University Transportation Research Center - Region 2

Final Report

Public Transit and Mandatory Evacuations Prior to Extreme Weather Events in New York City

Performing Organization: New York University

August 2017

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

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UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

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Table of Contents

EXECUTIVE SUMMARY

Public Transit and Mandatory Evacuations Prior to Extreme Weather Events in New York City

By Carlos E. Restrepo, Senior Research Scientist, Professor Rae Zimmerman and Robert A. Joseph (MUP 2017), with the assistance of Jimena Llopis Abella (MPA 2017).

Introduction. Extreme weather events and their consequences are posing a threat to large urban areas such as New York City, and this threat is increasing in many areas. Evacuations are often needed and public transit can play an important role before, during and after such events to move people to safe areas. Public rail transit is a valuable resource relatively less addressed in evacuation literature.

Objectives. The research objective is to identify public transit's potential for evacuation in NYC, focusing on subways and bus connectivity and NYC evacuation centers in Zone 1 hurricane-related risk.

Scope. The scope of the research is New York City, with an emphasis upon four of the boroughs, The Bronx, Brooklyn, Manhattan, and Queens. The focus is on rail transit, namely, the New York City subway system, and bus transit connectivity is included as well.

Methodology. The approach and methods use several data analyses at the U.S. Census Bureau block group level. The geographic analysis is for Zone 1, identified by NYC as having the greatest hurricane-related risk. Straight line distances define distances between subways, evacuation centers, and block group centroids, and this assumption could be refined to include more realistic distance measurements in future research. Block group data captured demographics of residents. Descriptive statistics and regression analyses were used to evaluate proximity of subways to evacuation centers, proximity of subways and evacuation centers to block group centroids, and relationships between characteristics of residents and proximity.

Results. Results were sensitive to whether block groups were completely or partially within Zone 1. Geographic characteristics such as density were most significantly related to proximity and further analyses could refine relationships with socioeconomic variables. A new index was developed, the Transit Evacuation Vulnerability Index (TEVI), using demographic and transit related variables to provide a quantitative measure of likelihood to evacuate at the block-group level. The TEVI is based on assumptions about factors that affect people's decisions to stay or evacuate during an emergency. This index could support decision-makers and communities in assessing where greater efforts may be needed to support evacuation efforts during a severe weather event, and where additional access to public transit could support vulnerable populations.

Public Transit and Mandatory Evacuations Prior to Extreme Weather Events in New York City
Final Report, August 2017

Carlos E. Restrepo, Senior Research Scientist; Rae Zimmerman, Professor of Planning and Public Administration; and Robert A. Joseph (MUP 2017) Graduate Student Researcher; with the assistance of Jimena Llopis Abella (MPA 2017) Graduate Student Researcher
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Part I. INTRODUCTION

Rationale, Scope and Goals

Extreme weather events and their consequences are considered a large and increasing threat to society, particularly to urban areas that have large population concentrations. Transit is a potentially rich resource for such purposes in many urban areas either before, during, or after such events. Given those threats a critical need is moving people to safety to locations such as evacuation centers and other forms of shelter. New York City has encouraged the use of mass transit in emergencies (NYC Emergency Management undated web page). One type of transit is public rail transit.

The objective of the research is to examine differences in the potential for using public transit for evacuation, whether voluntary or mandatory across New York City. The public transit focus is on subways and their connectivity to bus transit to convey people to one type of safe location, evacuation centers. Other means of transit are addressed briefly also.

As part of this overall objective, areas in need of improved access to public transit are identified, especially areas in which vulnerable populations are located. The literature on the use of transportation for evacuation including multi-modal connections tends to emphasize modes of transportation other than rail transit (Hess et al. 2015), and this report fills a gap in that area. The typical emphasis has been on road transportation (Yazici and Ozbay 2010; Ozbay et al. 2012), though rail transit studies of evacuation have been emerging (TRB 2008; Kaufman et al. 2012; Wilmot et al. 2015; Zhu et al. 2016; Zimmerman et al. 2017). Use of road systems often has limitations due to socioeconomic factors such as limited car ownership in some locations, limited access particularly for population sectors with fewer resources (Peacock et al. 2011:38), reduced access particularly in extreme weather events (Berube, Deakin and Raphael 2006; Bullard, Johnson and Torres 2009; Litman 2006), dangers associated with using private vehicles in extreme weather events, road congestion particularly in and around urbanized areas even in normal times (U.S. DOT FHWA 2010), and poor road condition (ASCE 2017a, b).

First, the proximity of populations in high risk areas to subways and evacuation centers and the proximity of subways to evacuation centers are analyzed with respect to NYC's hurricane-related risk Zone 1. Second, a key objective of the research is to develop a new index to rank areas at risk for not evacuating called the Transit Evacuation Vulnerability Index (TEVI). The index combines various factors, including proximity to transit systems and measures of social vulnerability to rank areas by whether people living there may be at risk for not evacuating when the City calls for a mandatory evacuation.

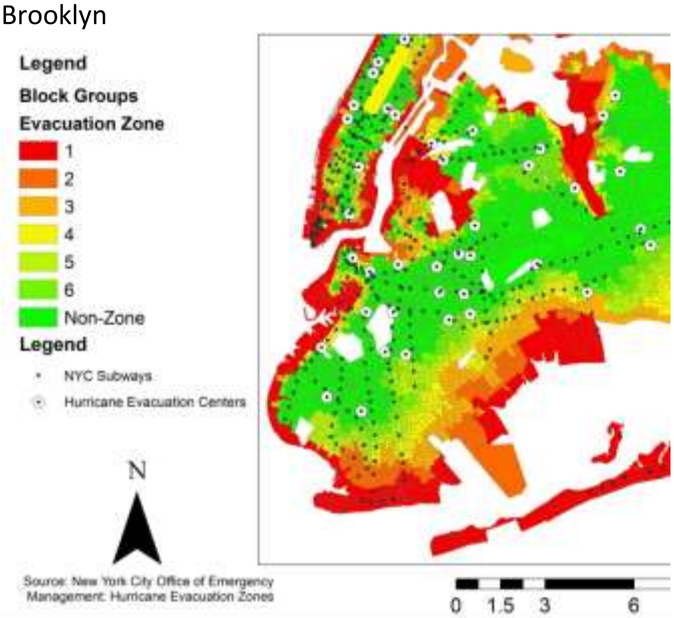
The Evacuation System in New York City

With increasing urban development in coastal areas (Wilson and Fischetti 2010), the prevalence of extreme weather events (Walsh et al. 2014) that is also a global phenomenon (Swiss re 2016: 2, 5), and the increasing risk of damage during extreme weather events, many cities are exploring ways to minimize casualties and injuries during these emergencies. New York City (NYC) recently experienced severe damage, including loss of life, during Superstorm Sandy (New York State 2100 Commission 2013). In order to address the risks posed by extreme weather, NYC has identified low-lying areas that are at risk for flooding and damage during hurricanes and coastal storms. These areas may be subject to mandatory evacuations. The idea is that if people evacuate prior to an extreme storm event, loss of life and injuries will be minimized. That evacuation has been an effective means of reducing casualties not only before an event but during and afterwards has been underscored in an extensive literature review of evacuation research by Thompson, Garfin, and Silver (2017).

The City of New York has defined and mapped six evacuation zones (New York City, undated web page). These have been communicated via the NYC government web pages and news media (NYC EM undated web page, 2017; The New York Times 2012). Of these, Zone 1 is defined as having the most risk of exposure to hurricane-related flooding. As indicated above, the goal of this report is to explore several factors that link transportation access to evacuation Zone 1 and to develop analytical tools that can help decision-makers identify where additional resources and efforts may be needed to ensure people evacuate when considered necessary. There are many reasons why people may decide not to evacuate when NYC calls for a mandatory evacuation. However, access to public transit, distance to the nearest evacuation center, and several socioeconomic factors may play a relevant role in these decisions.

The City has located 64 evacuation centers outside of the six evacuation zones, and has identified the location of these centers relative to the evacuation zones (See Figure 1). Before Hurricane Irene and Superstorm Sandy the Mayor's Office issued mandatory evacuations for residents in what is now known as Zone 1 (NOAA 2011; NYC Office of the Mayor 2012; Barrios and Dooley 2012; Kaufman et al. 2012).

Figure 1 Subway Station Location, Evacuation Zones and Evacuation Centers, Manhattan, Queens and Brooklyn



Note: This figure appeared in Zimmerman et al. (2017). Source: This map is based on and is an extract of the NYCEM NYC Hurricane Evacuation Zones. As part of this Project, subway locations are included. http://www.nyc.gov/html/oem/downloads/pdf/hurricane_map_english.pdf with selected subway station locations added using Geographic Information Systems.

Extreme Weather Threats and Occurrences in New York City

Patterns and Trends in Extreme Weather Events

The U.S. in general has seen an increasing number of extreme weather events. In the northeast, which is expected to get wetter, downpours are expected to increase (Walsh et al. 2014; Karl, Melillo and Peterson 2009). Walsh et al. (2014: 36) estimated that precipitation has been increasing since 1990 with the northeast among those areas experiencing the most precipitation. They further point out that North Atlantic hurricanes have been on the rise, specifically in the more severe categories (Walsh et al. 2014: 41). Wahl et al. (2015) pointed to the combined effects of precipitation and storm surge producing greater amounts of flooding particularly along the Atlantic Coast.

The history of many devastating hurricanes that have affected the City includes Hurricane Sandy that alone resulted in dozens of deaths in the New York area and many more elsewhere (Miles 2014; Hurricane Sandy Rebuilding Task Force 2013). Blake, Landsea and Gibney (2011: 7) identified hurricanes and tropical cyclones prior to Hurricanes Irene and Sandy resulting in 25 or more deaths from 1851-2010 along the northeastern U.S.: Diane (1955) - 184 deaths; Agnes (1972) - 122 deaths; Carol (1954) - 60 deaths; and Floyd (1999) - 56 deaths. In New York City specifically, the NYC Panel on Climate Change has traced the history of these trends and projections into the current century. Horton et al. (2014: 4) and Horton et al (2015a: 23) have identified a 0.8 inches/decade increase in mean annual precipitation and Horton et al (2015b: 36, 37) have estimated a 1.2 inch per decade increase in sea level at the Battery through the end of the 21st century. They observed that this is about double the rate that is occurring globally and about 40% of the increase is from land subsidence (Horton et al. 2015b: 36, 37).

The persistence of these trends for precipitation and sea level rise alone is portrayed in the NYC Panel on Climate Change (2015) projections through the end of the 21st century:
Precipitation (Horton et al. 2014: 9; Horton et al. 2015a: 30; Middle range, 1971-2000 50.1 in baseline)

2020s: +0-8%
2050s: +4-11%
2080s: +5-13%
2100: -1 to +19%

Sea Level Rise (Horton et al. 2014: 10; Horton et al. 2015b: 41; Middle range, 2000-2004 zero inches baseline)

2020s: +4-8 inches
2050s: +11-21 inches
2080s: +18-39 inches
2100: +22-50 inches

Effects of Extreme Weather on NYC Rail Transit

The City's subway system has been affected not only by many of these hurricanes, but by other severe storms as well. In general, however, the system has rebounded relatively quickly. For example, following Hurricane Sandy, the system recovered within a few days (Kaufman et al. 2012; Zimmerman 2014), however, a limiting factor in the return of more widespread recovery was electric power. The severe storms of August 2007 disabled most subway lines for an estimated 12 hours or more, and the MTA (2007) report details the effects of and responses to this storm and earlier ones. The City of New York has taken numerous steps to harden the transit infrastructure in preparation for extreme weather events (U.S. DOT, FTA 2011; Zimmerman 2012; New York City Office of the Mayor 2016, 2017; NYC Office of the Mayor ORR 2017; MTA 2017).

The NYC Transit System

New York City is very transit rich, and the full extent of the system covering three states is the largest system in the U.S. (APTA 2015, 2016), North America (MTA undated web site circa 2016) and among the largest in the world. Transit is very popular among the City's residents, particularly workers. The U.S. Census Bureau (2017c) reported that 56.5% of workers aged 16 or higher used public transportation to commute to work. The relatively low rates of access to private vehicles, for example, in the New York Region 42% lacked auto access in 2000 (Berube, Deakin and Raphael 2006: 23), underscores the likelihood of increased reliance on public transit. The rail transit system within New York City alone (New York City Transit) according to the MTA statistics (MTA undated web site circa 2016) consists of 469 stations over 23 lines with an annual ridership of 2.4 billion trips throughout four of its boroughs and an additional 22 stations over one line with an annual ridership of 4.5 million on the borough of Staten Island. New York City has a dense distribution of subway stations, and New York City's subway system is estimated as ranking sixth in the world in the number of stations per capita (Gonzalez-Navarro and Turner 2016). Yet, not all areas are equally accessible to subway stations (New York City Office of the Mayor 2015).

Subways are vulnerable to disruptions during such events, especially since many stations are at low-lying elevations subject to flooding (Rosenzweig et al. 2011; Zimmerman and Faris 2010). Given advanced warning, they can be used during such events to prepare for such events, when they are not disrupted. Moreover, when combined with other transport the adaptability of the subway system to serve more populations improves.

Buses are particularly important. Prior research evaluated the proximity of buses stopping within a 0.1-mile radius of all subway stations in the four boroughs (Zimmerman et al. 2014; Zimmerman et al. 2015). That work found considerable variation in such proximity, however, certain poorer areas not only had fewer subway lines and stations, but also fewer buses stopping at the stations that existed.

Part II. APPROACH AND METHODS

The analysis, focused on New York City, relied primarily upon GIS-based methods to develop databases to combine and derive statistical relationships among location or proximity to subway stations, inundation zones, evacuation centers, and demographic characteristics of populations in Zone 1 at the level of U.S. Bureau of the census block groups and/or tracts.

Proximity of populations to evacuation centers were analyzed in two ways: as proximity to subway stations near the centers and proximity to the centers directly.

Population data was obtained for 2008-2012 at the Census block group level. Population was assigned to Zone 1 areas using the various procedures that included block groups fully and partially falling within Zone 1.

Regression models were developed and applied to the constructed databases to evaluate ways in which demographics of populations in Zone 1 were related to the proximity of their location to subway stations and evacuation centers. Additional details for the methods used in the regression analysis and the databases used are presented in Section IV.

Part III. INTRODUCTORY DESCRIPTIVE FINDINGS

Introduction: Proximity of evacuation centers to Zone 1 areas and subway stations

A third out of 64 evacuation centers were located within about a half-mile of Zone 1 study areas, and a quarter of them were about a quarter-mile from the study areas. With respect to distance from subway stations, or the 64 subway stations in the Zone 1 study area, "only 2 are within a quarter mile of an evacuation center, and four are within a half mile of a center" (Zimmerman et al. 2017).

Demographic Characteristics of Populations in Zone 1 Areas

An initial review of Census data at the zip code level shown in Table 1 revealed that considerable differences in socioeconomic and demographic characteristics of populations located in Zone 1 exist defined in terms of income and poverty, age and reliance on public transportation for commuting to work. These are all factors that can affect decisions about whether to evacuate or stay in place prior to an extreme weather event. However, these zip code level data can mask important variations within each area and as part of this research U.S. Census block-group data is used to identify potentially vulnerable populations that may not have adequate access to public transit to use it for evacuation. Many areas in New York City are also experiencing rapid demographic changes (Bishaw 2013) and these trends can affect the short- and medium-term vulnerability of certain areas depending on the nature of these changes.

Table 1. Summary Data for Demographic Indicators for Selected Zip Codes in New York City Located Partially or Completely in Zone 1 Evacuation Areas

Zip Code	Borough	Population	Median Household Income	Individuals Below Poverty level	Median Age	Commute to Work (Public Transportation)
11697	Queens	4,344	86,731	1%	49.1	285 (18.4%)
11694	Queens	21,281	73,893	6.7%	44.7	2,619 (27.8%)
11224	Brooklyn	44,047	31,415	25.8%	48.7	8,756 (58.4%)
11232	Brooklyn	28,703	40,565	26.9%	30.9	8,367 (66.5%)
10314	Staten Island	87,921	79,820	8.2%	40.8	10,101 (25.9%)
10308	Staten Island	28,782	90,196	4.2%	42.0	3,392 (26.8%)
10280	Manhattan	7,610	125,830	4.8%	37.7	2,514 (51.1%)
10004	Manhattan	2,780	127,281	10.8%	33.8	979 (50.9%)
10464	Bronx	3,974	61,063	5.8%	52.6	395 (18.3%)

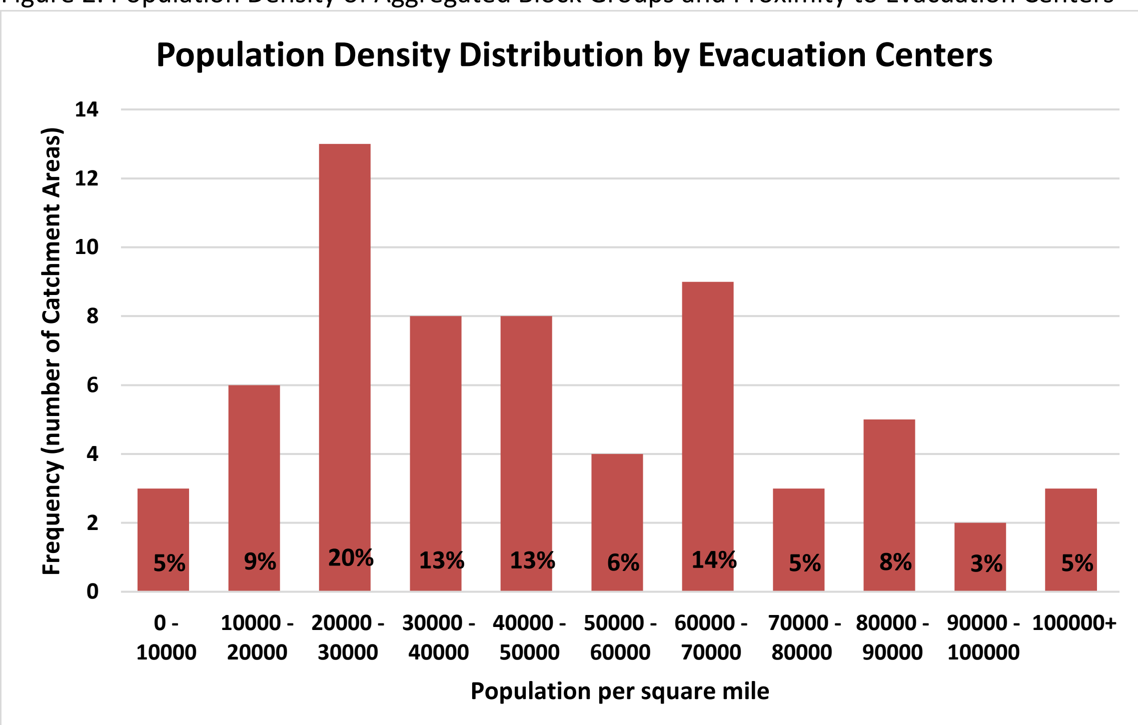
Source: U.S. Census Bureau, American Community Survey 2008-2012.

Demographic Characteristics of Populations in Zone 1 Areas and Proximity to Evacuation Centers

In order to obtain an initial picture of selected demographic characteristics of populations near evacuation centers, those block groups closest to the evacuation centers were aggregated into catchment areas. Catchment areas were created with two data sets: point data containing the location of Hurricane Evacuation Centers and polygon data for all the block groups in New York City. The "Near tool" command in ArcGIS (ESRI 2017) was used to compute the Evacuation Center that was nearest to each block group including all block groups in the calculation. The criterion for "nearest" was which Evacuation Center was the closest to any edge or part of any given block group.

The findings for two demographic characteristics, population density and median income, are shown as bar graphs in Figures 2 and 3. Figure 2 shows that about a fifth of the catchment areas were within the 20-30,000 people per square mile range, and by comparison, the average New York City population density in 2015 was 27,000 people per square mile (New York City Department of City Planning undated web page). Thus, the category with the largest number of catchment areas encompassed the City's average population density.

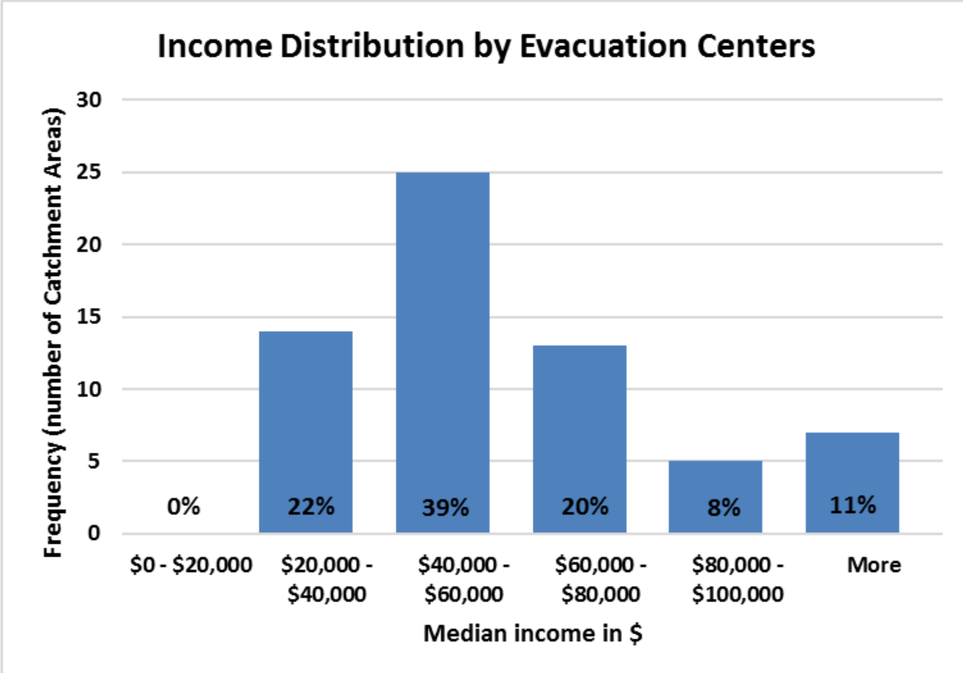
Figure 2. Population Density of Aggregated Block Groups and Proximity to Evacuation Centers



Note: This figure appeared in Zimmerman et al. (2017).
Source: This graph was computed from U.S. Census block group data for population density for block groups wholly or partly in Zone 1.

Figure 3 shows that 40% of the catchment areas were within the $40-60,000 median income category. By comparison, 2015 median household income for New York City was $53,373 (U.S. Bureau of the Census 2017c). Thus, the category containing the largest number of catchment areas encompassed the City's median household income category. About a fifth fell below and above the larger category.

Figure 3. Median Income of Aggregated Block Groups and Proximity to Evacuation Centers



Note: This figure appeared in Zimmerman et al. (2017).
Source: This graph was computed from U.S. Census block group data for median income data approximated for block groups wholly or partly in Zone 1.

Part IV. REGRESSION ANALYSIS

Introduction

This part, Part IV of the report, is divided in three sections. The first section describes the data used in the analyses. The second section presents descriptive statistics from an analysis of the data. The third section provides a statistical analysis using multiple regression modeling that examines whether there are any statistically significant associations between proximity to transit systems in areas designated as evacuation Zone 1 and various measures of social vulnerability, such as poverty and race. The next part, Part V, focuses on a new index called the Transit Evacuation Vulnerability Index (TEVI). It combines various factors introduced here in Part IV, including proximity to transit systems and measures of social vulnerability to rank areas by whether people living there may be at risk for not evacuating when the city calls for a mandatory evacuation.

Section 1. Data

Unit of Analysis

The geographical unit of analysis used in this report is the 2010 Census block group in New York City. Block group shapefiles were taken from the U.S. Census Bureau's online data (U.S. Census Bureau 2017a) for the five counties (boroughs) comprising New York City including: Bronx County, Kings County (Brooklyn), New York County (Manhattan), Queens County, and Richmond County (Staten Island). The U.S. Census Bureau's block group datasets include some block groups that are entirely uninhabited by humans, such as block groups in bodies of water or in open space. For the analyses presented in this report, block groups with zero population were excluded. The resulting dataset consisted of 6,227 block groups.

The next step was to identify NYC block groups that are either completely or partially in evacuation Zone 1. There are 577 block groups that are either completely or partially in evacuation Zone 1, and 97 of these are completely in evacuation Zone 1. The regression models included in section 2, and the index included in section 3 of this report, used the dataset with the 577 NYC block groups that are included completely or partially in evacuation Zone 1. Additional regression models using the more restricted dataset of block groups completely in evacuation Zone 1 were conducted for sensitivity analysis.
All block groups are given a unique ID by the U.S. Census Bureau that indicates the state, county, census tract, and number of the of block group. For example, block group 6 in census tract 179 in New York County in New York State may also be classified as 360610179006 where 36 represents New York State, 061 represents New York County, 0179 represents census tract 179, and 006 represents block group 6. Throughout the analysis and addition of variables, the unique twelve digit ID was used to match up records and ensure that data was correctly sorted to the appropriate block group. This 12-digit ID is also used to rank block groups in the index presented in section 3.

Geographic Data

The centroid of each block group was calculated in ArcGIS using the feature to point tool (ArcGIS 2017). The centroid is the geographic center of a shape, in this case, the block groups in New York City. The option to choose a centroid that falls inside of the boundaries of the block group was selected. In the analyses presented in this report, the centroid of a block group was used to provide a measure of proximity to nearest evacuation centers and to nearest transit systems for the average person living in that block group. Depending on the shape of the block groups there may be some limitations with this assumption, and these are discussed at the end of the report.

Census Data

The demographic data used in the analyses were obtained from the U.S. Census Bureau's American Community Survey (ACS) 2010-2014 five-year dataset (U.S. Census Bureau 2017b). Data were collected for several categories of variables and attached (using a join in ArcGIS or vlookup table in Excel) to the block groups with which they correspond by their twelve digit geographic ID number.

The demographic data used in the analyses includes information on race and ethnicity, age, and economic status. For each variable, the reporting population was collected along with the number of the variable being measured allowing for the normalization of data later on. The race and ethnicity includes the estimated number of individuals that self-identify as a given racial group including White, Black, American Indian, Asian, Native Hawaiian/ Pacific Islander, Other, or Two races or more. Ethnicity data includes those who consider themselves Hispanic or Latino of any race. Age indicators were collected for the number of households with persons over the age of 60 and households with persons under the age of 18 to estimate the relative populations of youth and elderly persons. In terms of economic indicators, the median household income for each block group was collected as well as the number of individuals in poverty and the number of households in poverty. An extensive review of the evacuation behavior literature by Thompson, Garfin, and Silver, R.C. (2017: 824) found that the studies they reviewed showed a number of positive relationships between these particular variables and evacuation behavior, but it varied depending on when the evacuation occurred: females correlated higher with evacuation during a disaster, older people were less likely to evacuate (though this finding was uneven), and race showed that whites were more likely to evacuate than blacks and hispanics.

Census data were also collected for commuting behaviors. The commuting mode of residents was gathered for all categories of commuting including those driving, taking public transportation, taking a taxi, bicycling, walking, or working at home. There were also a few subcategories for public transportation and driving included in the data. The U.S. Census Bureau (2017c) reported that more than half of the working population in NYC commutes via public transportation.

Nearby Transportation

The proximity of nearby transportation options was gauged by comparing straight line distance from the centroid of the block group to the nearest bus, subway, or Staten Island Railroad Station. First, shapefile data for New York City's bus and subway stations was collected from NYC Open Data (New York City 2017). These point datasets were then measured for proximity to each centroid of every block group in the city. The nearest station ID, distance in meters, latitude and longitude were then calculated using the near tool in ArcGIS. The unique station ID indicates which station was being referenced while latitude and longitude reference is absolute location. This process was completed for both subway and bus datasets.

Hurricane Evacuation Zones

Hurricane Evacuation Zone data was collected from NYC Open Data (New York City 2017) and mapped over the block groups of the entire city in ArcGIS. The spatial join tool was used to take the value of the lowest number evacuation zone that intersected each block group. If several different evacuation zones touched the same block group, the lower number representing the greater risk of damage from hurricanes was used.

Hurricane Evacuation Centers

Hurricane evacuation center point shapefile data were collected from NYC Open Data (New York City 2017) and compared in ArcGIS to the block groups. The near tool was used to calculate the straight-line distance from the centroid of a block group to the nearest evacuation center.

Section 2. Data Summary Results: Descriptive Statistics

Scatterplots and data summaries: Block groups that are completely classified as Evacuation Zone 1

The scatterplots and data summaries included in this section of the report consist of the first set of analyses of the data. Table 2 summarizes the data for the smaller dataset that includes block groups that are completely in evacuation Zone 1 (N=96). It includes minimum, maximum, mean and standard deviation values. Table 3 does the same for the larger dataset that includes all block groups that are completely or partially in evacuation Zone 1 (N=577).

Table 2. Descriptive statistics for selected variables (block groups completely in evacuation Zone 1).

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Percent Black	96	.00	88.17	21.28	24.61
Percent Hispanic	96	.00	62.42	18.42	16.61
Percent poor (individuals)	96	.00	67.11	23.71	16.68
Percent that do not speak English well	96	.00	57.00	18.55	15.02
Distance from centroid to nearest subway station	96	91.55	4,432.71	754.59	723.15
Distance from centroid to nearest bus station	96	14.15	6,768.50	993.78	1,801.09
Distance from centroid to nearest evacuation center	96	.70	8.01	4.68	2.17

Table 3. Descriptive statistics for selected variables (block groups completely or partially in evacuation Zone 1).

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Percent Black	577	.00	100.00	14.44	22.35
Percent Hispanic	577	.00	100.00	19.89	18.61
Percent poor (individuals)	573	.00	93.10	16.35	15.22
Percent that do not speak English well	577	.00	61.77	9.78	11.79
Distance from centroid to nearest subway station	577	42.68	8,465.78	1,366.73	1,586.15
Distance from centroid to nearest bus station	577	5.59	6,768.50	540.67	1,166.50
Distance from centroid to nearest evacuation center	577	.23	8.06	2.57	1.99

The tables show there is significant variation in the variables presented. This is particularly true of the variables that refer to distances between the centroid of a block group and the nearest subway and bus station.

The variation in the data is also shown in the scatterplots (Figures 4 through 10). The graphs included in this section of the report refer to the smaller dataset of block groups that are completely within evacuation Zone 1 (N=96). The first set of graphs consists of scatterplots of one variable with the X-axis showing the block groups arranged from first to last as they appear in the spreadsheet and provide a visual representation of the degree of variation in the data for each variable.

Figure 4. Demographics: Percent Black

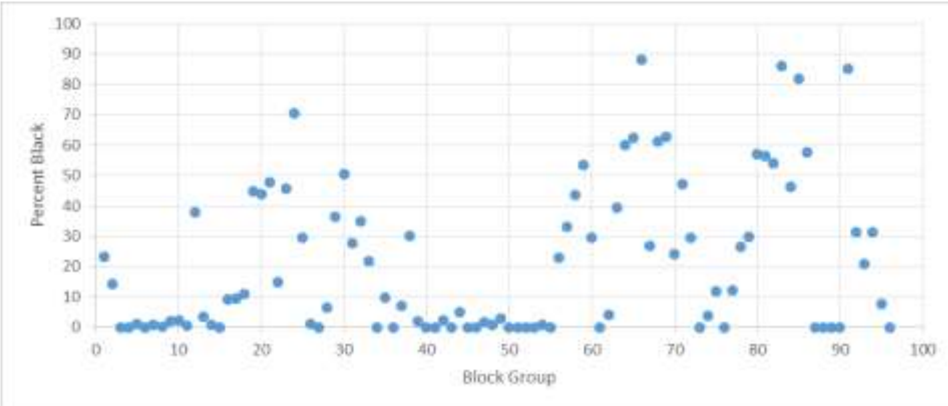


Figure 5. Demographics: Percent Hispanic

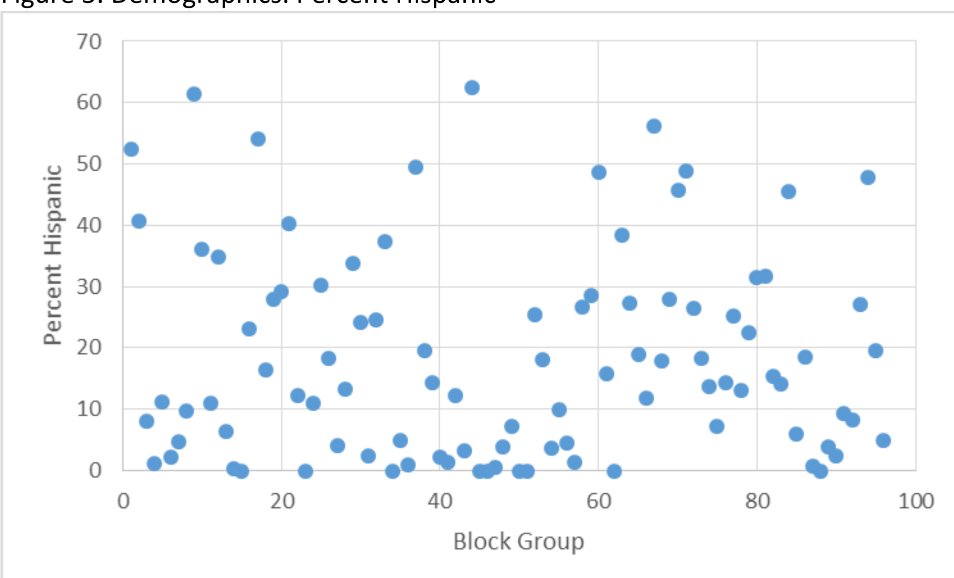


Figure 6. Socioeconomic Indicators: Percentage of Individuals below the Poverty Line

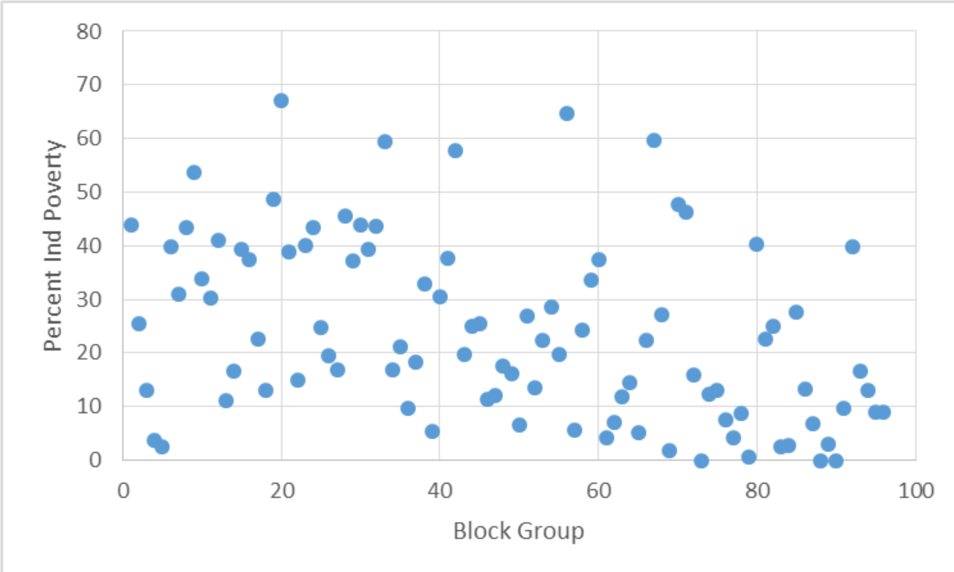


Figure 7. Socioeconomic Indicators: Percentage of people who do not speak English well

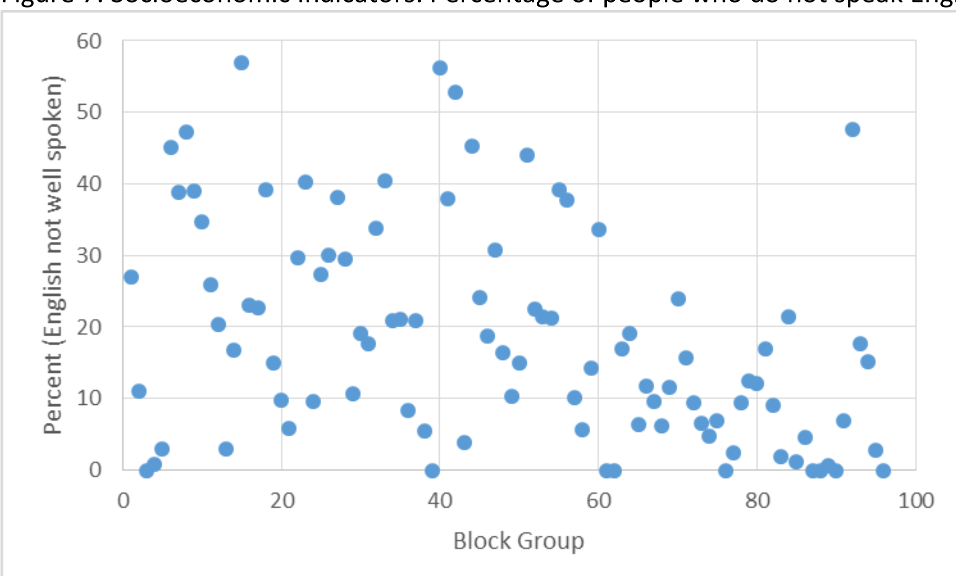
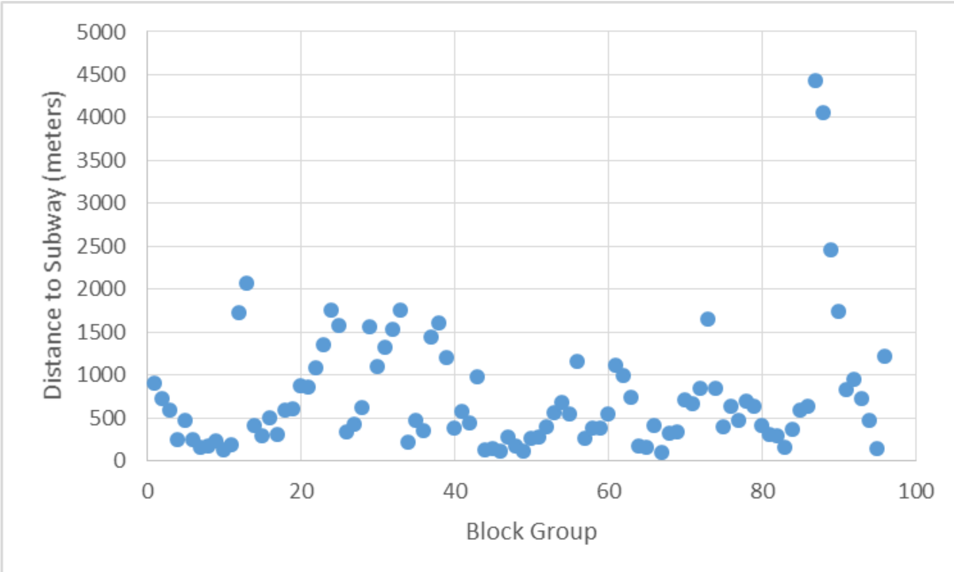


Figure 8. Transportation Indicators: Distance of centroid of the block group to the nearest subway station

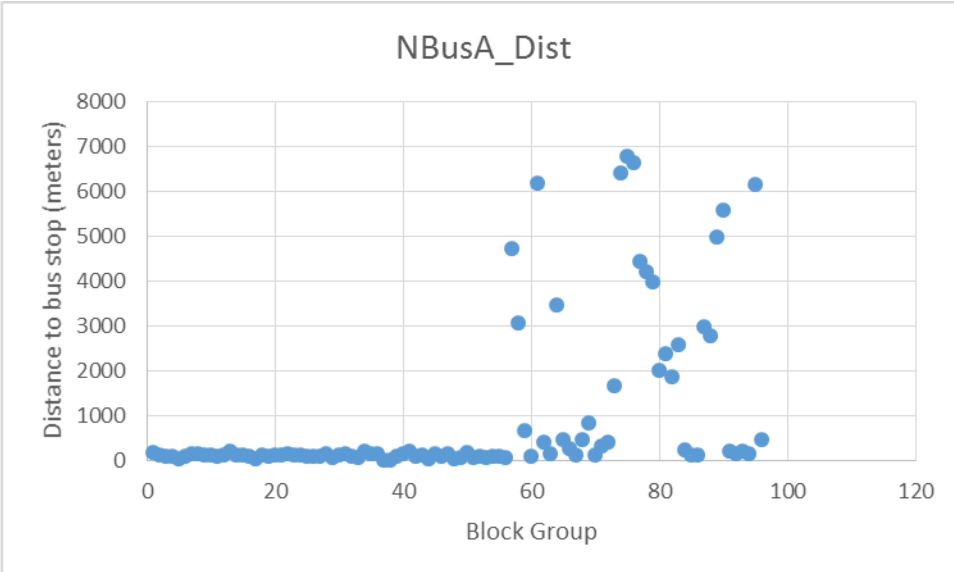


The variation in variables related to distance from the centroid of a block group to transit systems and evacuation centers might reflect differences in the counties with respect to geography and population distance. Table 4 shows the mean values for distance of centroid of a block group to nearest subway by county. New York County (Manhattan), which has the highest population density, has the lowest value. Queens has the highest value.

Table 4. Transportation Indicators: Distance of centroid of the block group to the nearest subway station (mean value by county)

County	Distance of centroid of the block group to the nearest subway station (meters)
Kings	711.79
New York	586.52
Queens	830.18

Figure 9. Transportation Indicators: Distance in meters of the bus stop nearest to the centroid of the block group (NBusA_Dist)



In the case of distance from centroid of a block group to the nearest bus stop there are some important differences at the county level, with some block groups in Queens having significantly larger distances than the values for Kings and New York counties. These block groups may be in low population density areas, or areas covered by large green areas, such as the areas around Jamaica Bay. These differences are summarized in Table 5.

Table 5. Transportation Indicators: Distance in meters of the bus stop nearest to the centroid of the block group (mean values by county)

County	Distance in meters of the bus stop nearest to the centroid of the block group (meters)
Kings	115.2
New York	109.0
Queens	2,224.5

Figure 10. Evacuation Indicators: Distance of centroid of the block group to the nearest evacuation center

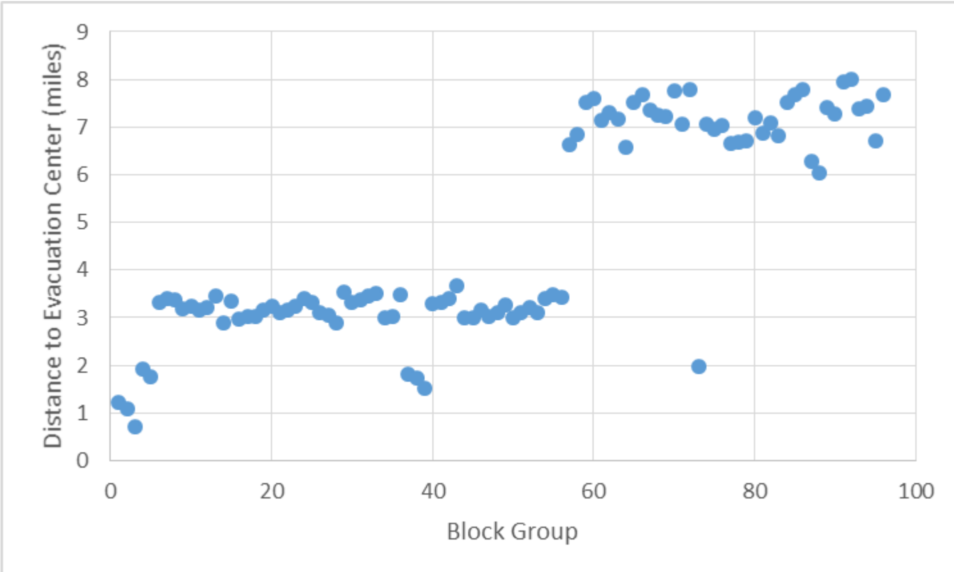


Table 6. Evacuation Indicators: Distance of centroid of the block group to the nearest evacuation center (mean value by county)

County	Distance of centroid of the block group to the nearest evacuation center (miles)
Kings	3.14
New York	1.34
Queens	7.07

As with distance to nearest bus station, the mean value of distance from the centroid of a block group to the nearest evacuation center differs significantly among the three counties as shown in Table 6. These differences probably reflect differences in population density and density of the built environment. New York (Manhattan) has the lowest average distance, while Queens has a much higher value.

Scatterplots of two variables

A number of scatterplots with two variables are presented in this section of the report. The graphs provide a visual way of assessing any potential associations between these variables. These graphs are for the subset of the data that includes block groups that are exclusively in evacuation Zone 1.

The first set (Figures 11-14) is for distance from the centroid of a block group to the nearest subway station (x-axis) and four demographic/social variables (y-axis): Percent black, percent Hispanic, percent of individuals below the poverty line and percent of individuals who report speaking English “not well”. This set of figures does not show any obvious associations between distance to subway and the selected socioeconomic variables.

Figure 11. Scatterplot of distance from centroid of a block group to nearest subway station and percent black

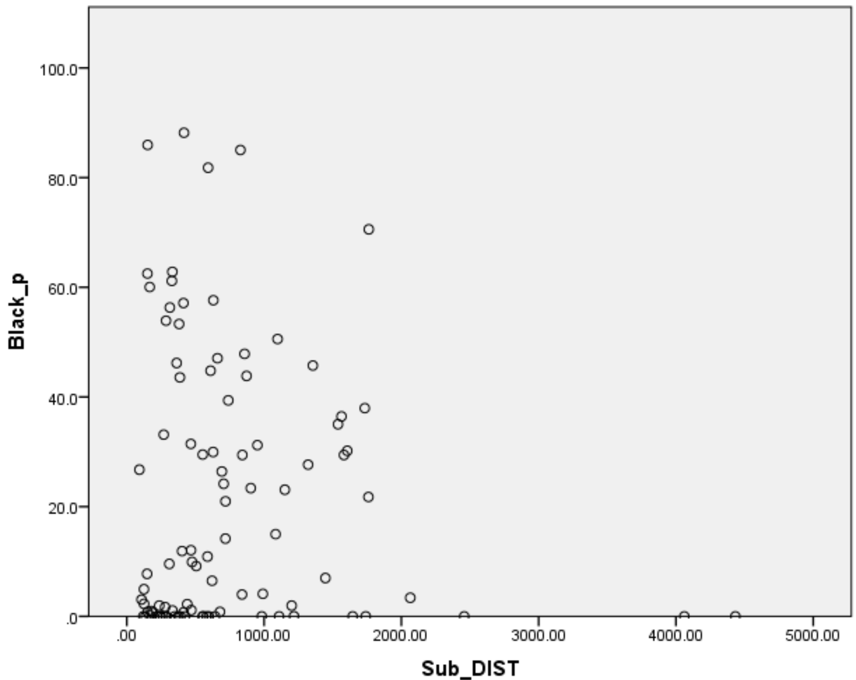
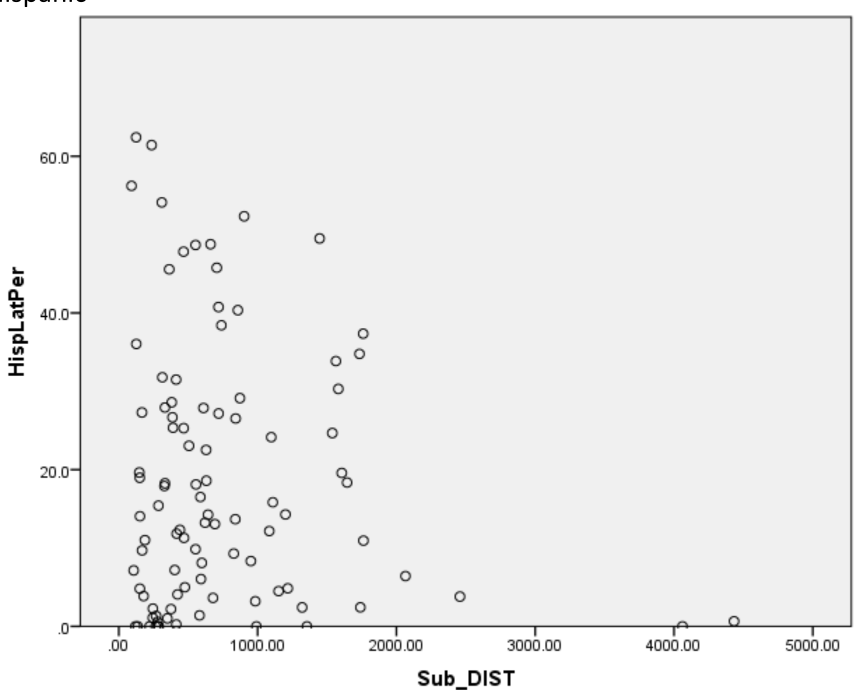


Figure 12. Scatterplot of distance from centroid of a block group to nearest subway station and percent Hispanic



13. Scatterplot of distance from centroid of a block group to nearest subway station and percent poor (individuals)

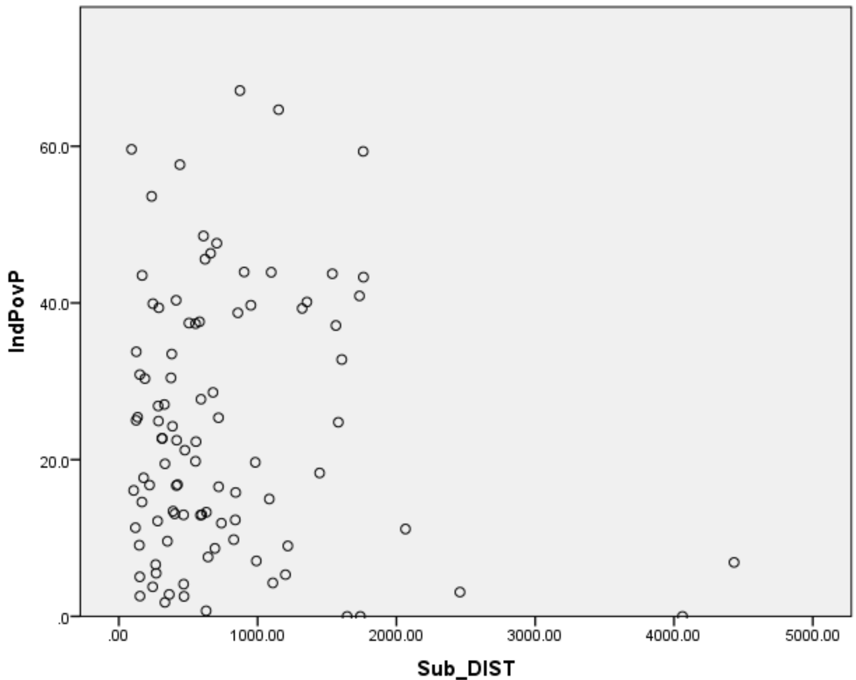
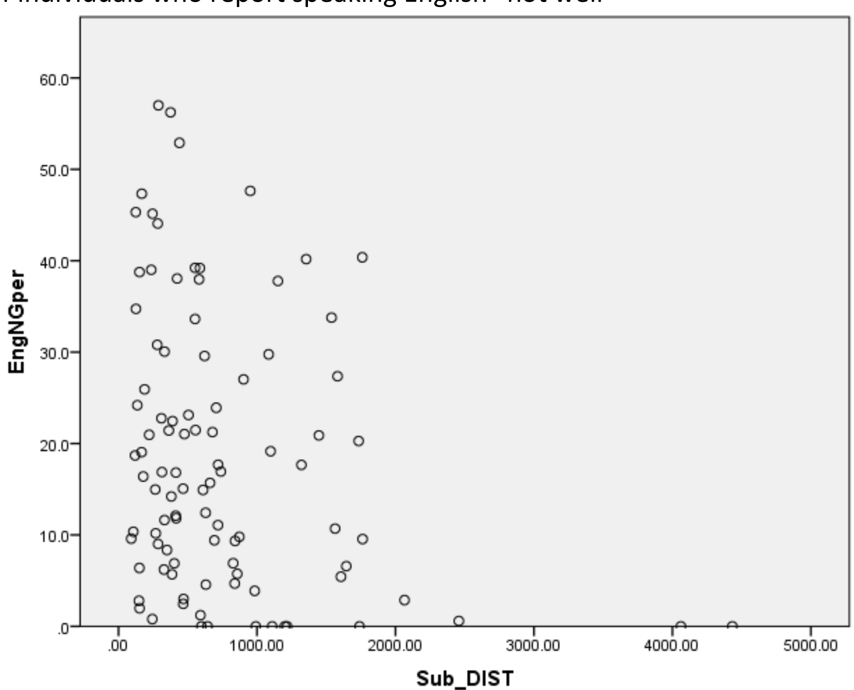


Figure 14. Scatterplot of distance from centroid of a block group to nearest subway station and percent of individuals who report speaking English “not well”



The second set is for distance from the centroid of a block group to the nearest evacuation center (x-axis) and the same four demographic/social variables (y-axis) as above (Figures 15-18). This set of graphs does not show any obvious associations between distance to nearest evacuation center and the selected socioeconomic indicators. It does show the data is roughly divided into two groups, which represents differences between Queens and the other two counties. Within these two groups there do not appear to be significant relationships between the variables.

Figure 15. Scatterplot of distance from centroid of a block group to nearest evacuation center and percent black

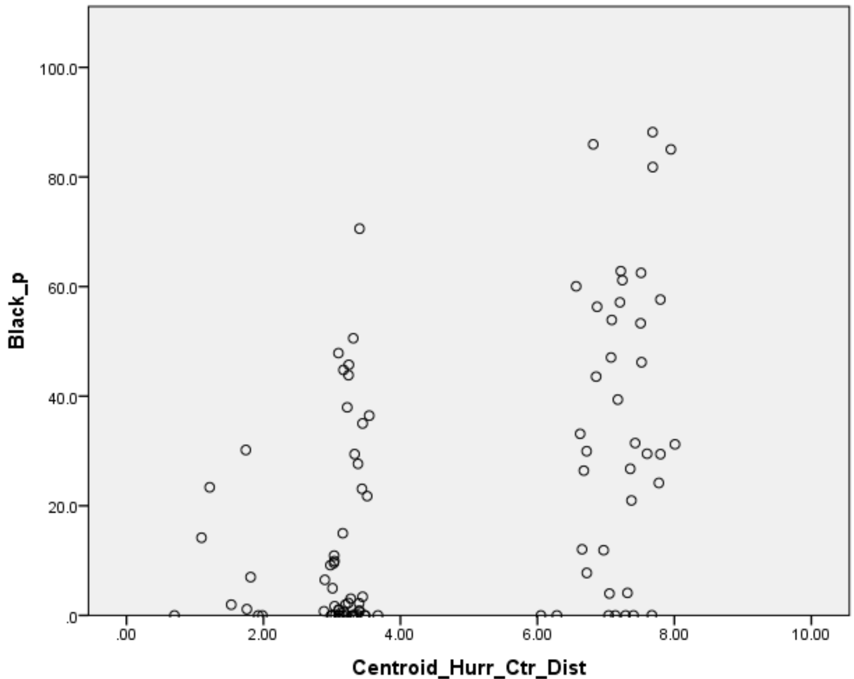


Figure 16. Scatterplot of distance from centroid of a block group to nearest evacuation center and percent Hispanic

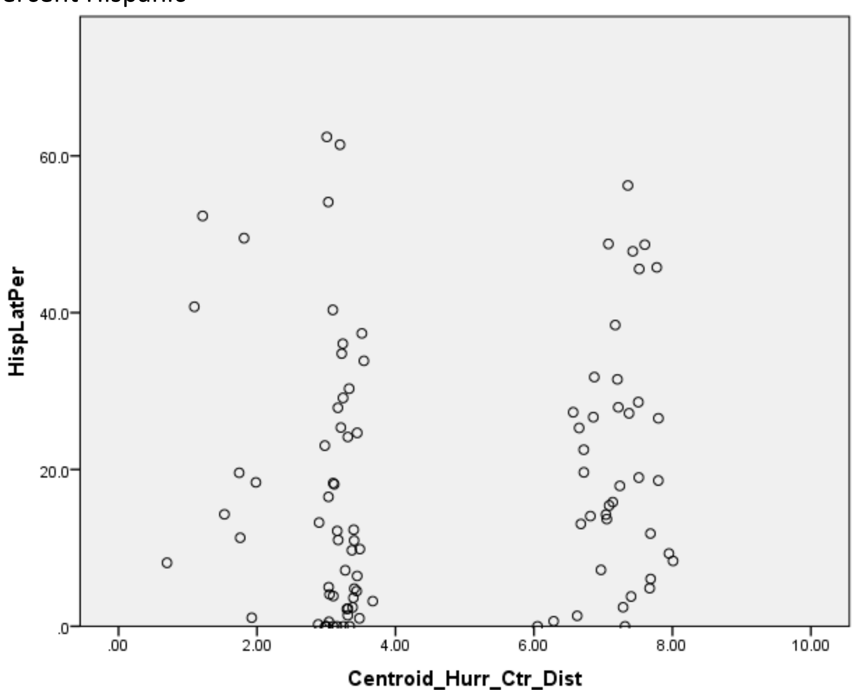


Figure 17. Scatterplot of distance from centroid of a block group to nearest evacuation center and percent poor (individuals)

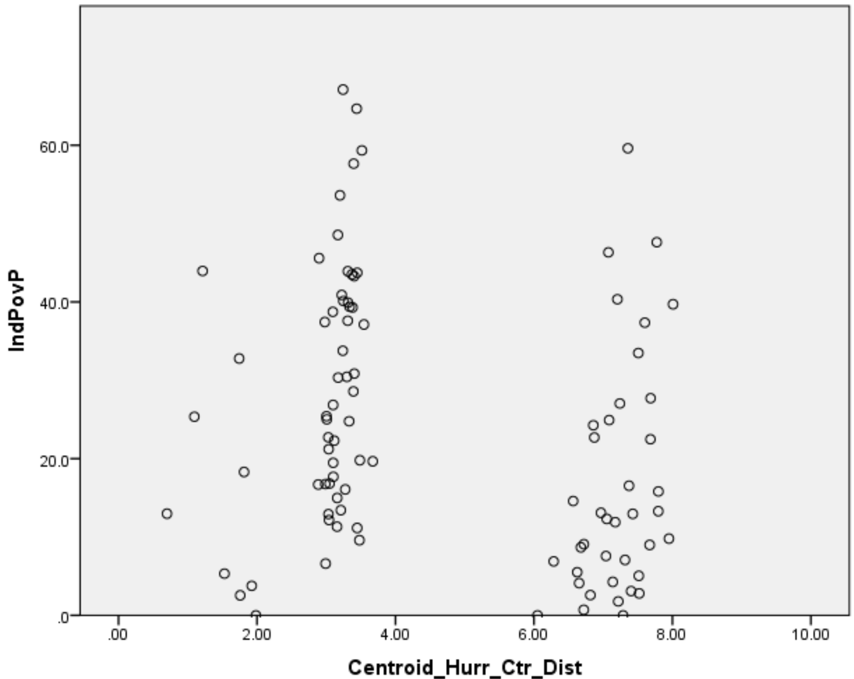
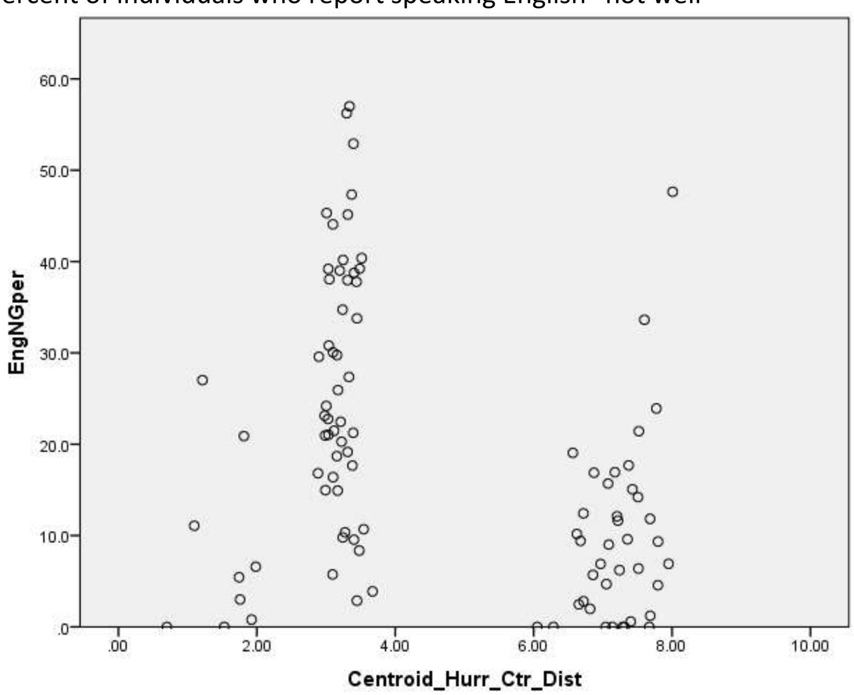
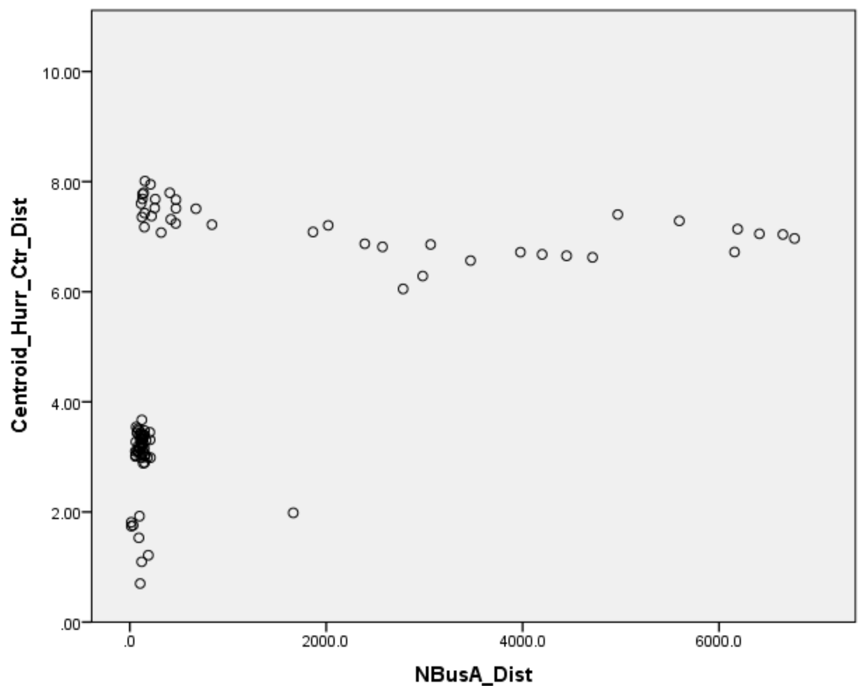


Figure 18. Scatterplot of distance from centroid of a block group to nearest evacuation center and percent of individuals who report speaking English "not well"



An additional two-way scatterplot is shown in Figure 19to explore any potential relationship between distance of the centroid of a block group to the nearest bus station (x-axis) and distance between the centroid of a block group and the nearest hurricane evacuation center. The graph does not show an obvious relationship between the two variables for the dataset that includes block groups that are completely within evacuation Zone 1. However, the graph shows that there are several block groups that have large distances between the centroid of the block group and both a bus station and an evacuation center. These block groups are located in Queens County. It is possible that vulnerable populations in these areas that do not have access to private vehicles may be at greater risk for not evacuating when a city calls for a mandatory evacuation in an emergency.

Figure 19. Distance to the nearest hurricane evacuation center in miles from the centroid of the block group (Centroid _Hurr_Ctr_Dist) versus distance in meters of the bus stop nearest to the centroid of the block group (NBusA_Dist)



Section 3. Regression Analyses

Multiple regression analysis is a statistical tool that can be used to assess whether there are any statistically significant associations between a dependent variable and a number of independent variables (Hamburg 1991). A number of linear regression models were used as part of this study to explore potential associations between distance to an evacuation center and a several variables that measure distance to transit and socioeconomic characteristics. SPSS version 24 software was used to run the regression models (IBM 2017).

Sub-section I. Analysis of Data for Block Groups Partially or Completely in Evacuation 1 Zones

Two linear regression models that use the dataset with block groups that are completely or partially in evacuation Zone 1 are summarized below (N=577). The goal was to assess whether there is a statistically significant association between the distance of the centroid of a block group and the nearest evacuation center. Table 7 includes some descriptive statistics for some of the socio-economic variables of interest in the dataset.

Table 7. Descriptive statistics for selected variables

Variable	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Stat	Std. Error	Stat	Std. Error
Percent White	577	.00	100.00	53.45	32.57	-.355	.102	-1.276	.203
Percent Black	577	.00	100.00	14.44	22.35	1.862	.102	2.761	.203
Percent Hispanic	577	.00	100.00	19.89	18.61	1.319	.102	1.445	.203
Percent Below Poverty	573	.00	93.10	16.35	15.22	1.408	.102	2.096	.204
Distance Centroid to Evacuation Center (miles)	577	.23	8.06	2.57	1.99	1.260	.102	.736	.203
Percent Aged 65 and over	577	.00	100.00	15.58	12.29	2.372	.102	9.798	.203
Percent reporting poor English skills	577	.00	61.77	9.78	11.79	1.721	.102	2.882	.203

Table 8 shows the frequency distribution of the data by County. The county with the most block groups in the data is Kings (Brooklyn) and the county with the least number of block groups is Bronx.

Table 8. Frequency distribution by County

County	Frequency	Percent
Bronx	43	7.5
Kings	172	29.8
New York	137	23.7
Queens	142	24.6
Richmond	83	14.4
Total	577	100.0

The two exploratory linear regression model runs included the following variables:

- Dependent variable: Distance from the centroid of a block group to nearest evacuation center (miles)
- Independent variables: percent black, percent Hispanic, percent below poverty (individuals), percent aged 65 and over, and percent reporting poor English skills

Model I.

Tables 9-11 summarize the results for this model. As Table 9 shows, the adjusted R Square value of this model is relatively low, which suggests that the data are not very close to the fitted regression line, and the model does not fit the data very well. However, Table 10 shows the F test statistic, and the p value indicates that there is a significant linear regression relationship between the independent variable and the dependent variables. Table 11 shows that there are some small, statistically significant associations between the dependent variable and some of the socioeconomic variables, including percent black, percent Hispanic, and percent elderly (aged 65 years and above). The association with percent black is positive, which means greater distances to an evacuation center are associated with higher percentages of African Americans, while holding all else in the model constant. The opposite is true of Hispanics. With this variable the association has a negative sign. With the elderly population there is a positive association, which means higher percentages of elderly people are associated with longer distances to the nearest evacuation center. Since the elderly could be considered a vulnerable population with respect to access to transportation and evacuation, this association could be important.

Table 9. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.366[a]	.134	.127	1.860

a. Predictors: (Constant), EngNGper, Black_Per, 65_Per, HispLatPer, IndPovP

Table 10. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	304.215	5	60.843	17.575	.000[b]
	Residual	1962.937	567	3.462		
	Total	2267.152	572			

a. Dependent Variable: Centroid_Hurr_Ctr_Dist
b. Predictors: (Constant), EngNGper, Black_Per, 65_Per, HispLatPer, IndPovP

Table 11. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.188	.176		12.420	.000
	Black_Per	.034	.004	.375	8.752	.000
	HispLatPer	-.012	.005	-.115	-2.623	.009
	IndPovP	-.009	.007	-.069	-1.373	.170
	65_Per	.018	.007	.107	2.513	.012
	EngNGper	.003	.008	.018	.372	.710

a. Dependent Variable: Centroid_Hurr_Ctr_Dist

Model II.

The second model includes the same variables as Model I but adds a series of indicator (0/1) variables for the counties to account for differences among the counties, such as density of development. Since there are 5 counties, one is left out of the model and is used as the reference county for the comparison of the variable coefficients. In this case New York is left out so that the coefficient values of the four other counties are relative to New York County.

Tables 12-14 summarize the results for this model. As Table 12 shows, the adjusted R square value for this model is significantly higher than for the previous model. Adding country specific indicator variables captures the fact that Queens, for example, has many block groups that seem different from many in the other counties, in that they have longer distances to a bus station, etc. As with the previous model, Table 13, which shows the F test statistic and the p value, indicates that there is a significant linear regression relationship between the independent variable and the dependent variables. Table 14 shows that the coefficient for Queens is about 3.3, which means that a block group in Queens is likely to have a distance to an evacuation center that is over three miles higher than a block group in Manhattan, holding everything else in the model constant. The coefficients for the counties have much higher values than the socioeconomic variables, and suggest that these differences between distances are more related to the geographic and density characteristics of the counties than to the socioeconomic variables.

Table 12. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.659[a]	.435	.425	1.509

a. Predictors: (Constant), EngNGper, Black_Per, Bronx, Richmond, 65_Per, Queens, HispLatPer, Kings, IndPovP

Table 13. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	985.108	9	109.456	48.067	.000[b]
	Residual	1282.044	563	2.277		
	Total	2267.152	572			

a. Dependent Variable: Centroid_Hurr_Ctr_Dist
b. Predictors: (Constant), EngNGper, Black_Per, Bronx, Richmond, 65_Per, Queens, HispLatPer, Kings, IndPovP

Table 14. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.906	.180		5.041	.000
	Bronx	1.753	.285	.232	6.144	.000
	Kings	1.430	.179	.329	8.004	.000
	Queens	3.273	.190	.707	17.241	.000
	Richmond	1.332	.212	.236	6.293	.000
	Black_Per	.017	.003	.188	5.136	.000
	HispLatPer	-.015	.004	-.142	-3.659	.000
	IndPovP	.002	.005	.014	.348	.728
	65_Per	.011	.006	.066	1.852	.065
	EngNGper	-.001	.007	-.008	-.194	.846

a. Dependent Variable: Centroid_Hurr_Ctr_Dist

In summary, the results of these initial models suggest that differences among the counties related to density explain a lot of the variation in the data with regard to distance between the centroid of a block group and the nearest hurricane evacuation center. Of the socio-economic variables percent Black is positively associated with the dependent variable and percent Hispanic is negatively associated with it. The variables that measure percentage of poverty, those aged 65 and over, and English language skills, are not associated with the dependent variable.

<u>Sub-section II. Analysis of Data for Block Groups Completely in Evacuation 1 Zones</u>

The same analyses done in the previous section for block groups that are partially or completely in evacuation 1 zones were done for a subset of the data that only includes block groups that are completely in evacuation 1 zones (N=96).

Table 15 includes descriptive statistics for selected socio-economic variables.

Table 15. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
Variable	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Percent White	96	.00	100.00	49.23	35.49	.11	.246	-1.564	.488
Percent Black	96	.00	88.17	21.28	24.61	1.01	.246	.038	.488
Percent Hispanic	96	.00	62.42	18.42	16.61	.86	.246	-.119	.488
Percent Below Poverty	96	.00	67.11	23.71	16.68	.58	.246	-.456	.488
Distance Centroid to Evacuation Center (miles)	96	.70	8.01	4.68	2.17	.24	.246	-1.550	.488
Percent Aged 65 and over	96	1.64	91.90	20.30	15.41	1.74	.246	4.626	.488
Percent reporting poor English skills	96	.00	57.00	18.55	15.02	.71	.246	-.377	.488

For this data set, Kings and Queens Counties have the majority of block groups, with New York having only 5, and Bronx and Richmond counties not having any block groups that are completely in evacuation Zone 1. The figures are summarized in Table 16.

Table 16. Frequency Distribution by County

County	Frequency	Percent
Kings	51	53.1
New York	5	5.2
Queens	40	41.7
Total	96	100.0

Model I. Selected socio-economic variables

As Table 17 shows, the adjusted R square value of this model is higher than the value for the larger dataset, and the model is a better fit of the data, but it is still a relatively low value. Table 18 shows the F statistic, and the p value indicates that there is a significant linear regression relationship between the independent variable and the dependent variables.

Table 17. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.613[a]	.376	.341	1.764

a. Predictors: (Constant), EngNGper, HispLatPer, Black_p, IndPovP, I65andOverP

Table 18. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	168.518	5	33.704	10.827	.000[b]
	Residual	280.169	90	3.113		
	Total	448.687	95			

a. Dependent Variable: Centroid_Hurr_Ctr_Dist

b. Predictors: (Constant), EngNGper, HispLatPer, Black_p, IndPovP, I65andOverP

Table 19 shows the coefficients for this model. The results are different from the previous model. Percent Black is still statistically significant and the direction is also positive. Percent Hispanic and percent elderly (aged 65 years and over) are not significant in this model. This shows that the results are sensitive to the dataset used. Unlike the model with the larger set, percent of individuals below the poverty line is statistically significant in this model. The size of the coefficients is still pretty small. For example, increasing percent black by one percent translates to an increase of 0.045 miles for distance to an evacuation center.

Table 19. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.236	.484		8.760	.000
	Black_p	.045	.008	.508	5.437	.000
	HispLatPer	.022	.014	.166	1.557	.123
	IndPovP	-.044	.014	-.340	-3.057	.003
	I65andOverP	.027	.016	.195	1.747	.084
	EngNGper	-.023	.016	-.156	-1.387	.169

a. Dependent Variable: Centroid_Hurr_Ctr_Dist

The results of the first model suggest that percent Black and percent of individuals below poverty are associated with the distance from the centroid of the block group to the nearest evacuation center. The association with percent black is positive so higher percentages of blacks is associated with longer distances but the coefficient for poverty is negative which suggests an inverse relationship all else equal in the model. The adjusted R square is quite low for this model.

Model II. Selected socio-economic variables and indicator variable for Queens

For model II and the restricted dataset (N=96) the independent variables are a little different than Model II for the larger dataset containing all the block groups that are partially or completely in evacuation Zone 1 (N=577). In the smaller dataset there are block groups in only three counties, and New York County only has 5 block groups. As a result, instead of including indicator variables for all NYC counties, only an indicator variable for Queens was included. The rationale for including this variable is that Queens seems different from the other two counties in this data set in that the distances from the centroid of the block group to transit and evacuation centers are larger than in the other two counties.

As Table 20 shows, including an indicator variable for Queens dramatically increases the adjusted R squared value from .341 in Model I to .893 in Model II. This means that this model is a better fit of the data, and this can be attributed to including an indicator variable for Queens, where geography and density of the built environment are probably responsible for the variation in the data.

Table 21 shows the F test statistic for this model, and the p value indicates that there is a significant linear regression relationship between the independent variable and the dependent variables.

Table 20. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.948[a]	.900	.893	.712

a. Predictors: (Constant), Queens, HispLatPer, I65andOverP, Black_p, EngNGper, IndPovP

Table 21. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	403.607	6	67.268	132.805	.000[b]
	Residual	45.080	89	.507		
	Total	448.687	95			

a. Dependent Variable: Centroid_Hurr_Ctr_Dist
b. Predictors: (Constant), Queens, HispLatPer, I65andOverP, Black_p, EngNGper, IndPovP

Table 22 shows the coefficients of the variables. In this model the statistically significant socioeconomic variables are percent Hispanic and percent who do not speak English well. The size of the coefficients for these variables is pretty small. For example, a one percent increase in Hispanic population is associated with a decrease in the distance from the centroid of a block group to the nearest evacuation center by 0.016 miles, while holding everything else in the model constant. This indicator variable for Queens County is also statistically significant, and the magnitude of the coefficient is much higher than for the socioeconomic variables. A block group that is completely in evacuation Zone 1 in Queens is associated with a 4.4 higher distance from its centroid to the nearest evacuation center relative to block groups in Kings and New York Counties, while holding everything else in the model constant.

Table 22. Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.499	.211		11.839	.000
	Black_p	.007	.004	.075	1.749	.084
	HispLatPer	-.016	.006	-.121	-2.670	.009
	IndPovP	.014	.006	.106	2.140	.035
	I65andOverP	-.010	.007	-.069	-1.482	.142
	EngNGper	.020	.007	.135	2.858	.005
	Queens	4.419	.205	1.008	21.544	.000
a. Dependent Variable: Centroid_Hurr_Ctr_Dist						

In summary, the results for model II are very different to those of model I. The statistically significant variables are percent Hispanic, percent of individuals with poor English language skills and the indicator variable for Queens. This last variable seems to explain a lot of the variation in the data and suggests differences in density and geography explain a lot of the difference in terms of distance from the centroid of the block group to the nearest evacuation center. The inclusion of the indicator variable for Queens increases the adjusted R square value very significantly compared to the model that does not include it (Model I).

The differences in the results for models with the larger dataset, block groups that are partially or completely in evacuation Zone 1, and the smaller dataset, block groups completely in evacuation Zone 1 are also pretty significant in terms of the socioeconomic variables. This is not true of the indicator variables for the counties, which in both cases tend to increase the adjusted R square value of the models significantly. The coefficients for the indicator variables that account for county-level differences are all statistically significant in the models. This suggests that variation in the data related to distances to nearest evacuation center are more likely to be related to geographical constraints and density of the built environment than to socioeconomic characteristics, though there may be some associations that could be further teased in the future with these socioeconomic variables if additional analyses are carried out.

A potential future research direction would be to conduct spatial regression models. Linear regression models have a limitation in this kind of geographical analysis since there may be spatial autocorrelation, and such limitations could be addressed by spatial regression models (Bailey and Gatrell 1995).

Part V. Transit Evacuation Vulnerability Index (TEVI)

Indexes have become a common numerical tool to synthesize various sources of information and variables into one figure that can help decision-makers assess performance or identify important needs. Popular examples of indexes in the literature include the UN Development Program's Human Development Index (UNDP 2017), the Social Vulnerability Index (ATSDR 2017; Borden et al. 2007; Dunning and Durden 2013), the ARCADIS Sustainable Cities Index (ARCADIS 2016) and the Happy Planet Index (New Economics Foundation (NEF) 2017). Many of these are based on the literature on the social vulnerabilities of populations particularly in extreme events (Cutter and Finch 2008; Dunning and Durden 2013). This report introduces the transit evacuation vulnerability index (TEVI), which is intended to provide a measure of risk factors that influence the decision of individuals and families to evacuate for populations that live in areas of New York City that are likely to see a mandatory evacuation order.

During extreme cases when the city issues a mandatory evacuation order, people may decide not to evacuate, putting themselves and rescuers at risk of injury or death. There are many factors that determine why people may decide to stay in their place of residence (Dombrowki, Fischhoff and Fischbeck 2006; Strang 2014; Thompson, Garfin, and Silver 2017). Some of these include mobility limitations (Renne, Sanchez and Litman 2006), distance to shelters, lack of understanding of the risks involved, lack of access to communications about an impending disaster (Turner et al. 2010), fear of looting if they leave, and others. Mobility limitations include various factors, including physical mobility for elderly (Zimmerman et al. 2007) and other vulnerable populations for whom physically moving is more difficult, lack of access to an automobile, and lack of easy/convenient access to public transit.

TEVI includes traditional variables included in social vulnerability and hazard indexes such as percent poor, percent of households where English is a second language and percent elderly. In addition, the index includes measures of proximity to public transit, distance to shelters and vehicle ownership rates. The index is presented as a value between 0 and 1. Higher values indicate higher vulnerability, which means more likelihood that individuals will choose not to evacuate during a mandatory evacuation event. The unit of analysis for the TEVI is the block group as defined in the U.S. Census. For the purposes of this study 577 block groups that are completely or partially within evacuation Zone 1 are included.

Zone 1 includes those areas that are at most risk during an extreme weather event for flooding. The variables included in the TEVI are the following:

- Percent of individuals below the poverty rate
- Percent of population who are Non-English Speakers (including Spanish) and who speak English "Not Well" or "Not at All"
- Percent elderly (over 65 years of age)
- Percent of household with no vehicle
- Distance of the centroid of a block group to the nearest subway station (normalized between 0 and 100)
- Distance of the centroid of a block group to the nearest bus stop (normalized between 0 and 100)
- Distance of the centroid of a block group to the nearest shelter (normalized between 0 and 100)

The estimation of the TEVI is a simple average of the various components that make up the index. In order to be able to take an average of these variables they have to be comparable ranges (normalized). The variables that include percentage values are all in ranges 0-100 and are comparable. The distance variables are in very different ranges. Simply averaging them with percentage values would mean that distance variables, which are significantly higher than 100 in many cases, would dominate the index. To avoid that these values were normalized so that the highest values in the range was multiplied by a factor to make it 100 and every other value in the variable was multiplied by the same factor. This turned all the values in the distance variables into ranges 0-100. The seven components included in the TEVI are equally weighted.

Table 23 shows descriptive statistics for the components included in the TEVI, as well as for the index. As shown, 571 block groups have complete information for all the variables.

Table 23. Descriptive Statistics

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Population	577	4	8598	1499.85	857.91
TEVI_Poverty	573	.00	93.10	16.35	15.22
TEVI_Subway	577	.50	100.00	16.14	18.74
TEVI_Bus	577	.08	99.99	7.99	17.23
TEVI_EvacCenter	577	2.87	99.52	31.76	24.57
TEVI_Elderly	577	.00	100.00	15.58	12.29
TEVI_Language	577	.00	61.77	9.78	11.78
TEVI_Vehicle	571	.00	100.00	44.21	27.69
TEVI	571	6.04	51.94	20.24	7.23

Figure 20 shows the distribution of the TEVI, arranged from smallest to largest value. According to the assumptions made in this report, the largest values on the right side of the graph correspond to block groups that have the highest risks in terms of people not evacuating when the city issues a mandatory evacuation order. Table 24 shows the values for the block groups with the top 10 TEVI values. Of the top 10 block groups with the highest TEVI values, five are in Queens, four are in Brooklyn, and one is in the Bronx.

Figure 20. Distribution of TEVI

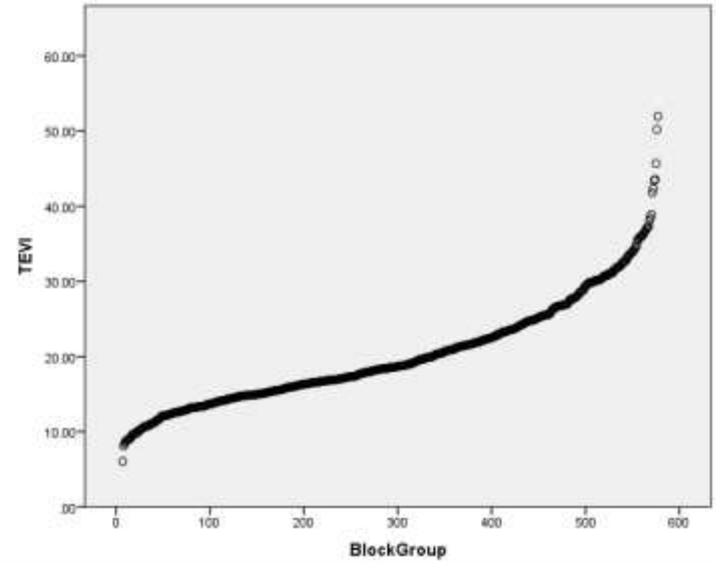


Table 24. TEVI for the Top 10 Block groups

Block Group ID	County	Poverty	Subway	Bus	Evacuation Center	Elderly	Language	Vehicle	TEVI
360810998023	Queens	39.7	11.2	2.3	98.9	71.4	47.6	92.5	51.9
360470340002	Kings	64.7	13.6	1.1	42.5	91.9	37.8	100.0	50.2
360050462011	Bronx	79.0	18.9	1.9	30.7	63.9	25.4	100.0	45.7
360810938003	Queens	16.6	3.9	96.2	82.8	28.3	7.5	69.7	43.6
360470342004	Kings	59.3	20.8	1.2	43.4	42.2	40.4	96.6	43.4
360470352001	Kings	50.3	5.5	3.8	40.6	70.8	36.7	88.9	42.4
360811010022	Queens	44.9	17.9	4.4	98.4	35.3	25.5	66.0	41.8
360470342003	Kings	43.7	18.2	1.7	42.6	47.8	33.8	84.5	38.9
360810972033	Queens	54.8	5.3	20.7	88.5	9.3	5.7	85.0	38.5
360810972034	Queens	45.5	5.1	37.7	82.2	9.8	13.4	72.8	38.1

Figures 21-23 show the relationship between the TEVI and some of its components.

Figure 21. TEVI and Poverty

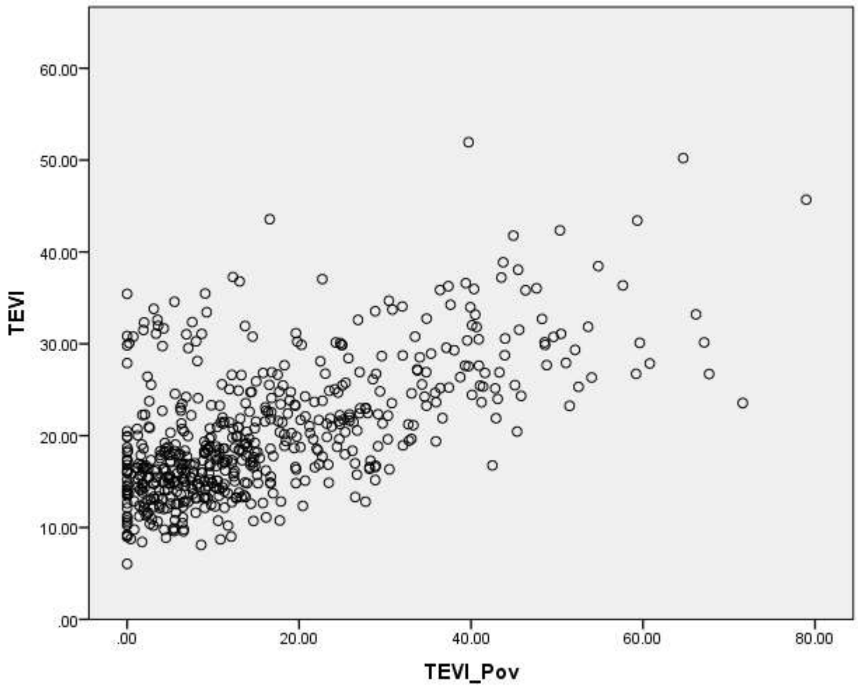


Figure 22. TEVI and distance from the centroid of the block-group to the nearest subway station

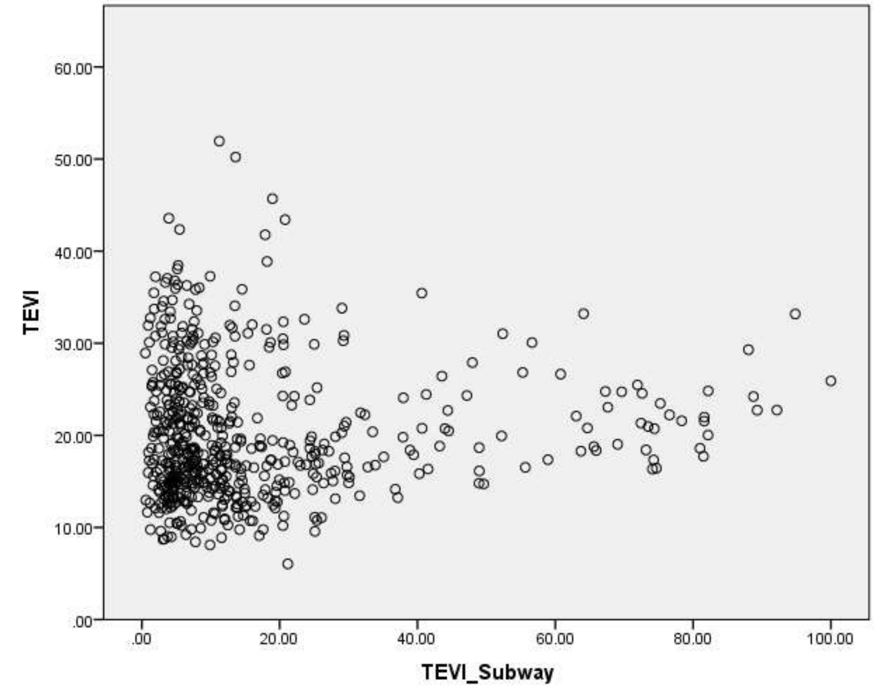
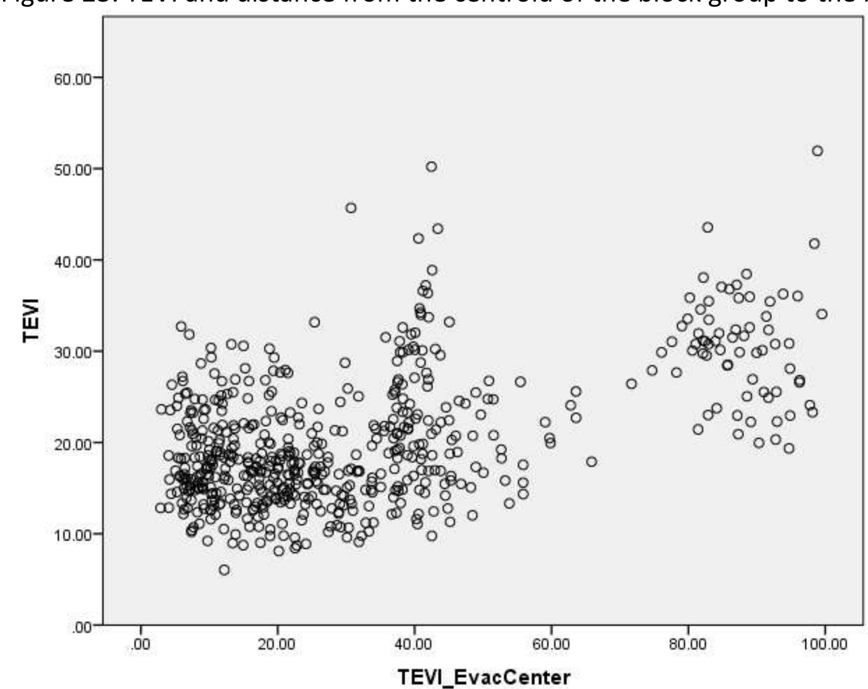


Figure 23. TEVI and distance from the centroid of the block group to the nearest evacuation center



Figures 24-26 show some of the relationships between the different components of the TEVI.

Figure 24. Distance from the centroid of a block group to the nearest evacuation center and to the nearest subway station

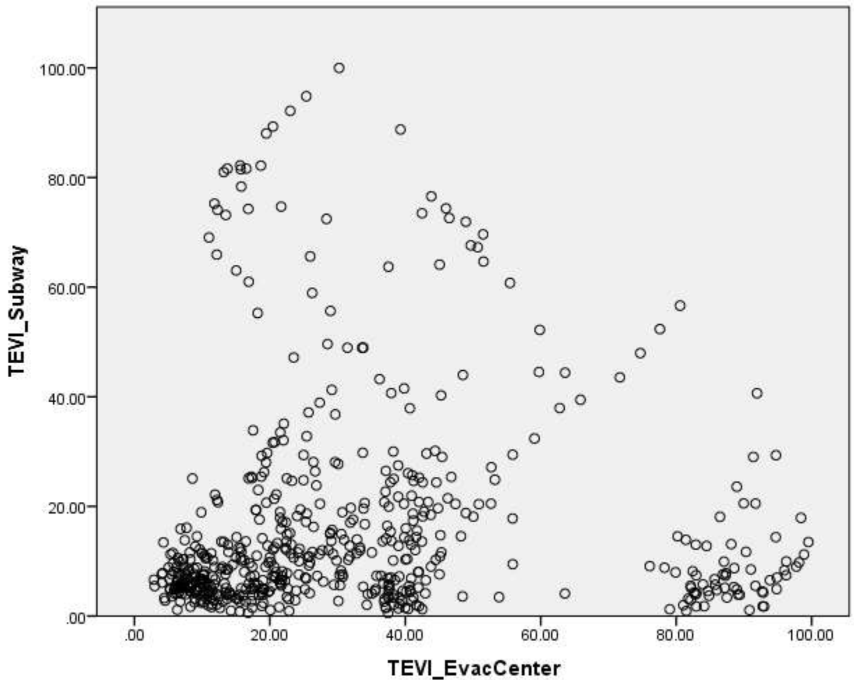


Figure 25. Percent individuals below the poverty line and percent of households without a private vehicle

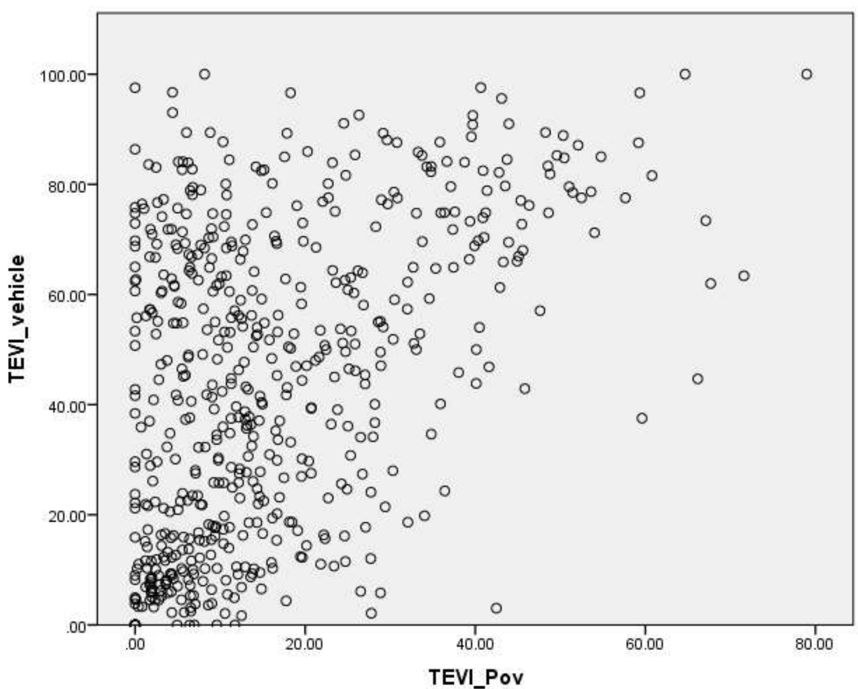
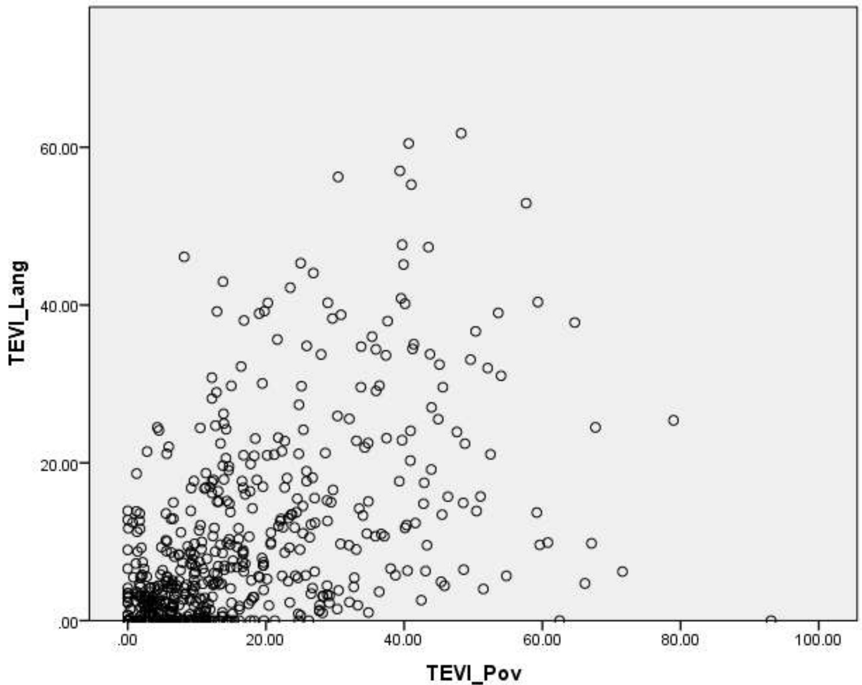


Figure 26. Percent of individuals below the poverty line and percent of households that speak English "not well" or "not at all"



In summary, TEVI values could potentially be used to identify communities and areas where special efforts in risk communication and risk management may be needed to ensure that people evacuate during a disaster situation.

Part VI. Concluding Remarks

The work presented in this report includes three types of data analyses that explore various variables related to potential risk factors for not evacuating when New York City calls for a mandatory evacuation.

The data refer to New York City and the unit of analysis is the block group as defined by the U.S. Census Bureau. Measures of distance between subways and evacuation centers and both of those facilities to block group centroids are generally straight line distances and a future direction for such research might factor in other ways of measuring distance.

The statistical summaries, graphical analyses and linear regression models show weak and inconsistent statistical associations between distance from the centroid of a block group and nearest hurricane evacuation center for various socioeconomic variables. The results are sensitive to whether the smaller dataset, with block groups that are exclusively in evacuation Zone 1, or the larger dataset, with block groups that are partially or completely in evacuation Zone 1, are used. The distance variables to nearest subway, bus and hurricane evacuation center are much more strongly related to county, and these distances seem to be affected by density of the built environment and other county-level characteristics.

A future research direction in the area of regression modeling would be to explore alternative regression models to linear regression. Spatial regression models which address potential spatial autocorrelation among neighboring block groups could produce different results.

As part of the third analysis presented in this report, a new index was created to combine a number of variables that the authors consider to represent a risk for not evacuating when the city calls for a mandatory evacuation into one value between 0 and 100. This approach allows a ranking of block groups by this index. The interpretation of the index is that those block groups with the highest values include populations that may be less likely to evacuate when there is a call for a mandatory evacuation, and provides a potential tool for assessing where resources should be used to ensure these communities evacuate.

A future research direction of this work would be to work with communities in areas identified as having a high TEVI and validating whether those with high values for the different components of the TEVI may be less likely to evacuate when the city calls for a mandatory evacuation. This could be accomplished through interviews and focus groups designed to examine what factors members of these communities consider to be important when making decisions about whether to evacuate. This kind of validation could also inform whether some components of the TEVI should be weighed more than others. This behavioral element is an important direction for refining the determinants of why and how people evacuate and is one that has been explored in other studies as well (Thompson, Garfin and Silver 2017).

Finally, the use of public transportation, particularly rail transit, will depend on the quality of the system and the ability of its capacity to sustain the large number of populations that could evacuate in extreme weather events. These are important elements to be explored in future research.

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