FINAL TERM PROJECT REPORT:

Analysis of Alternate Hurricane Evacuation Shelters Routes

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April 6 2018

GEOG 491 / EESC 418

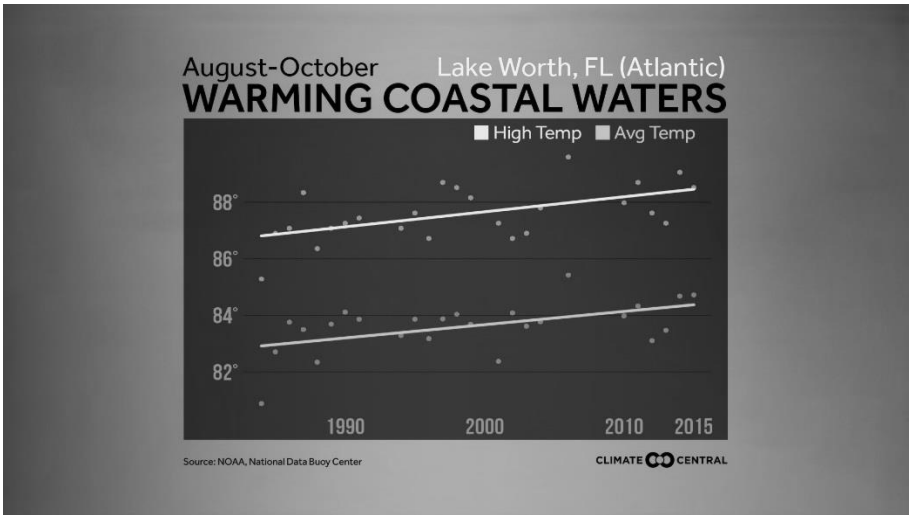
Objective

Identify the shortest paths from a location to the nearest hurricane shelters within Broward County, Florida considering distance by road, traffic lights and time needed to reach destination.

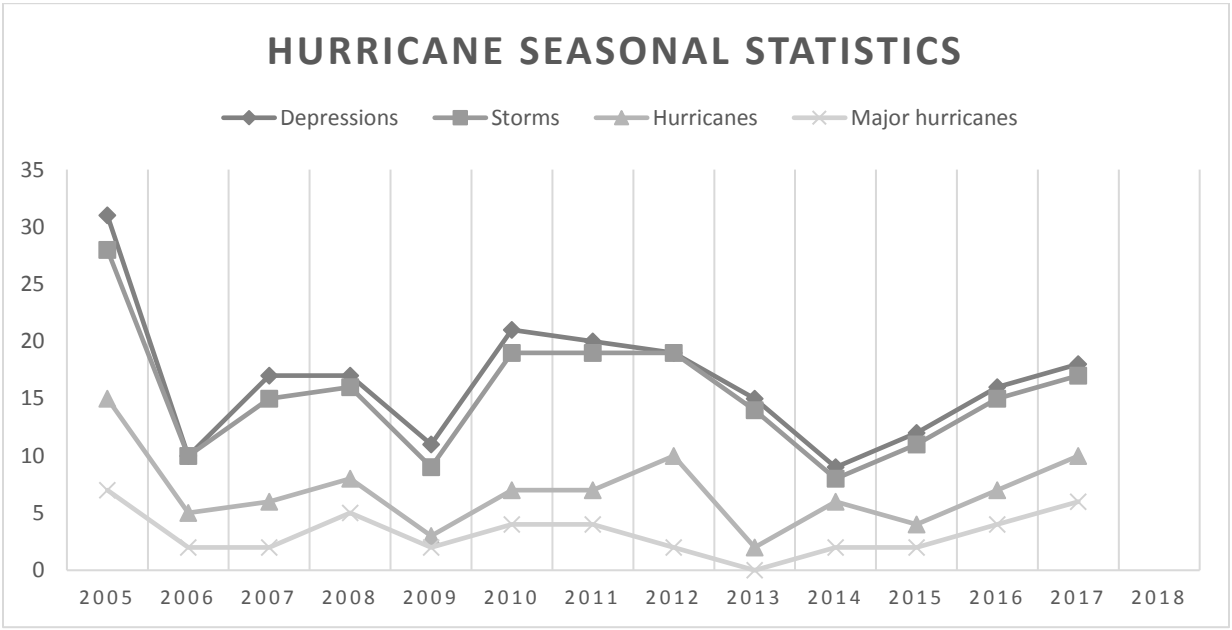
Background and Implementation

Currently there are no developed applications that assist residents within Broward County to access the closest available hurricane shelters during times of need and evacuation. For the past couple of years, mandatory evacuation orders have only been ordered for people who live in the coastal areas of the county as well as the low-lying areas and mobile homes; over home, it is inevitable that people who live inland will have to make use of these hurricane shelters. Some people tend to flee north to escape hurricanes but most people do not have the privilege to do so and thus, hurricane shelters are needed.

This is important because, over the years, the occurrence of tropical storms and hurricanes have steadily been increasing though there has been a drastic drop after 2005. As a side note, this increase can be correlated with the rising average temperatures of the Atlantic Ocean. *Refer to Graph 1, Graph 2, and Table 1.*



Graph 1
Source: National Oceanic and Atmospheric Administration (NOAA), National Data Buoy Center



Graph 2
Sourced from the National Hurricane Center (nhc.noaa.gov)

Seasonal Statistics				
	Depressions	Storms	Hurricanes	Major hurricanes
2005	31	28	15	7
2006	10	10	5	2
2007	17	15	6	2
2008	17	16	8	5
2009	11	9	3	2

2010	21	19	7	4
2011	20	19	7	4
2012	19	19	10	2
2013	15	14	2	0
2014	9	8	6	2
2015	12	11	4	2
2016	16	15	7	4
2017	18	17	10	6
2018				
				(Category: 3 +)

Table 1
Sourced from the National Hurricane Center (nhc.noaa.gov)

When evacuation orders are made, people tend to flock to their closest hurricane shelter but what they do not realize is that these shelters have a limit as to how many people can be sheltered within the shelter. As per the Federal Emergency Management Agency's (FEMA) Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms ICC 500 Section 501.1.1, a minimum of 20 square feet per person is required for hurricane community storm shelters[1]. In regards to escaping the storms, a commonly proposed solution is to flee north toward Georgia and Alabama, where the storms' winds are less dangerous. The process of turning southbound lanes on highways is contraflow. This aims to increase the rate of the flow of traffic going north. This concept was not used during times of Hurricane Irma in September 2017. Although the majority of public opinion was to make use of the contraflow concept, it has been stated, by the Government of Florida, that by not using contraflow, interstate congestion was eased and emergency services had no problem getting to their destinations[2]. According to Governor Rick Scott, "We still need southboard lanes to get needed gas and

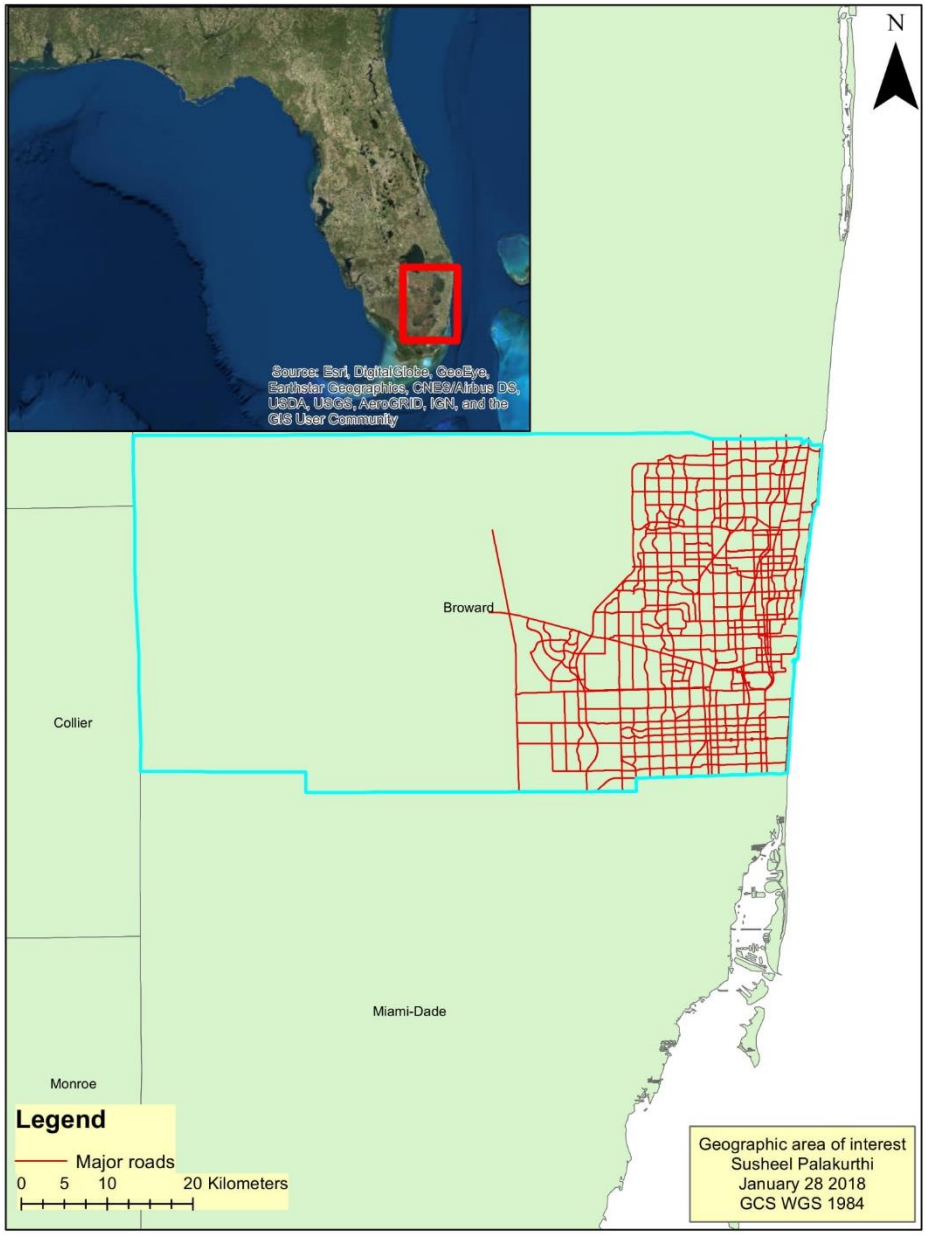
[1] Safe Rooms for Tornadoes and Hurricanes . 3rd ed., 2015, www.fema.gov/media-library-data/1467990808182-0272256cba8a35a4e8c35eeff53dd547/fema_p361_July2016_508.pdf.
[2] http://www.miamiherald.com/news/weather/hurricane/article172000577.html

supplies down to shelters and families that need it [in] the southern parts of the state". This project is the precursor solution to developing a solution to the multiple problems created by ordering hurricane evacuations.

Using the Network Analysis extension in ArcMap, this project will calculate the paths possible, by shortest distance and least time, from certain locations to the closest hurricane shelters.

Geographic Area of Interest

Broward County is north of the well-known Miami-Dade County and is the second most populous county in Florida. Due to the state being covered mostly by the Everglades, this project aims to focus on the populated non-Everglades portion of the county. *Refer to Map 1 for the geographic area of interest*.



Map 1

Proof of Concept

Due to difficulty in finding data for the project, alternate data had to be used in order to complete the project. By using a different location for the project, the results are not the same but proof of concept is established. Due to the lack of complete data for the Broward County, Miami-Dade County data was used. Due to the unavailability data for the Miami-Dade County,

data from ESRI was used: Bay Area, California network data. Further details are established below.

Data

Broward County:

- *FDOT Local Names January 2018.* Florida Geographic Data Library.
- *County Boundary.* Broward County Geographic Information Systems
- *GIS Address Points.* Broward County Geographic Information Systems
- *Cities.* Broward County Geographic Information Systems
- *Traffic Ways.* Broward County Geographic Information Systems
- *Traffic Signals.* Broward County Geographic Information Systems
- *Hurricane Evacuation Routes.* Homeland Infrastructure Foundation-Level Data.

Miami-Dade County:

- *Street.* Miami-Dade County GIS Open Data
- *Hurricane Shelter.* Miami-Dade County GIS Open Data
- *Property Point.* Miami-Dade County GIS Open Data
- *Property Boundary.* Miami-Dade County GIS Open Data

Bay Area, California:

- *Network Analyst.* ESRI Geographic Information Systems

Network Analyst Extension

The main ArcMap extension used for this project is the Network Analyst extension. It offers a great deal of functions, including finding the best routes, calculating service areas, and servicing a set of orders, among many others. The functions used for this project are service area and OD (origin destination) cost matrix. The service area function calculates the service area around any location on a network, according to the service area analysis from ArcGIS Desktop. The OD cost matrix, origin destination cost matrix, according to the ArcGIS Desktop, measures the cost of traveling from origins to destinations. Although the Network Analyst extension is helpful, it requires a great deal of complete network data. To make full use of the Network Analyst extension, streets and turns data has to be used. In the general network science fields, nodes and edges have to be defined in order to create a complete network. The nodes represent the intersections and define the turns of a network, while the edges represent the roads and highways. Though, with a geographic network, directions have to be defined for edges.

Methodology

Broward County

Due to the main motivation of the project as well as personal relation to the project, Broward County was selected as the geographic area of interest. Data relating to the Broward streets was obtained, mainly from the Broward County Geographic Information Systems website[3]. This data was overlaid a basemap of Florida. Some shapefiles were removed, i.e. traffic ways because they were the same streets as the FDOT (Florida Department of Transportation)

[3] https://bcgis.broward.org/

local street names. The roads file contained roads of all of Florida so the *Clip* tool was used to clip the roads using the county as the input feature to only retain the roads in Broward County. It is important to note that the roads file does not contain roads that are within residential communities. Due to this, time from a specific residential locations to local roads are considered to be negligible. The GIS Address Points shapefile contains the points of all residences within Broward County, containing 477759 residences. It is considered to be accurate as the population of Broward County as of 2015 is 1.896 million and the average number of family members in a single address is 4. It is also assumed that each residence (each family) has proper transportation to transport those 4 people.

Locations of hurricane shelters were obtained from news articles about Hurricane Irma. According to the Sun-Sentinel's article on Hurricane Irma (Hurricane Irma: Most Broward shelters full; 5 new locations opened plus 1 for pets)[4]. 18 shelter locations were recorded into an Excel file from the article. An online geolocator application[5], created from a Google Maps API, was used to obtain the coordinates of each location. These locations and coordinates were downloaded as a KML file and the Geoprocessing tool *KML to Layer* was used to display the hurricane shelter locations on the Broward County data.

The problem with this data, as much as it seems to be tremendous, is the lack of complete data. *Figure 1 displays the problem with the data for Broward County.*

[4] http://www.sun-sentinel.com/news/weather/hurricane/fl-sb-hurricane-irma-broward-friday-20170908-story.html
[5] https://www.doogal.co.uk/BatchGeocoding.php

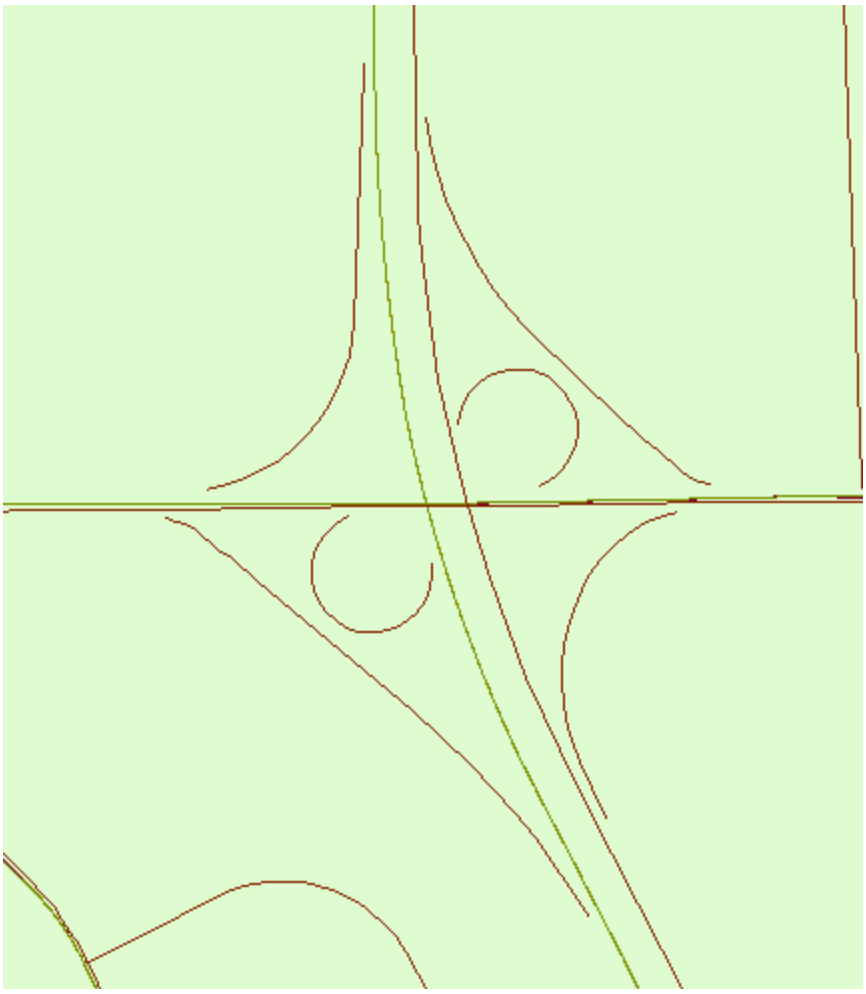


Figure 1

In detail, the problem with *Figure 1* (intersection of Interstate 75 and Pines Blvd) is the incomplete connection of roads. The image displays the interstate highway roads not being connected to the local roads. The network analyst extension cannot be run with roads that do not connect to each other. Due to this issue, the Network Analyst cannot run on the Broward County data. Hence, this project cannot be done on Broward County. Even with all the data collected, the Network Analyst extension functionalities cannot be used on Broward County data.

Miami-Dade County

Due to the lack of complete street network data for Broward County, Miami-Dade County street data was considered. All the layers were overlaid and the basemap was once again

used as a background. Less data was found for the Broward County but it was considerably more complete. For example, each road and highway was connected. But similar to the Broward County data, directional data for the streets was not recorded so the Network Analyst functions could not have been used.

The same method for obtaining hurricane shelter locations and geocoding them was done for Miami-Dade County, as was done for Broward County.

Bay Area, California

In order to complete the tasks, a complete network dataset had to be used so the ESRI provided tutorial data was used. Although many assumptions were made and ignored, the San Francisco data had to be used to accomplish the goals of the project, as proved by proof of concept.

Before the dataset can be completely used, the data has to be processed. This was done following the tutorial from ESRI. The data obtained from ESRI for the network analyst tutorial is, within the Transportation folder in the San Francisco: Restricted Turns, Signposts, and Streets.

These shapefiles were used to create a network dataset and later on, for analysis. The steps can be rewritten here but due to the similarity of the process from the online Network Analyst exercises 1[6], 5[7], 10[8], and 11[9].

Following Exercise 1, a network dataset was created from the restricted turns, signposts, and streets datasets downloaded from ESRI.
Following Exercise 5, the service areas were calculated and an OD cost matrix was created.
Following Exercise 10, live traffic was configured on the previously created network dataset.
Following Exercise 11, network analysis was performed on the integrated traffic data.

The only modifications done for the purposes of the project were to define the hurricane shelters and the origin locations for the OD cost matrix.

An observation that was made from the hurricane shelter locations from the Broward County and Miami-Dade County maps was the distance from the hurricane shelters to the nearest coast. The average distance was 3 kilometers. Also, these hurricane shelters were middle and high school educational institutions. Hence, a shapefile was created with random education institutions as points that were at least 3 kilometers away from the nearest coast. The following table (*Table 2*) contains the 9 created hurricane evacuation shelter points.

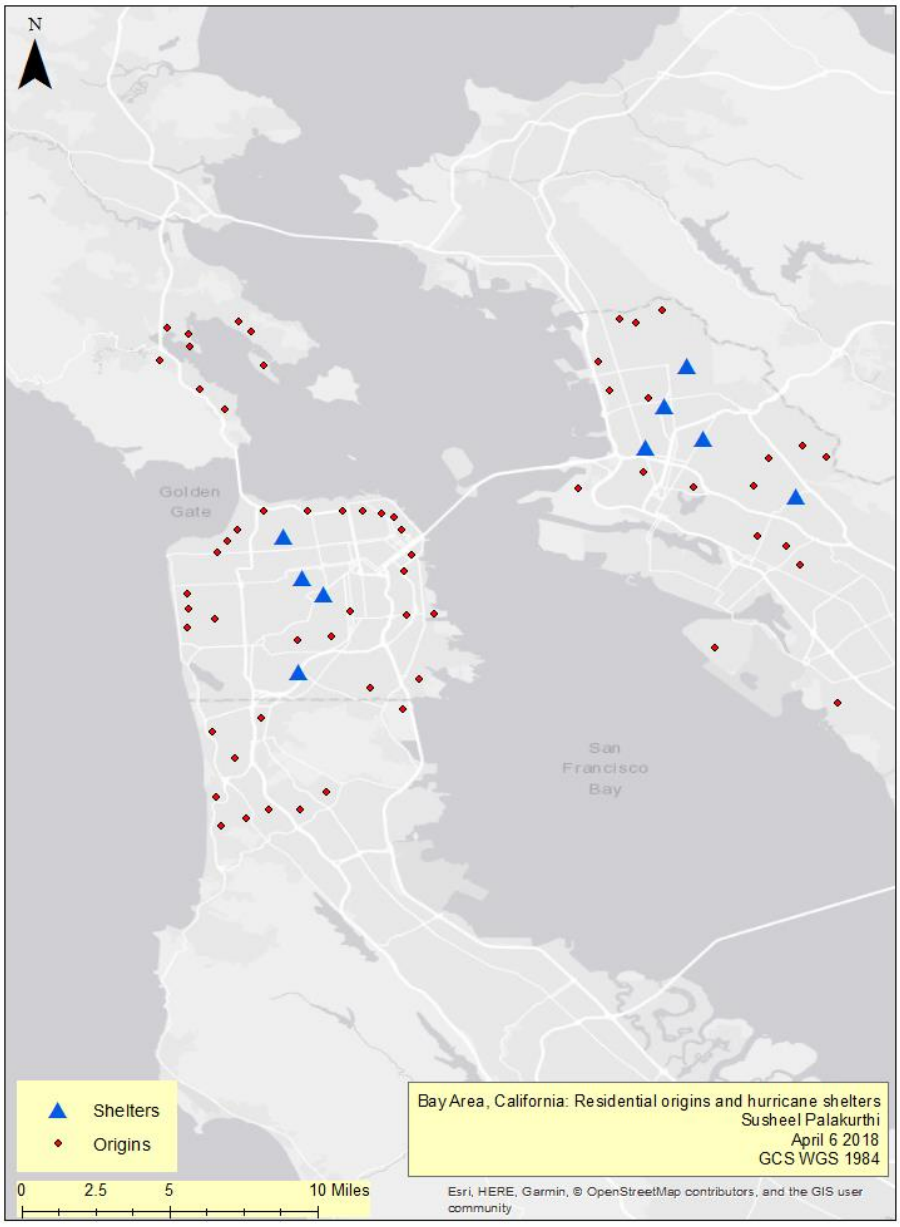
[6] http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/exercise-1-creating-a-network-dataset.htm
[7] http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/exercise-5-calculating-service-area-and-creating-an-od-cost-matrix.htm
[8] http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/exercise-10-creating-a-network-dataset-that-uses-live-traffic-data.htm
[9] http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/exercise-11-solving-a-network-analysis-using-traffic-data.htm

Points

OID *	Shape *	Name	Long	Lat
1	Point Z	Lick Wilmerding High School, San Francisco, CA	-122.448946	37.722267
2	Point Z	California College of the Arts, CA	-122.250354	37.836251
3	Point Z	Head-Royce School, CA	-122.205129	37.807941
4	Point Z	San Francisco Institute of Architecture, CA	-122.269287	37.852505
5	Point Z	German International School of Silicon Valley - Berkeley/East Bay Campus, CA	-122.278705	37.832436
6	Point Z	Lycée Français de San Francisco - Ashbury Street Campus	-122.44681	37.768091
7	Point Z	Marin Preparatory School, San Francisco, CA	-122.436896	37.760219
8	Point Z	Presidio Hill School, San Francisco, CA	-122.456145	37.78857
9	Point Z	University of California, Berkeley	-122.25854	37.871899

Table 2: Hurricane evacuation shelter points created for the Bay Area, California

In order to use the Network Analyst extension, origin destinations also have to be created so another shapefile was created with 58 individual locations representing locations from which residents would have to escape from. These 59 individual locations were chosen to be sparsely located around the Bay Area from where the hurricane shelters are accessible as well as the network analyst is available. *Refer to Map 2.*



Map 2

The settings for the service area are as follows for the analysis and polygon generation. Refer to *Figure 2* and *Figure 3.*

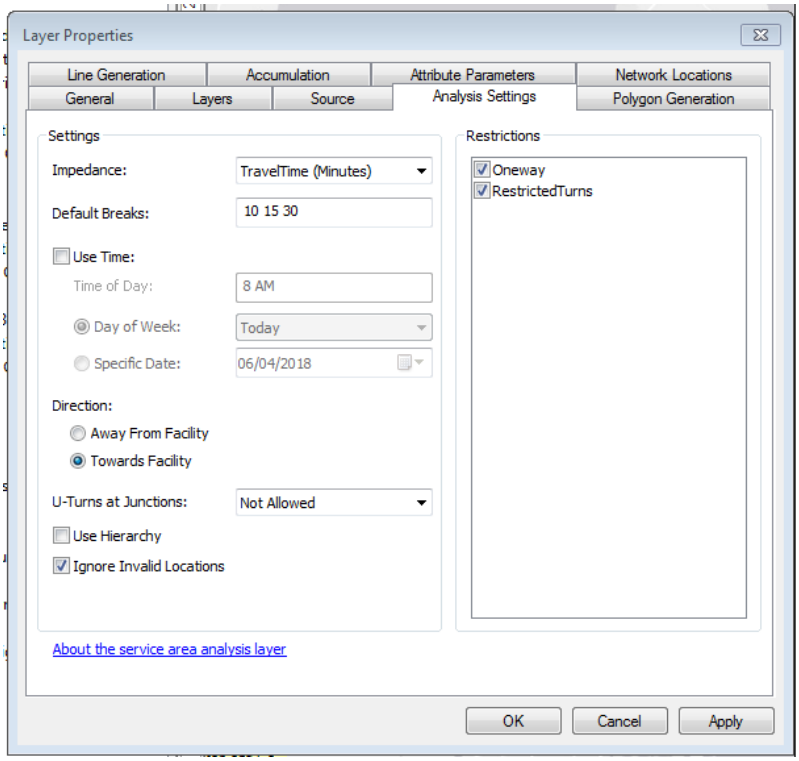


Figure 2

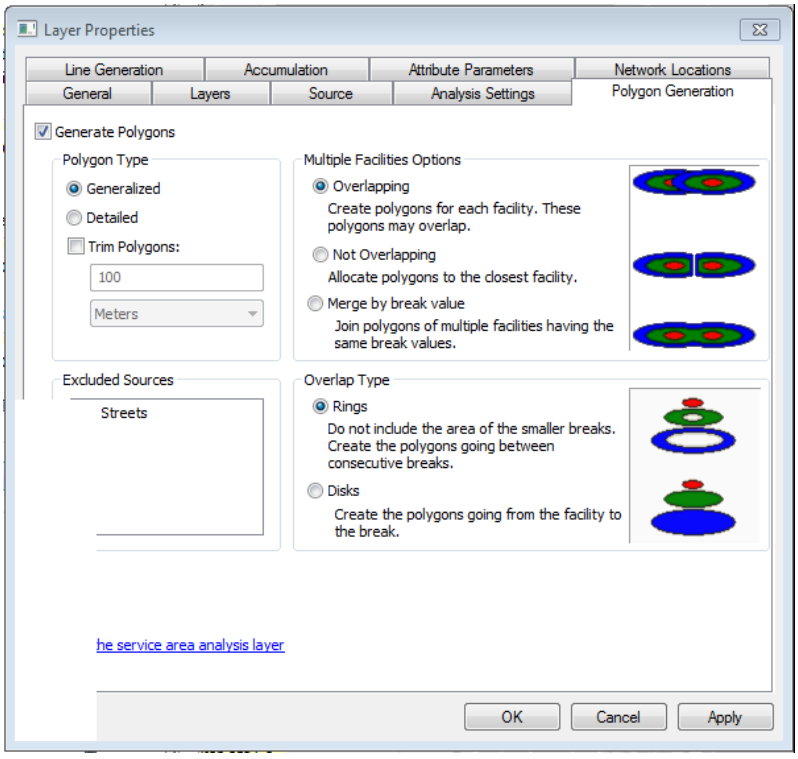


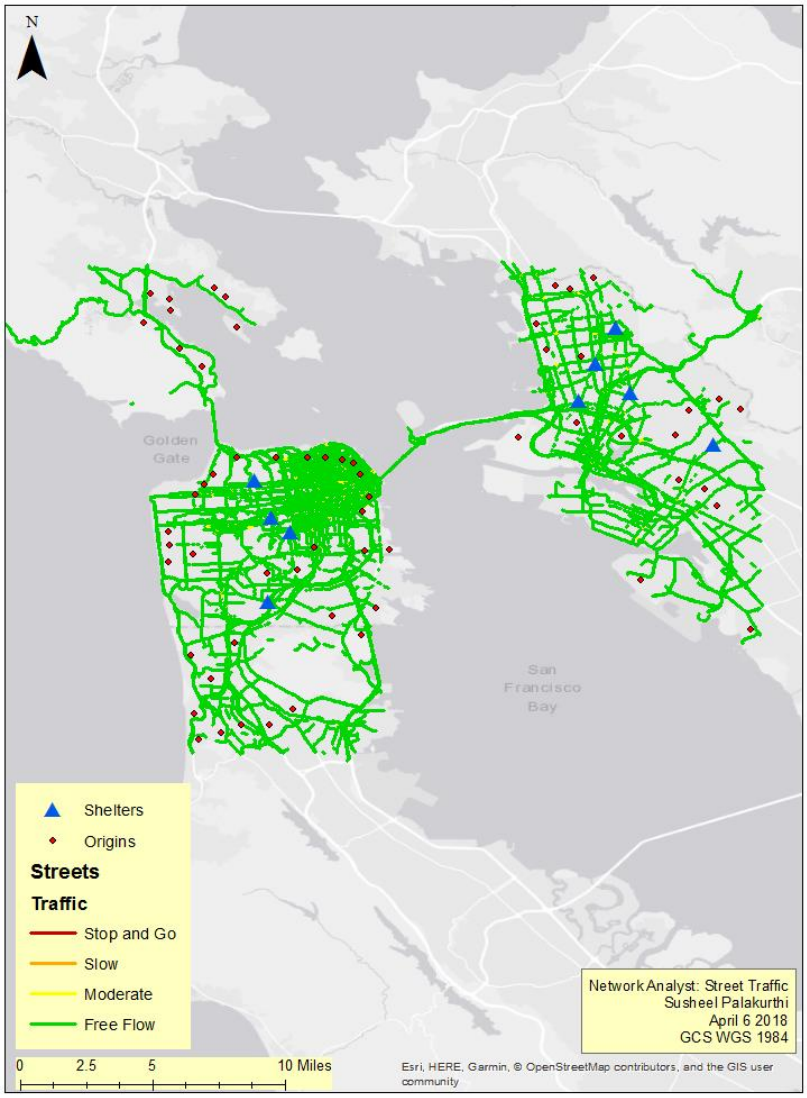
Figure 3

Assumptions

The main assumption that had to be considered was that the geographical landscape and the natural disasters occurring in the Bay Area is very similar to that of South Florida. California is not usually struck with hurricanes so that had to be considered. The elevation of California is drastically different than of Florida's. California's elevation, on average, is 2900 feet and Florida's average elevation is 100 feet, though both Broward and Miami-Dade are just 1.8 meters above sea level. California's geographic landscape is also vastly different compared to Florida. California is very much hilly while Florida is mostly flat land and swamplands, contributed from the Everglades. The space requirements for public hurricane shelters were also ignored. Though the observed requirement of distance from the nearest coast being 3 kilometers was followed.

Results

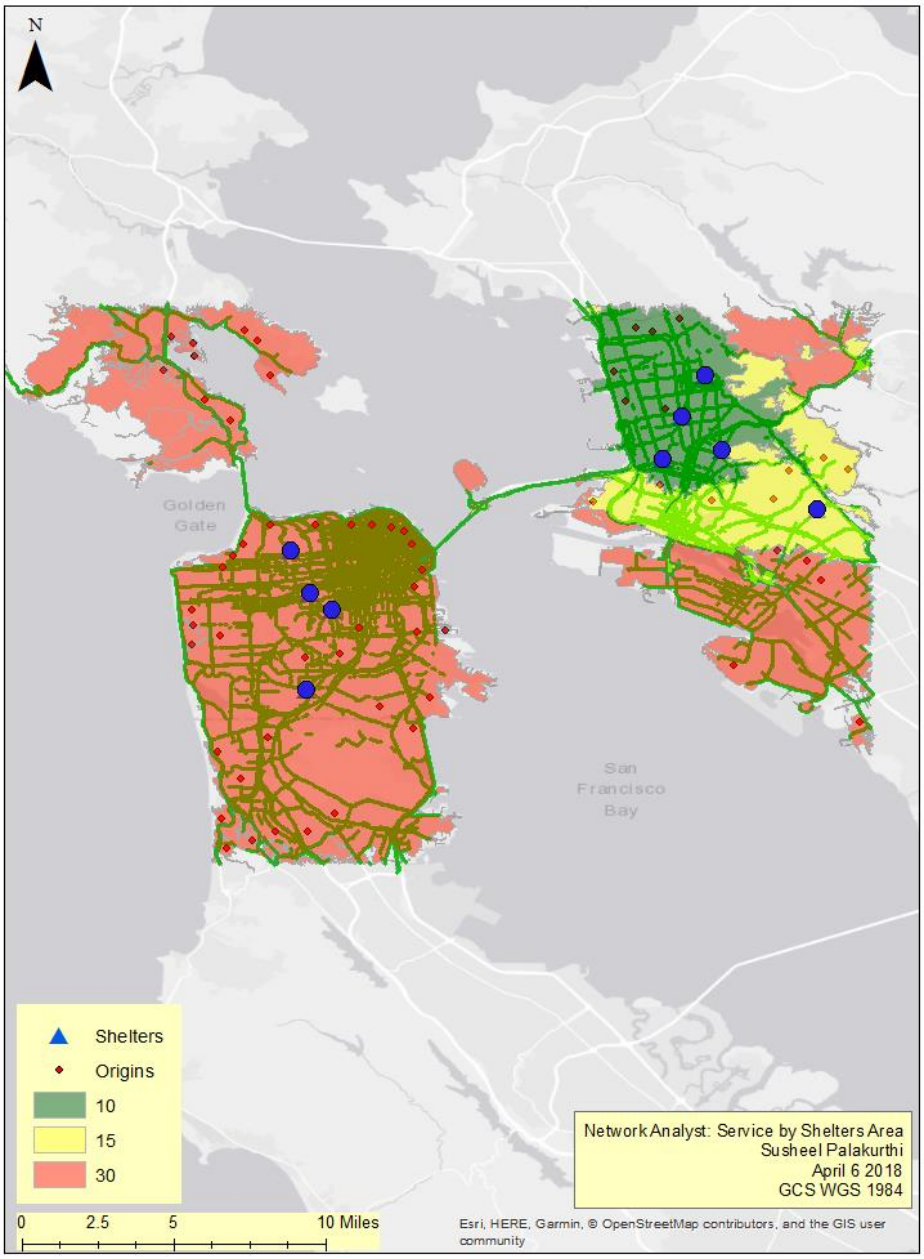
The final map when the steps for creating a network dataset are followed is below as *Map 3.*



Map 3

The blue triangles and red dots, respectively, represent the hurricane evacuation shelters and the residential origins. Although much of the map seems to have free flow traffic, when the individual streets are zoomed, the traffic can be seen as stop and go.

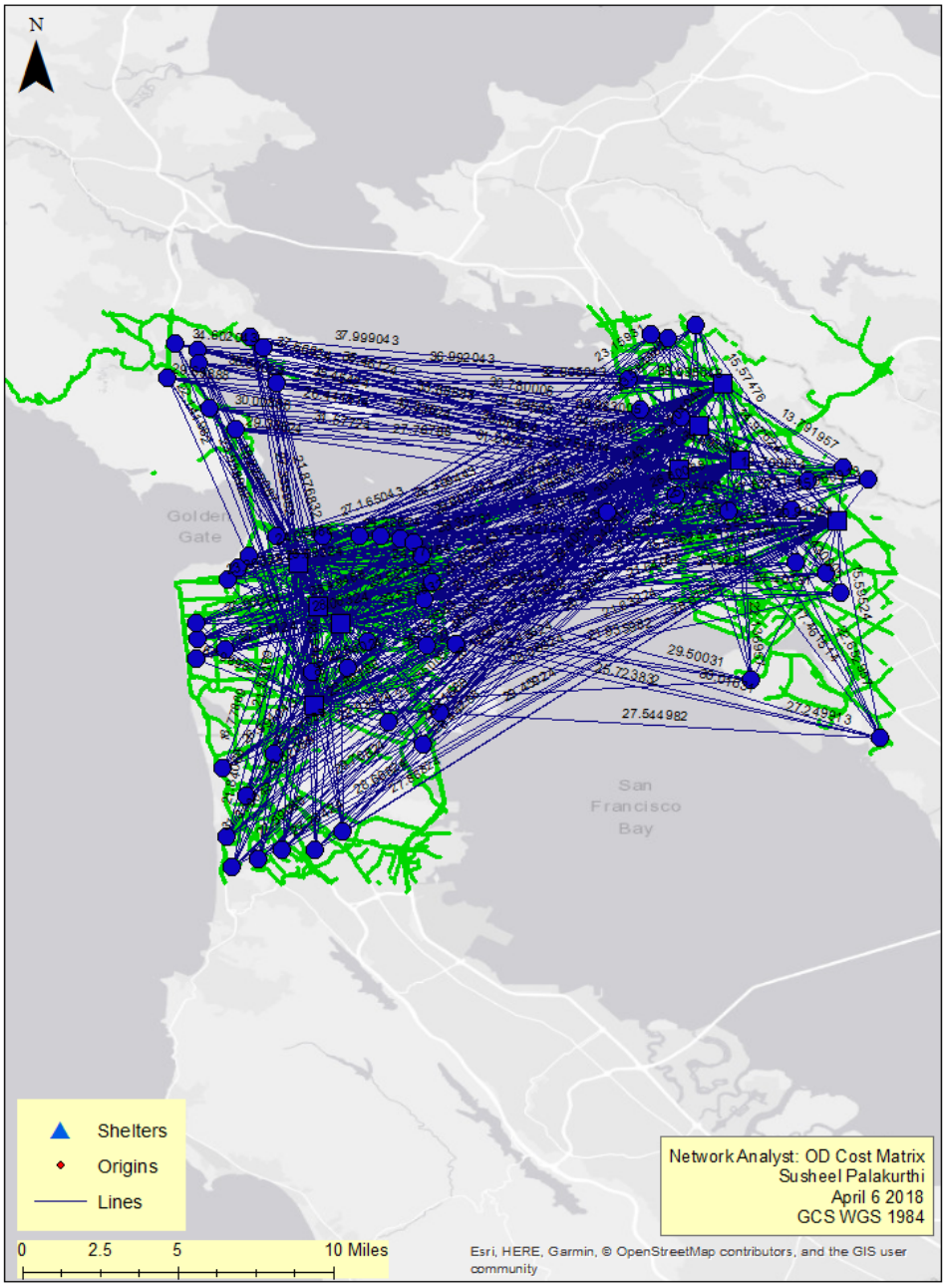
The following map (*Map 4)* displays the service areas for each hurricane shelter. Although the legend doesn't explicitly state the time units, the time intervals for 10, 15, and 30 are in minutes. Hence, within 30 minutes of a service (hurricane evacuation shelter), residents in the red colored locations would be able to reach the hurricane evacuation shelter.



Map 4

The following map (*Map 5)* displays the OD (Origin Destination) Cost Matrix map. The OD Cost Matrix calculates the time taken to go from each of the origins to each of the destinations. Hence, 540 rows are created due to each of the 60 origins ranging to all of the 9 destinations. The lines are labeled by the time it takes to reach from the origin to the destination. *Table 3* displays a few of the timings, especially by decreasing order of the total travel time of all

540 possible combinations of origin-destination routes. The unit of the total travel time is minutes.



Map 5

Lines

ObjectID	Shape	Name	Total_TravelTime	OriginID	DestinationID	DestinationRank
495	Polyline	Location 55 - University of California, Berkeley	41.874043	55	9	9
494	Polyline	Location 55 - Head-Royce School, CA	40.33624	55	3	8
459	Polyline	Location 51 - University of California, Berkeley	39.206043	51	9	9
493	Polyline	Location 55 - California College of the Arts, CA	38.76788	55	2	7
492	Polyline	Location 55 - San Francisco Institute of Architecture, CA	38.052005	55	4	6
441	Polyline	Location 49 - University of California, Berkeley	38.038043	49	9	9
450	Polyline	Location 50 - University of California, Berkeley	37.999043	50	9	9
458	Polyline	Location 51 - Head-Royce School, CA	37.66824	51	3	8
432	Polyline	Location 48 - University of California, Berkeley	36.992043	48	9	9
440	Polyline	Location 49 - Head-Royce School, CA	36.50024	49	3	8
449	Polyline	Location 50 - Head-Royce School, CA	36.46124	50	3	8
457	Polyline	Location 51 - California College of the Arts, CA	36.09988	51	2	7
491	Polyline	Location 55 - German International School of Silicon Valley - Berkeley/East Bay Campus, CA	35.510514	55	5	5
431	Polyline	Location 48 - Head-Royce School, CA	35.45424	48	3	8
456	Polyline	Location 51 - San Francisco Institute of Architecture, CA	35.384005	51	4	6
439	Polyline	Location 49 - California College of the Arts, CA	34.93188	49	2	7
448	Polyline	Location 50 - California College of the Arts, CA	34.89288	50	2	7
423	Polyline	Location 47 - University of California, Berkeley	34.602043	47	9	9
438	Polyline	Location 49 - San Francisco Institute of Architecture, CA	34.216005	49	4	6
447	Polyline	Location 50 - San Francisco Institute of Architecture, CA	34.177005	50	4	6
430	Polyline	Location 48 - California College of the Arts, CA	33.88588	48	2	7

Table 3

Discussion and Implementation

This project is an exploratory analysis for the routes to hurricane evacuation shelters. Although the project wasn't done for the main geographic area of interest, Broward County, proof of concept can be established by using the Bay Area of California. In Broward County, there are three main regions of evacuation. Evacuation Zone A is defined for all the residents east of the intracoastal waterway, mobile home residents, residents beside tidal bodies of water and in low-lying areas in Broward County. When evacuation orders are first made, these are the residents that should leave the area as soon as possible. Evacuation Zone B is defined for all the residents east of the Federal Highway 1, mobile home residents, residents beside tidal bodies of water and in low-lying areas[10].

Further analysis in regards to adding traffic data and analyzing the service area and OD cost matrices wasn't established due to complications in processing traffic data. Though, it

[10] http://www.broward.org/Hurricane/Documents/HurricaneEvacMap.pdf

would not have caused significant changes in the results as the traffic speed limits during evacuation orders are kept the same as non-emergency times.

Restriction studies also weren't established due to complications in the model. For example, if the bridge connecting the North Bay and San Francisco were to collapse, how would people evacuate to the San Francisco or East Bay? This would be done by restricting the data and deleting the row corresponding to that bridge in the Streets data. Logically, it would make sense for the residents in North Bay to just evacuate the area days prior to the hurricane or when evacuation orders are made, 4 hours before landfall.

In regards to implementation: if there were an SMS channel established for people to text their address to a number, they would receive a text containing information about the two closest hurricane shelters. This would be especially helpful in times of no internet or phone connection.

Conclusion

The project proves that an application can be established to assist residents in an area affected by hurricane evacuation orders. By completing this project in the Bay Area, it proves that the same methods can be applied in any area, especially hurricane-prone areas, such as Broward County and Miami-Dade County. Although a huge part of the project wasn't accomplished due to the lack of complete data, change of location, and difficulties implementing traffic data and analyzing the service areas and OD cost matrix with the traffic data, the main goal of the project is still accomplished.