GSA Team 14 - dela Resma, La Rosa, Pingol, Soriano

CATCHING FIRE

Fire Station Coverage in Metro Manila

Executive Summary

In 2017, the Bureau of Fire Protection (BFP) in the Philippines reported a record high of the number of fire incidents in the Philippines that cost about 500 billion pesos. Metro Manila accounts for 32% of these incidents. In the Philippines, the ideal response time is 5 to 7 minutes.

Recently, President Duterte signed a BFP modernization act to strengthen and modernize the BFP that would include acquisition of modern fire equipment, expansion of manpower, provision of training for the firefighters and most importantly, building new fire station infrastructure. This study aims to help in creating insights on how to attack the current problems the BFP is facing.

The datasets that were used for this project were the OSM data, GADM data, and BFP data. The team conducted exploratory data analysis, and treated it as a facility location problem where we used two methods such as LSCP and MCLP.

With 3 km distance to the fire stations, using LSCP, the team found that only 85% of amenities were covered by the fire stations while using MCLP with weights as the number of fire incidents over the number of amenities per municipality. The team got a coverage of 98% of the amenities. The team also saw that only 30 fire stations are needed to get a high coverage of the amenities which means that the placement of the fire stations are not that optimized.

In this study, we have presented two methods to solve the problem of the Philippine Government to assess the placement of fire stations around the nation to optimize their allocated budgets for fire safety to ensure that the Filipino people would be served in the times of emergency when they need it the most.

We found out that based on distance alone, there is a possibility of inefficient distribution of fire stations in Metro Manila while not reaching full coverage.

Lastly, this study can be further improved by using road networks to determine the distance for cost function, inclusion of residential data, and capacity of fire stations as constraints.

I. Introduction

Situationer

In 2017, the Bureau of Fire Protection reported that the number of fire incidents reached a record high of 14,197 incidents in the Philippines. Metro Manila accounts for 32% of these incidents. Half of these incidents are classified as structural related incidents which involve residential and industrial fires. Based on submitted affidavits of loss the amount of damage caused by fire amounts to PHP 462,146,600.00 for NCR alone. Included in the damage are 219 people injured and 105 lives lost.

Problem Statement

This begs many questions that concern the nation's capability to assist its citizens, such as: Are there enough fire stations distributed amongst the different cities within Metro Manila? Are these fire stations at a reasonable distance from the different amenities within the various cities? And many others.

Motivation

A famous saying in fire incident discussions is: "It is better to be a victim of theft 10 times than to be a victim to fire." perfectly describes how fires can take property and lives in an instant. The current situation of the BFP, being undermanned, with a low number of functional trucks and apparatus, calls for another perspective in ensuring that the institution can confidently respond to incidents across the country. With the recently signed BFP Modernization Act, this study aims to help in creating insights on how to attack the current problems the BFP is facing.

Business Value

This report aims to provide a methodology of determining the placements of fire stations for efficient coverage of amenities in Metro Manila using Geospatial and Machine Learning techniques.The study aims to address the needs of identified out of coverage areas.

II. Dataset

A. Extract Data

The datasets used for this project were:

Table 1. Datasets Used.

Dataset	Description	Source
OSM Data	Contains the amenities found in Metro Manila	Jojie
GADM Data	Contains the shape file of the cities in Metro Manila	Jojie
BFP Data	Fire incidents recorded from 2012 - 2016	https://data.gov.ph/dataset/bfp-nationwide-fire-incidents-statistics-cy-2012-2016.xml

B. Data Cleaning

The group performed data cleaning to the OSM and GADM data to filter only those amenities and locations in Metro Manila. The data was also merged with the BFP data to check on the number of fire incidents for each city as well as the cost of the incident. A sample snippet of the cleaned dataset used throughout the project is seen in table:

Table 2. Sample dataset for the merged final dataset.

Fire Stations	Incidents	Injuries	Deaths	Estimated damages	Amenities	Province	Municipality
3	1405	116	20	1.24E+08	470	Metropolitan Manila	Kalookan
2	1210	65	14	54778650	612	Metropolitan Manila	Las Pinas
8	1600	135	20	1.04E+08	2325	Metropolitan Manila	Makati
3	571	61	6	50766050	187	Metropolitan Manila	Malabon

C. Data Description

Description of each feature in the cleaned dataset can be found in table:

Table 3. Data feature types.

Features	Data Type	Description
Fire stations	Int	Number of fire station in a municipality
Incidents	Int	Number of Incidents in a municipality
Injuries	Int	Number of injuries in a municipality
Deaths	Int	Number of deaths in a municipality
Estimated damages	Int	Cost of incidents in pesos
Amenities	Int	Number of amenities not including fire station in a municipality
Province	Str	Metropolitan Manila
Municipality	Str	Cities in Metro Manila

III. Methodology

A. Exploratory Data Analysis

After cleaning and preparing the data, descriptive data analysis was performed to gain initial insights.

For the number of fire incidents (Figure 1), Quezon City had the highest number of fire incidents during the period of study. This can be attributed to its large land area as well as seen in Figure 2. Some of the other municipalities with a high number of fire related incidents are Manila, Makati, Valenzuela and Caloocan, with varying values for area size. Navotas, San Juan and Pateros all show low incident count, matching with their low land area values.

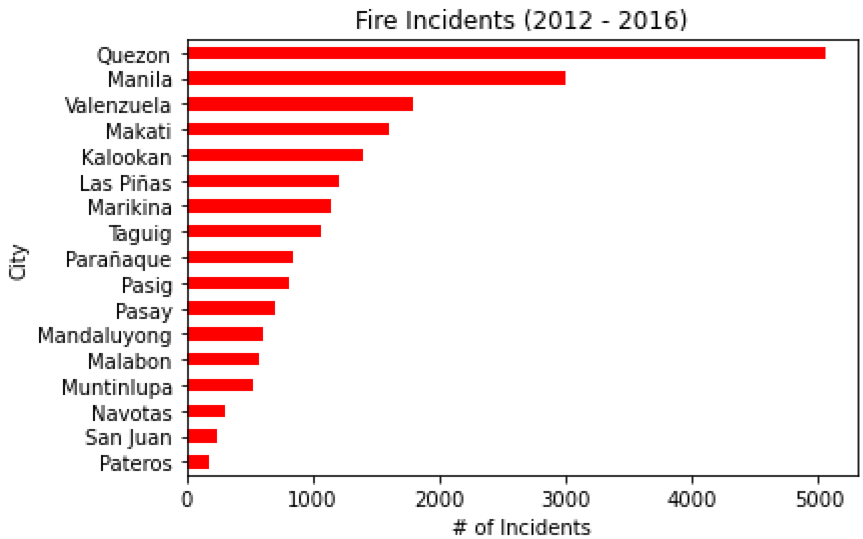

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Figure 1. The number of fire incidents per City or Municipality in Metro Manila for 2012 to 2016

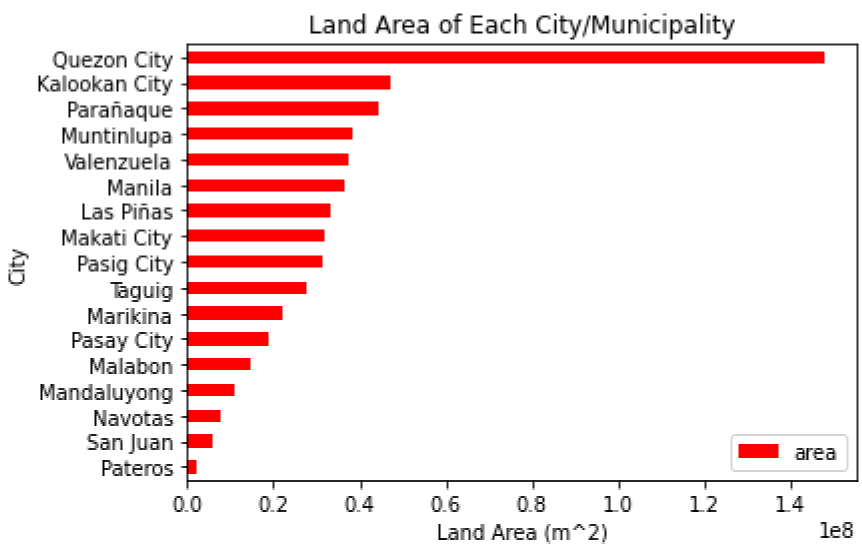

Figure 2. The land area of each City or Municipality in Metro Manila

Meanwhile, estimated damages (Figure 3) are highest in the City of Manila is almost 3 billion Pesos, with a total amount surpassing that of all the other cities and municipalities combined. It seems more valuable property is subject to fire incidents in the country's capital.

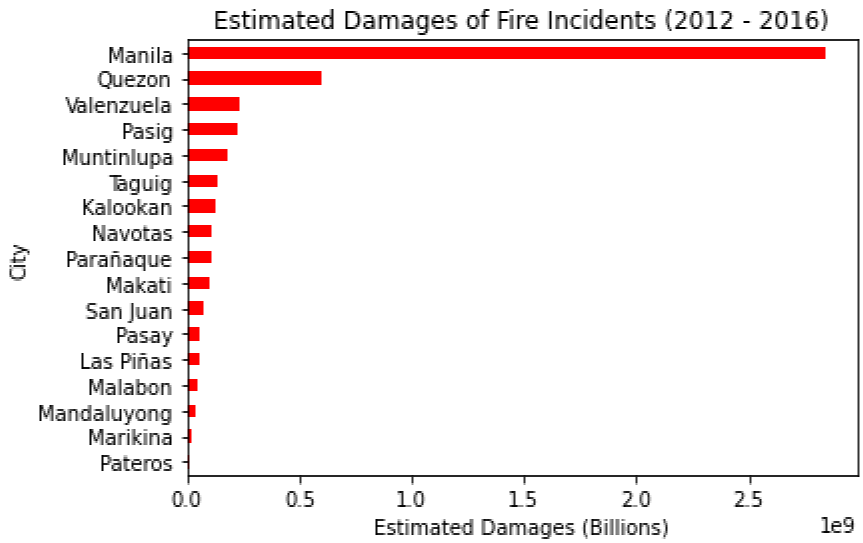

Figure 3. The estimated amount of damages caused by fire incidents for each City or Municipality in Metro Manila for 2012 to 2016.

The top 5 nearest fire stations were identified for each amenity, with their distance averaged. The average amenity to fire station distance for each municipality (Figure 4) was then computed by average all of the amenities per area.

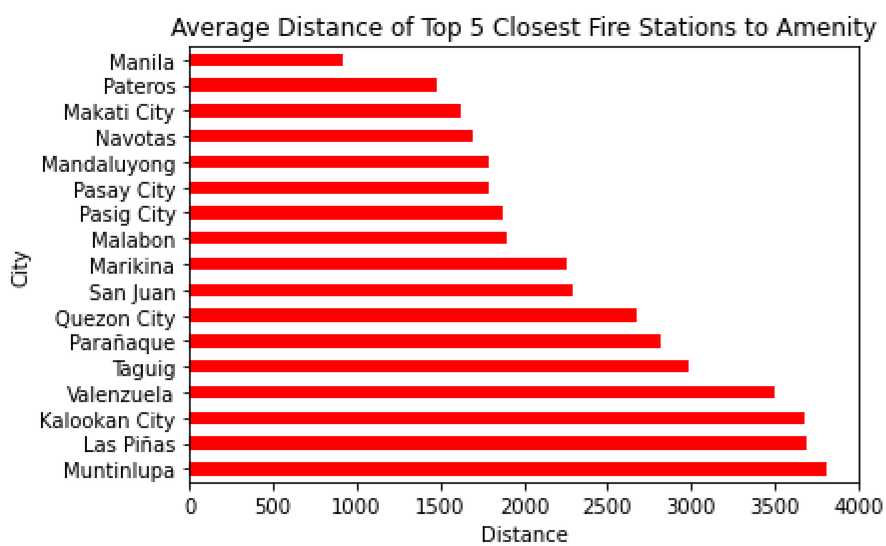

Figure 4. The average distance per CIty or Municipality in Metro Manila of the top 5 closest fire stations for each amenity.

Based on the analysis, Manila has the shortest average distance to a fire station at less than a kilometer away. We can see that this could be counter intuitive when analyzed with the number of incidents in the city. Instead, it can be said that the low distance between amenities and fire stations in Manila could be a product of the increasing number of fire incidents in the city which might be the primary solution that was thought of. Meanwhile, amenities from Muntinlupa, Las Pinas, Caloocan and Valenzuela have an average distance of at least 3 kilometers from the nearest fire station.

B. Cost Matrix

The cost matrix of the facilities and service sites was first created which will be used in facility location optimization in the next step. A cost matrix represents the cost of use of a facility for a service site. The cost is usually the standard for a certain coverage. In terms of emergency response, it can be measured by either time or distance. Distance can be calculated by Euclidean distance, Dijkstra's algorithm, or the shortest path of road networks. The cost matrix depends on the granularity of the data available.

For this study, the facility sites were defined as the Metro Manila Fire Stations and amenities were defined as the client/service sites. A cost matrix was created by calculating the Euclidean distance of each Metro Manila amenity site to each Metro Manila Fire Station. The Euclidean distance is calculated using Eq 1.

$$d(x, y) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)} \quad [1]$$

The implementation of calculating the cost matrix used SQL query and PostGIS in python to achieve this. With 14,313 amenity sites and 106 fire stations, this would result in a matrix with dimensions 14,313 rows by 106 columns. A part of the cost matrix is shown in the table below:

Table 4. Sample cost matrix.

Amenity	**Distances**						
	FS0	**FS1**	**FS2**	**…**	**FS1033**	**FS104**	**FS105**
0	17920.67	13538.54	14909.53	…	16635.34	17449.24	18559.25
1	17963.31	13708.39	15001.85	…	16630.08	17415.65	18561.24
…	…	…	…	…	…	…	…
14311	24605.21	18342.67	21087.32	…	10001.12	11246.20	11796.79
14312	24605.20	18340.99	21086.73	…	10002.02	11247.81	11797.32

C. Facility Location Optimization (FLP)

Faculty Location Optimization in this context is aimed towards maximizing the coverage of fire station emergency services in Metro Manila. In the case for our implementation, fire stations are the facilities candidate site and serviceable amenities would be the demand points.

1. Location Set Covering Problem (LSCP)

There should be a maximum allowable response time in service provision in order to handle a fire before it gets out of hand. The aim of LSCP is to minimize the number of facilities, in this case fire stations, needed and locate them so that every demand area is covered within a predefined maximal service distance or time. LSCP seeks to locate the minimum number of facilities to cover all demand in an area. Since there is no maximum value of facilities, this is an uncapacitated facility location problem. LSCP is implemented using the spatial optimization (spopt) python package. The formulation is seen below:

Minimize

$$\sum_{j=1}^{n} x_j \qquad (1)$$

Subject to:

$$\sum_{j=1}^{n} x_j \geq 1 \qquad \forall_i \ (2)$$

$$x_j \in 0, 1 \qquad \forall_i \ (3)$$

Where:

i = index referencing nodes of the network as demand

j = index referencing nodes of the network as potential facility sites

S = maximal acceptable service distance or time standard

d_{ij} = index referencing nodes of the network as demand

N_i = $\{j | d_{ij} < S\}$

x_j = $\{1,$ if a facility is located at node j

{0, otherwise

2. Maximal Coverage Location Problem (MCLP)

There are circumstances when the resources required to provide complete coverage for urban and rural emergency services exceeds the budget allocated to operate those facilities. Thus, LSCP may be too expensive to implement.

A solution to this is the use of MCLP. This method tries to maximize the amount of demand covered within a maximal service distance or time standard by locating a fixed number of facilities. Demand is covered if at least one facility can cover the particular service node. Since there is a maximum value of facilities, this is a capacitated facility location problem. This is formulated as seen below:

Maximize

$$\sum_{i=1}^{n} a_i y_i \qquad (1)$$

Subject to:

$$\sum_{j=N_i} x_j \geq y_i \qquad \forall_i \ (2)$$

$$\sum_{j} x_j = p \qquad \forall_j \ (3)$$

$$y_i \in \{0, 1\} \qquad \forall_i \ (4)$$

$$x_j \in \{0, 1\} \qquad \forall_j \ (5)$$

Where:

i = index referencing nodes of the network as demand
j = index referencing nodes of the network as potential facility sites
S = maximal acceptable service distance or time standard
d_{ij} = index referencing nodes of the network as demand
N_i = $\{j | d_{ij} < S\}$
p = number of facility sites to be located
x_j = {1, if a facility is located at node j
{0, otherwise
y_i = {1, if demand i is covered within a service standard
{0, otherwise

Weights

MCLP also uses weights of demand for each service site. To include more context into our optimization, we adjusted the demand weights using the ratio of incidents to amenities (as seen below) for each municipality as this is the only data available. It would be possible to use other weight adjustments such as incident type for each amenity and incidents per barangay.

$$w_i = \frac{incidents\ per\ municipality}{total\ number\ of\ amenities\ per\ municipality} \qquad [2]$$

IV. Results and Discussion

A. LSCP

Using the OpenStreetMaps dataset, over 14,313 amenity points (client sites) and 106 fire stations (service sites) were identified in Metro Manila. Euclidean distance was then measured from each of the different amenity points to the fire stations for the values of the cost matrix.

Using the spopt package's LSCP module, this report opted to use a 3 km service distance as the constraint. This distance matches the average emergency response time used in the United States. Since LSCP determines whether placed service facilities are able to accommodate client facilities based on a predetermined distance, the algorithm detected that 12,291 amenities or 85.87% of amenities in Metro Manila are covered by existing fire stations.

Table 5. Summary of statistics for LSCP results.

Total Service Facilities (Fire Stations)	106
Total Clients (Amenities)	14,313
Client Sites Covered	12,291
% of Client Sites Covered (LSCP)	85.87%

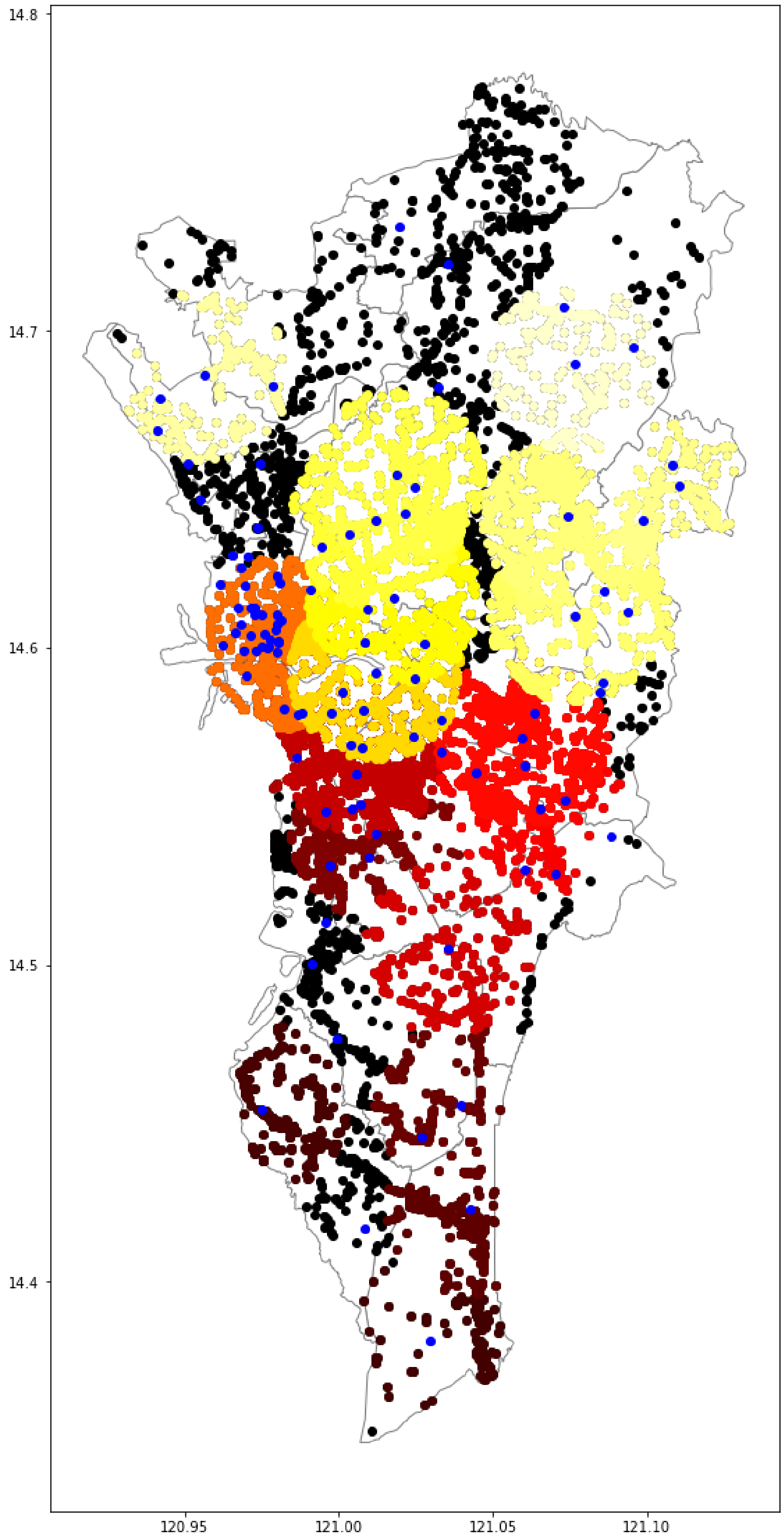

Figure 5. Colored dots are amenities clustered by service facility, blue representing fire stations, with black dots representing unserviced amenities.

B. MCLP

This time, using the spopt package's MCLP module, this report again opted to use a 3 km service distance. However, the given constraint would be the limited number of fire stations, which is 106 sites according to our data. The MCLP algorithm has determined that the existing fire stations have 97.91% coverage.

Table 6. Summary of statistics for MCLP results.

Total Service Facilities (Fire Stations)	106
Total Clients (Amenities)	14,313
Client Sites Covered	14,014
% of Client Sites Covered (MCLP)	97.91%

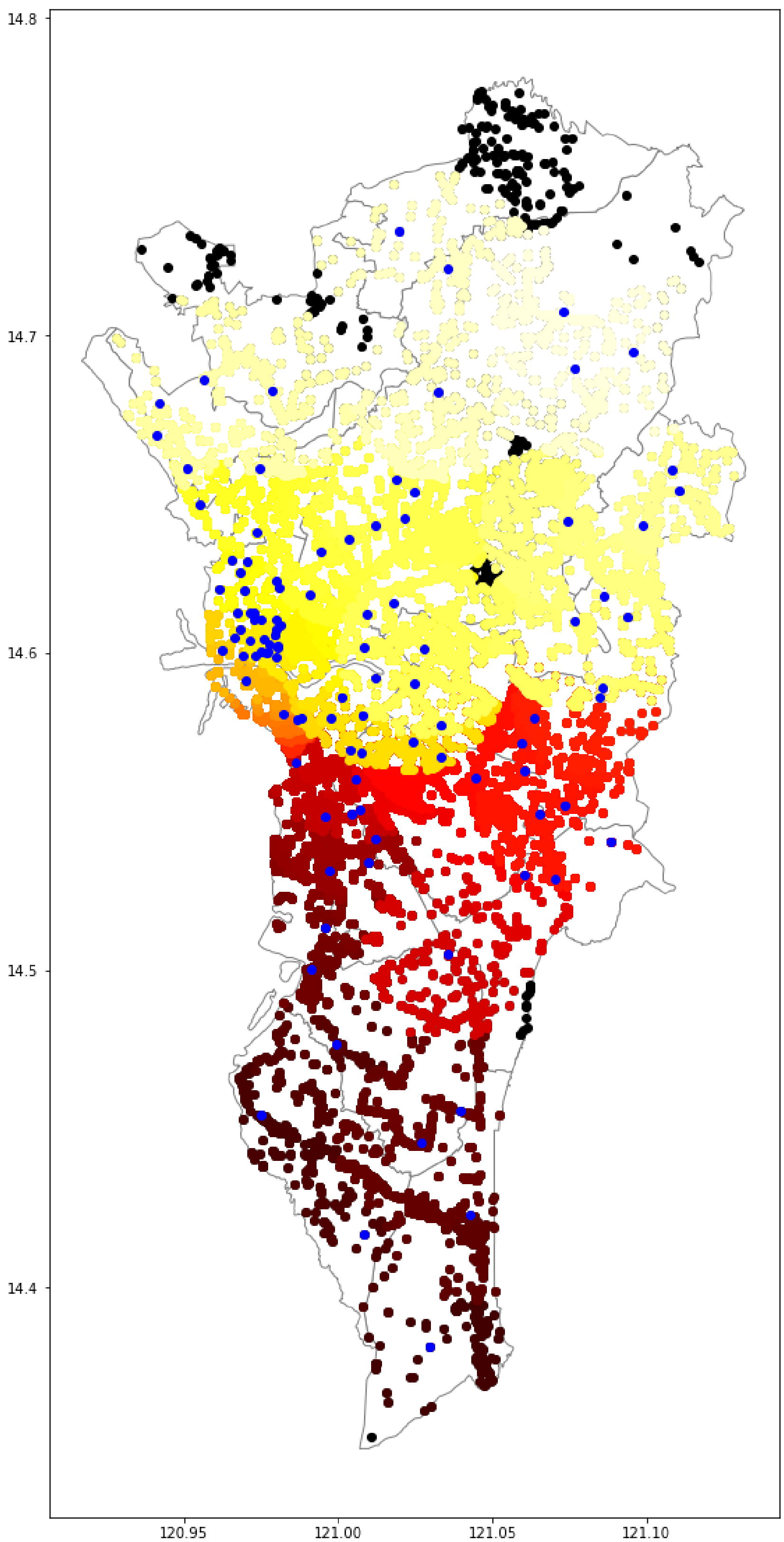

Figure 6. Colored dots are amenities clustered by service facility, blue representing fire stations, with black dots representing unserviced amenities

By plotting the number of service facilities (fire stations) against the coverage percentage, there is an apparent diminishing return as we increase the number of fire stations beyond a certain point. There is the possibility of an inefficient number of fire stations in Metro Manila, which would need to be verified with a domain expert.

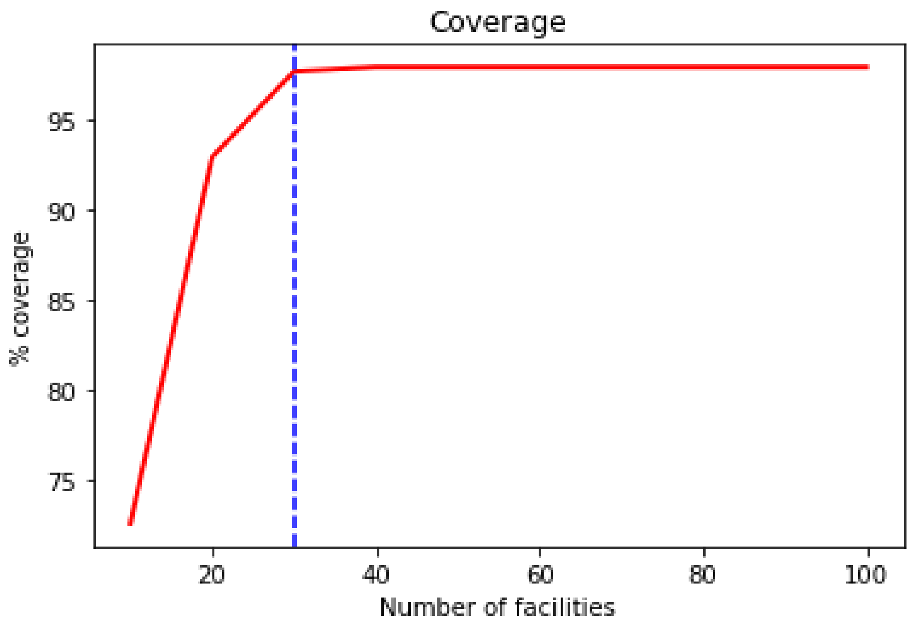

Figure 7. The red line represents the plotted percentage coverage as determined by the LSCP and MCLP and the blue line represents the elbow wherein additional facilities no longer affects coverage

V. Conclusion

A fire can take so much from a person’s life in a short amount of time. With this report, we hope to encourage the Philippine Government to assess the placement of fire stations around the nation to optimize their allocated budgets for fire safety to ensure that the Filipino people would be served in the times of emergency when they need it the most.

By utilizing Facility Location Problem algorithms such as Location Set Covering Problem and Maximal Coverage Location Problem, both were able to determine the amenities that would not be covered by already placed fire stations. Urban planners and local governments may be able to utilize machine learning methods along with these algorithms for a more effective deployment of government services for the benefit of their citizens.

VI. Recommendations

A. Recommendations for BFP

Based on the above study, increasing the number of facilities gives diminishing returns if not placed in areas that are in need of service. Additionally, there is a possibility of inefficient distribution of fire stations in Metro Manila while not reaching full coverage. Figure 8 shows two sample locations which can be studied as possible locations of new fire stations which will serve the corresponding area which is out of coverage. Both of the areas are in Quezon City and in the vicinity of Tandang Sora and Cubao.

B. Recommendations for improvements

Given the time limitation of our study, there is much room for improvement. For example, using road networks to determine the distances for the use of the cost function. Varying the value of maximum distance could also be determined for more stringent government standards. The use of response time rather than distance could also be considered. Additional data such as barangay level fire incidents (would help with the identification of service sites), inclusion of residential data (demand weights for MCLP), and inclusion of capacity of fire stations (as a constraint), would help the study produce better results.

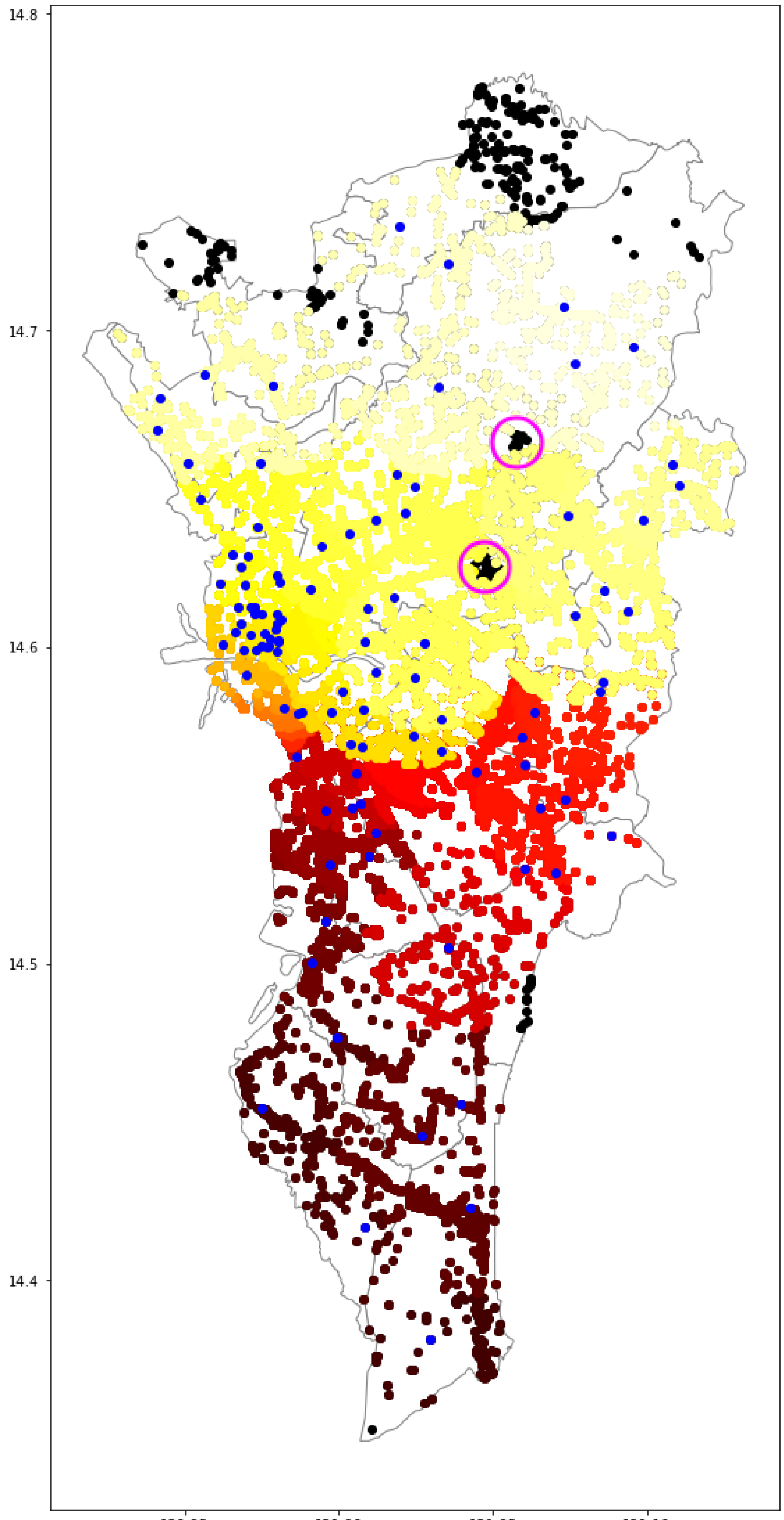

Figure 8. Areas lacking coverage as encircled in pink. These are areas where fire stations should be built nearby.

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