. This research could be useful when determining areas to target for better infrastructural funding. Another objective of this research is to refine the use of GIS technology in the field of Emergency Response. Developing an important methodology to optimize the latest mapping technology for finding the quickest routes available.

### Research Contributions

The main contribution of this research is understanding response time accessibility for communities. Using GIS analyses to create maps and data tables dedicated to understanding hospital service areas. Also, the communities that fall outside of these service areas and understanding the populations of these communities. This research seeks to modernize and update how emergency response is thought of in Puerto Rico. This investigation will create a methodology for understanding the relationship between the

proximity of communities to emergency response locations in Puerto Rico.

## LITERATURE REVIEW

This section discusses the main themes of the investigation and the historical context, through the lens of the available literature. This section also determines how the research fits into the larger scope of using GIS technology to aid public health.

### Background

In 1969, the Puerto Rico Medical Emergency Corps (*Cuerpo de Emergencias Médicas de Puerto Rico* or CEMPR) was implemented as a division within Puerto Rico's Department of Health. The purpose was to create a unified center for receiving emergency phone calls and dispatching the necessary response needed. Today, when an emergency call is placed and an ambulance is required, according to the CEMP's official Dispatch Chart, either a private or public ambulance will be called according to the closest available option. Private ambulance companies were entered into the CEMP system in 2008, while public ambulance can range from CEMPR's ambulances, municipal ambulances, or even rescue volunteers with the mission of assisting if ambulances are in high demand. The CEMPR's dispatch flow chart provides a summarized version of how emergency response calls are handled (Figure 1). Different types of services are called upon depending on distance from the location of the emergency.

Puerto Rico is divided into four regional dispatch offices across the island which is separated into the Northern, Eastern, Southern, and Western dispatch center (Figure 2). These regions are further divided into operational zones (Figure 3). These zones are of particular interest because this investigation seeks to analyze if these zones are ideally distributed based on drive time to nearest hospitals. Other spatial analysis will be conducted to determine if the operational maps are ideal for the present demographics in Puerto Rico.

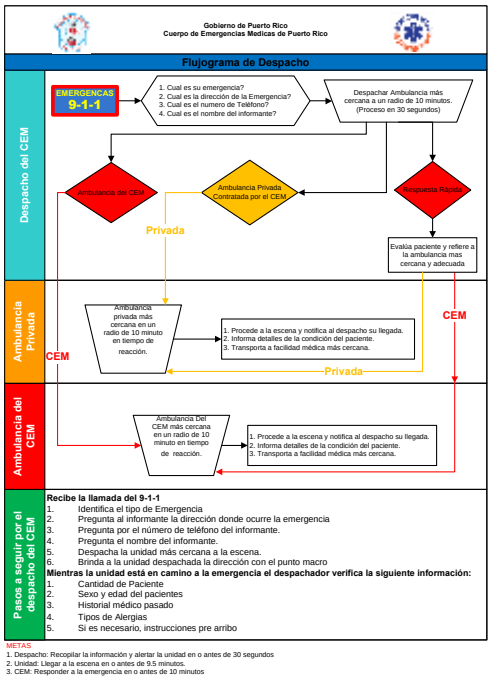


**Figure 1**
**Puerto Rico CEMPR Dispatch Chart**


**Figure 2**
**Regional Dispatch Offices**

**Figure 3**
**Puerto Rico CEMPR Operational Zones**

### Service Areas

This investigation determines community's proximity to hospitals by creating service areas around the location of hospitals in Puerto Rico. These service areas are determined by using GIS technology to find the area a car can travel from the hospital within 5 minutes. Investigating how service area within the medical field and other industries is

calculated is valuable insight. According to Maconick et al. (2021) there is evidence that service limits that are constrained by geographical variation in the number of people in contact with services may not be able to expand sufficiently to meet the needs of patients [1]. This can be extremely worrisome in the case of high medical risk areas. The investigation focuses on mental health issues and socio-economic factors to determine the most at-risk areas in England.

Similarly, this research will use methods to look at communities that fall outside hospital service areas. Golbersteing et al. (2015) described the extent of geographic variation in four measured of service use, creating distributional plots and describing the distributions of these measures in terms of their means [2]. Finding that mental health services varied considerably on the basis of geography. Once again showing the importance of communities having proper access to health services. These regions outside of service areas are treated as clusters and to understand areas. Clustering is an extremely important practice in the field of GIS analysis and determining clusters properly is crucial to the results of analysis [3].

### Network Analysis

Network Analysis is an extremely powerful tool analysis that, according to Lippi et a. (2020) has been long used in the realm of public planning to effectively improve operations [4]. “This family of analyses is particularly useful in the assessment of service demand, planning of delivery routes, and evaluation of deployment facilities in relation to underlying road networks” Lippi continues saying that network analysis has been used extensively in various fields but is not often used in the health sector [4]. This investigation will attempt to bridge the gap and create a methodology for approaching network analysis research in the health sector. Using drive time perimeters to determine service areas can highlight underserviced areas in Puerto Rico. Finding block groups completely outside of hospital service areas is a valuable way to gather statistical data on populations being underserved [5].

Higgs et a. (2018) states that access to health care is comprised of five different dimensions: availability, affordability, accessibility, acceptability, and accommodation. Implementing network analysis aids in demonstrating the dimension of accessibility of health care [6].

## METHODOLOGY

This section focuses on the processes used to analyze the data for the investigation. The methodology was determined using knowledge of previous investigations related to the subject matter.

### Data Sources

The census data acquired for this investigation was downloaded directly from the American Census Bureau data base. The specific census surveys being utilized are the 2019 and 2014 ACS 5 Year Estimates Profile. The purpose is to gain an understanding of how demographic shifts are occurring in areas that are underserviced by hospitals. The data is aggregated at the block group level. Previous investigations looked at variables such as: age, gender, percentage unemployed, population density, amongst others [1]. Additionally, this investigation will look at percentage uninsured and percent population with disability. The combination of the aforementioned variables will be used to create a health index of the areas outside of hospital service areas. The index will be created by getting the average z score of each variable per block group.

The location of the hospitals in Puerto Rico were acquired by georeferencing a combination of various lists of hospitals available online. Ensuring that the lists were up to date and that the hospitals were in fact operational response locations was crucial for this investigation. The list was then converted into a geographic shapefile file using the longitude and latitude of the hospitals. Once in the GIS software, the layer was compared to the Google Earth base layer to check the precision of the coordinates for each hospital. A map illustrating the location of the hospitals used in this investigation was created (Figure 4).

**Figure 4**
**Emergency Response Hospitals**

### Network Analysis Framework

This investigation was done using QGIS, a free and open-source GIS platform, to conduct the network analysis for the hospitals. Specifically, the plug-in ORS Tools which provides access to OpenStreetMap functions was implemented. The service areas were determined by creating perimeters of 5- and 10-minute drive times around the hospitals. Overlap between service areas happened in different areas but for the purpose of this investigation they were ignored. Areas of overlap signals that the block group is highly likely to be properly serviced and this investigation seeks to highlight and determine how to best service areas that fall outside of drive time radiuses.

### Vulnerability Index

The index is comprised of the various variables stated above: age, gender, percentage unemployed, population density, percentage uninsured and percent population with disability. While also taking into consideration the distance of the block group from the nearest hospital. A z-score will be determined for each variable within each block group by first determining the mean value of the variable, then the standard deviation. Then those values will be plugged into the formula for z-scores:

$$Z = (x - \mu)/\sigma \quad (1)$$

Once this is done for each variable the data has thus been normalized and can be used in computations along with other variables. The average of the z-score values for each block group will be calculated to determine which block groups have the highest vulnerability index.

## Results and Discussion

This section is dedicated to describing the results of what was found throughout the investigation. The discussion details the most important findings and why they are significant.

### Network Analysis Results

Running the ORS Isochrone tool in QGIS for 5, 10-, and 15-minute intervals yields results of interest (Figure 5). An important factor to consider when understanding the importance of network analysis is that it is determined by road accessibility. The direct distance, although the fastest, may not always be possible in real world application because of the way roads have been designed or the current conditions of those roads [7].

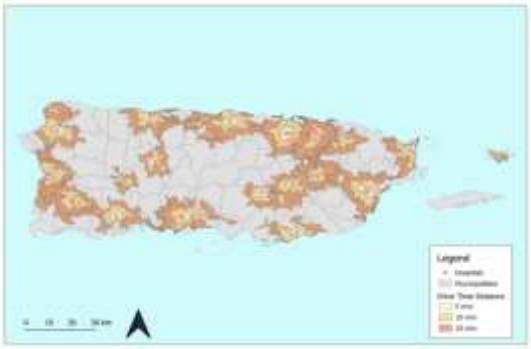

**Figure 5**
**Drive Time Perimeters for Hospitals**

There are 360 block groups that are completely outside of the 15-minute drive time boundary of any hospital (figure 6). That is equal to 14.07 percent of block groups in Puerto Rico. The largest cluster of block groups outside of any hospital 15-minute drive time perimeter is found in the center of the island. The second largest cluster is found near the Northwestern corner of the island.

According to the 2019 5 Year American Census Survey, the total population of citizens living within these block groups equates to 13.82 percent of the population. A map to illustrate the distribution of population within the block groups of interest was created (Figure 7).

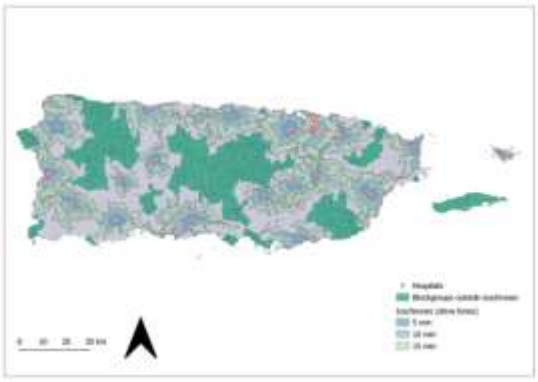

**Figure 6**
**Block groups Completely outside Drive Time Perimeters**

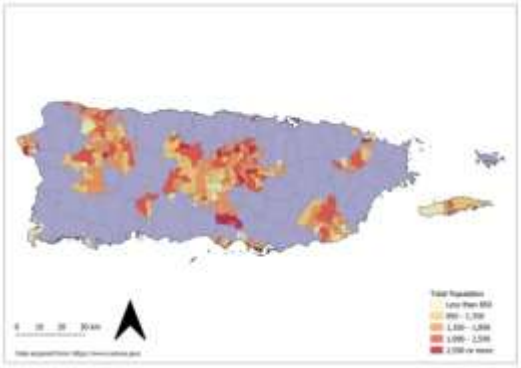

**Figure 7**
**Total Population of Block groups outside of Drive Time Perimeter**

Following a similar trend, the total population of people over 65 living in the block groups outside of the 15- minute drive time equates to 14.94 percent of the population. The geographic distribution of this data has been mapped (Figure 8).

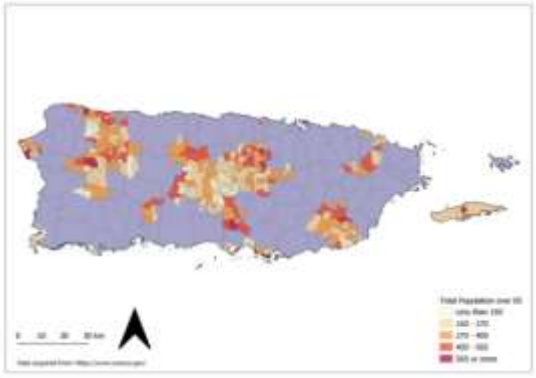

**Figure 8**
**Population over 65 years old in Block groups outside of Drive Time Perimeter**

Overall, hospital coverage in Puerto Rico broadly covers the majority of the island. Looking at this data using a geographic model allows one to gain a better understanding of the distribution of the study area. The preliminary population data proved to be of interest. With around 15 percent of the population outside of the drive time perimeter it is important to investigate further utilizing a broader range of factors to determine the extent to which people are underserviced in Puerto Rico. Thus, this investigation will take a deep dive into the demographics of those living in the non-covered block groups.

## Z- Score Results

Once the block groups of interest were determined using Isochrone perimeters, various census data variables can be used to further analyze these regions. It is important to consider each variable carefully because the factors can skew the data. The variables chosen are: total population, median age, population over 65, percent population over 65, population below poverty level, percent of population below poverty level, population without health insurance, percent population without health insurance, aggregated household income and percent of population non- high school graduates. Using the total value and percent of total gives a wider range of analysis for the area of interest. The percentages reflect the percentages across the island and thus can counter any skew in the data that may have been created from the block groups chosen. For example, the total population of a block group may be relatively large in comparison to the other block groups in the study area, without also using the percent of total, this may place more weight on that block group.

For each variable the mean and standard deviation were calculated. Inputting the variable value for each block group along with the mean and standard deviation, the z score was calculated. Calculating z scores is a way to easily compare values amongst different datasets. Z scores reveal whether a value is typical in comparison to the rest of the data points in the dataset. Once the z score

value for each variable was calculated, the average z score was determined by summing the z scores and dividing by the number of variables.

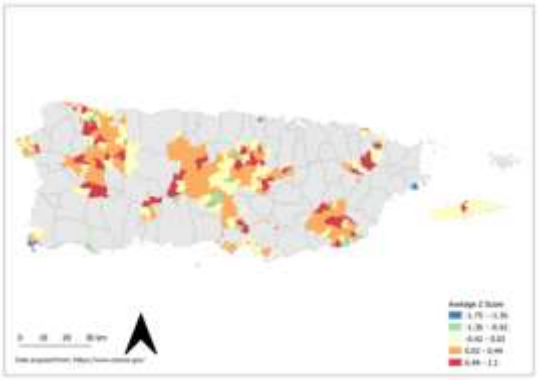

**Figure 9**
**Average Z Score of Block Groups outside of 15 Minute Drive Time Perimeter**

The map shows that the majority of block groups average around a z score of 0 which is what one would expect (Figure 9). However, we can see that the northwestern cluster of block groups has a high concentration of block groups above the average. Areas with higher z score averages tend to have above average values for each variable. This is important because the variables chosen reflect specific demographics of higher health vulnerability according to investigations into the previous literature. The cluster on the southeastern part of the island also is a particular area of interest. In total, 192 of 360 block groups have a z score greater than 0. This is to be expected when calculating for in comparison to the mean of the data. Similarly, 39 out of 360 block groups have an average z score greater than .5 which equals to 10.8 percent. However, in the southeastern region 22 out of 32 block groups have a z score above 0, which means equals to 68.75 percent. This region is of particular interest when understanding areas that are underserviced and have higher rates of medical needs.

Although the average z score is useful to get a general understanding of the trends across Puerto Rico, it is also important to see what factors are pushing the average above the mean value. The variable that stands out the most in that region is when looking at aggregated household income. A map was created to show the distribution of z scores for aggregated household income in the southeastern region of Puerto Rico (Figure 10).

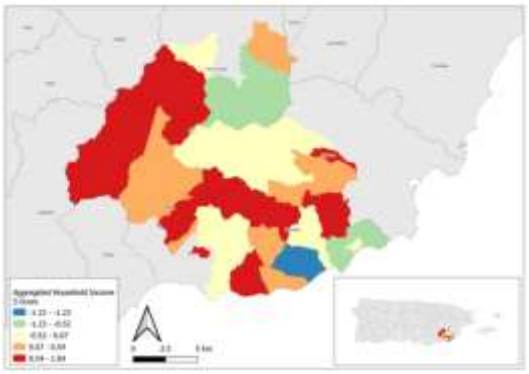

**Figure 10**
**Aggregated Household Income Z Scores Southeastern Region of Puerto Rico**

The map shows that the majority of block groups in the region have a z score greater than 0. Lower overall income can lead to serious barriers for getting medical attention. The regions were created using 15-minute drive time perimeters for hospitals but many people with lower incomes do not own a car and thus will have a harder time in the case of an emergency. That is just one of the many factors to consider when it comes to how income is connected to public health. Overall, the regions were fairly evenly distributed and hovering around the average, that is why many of the average z scores were close to 0. Further analysis can be conducted on the individual block groups with the highest z scores but that is beyond the scope of this investigation, which seeks to highlight overall regions that may be underserved.

## CONCLUSION

This investigation has shown how the use of Network Analysis can be implemented to aid in public health research. Drive time is a strong indicator of accessibility and creating isochrone distances based on a 15-minute drive radius from hospitals highlights areas that are underserviced.

Using network analysis tools during city planning could be a powerful way of determining ideal locations for potential hospitals. This

investigation, using knowledge of previous literature, used Geographic Information Systems to analyze hospital locations from a geographic perspective. The results produced a fairly even distribution. Overall, this investigation found 360 block groups that are completely outside of the 15-minute drive time boundary of any hospital, which is equal to 14.07 percent of block groups in Puerto Rico. This percentage is significant especially when considering the total population that lives within those block groups. For individual statistics, such as population and population over 65 years of age, this investigation found that nearly 15 percent of both categories live within those block groups in Puerto Rico.

After compiling the block groups of interest, census data was used to create a demographic profile of the regions. Using a wide variety of variables chosen by researching previous literature's investigations into factors that determine areas that need more access to health facilities. The variables used were the following: total population, median age, population over 65, percent population over 65, population below poverty level, percent of population below poverty level, population without health insurance, percent population without health insurance, aggregated household income and percent of population non- high school graduates. To create an index using the previous variables, first the data had to be normalized. To do this the z score for each data point was calculated. Once the data was converted into z scores, the average for each block group was calculated. Z scores are a measure of tendency within a dataset, the closer to 0 a z score is the closer to the mean the data point is. This investigation found two general areas, one cluster of block groups on the Northwestern side of the island and another cluster on the Southeastern part of the island. Both clusters had a majority of block groups above an average z score of 0, notably the southeastern region has 68.75 percent above an average z score of 0. This is important to understand because it proves that these areas of lower accessibility are also of high potential risk of needing medical services.

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