University Transportation Research Center - Region 2

Final Report

Promoting Transportation Flexibility in Extreme Events through Multi-Modal Connectivity

Performing Organization: New York University

June 2014

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.

Technology Transfer

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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PROMOTING TRANSPORTATION FLEXIBILITY IN EXTREME EVENTS THROUGH MULTI-MODAL CONNECTIVITY

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16. Abstract
Extreme events of all kinds are increasing in number, severity, or impacts. Transportation provides a vital support service for people in such circumstances in the short-term for evacuation and providing supplies where evacuation is not undertaken, yet, transportation services are often disabled in disasters. Nationwide and in New York and New Jersey record-setting weather disasters have occurred and are expected to continue. Disadvantaged populations are particularly vulnerable. Network theories provide insights into vulnerability and directions for adaptation by defining interconnections, such as multi-modality. Multi-modal connectivity provides passenger flexibility and reduces risks in extreme events, and these benefits are evaluated in the NY area. Focusing on public transit, selected passenger multi-modal facilities are identified that connect to transit, emphasizing rail-bus connectivity. Publicly available databases are used from MTA, NJ rail, and U.S. DOT's IPCD. For NYC, statistical analyses suggest there may be some differences by poverty levels. For NYC and three northeastern NJ cities connectivity differs for stations that are terminuses and have high rail convergence. This report provides statistical summaries, cases, and a literature review to characterize multi-modal facilities and their use in extreme events. Recommendations and future research directions are provided for the role of passenger multi-modality to enhance transit flexibility.

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Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

Extreme events of all kinds are increasing in number, severity, or impacts, and include many kinds of natural and human induced disasters. Transportation provides a vital support service for people in such circumstances for safe and rapid evacuation and the provision of supplies where evacuation is not an option. Yet, transportation services are often disabled in such disasters. Nationwide and in New York and New Jersey record-setting weather disasters have occurred and are expected to continue. For example, within the New York area, the December 2010 snowstorm disabled NYC's transportation systems and their emergency capability. Hurricane Irene in 2011 disrupted local transportation services throughout the area and regional Amtrak service, and numerous flash floods have brought local and regional rail and road transportation to a standstill. Hurricane Sandy's catastrophic impacts resulted initially in the pre-emptive closure and extensive flooding of NYC subways and regional transit. Most impacts are relatively short-lived; however, long-term network closures for transit repairs following Hurricane Sandy and intermittent transportation delays from signal, switch and other facility damages were common.

Network theory concepts provide insights into vulnerability and directions for adaptation, for example, by defining interconnections, dependencies and other interrelationships. Transportation is heavily dependent on electric power and information technology. When disasters affect these systems, transportation impacts are magnified. Disadvantaged populations are particularly vulnerable to lack of access to vehicles, travel routes, and transportation services that they depend on. Concentrated transportation facilities and usage increase vulnerability. Examples are roadway convergence at single locations such as intersections including NYC's Cross-Bronx Expressway (one of the most heavily congested U.S. roadways) or rail line convergence at a single transfer point, such as the Long Island Railroad's Jamaica Station. Thus, disabling a single facility can affect an entire network and its users. NYC Transit (NYCT) and the Port Authority Trans-Hudson (PATH) provided flexible rail transit with alternative routes after the September 11, 2001 attacks. Multi-modal bus and rail transit connections also provide flexibility. Though dispersed services are needed for flexibility, urban population density must be preserved to support multiple travel choices for transportation users.

In light of these conditions and threats, multi-modal connectivity of transportation facilities, emphasizing rail and bus transit, is investigated as an important strategy for passenger flexibility and risk reduction in extreme events. Transit users can make connections between buses and subways in emergencies where buses stop more frequently at subway stations. This strategy is evaluated focusing on public transit by identifying selected passenger facilities in the region that connect to rail transit, emphasizing bus connectivity. Various publicly available national and local databases are used, including information from the Metropolitan Transportation Authority, NJ and regional rail agencies, and the U.S. DOT Intermodal Passenger Connectivity Database (IPCD) for general connectivity patterns. Findings indicate variations in bus connectivity among selected rail transit stations included in the study. For NYC, statistical analyses suggest there might be some differences in connectivity between bus and subway service by area depending on poverty levels. In NYC, rail and bus connectivity differs for stations that are terminuses, and for NYC and three northeastern New Jersey cities differences exist for stations with a high convergence of rail lines. This report provides statistical summaries, cases, a literature review of the state of research, the utility and usage of databases in characterizing multi-modal facilities, and recommendations and future research directions for the role of passenger multi-modality to enhance transit flexibility.

I. INTRODUCTION

Research Objectives

The problems associated with extreme events often compromise transportation services. This study suggests ways to address these problems and to move forward in ways that support the adaptability of transportation to these challenges. It also provides examples of a methodology that could be expanded to assess connectivity among different modes of transportation in urban areas. The research objectives are to determine (1) when and where multi-modal connectivity provides the flexibility for transportation infrastructure that will reduce consequences of extreme events, enhancing effective responses to them and (2) the components and structure of such connectivity.

This analysis focuses on passenger multi-modality in terms of rail transit and its connectivity to buses in the New York region, focusing primarily on (1) the New York City rail and bus transit system under the Metropolitan Transportation Authority (MTA) New York City Transit (NYCT) jurisdiction (2) the Port Authority of NY and NJ (PANYNJ) Port Authority Trans-Hudson (PATH) rail system, (3) NJ Transit, and (4) to a lesser extent Amtrak.

Research Problem, Background and Regional Significance

Many kinds of emergencies and disasters are increasing. Transportation provides vital support to people under such conditions, but it is often disabled in such disasters and thereby cannot perform its needed functions. The connections among transportation facilities have become increasingly more concentrated as have other infrastructure networks, such as electric power, upon which transportation depends (Perrow 2007). Such concentration is often justified on the basis of geography, economic and user benefits. However, at the same time such concentrations can increase vulnerability in times of crises. The magnitude of adverse consequences of disasters for transportation and its users can be affected by the lack of flexibility to accommodate alternative routes for escape, response and recovery during and after a disaster: concentrated infrastructure can contribute to flexibility limitations. There are ways of providing alternatives that are more dispersed, which can enable such flexibilities to occur while preserving the density and richness of urban areas and regions.

One alternative is the connectivity between bus and rail transit, which is the focus of this research since it provides a decentralized system of access to multiple transit modes. The connectivity between bus and rail transit is significant in emergencies, particularly emergencies related to weather and climate change. A strong relationship already exists between where buses stop and subway station location that provides a foundation of such multi-modal connectivity. These connection points can be an attraction for people trying to obtain or use alternative modes and combinations of transportation not only to connect to subways but also as familiar places to connect to bus service when subways are disabled. Examining buses connecting to and stopping near transit stations is useful since the stations are places where people are used to going for public transportation. The use of buses as an alternative to subways in weather-related hazards is supported by the fact that (a) they are a common mode of transportation for evacuation (Litman 2006), (b) electric power outages produced by storms usually do not disable buses but almost always disable rail transit, and (c) flooding that disables rail transit can also disable buses however probably not as severely if roads drain faster than subway tracks.

Exposure of Transportation to Disasters

The increasing frequency, consequences, and/or severity of disasters are apparent from a number of U.S. cases and trends that pose risks to transportation systems. These conditions are documented in numerous studies. Climate and severe weather trends point to historical and projected future increases in temperature, heavy precipitation, hurricanes, and sea level rise among others, occurring globally, within the U.S., and in the New York area (Walsh et al. 2014; Rosenzweig et al. 2013). Walsh et al. (2014: 20, 24, 25) in the National Climate Assessment, for example, indicate that average temperatures have increased 1.5 degrees Fahrenheit globally from 1880-2012 and 1.3 to 1.9 degrees Fahrenheit in the U.S. between 1895 to the present. They indicate that average sea level has increased globally since 1990 by about 8 inches and by 2100 an increase of another 1-4 feet is expected (Walsh et al. 2014: 44). Walsh et al. (2014: 41) also cite increases in the frequency of hurricanes particularly in the higher intensity categories in the North Atlantic. For New York City Rosenzweig et al. (2013: 4) indicate trends for 1900-2011 of a 4.4 degree Fahrenheit increase in mean annual temperature, 7.7 inches for mean annual precipitation, and 1.1 inch increase in sea level (measured at the Battery). As an example of future changes, their "mid-range" projections for the 2020s are an increase of 2-3 degrees Fahrenheit for temperature, 0-10% for precipitation, and 4-8 inches for sea level (Rosenzweig et al. 2013: 4). Blake et al. (2013) described how Hurricane Sandy of October 2012 ranked very high among other hurricanes in costs and fatalities, e.g., ranking second in the cost of damages since 1900 when such accounting began (Blake et al. 2013: 1; unadjusted for population or inflation and sixth if adjusted) and was one of the deadliest with the exception of the southern states since Hurricane Agnes in 1972 (Blake et al. 2013: 14). Earlier studies by Pielke et al. (2008) and Blake et al. (2011) support the existence of extreme weather conditions. Pielke et al. (2008) reported that costs from weather damages alone in the 1996-2005 time period were exceeded only in the 1926–1935 period. Blake et al. (2011) noted that ninety percent of hurricanes whose costs exceeded $7 billion have occurred since 2000, and the Atlantic coast is one of the major vulnerable areas (summarized from Zimmerman 2012: 187). Moreover, as summarized by Zimmerman (2012) infrastructure has probably not kept pace in areas where population is increasing very fast and those areas are feeling the severe effects of these disasters, since they are not the most populous areas (Wilson and Fischetti 2010) and cannot easily support more infrastructure. Many of these fast growing areas are accounting for a larger share of future population growth (Romero-Lankao and Dodman 2011). Many of them are coastal areas and New York and New Jersey contain extensive coastlines. The New York area has experienced many weather extremes and some of these events are described below with implications for transportation.

Impairment of Transportation Systems by Extreme Events

Impairment of transportation systems has been identified in numerous studies and "after action" reports of past extreme events nationwide, worldwide, and for New York State and the New York City area. The impacts of extreme events on transportation range from temporary to long-term network closures. In many cases, damages to rail transit lines occur at the component level, producing structural as well as material damages, and single disruptions often can disrupt entire systems. Many weather and climate related causes of such disruption have been identified for rail (Hodges 2011). Historical trends and estimates for actual and potential impairment specifically of transportation systems from climate change exist as well (U.S. DOT 2008; U.S. Climate Change Program 2009; Melillo, Richmond and Yohe 2014) and many are specific to the New York area (Rosenzweig, et al. 2011; NYC Office of the Mayor 2013; NYS 2100 Commission 2013).

The toll that disasters take on transportation facilities is magnified by the fact that transportation services, particularly public transit are sorely needed for the evacuation of people (Transportation Research Board 2008). Transportation services are also needed for the transportation of supplies to those who remain in place. The TRB evaluated the evacuation capacity of 38 large U.S. urban areas and also reviewed efforts nationwide in providing transit in emergencies in general. They observed that following the attacks on the WTC in 2001, transit in New York City provided services to people leaving the area and in Washington DC rail transit provided that service (TRB 2008: 1). On the other hand, the TRB noted that after Hurricane Katrina the capacity to meet the demand of transit-dependent populations was needed, but did not match the demand because workers would not report to drive the vehicles and transit equipment was unprotected from impacts. Moreover, the study pointed out that transportation planning and particularly transit were not consistently or comprehensively incorporated into early emergency planning efforts in spite of the importance of transit in such circumstances (TRB 2008: 48). The TRB (2008: 52) study underscored the importance of the role of transit especially for transit dependent and vulnerable populations because they have relatively less access to private vehicles, the large numbers of such people, and their specialized service needs; moreover, public transit can alleviate traffic congestion produced by individual private vehicles. Hess, Conley and Farrell (2013: 11, 14) have underscored the importance of multimodal transportation in providing flexible evacuation options where needs and options are uncertain. They provide a number of examples of the use of multi-modal transportation in evacuation in addition to those provided by the TRB, for example, the use of Metro Transit buses following the 1993 bombing of the federal building in Oklahoma and the use of the San Francisco Bay Area Rapid Transit rail service following the 1989 San Francisco earthquake. Their review, like the TRB report, also concludes that multi-modal transportation options in evacuation plans need to be strengthened.

Statewide and Regional Consequences

A few catastrophic events have impacted the New York region and area transportation infrastructure severely, most recently, Hurricanes Sandy (2012) and Irene (2011). After Hurricane Sandy, transportation damages were estimated at $5 billion for the MTA from storm surge and flooding alone and $2.5 billion for other transportation infrastructure in New York (Blake et al.: 2013: 18). The damages from Hurricane Sandy alone to the New York area were extensively studied by NYC's PlaNYC (NYC Office of the Mayor 2013) and after-action report and the NYS 2100 Commission (2013). Such damages often result in lingering effects for transit and the services it provides. After Hurricane Sandy, for example, Straphangers (2013) found that the number of subway system alerts increased in New York City in the time period following the Hurricane related to switches and signals among other components. For the four boroughs in New York City alone, the MTA Capital Program Oversight Committee identified damages to nine East River subway tunnels whose repairs will extend at least through 2016; damage to numerous transit structures such as yards, terminals, shops, and stations; and the award of construction contract awards totaling almost $1 billion in 2014 (MTA April 2014).

New York and New Jersey have experienced record-setting weather disasters other than hurricanes, most notably the December 2010 snowstorm that disabled much of New York City's transportation systems and its emergency capability. Other snowstorms and tropical storms have disabled major parts of the transit and road systems throughout New York and New Jersey. In the first decade of the 21st century, major flash flooding episodes occurred disabling multiple New York City subway lines simultaneously and allowed little adaptation or the ability to move to another mode of travel at least in the short-term (MTA 2007). Accidents combined with natural hazards and concentrated transportation design can escalate emergency conditions and consequences.

Rosenzweig et al. (2011: 34-37) provided trends in extreme events throughout New York State as described above. Within New York City alone, the New York City Panel on Climate Change (NPCC) (2013) and MTA (2007) have identified numerous extreme events actually and potentially affecting transportation. Rosenzweig et al (September 18, 2007: 7, 10, and 11) identified the numerous storms that have affected the New York Region alone prior to the August 2007 storm.

New York and New Jersey have among the most extensive and in some areas the densest road and rail network usage in the nation. Rail systems in the two states account for close to half of the nation's rail transit infrastructure and usage and the road systems similarly account for a large share of vehicle miles of travel (VMT) according to U.S. data (cited and summarized by Zimmerman 2012). Thus, the significance of extreme weather events for the populations they served by transportation can and has been substantial.

Vulnerability of Disadvantaged Populations

Disadvantaged populations such as minorities and the poor (Bullard 2007) and the elderly (Zimmerman et al. 2007) are often disproportionately affected by disasters. In particular these effects center around a lack of access to transportation and its services (Hess, Conley and Farrell 2013; TRB 2008) which has been specifically explored in the context of different hurricanes, such as Hurricane Katrina (Bullard and Wright 2009) and Hurricane Ike (Peacock et al. 2011). Even in non-emergency contexts, weak transit services exist, for example, for access to jobs (Brookings 2014), and emergencies often make these conditions worse. A systematic approach to the problem is now needed, and in order to move in this direction, this report provides a focus on the New York – New Jersey region in the context of bus and rail transit connectivity in weather emergencies and the implications for low income populations.

Transportation Networks and Network Theory as a Foundation for Transportation Connectivity

Network theories support several streams of inquiry to understand connectivity of transportation systems and provide a useful foundation for the analysis of the connectivity of different modes. Network theory principles, for example, those summarized by Newman (2010) have been applied to transportation systems, including the connectivity measures described below. Zimmerman (2012: 6-8) summarized some of these applications, for example, how networks are used to describe transportation system behavior, the significance of how nodes are placed among links in a network, the implications of eliminating a node such as a station in an attack or natural hazard, and the degree of concentration of activity and network components (such as passengers, lines or roadways).

Network concepts have been extended to understand interdependencies and dependencies among systems, increased concentration of facilities, and the combined effects of all of these factors on transportation systems. Each of these is discussed briefly below in the context of transportation networks.

Interdependencies and Dependencies and their Escalating Effects

Relationships among different kinds of infrastructures occur in a number of different forms (Rinaldi, Peerenboom and Kelly 2001) and these interconnections can often result in the escalation of the impacts of disasters. For example, transportation is heavily dependent on electric power and is increasingly dependent on information technology. When disasters affect these other systems, effects on transportation and its users can be magnified (Zimmerman 2012). This occurred in the 2003 northeast U.S. and Canada blackout, when it took several times as long for subway signals and traffic controls to return after the power was back on in New York City (Zimmerman and Restrepo 2006).

Concentrated Transportation Infrastructure

Transportation systems are very concentrated and in some cases are becoming even more concentrated to achieve economies of scale. Concentration effects occur at many scales - from the design of individual structures to the design of transportation routes. At the facility level, bridges constructed in the 1950s and 1960s that had non-redundant designs where all of the loads were concentrated on just one or two components, contributed to several massive collapses that occurred. With respect to routing, people require more than one way to move especially in a disaster in order to respond effectively, and emergency planning needs to recognize this. After the September 11, 2001 attacks on the World Trade Center in New York, trains had the flexibility to shuttle and avoid damaged areas leading to a relatively quick restoration. PATH stations north of the WTC station absorbed much of that station’s traffic. Similarly, after Hurricane Sandy, when the subway system was running, trains exhibited a similar flexibility.

Combined Effects of Multiple Extreme Events and Infrastructure Inflexibility or Concentration

Many of the effects of extreme events cited earlier and others are often a combination of different types of extreme events occurring at that same time and exacerbated by concentrations of infrastructure. For example, the Long Island Railroad experienced the combination of lightning strikes and programming errors, heavy precipitation and a control room fire, and computer control system failures that caused considerable service delays due to the concentration of effects at the Jamaica station where many lines converge, as the MTA and others (Grynbaum 2010) have reported (summarized by Zimmerman 2012). Thus, people need greater flexibility for transportation in times of disaster. People often rely on ad hoc and informal transportation in such emergencies, for multi-modal connectivity, such as for-hire vehicles. It would be important to understand these patterns and how more predictable methods can be institutionalized.

Defining Multi-modal Connectivity and Highlights for Other Forms of Multi-Modal Connectivity with Transit in the New York Area

Multi-modal facilities are typically defined as any combination of two or more transportation modes. For land-based modes, these include for example, biking, walking, para-transit, rail and bus transit, and various vehicular modes such as personal automobiles and for-hire vehicles. For water-based transportation there are other options. Each type has specific attributes in terms of speed, user compatibility, potential passenger sharing possibilities, and advantages and disadvantages (Litman 2014: 6). Bak, Borkowski and Pawlowska (2012: 22) define multi-modal or inter-modal to characterize transfer among two or more facilities, recognizing that the definition as applied to passenger transport has not been a definitive, agreed upon concept. The term has been more commonly used for goods movement transfers. Moreover, the concept is applied to facilities that allow such transfers, such as parking facilities, as well as the actual means of travel (such as types of vehicles used).

Multi-modal transportation often requires several modes of transportation. In the New York area, for example, Shannon and Wells (2007) identified the disconnectedness of outlying areas populated by lower income groups in New York City, primarily focusing on the lack of connectivity between rail transit and bus service. Zimmerman and Sherman (2011) found that multiple modes of travel were commonly used by many survivors of the September 11, 2001 attacks in New York City who shifted from one mode to another over time.

Other means of transportation are sometimes used in lieu of rail transit or to complement rail transit. In New York City, modes exist that have met with various levels of support or controversy. Several types of multi-modal trips are common in outer boroughs where rail transit is not as available or near passenger destinations. Modes of travel that do or can connect to rail or bus transit are generally categorized as motorized or non-motorized, though the distinction is often not that well-defined.

Motorized

Taxi Service in Outer Boroughs. The NYC Taxi and Limousine Commission (TLC) issues licenses for yellow cabs. It has also initiated a program for additional taxi permits for a green taxi program, to increase taxi service in outer boroughs (Durkin 2014). In order to reduce market conflicts between yellow and green cabs, the City restricted yellow cabs to certain areas of Manhattan and green cabs to the other boroughs. However, yellow cabs are able to bring passengers into green taxi areas and vice versa depending on passenger destinations.

The NYC TLC (2014: 4) in its recent report summarized the benefit and the status of use of green taxis: “Boro Taxis extend the reach and fill in the gaps of the public transit system. Because many NYC residents do not own personal vehicles, they rely heavily on taxis and FHVs [For-Hire Vehicles] to perform trips that are not fast or convenient by public transit. According to a passenger survey, 44% of Boro Taxi trips involved a connection with either a bus or the subway to complete the trip. Trip records show that 52% of pickups occurred very close to subway or commuter rail stations. This suggests that some riders take subways as far as they can go, then complete their trips by transferring to Boro Taxis.” Whether taxis serve low income communities, given their cost and availability, is yet to be determined.

Vans. Van service is a typical on-demand service that has been in use for a long time to supplement or substitute for rail and bus transit. Sclar and Paaswell (September 24, 2010) recently argued that the expansion in the use of vans in outer boroughs could result in competition with bus transit, higher expense, restricted access, and equity issues.

Non-motorized

Bicycles. Bicycles are both a full, stand-alone transportation mode as well as a complement to transit. These include bike share facilities such as Citi-bike and privately owned bikes. Many Citi-bike stations are located near transit stations described in the literature review in the next section. Although bikes are considered non-motorized, electric motors have been used to power some bikes.

Other. Skates, skateboards, and similar types of vehicles are among the numerous non-motorized means of transportation that use urban streets and sidewalks.

Literature Review of Multi-Modal Connectivity Research

Multi-modal connectivity is considered an important aspect of modern transportation systems since it allows transportation users to minimize their travel time and can improve quality of life. Service connectivity is considered a necessary condition for acceptable public transit since it allows for transit service between origin and destination points and keeps travel time within users' schedules (Ceder and Teh 2010). Transportation systems with significant amounts of connectivity provide more options that can also improve the resiliency of systems and that could make responding to extreme events easier and more effective.

Multi-modal connectivity among different transportation services has also been divided into three transfer categories in the literature. Non-adjacent transfer points require travelers to walk a distance between transit stops. Adjacent transfer points require travelers to cross the street to board another transportation service or vehicle. Shared transfer points are those that allow travelers to remain at the same stop to board another vehicle or transit service (Hadas and Ceder 2010).

In describing multi-modal connectivity in transportation systems, non-adjacent transfer points are very common for commuters who rely on using rail and bus transit or other transportation services as part of their commutes. A recent study compared connectivity between bike share systems and heavy-rail systems in New York City, Chicago and the Washington, DC metropolitan area (Gordon-Koven and Levenson 2014). To assess connectivity the study used a 400 meter (1/4 mile) buffer around the transportation facilities and used this radius as an acceptable distance that would qualify a bike share station and a heavy-rail station as being non-adjacent points with connectivity. They extended the analysis to several smaller buffers. Table 1 summarizes some of the results presented in the study.

Table 1. Connectivity Between Subway Stations and Bike Share Stations

City	Percent of bike share stations within buffer (distance to heavy rail station centerpoint)			
	100 feet	200 feet	500 feet	¼ mile
New York City	3	8	25	72
Chicago, IL	2	9	20	41
Washington, DC	<0.01	1	11	36

Source: Summarized from Gordon-Koven and Levenson 2014: 8 and 11

In the transportation literature the relative service area of a transit stop is considered to be a 400 meter (437.45 yd or 1/4 of a mile) radius by some authors and is considered the furthest distance that most people are willing to walk to transfer to another transportation mode (Ceder and Teh 2010). This distance is often equated to a five minute walk, and it is considered acceptable under normal circumstances for commuting.

Later in this UTRC report the authors present an analysis of heavy rail and bus transit connectivity in New York City. The analysis is conducted in order to provide inputs to transportation planners thinking about vulnerable populations and about the effectiveness of these public transportation systems under unusual circumstances such as emergencies and extreme weather events. Hence, in contrast to other studies, a more conservative distance of 1/10 of a mile was chosen for the analyses.

In addition to distance and relative service areas that allow for multi-modal connectivity among transportation systems the literature has recently been extended to also include the use of measures of connectivity to address transportation system performance. This use of connectivity measures goes beyond distances between systems and includes other characteristics such as number of transportations alternatives, nodes, lines, quality of service and others that allow for a connectivity measure to provide insights into system performance. Mishra, Welch and Jha (2012) conducted a survey of the literature on connectivity measures. Table 2 summarizes the main types of measures included in their review. Many of these measures are consistent with those used in network theory (Newman 2010). This perspective is important for understanding the characteristics of connectivity in transportation. These kinds of measures are beyond the scope of work for the analyses conducted as part of this report, but they point to future research directions.

Table 2. Summary of Connectivity Measures

Measure	Definition
“Node-measure: degree centrality”	“Normalized score based on total number of direct connections to other network nodes”
“Node-measure: eigenvector centrality”	“Assigns relative ‘scores’ to all nodes in the network based on the principle on connections”
“Node-measure: closeness centrality”	“Sum of graph-theoretic distances from all other nodes”
“Node-measure: betweeness centrality”	“Sum of the number of geodesic paths that pass through a node n”
“Node-measure: connectivity index”	“Sum of connecting powers all lines crossing through a node n”
“Node-measure: transfer center (cluster): connectivity index”	“Sum of connecting powers all lines crossing through a transfer center”
“Node-measure: region connectivity index”	“Sum of connecting powers all nodes in a region”
“Line-measure: connecting power”	“Connectivity power of a line which is a function of transit characteristics”
“Line-measure: connectivity index”	“Sum of connecting powers all nodes in a line”

Source: Mishra, Welch and Jha (2012: 1068).

II. RESEARCH APPROACH AND METHODS

Scope and Geographic Extent

This research focuses mainly on rail and bus transit connections and where they are placed. Extreme events encompass an extensive set of natural hazards (weather and geophysical) and man-made intentional (e.g., terrorism) and unintentional acts (accidents). Weather related extremes are emphasized, but the concepts are applicable to other extremes. The emphasis will be on the UTRC region and within the region, New York City and portions of northeastern New Jersey.

Study Methodology and Assumptions

A number of analyses are presented. The first analysis describes the kind of connectivity that exists between buses and subways defined in terms of buses stopping within a certain distance of subway stations. The second relates these to demographic characteristics of resident populations and degree of connectivity. The third provides characteristics of connectivity at special areas within the system; these include high density stations defined in terms of ridership and number of intersecting train lines, system end points, and poor areas supporting the demographic analysis. The analyses are both statistical and case-based. Statistical analyses use several publicly available national and regional transportation databases that provide multi-modal data and the basis for constructed datasets. The database of bus and subway connectivity has been created as part of this study.

The purpose of the case-based approach is to identify key intermodal facilities that accommodate large numbers of people, the structure of multi-modal connectivity drawing from network science, and the implications of connectivity for reducing consequences or promoting response to extreme events.

Database Review

A number of publicly available databases provided inputs to and guidance for the research. These included the Intermodal Passenger Connectivity Database (IPCD), the New York State Metropolitan Transportation Authority subway station, subway line, and ridership characteristics, bus routes and bus stops, and New Jersey and regional transit system databases. Other relevant databases, such as the National Transit Database were also used. For demographic information, the U.S. Census' American Community Survey (U.S. Census 2013) was used.

The IPCD was started in 2006 for intermodal passenger connectivity. It identifies transportation terminals for passengers and the modes for public transportation connections. It began with "intercity rail stations, commuter rail stations, airline airports, and ferry terminals" and by 2011 it included heavy rail and light rail. Its aim is to include complete geographic coverage for "regularly scheduled service of the following modes: scheduled intercity rail, commuter rail, heavy rail transit, light rail transit, intercity bus, code-share buses and supplemental service buses operated for intercity rail (Amtrak Thruway) and air carriers, intercity ferries, and transit or local ferries. Included in the intercity bus category are intercity airport bus services" (U.S. DOT).

Census data from the American Community Survey were used at the census tract level for demographic characteristics of resident populations in the immediate vicinity of the subway stations. Databases on the suburbanization of poverty and access to transportation provided the context for transportation access for disadvantaged populations. Portions of the Brookings Institution database by Kneebone (2011) on the suburbanization of the poor using data from the American Community Survey were examined in an initial analysis by Zimmerman (2012) for about a dozen communities nationwide in that database. This analysis found that very few of the communities where the increases in poor households had increased by at least 20% between 2000 and 2010 had rail transit access. The IPCD database for New York City and New Jersey described below serves as a context for more in-depth statistical analyses of connectivity.

The Intermodal Passenger Connectivity Database (IPCD)

The Intermodal Passenger Connectivity Database (IPCD) is a national transportation facility database maintained by the U.S. DOT Research and Innovative Technology Administration (RITA). The 2012 database covers approximately 7,100 transportation facilities, and contains information that allows for the characterization of intermodal connectivity at these facilities in terms of the availability of intercity and transit rail, bus and ferry service and airline service. The facilities included in the database consist of rail, air, bus and ferry passenger transportation terminals and the distribution by type in the U.S. is shown in Table 3 (See U.S. DOT Research and Innovative Technology Administration (RITA) 2013). Table 3 summarizes the type of facilities included in the database.

Table 3. Facility Type in the IPCD, U.S., 2012

FACILITY TYPE		
Facility Type	Frequency	Percent
Facility is primarily an airport	667	9.4
Facility is primarily served by intercity bus	2,383	33.5
Facility primarily serving intercity passenger ferries	104	1.5
Facility primarily serving transit or local area ferries	184	2.6
Facility primarily serving light rail transit	1,189	16.7
Facility primarily serving heavy rail transit	992	13.9
Station on the national railroad network served by intercity and/or commuter trains	1,595	22.4
Total	7,114	100.0

In terms of intermodal connectivity characteristics, the U.S. DOT RITA BTS (c2014) observed that for the national database overall:

- “55 percent of all U.S. passenger transportation terminals offer intermodal connectivity among at least two scheduled passenger transportation modes.
- Considering only communities served by more than one mode, 75 percent of terminals offer intermodal connections.
- Rail stations are more likely than terminals of other modes to offer intermodal connections.
- Airports are least likely to offer intermodal connections.
- 97 percent of intermodal terminals are served by transit, but only 43 percent are served by an intercity mode.
- 68 percent of terminals in urbanized areas offer intermodal connections, but only 7 percent of terminals in rural areas.
- Transit buses are the most frequent intermodal mode, serving 93 percent of all intermodal terminals.
- Connections are available to at least one other mode or between intercity and transit service at:
    - 83.1% of heavy rail stations
    - 70.2% of commuter rail stations
    - 67.0% of light rail stations
    - 54.3% of intercity rail stations
    - 43.1% of intercity bus stops
    - 42.4% of transit ferry terminals
    - 38.5% of interstate ferry terminals
    - 24.0% of airline airports”

According to the IPCD, for intermodal connectivity New York ties with New Jersey as tenth in the U.S. with 63.4% of facilities as intermodal, higher than the national average of 56% for 7,240 facilities in 2013 (U.S. DOT, RITA 2013). The IPCD includes data for NYC and NJ Distributions are shown in Tables 4 and 5 for 2012. In NYC, most facilities are heavy rail (86.4%) exceeding the U.S. average; in New Jersey, intercity / commuter rail dominate (57.8%).

Table 4. Facility Type and Multi-modal Connections, New York City, 2012

FACILITY TYPE		
Facility Type	Frequency	Percent
Facility is primarily an airport	2	0.4%
Facility is primarily served by intercity bus	39	7.2%
Facility primarily serving intercity passenger ferries	0	0.0%
Facility primarily serving transit or local area ferries	11	2.0%
Facility primarily serving light rail transit	0	0.0%
Facility primarily serving heavy rail transit	469	86.4%
Station on the national railroad network served by intercity and/or commuter trains	22	4.1%
Total	543	100.0

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT (RITA), 2013.

Table 5. Facility Type and Multi-modal Connections, New Jersey, 2012

FACILITY TYPE		
Facility Type	Frequency	Percent
Facility is primarily an airport	3	1.2%
Facility is primarily served by intercity bus	14	5.4%
Facility primarily serving intercity passenger ferries	1	0.4%
Facility primarily serving transit or local area ferries	14	5.4%
Facility primarily serving light rail transit	61	23.6%
Facility primarily serving heavy rail transit	16	6.2%
Station on the national railroad network served by intercity and/or commuter trains	149	57.8%
Total	258	100.0

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

The New York City and New Jersey data are used below to describe how transportation facilities are connected to the following modes of transportation: bus transit, bus intercity, light rail, heavy rail and commuter rail. First, the interconnectivity is described for each type of transportation facility from the IPCD database beginning with bus transit. Then, a more detailed summary of bus transit interconnectivity with the other modes is provided as a context for the analyses that follow.

Tables 6 and 7 show the intermodal connectivity for the types of transportation facilities included in the data and bus transit in New York City and New Jersey respectively. The connectivity is coded according to the following key:
0 - Service not provided at this facility but elsewhere in the city
1 - Service provided at this facility
2 - Service provided but does not qualify as a connecting mode because proximity, timing, or bi-directional service criteria are not met
3 - Service by this mode not offered in this city

For each type of facility the number of facilities coded with a 1 indicates the number of facilities that have interconnectivity with bus transit.

Bus transit

In New York City, 20 of the 22 intercity train stations and 337 out of 469 heavy rail transit stations are connected to bus transit. Both airports included in the database and 38 out of 39 intercity bus facilities are connected to local bus transit.

In New Jersey 2 out of 3 airports, 7 out of 14 intercity bus facilities and 31 out of 60 light rail facilities, 12 out of 16 heavy rail facilities, and 95 out of 149 intercity train facilities are connected to bus transit.

Table 6. Intermodal connectivity of bus transit by type of facility in New York City, 2012

Facility Type	BUS_TRANSIT				Total
	0	1	2	3	
Airport	0	2	0	0	2
Intercity Bus	0	38	1	0	39
Transit or local area ferries	2	7	2	0	11
Heavy rail transit	0	337	73	59	469
Intercity trains	0	20	1	1	22
Total	2	404	77	60	543

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Table 7. Intermodal connectivity of bus transit by type of facility in New Jersey, 2012

Facility Type	BUS_TRANSIT				Total
	0	1	2	3	
Airport	1	2	0	0	3
Intercity bus	0	7	1	6	14
Intercity passenger ferries	0	1	0	0	1
Transit or local area ferries	6	6	2	0	14
Light rail transit	1	31	16	13	61
Heavy rail transit	1	12	1	2	16
Intercity trains	5	95	3	46	149
Total	14	154	23	67	258

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Intercity bus

Tables 8 and 9 provide information about interconnectivity between intercity bus and the different types of transportation facilities included in the database. As expected, intercity bus service is less well connected than local bus transit which is much more commonly provided. In New York City both airports are connected to intercity bus but only 13 out of 469 heavy rail transit facilities are connected to intercity bus services. Only one intercity train facility is connected to intercity bus service.

In New Jersey interconnectivity with intercity bus is less common than in New York City. In New Jersey, intercity bus is connected to only two out of 61 light rail facilities, three out of 16 heavy rail facilities and two out of 149 intercity trains.

Table 8. Intermodal connectivity of intercity bus by type of facility in New York City, 2012

Facility Type	BUS_INTERCITY				Total
	0	1	2	3	
Airport	0	2	0	0	2
Intercity bus	0	39	0	0	39
Transit or local area ferries	8	0	0	3	11
Heavy rail transit	0	13	18	438	469
Intercity trains	3	1	0	18	22
Total	11	55	18	459	543

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Table 9. Intermodal connectivity of intercity bus by type of facility in New Jersey, 2012

	BUS_INTERCITY				Total
	0	1	2	3	
Airport	1	1	0	1	3
Intercity bus	0	14	0	0	14
Intercity passenger ferries	0	0	0	1	1
Transit or local area ferries	2	1	0	11	14
Light rail transit	0	2	0	59	61
Heavy rail transit	0	3	0	13	16
Intercity trains	1	2	1	145	149
Total	4	23	1	230	258

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Heavy rail

Tables 10 and 11 summarize the information about interconnectivity between the various types of transportation facilities in the database and heavy rail for New York City and New Jersey. In New York City, one of the two airports in connected to heavy rail; seven out of 22 intercity train facilities are connected to heavy rail; and four out of 11 transit or local area ferries are connected to heavy rail. In New Jersey interconnectivity with heavy rail is limited. None of the three airports is connected to heavy rail and only two out of 149 intercity train facilities are connected to heavy rail services.

Table 10. Intermodal connectivity of heavy rail by type of facility in New York City, 2012

Facility Type	RAIL_HEAVY				Total
	0	1	2	3	
Airport	1	1	0	0	2
Intercity bus	9	17	11	2	39
Transit or local area ferries	4	4	3	0	11
Heavy rail transit	0	469	0	0	469
Intercity trains	2	7	3	10	22
Total	16	498	17	12	543

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Table 11. Intermodal connectivity of heavy rail by type of facility in New Jersey, 2012

Facility Type	RAIL_HEAVY				Total
	0	1	2	3	
Airport	0	0	0	3	3
Intercity bus	0	1	0	13	14
Intercity passenger ferries	0	0	0	1	1
Transit or local area ferries	4	2	1	7	14
Light rail transit	0	5	0	56	61
Heavy rail transit	0	16	0	0	16
Intercity trains	0	2	0	147	149
Total	4	26	1	227	258

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Interconnectivity of transportation facilities with light rail services for New York City and New Jersey is shown in Tables 12 and 13. In New York City interconnectivity with light rail does not exist, since all the transportation facilities are coded with a 0 (Service not provided at this facility but elsewhere in the city) or a 3 (Service by this mode not offered in this city).

In New Jersey interconnectivity with light rail is limited with 5 out of 14 transit or local area ferries, 5 out of 16 heavy rail facilities and 4 out of 149 intercity facilities.

Table 12. Intermodal connectivity of light rail by type of facility in New York City, 2012

Facility Type	RAIL_LIGHT		Total
	0	3	
Airport	1	1	2
Intercity bus	1	38	39
Transit or local area ferries	0	11	11
Heavy rail transit	0	469	469
Intercity trains	0	22	22
Total	2	541	543

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Table 13. Intermodal connectivity of light rail by type of facility in New Jersey, 2012

Facility Type	RAIL_LIGHT				Total
	0	1	2	3	
Airport	1	0	0	2	3
Intercity bus	0	2	0	12	14
Intercity passenger ferries	0	0	0	1	1
Transit or local area ferries	4	5	1	4	14
Light rail transit	0	61	0	0	61
Heavy rail transit	0	5	0	11	16
Intercity trains	0	4	0	145	149
Total	5	77	1	175	258

Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Summary of IPCD connectivity characteristics

Of particular interest are connections that exist between pairs of facilities, i.e., for IPCD database values of "1." These results are summarized in Tables 14 and 15 for New York City and New Jersey respectively.

Table 14 IPCD Bus Connectivity Summary, New York City, 2012

Facility Type	Bus Transit		Intercity Bus		Rail Heavy		Total
	#	row %	#	row %	#	row %	#
Airport	2	100%	2	100%	1	50%	2
Intercity bus	38	97%	39	100%	17	44%	39
Transit or local area ferries	7	64%	0	0%	4	36%	11
Heavy rail transit	337	72%	13	3%	469	100%	469
Intercity trains	20	91%	1	5%	7	32%	22
Total	404	74%	55	10%	498	92%	543

Note: New York City has no light rail facility so that row is not shown.
Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

Table 15 IPCD Bus Connectivity Summary, New Jersey, 2012

Facility Type	Bus Transit		Intercity Bus		Rail Heavy		Rail Light		Total
	#	row %	#	row %	#	row %	#	row %	#
Airport	2	67%	1	33%	0	0%	0	0%	3
Intercity bus	7	50%	14	100%	1	7%	2	14%	14
Intercity passenger ferries	1	100%	0	0%	0	0%	0	0%	1
Transit of local area ferries	6	43%	1	7%	2	14%	5	36%	14
Light rail transit	31	51%	2	3%	5	8%	61	100%	61
Heavy rail transit	12	75%	3	19%	16	100%	5	31%	16
Intercity trains	95	64%	2	1%	2	1%	4	3%	149
Total	154	60%	23	9%	26	10%	77	30%	258

Note: The term "row %" in Tables 14 and 15 pertains to the row %s calculated from data in earlier tables 6 through 13.
Source: Intermodal Passenger Connectivity Database (IPCD), U.S. DOT Research and Innovative Technology Administration (RITA), 2013.

III. RESEARCH RESULTS: BUS AND RAIL CONNECTIVITY

Bus Connectivity and Demographic Characteristics of Resident Populations Near Transit Stations: New York City

Bus and Subway Connectivity

Heavy rail (subway) and bus transit are two common means of transportation in New York City, and the connections between these two modes are the focus of this report. In order to assess whether there are potential limitations that could arise from the way these two critical transportation systems are connected it is important to analyze the proximity of the provision of these services to each other. Transferring from subway to bus or vice versa is possible when a bus line stops at a subway station or in close proximity to one. The connectivity of these two types of transportation may vary from one area to another across New York City.

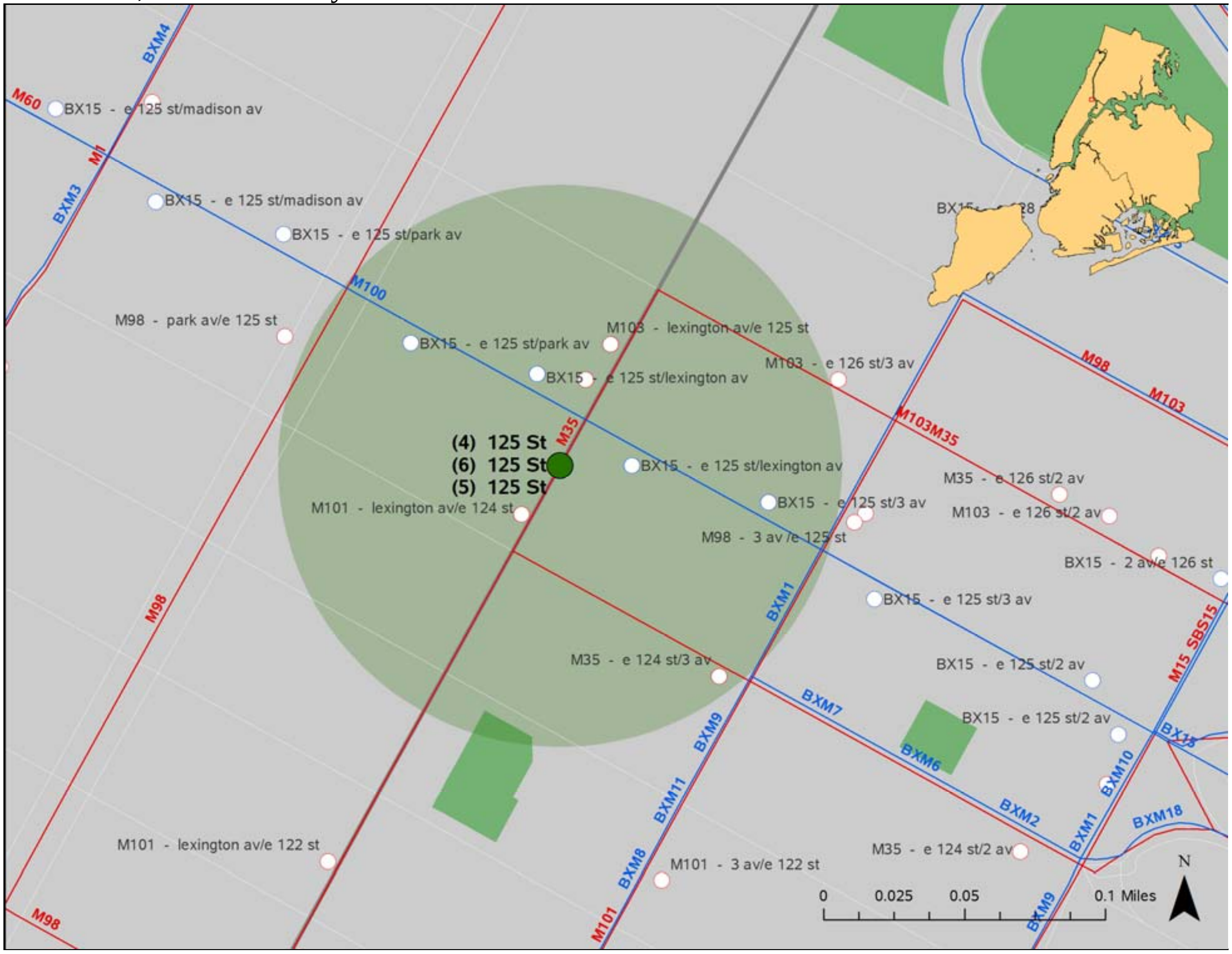
Bus and Subway Connectivity and Demographic Characteristics

Introduction to spatial proximity of location of buses stopping and subway stations:

As part of this research project publicly available data from the Metropolitan Transportation Authority (MTA) and the U.S. Census Bureau (2013) 2012 American Community Survey were used to construct a database that links the number of bus lines stopping near a subway station to selected demographic variables. The goal was to analyze the data and evaluate whether there are significant differences in terms of the connectivity between these transportation systems across the city that could affect vulnerable populations. The data sets from the MTA include the latitude and longitude data from each subway station in New York City and for the location of each stop for every MTA bus in the city. Using ArcGIS (ESRI 2014) the data sets were mapped and a one-tenth of a mile buffer was constructed around each subway stop. A variable titled 'bus counts' was constructed by counting how many buses stop inside this buffer for each station. If a bus from the same bus line stops more than once inside the buffer it is counted more than once. The frequency of the buses stopping is not part of the analysis given data limitations for frequency. A bus is included in the counts only on the basis of whether or not it stops in the buffer area on any given day.

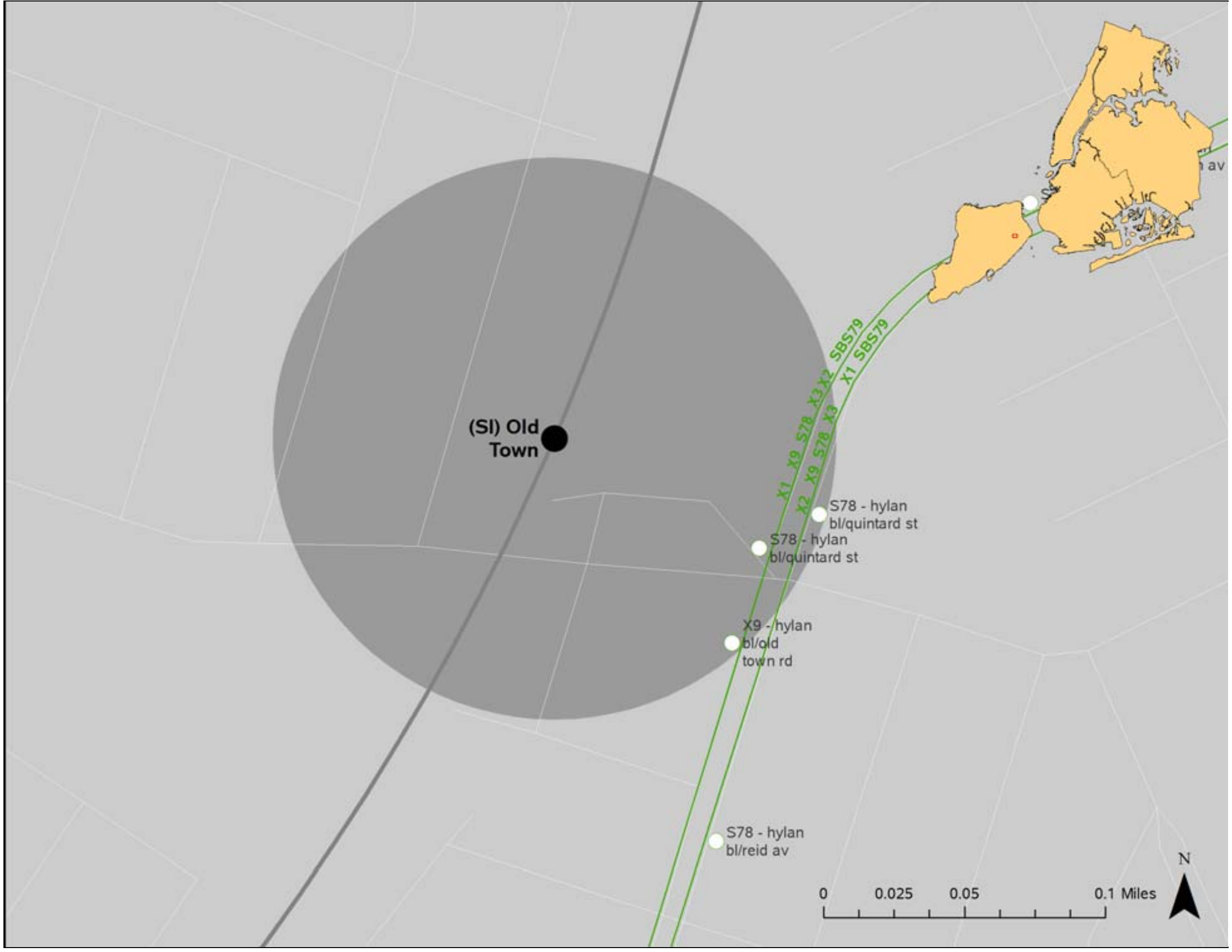
Figures 1 and 2 are maps for two different stations with buffers around them and illustrate the concept of the bus counts variable. In each case bus counts would refer to the number of buses stopping inside the buffer around each station. For the 125th Street (Lexington Avenue) station in Manhattan shown in Figure 1 the bus count is 8. For the Old Town station in Staten Island shown in Figure 2 the bus count is 3. The total number of subway stations included in the database was 493.

Figure 1. 125th Street Lexington Avenue Subway Station (4,5,6 trains) Buffer with Buses in Manhattan, New York City



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See “Bus and Subway Connectivity and Demographic Characteristics” section for a description of the method

Figure 2. Old Town Station Buffer in Staten Island, New York City



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See “Bus and Subway Connectivity and Demographic Characteristics” section for a description of the method

Descriptive statistics:

Table 16 shows the descriptive statistics for these variables. The first two variables were obtained using data from the MTA. The bus stops within the one-tenth mile buffer range from none to 21. The number of trains per station ID refers to the number of different train tracks that stop at a subway station. For example, Union Square station in Manhattan has the following subway lines stopping there: the 4, 5, 6 trains stop at one train track, the L stops at another train track, and the N, Q and R trains stop at another train track. Although there are 7 subway lines stopping there the value of the “number of trains per station ID” is 3, since that is the number of train tracks accessible at the station. This variable can be considered a proxy for train traffic and ridership. The hypothesis is that a higher number of train tracks at a station is associated with a higher number of transit users and with a higher number of buses stopping in close proximity to the station.

Data from the U.S. Census tract of the location of each subway station was used as a proxy for the demographic characteristics of the area around each subway station. Subway stations located in Census tracts with zero population were removed from the database for the statistical analyses.

Population density is in persons per square mile. The race and ethnicity variables show the percentage of the population in the census tract of each of the subway stations for each of the racial and ethnic categories included. In addition, a few variables that show the different ways that people living in the census tract of the subway stations commute were also added to the database.

Table 16. Descriptive Statistics (N=487)*

Variable	Minimum	Maximum	Mean	Std. Deviation
Bus Counts	0	21	5.12	3.803
No of Trains per Station ID	1	4	1.54	.744
Population Density	2.0	156,942.0	53,350.3	34,465.7
% White	2.0	100.0	51.3	28.4
% Black	.0	94.0	22.1	30.0
% Native American	.0	25.0	.9	1.8
% Asian	.0	74.0	13.4	14.8
% Pacific Islander	.0	9.0	.1	.6
% Other	.0	78.0	15.1	16.7
% Hispanic or Latino	.0	100.0	29.5	25.2
% Below Poverty Line (Individuals)	.0	100.0	21.3	15.4
Median HH Income ($)	0	201,731	62,141.8	38,445.3
% Commute SOV	.0	71.0	15.6	13.9
% Commute HOV	.0	17.0	3.6	3.4
% Commute Public Transit	.0	88.0	59.8	15.5
% Commute Walk	.0	100.0	12.8	12.6
% Commute Other	.0	27.0	2.6	2.9
% Work from Home	.0	24.0	4.6	4.0

*Note: The number of cases is 487, since stations with zero population are excluded (see above).

Table 17 shows correlations between selected variables. The data suggest there is very little evidence of any correlation between bus counts and the other variables included in the table, and many of the correlations are not statistically significant. As expected, the variables related to race and ethnicity and income and individuals below the poverty line are correlated with one another. However, these variables are not correlated with bus counts, and this finding suggests that the connectivity of buses and subways may not be related at least linearly to these demographic variables.

Table 17. Variable Correlations

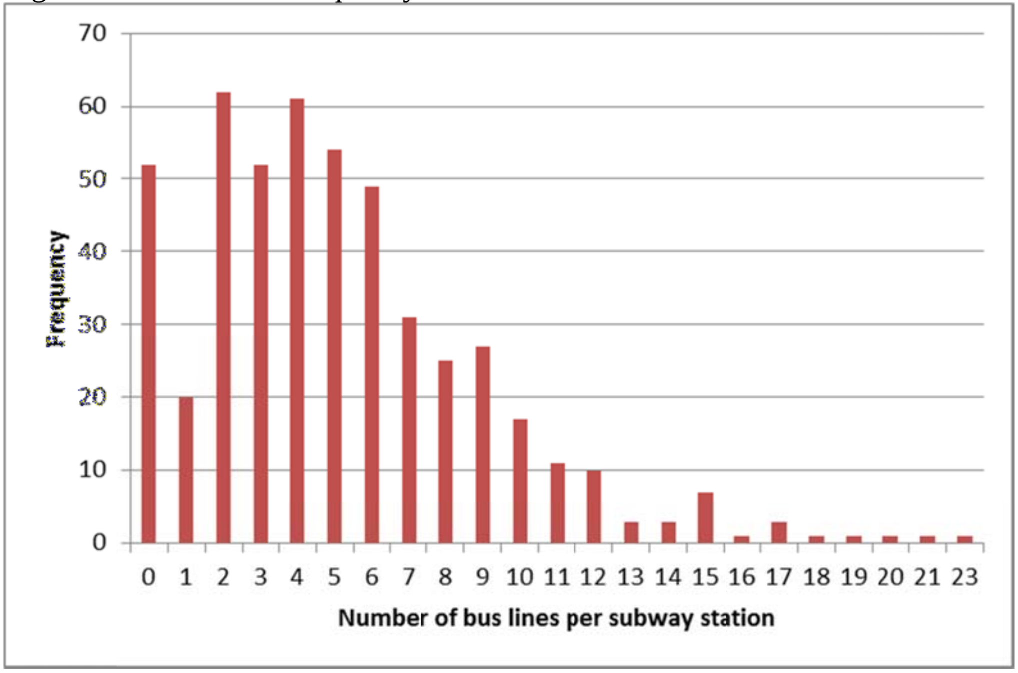
		Bus Counts	Population Density	% Black	% Hispanic or Latino	% Below Poverty Line	Median HH Income	% Commute Public Transit
Bus Counts	Pearson Correlation	1	.038	-.063	.020	-.087	.202**	.067
	Sig. (2-tailed)		.406	.164	.654	.054	.000	.140
	N	487	487	487	487	487	487	487
Population Density	Pearson Correlation	.038	1	.043	.225**	.114*	-.127**	.344**
	Sig. (2-tailed)	.406		.343	.000	.012	.005	.000
	N	487	487	487	487	487	487	487
% Black	Pearson Correlation	-.063	.043	1	.106*	.412**	-.435**	.226**
	Sig. (2-tailed)	.164	.343		.019	.000	.000	.000
	N	487	487	487	487	487	487	487
% Hispanic or Latino	Pearson Correlation	.020	.225**	.106*	1	.560**	-.556**	.207**
	Sig. (2-tailed)	.654	.000	.019		.000	.000	.000
	N	487	487	487	487	487	487	487
% Below Poverty	Pearson Correlation	-.087	.114*	.412**	.560**	1	-.661**	-.006
	Sig. (2-tailed)	.054	.012	.000	.000		.000	.902
	N	487	487	487	487	487	487	487
Median HH Income	Pearson Correlation	.202**	-.127**	-.435**	-.556**	-.661**	1	-.214**
	Sig. (2-tailed)	.000	.005	.000	.000	.000		.000
	N	487	487	487	487	487	487	487
% Commute Public Transit	Pearson Correlation	.067	.344**	.226**	.207**	-.006	-.214**	1
	Sig. (2-tailed)	.140	.000	.000	.000	.902	.000	
	N	487	487	487	487	487	487	487

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figures 3-8 provide additional information about the bus counts variable and selected variables. Figure 3 shows a frequency distribution for the bus counts variable for the original 493 subway stations in the database. It shows a long right-tailed distribution. At the low end of the distribution, fifty-two stations have zero buses stopping within a tenth of a mile buffer around them. At the high end of the distribution, one station has 23 buses stopping within a tenth of a mile of the station. This one station with 23 bus counts in Jamaica, Queens was removed from the database used for the statistical analyses since it is located in a Census tract with zero population. That is why Table 1 shows a maximum number of bus counts of 21; it does not include the station with 23 bus counts.

Figure 3. Bus Counts Frequency Distribution



Figures 4-8 are scatter plots with bus counts on the y-axis and population density, number of train tracks per subway station, percent black, percent Hispanic or Latino and percent below the poverty line (individuals) respectively on the x-axis. As with the correlation table, the scatter plots do not show evidence of an association between bus counts and these variables.

Figure 4. Scatter Plot of Bus Counts and Population Density

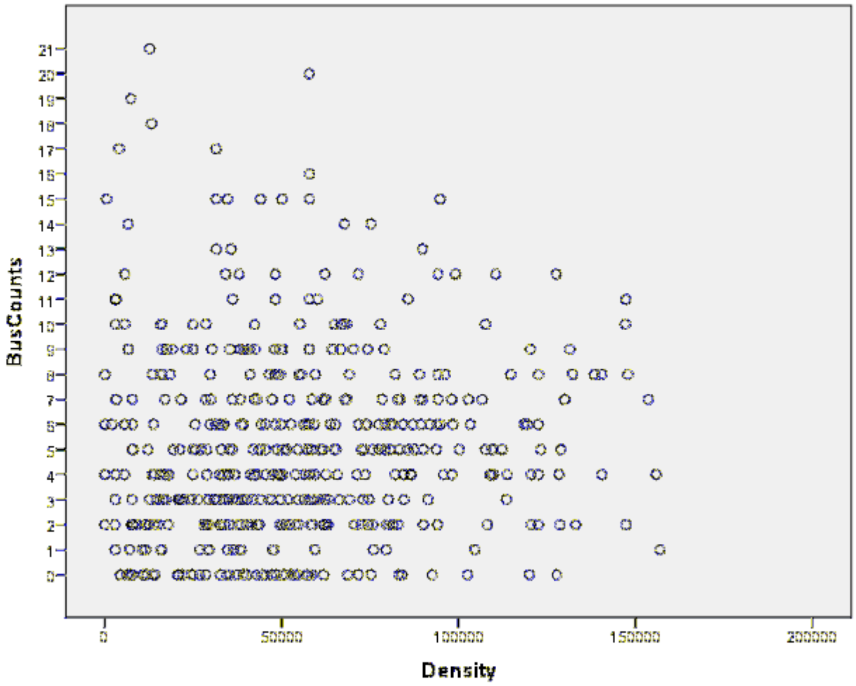


Figure 5. Scatter Plot of Bus Counts and Number of Train Tracks per Subway Station

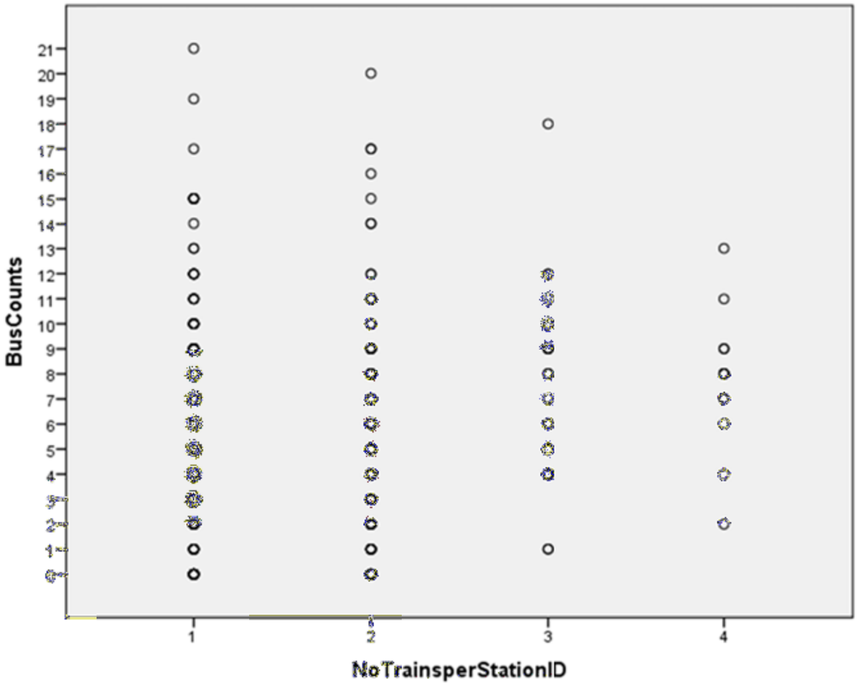


Figure 6. Scatter Plot of Bus Counts and Percent Black

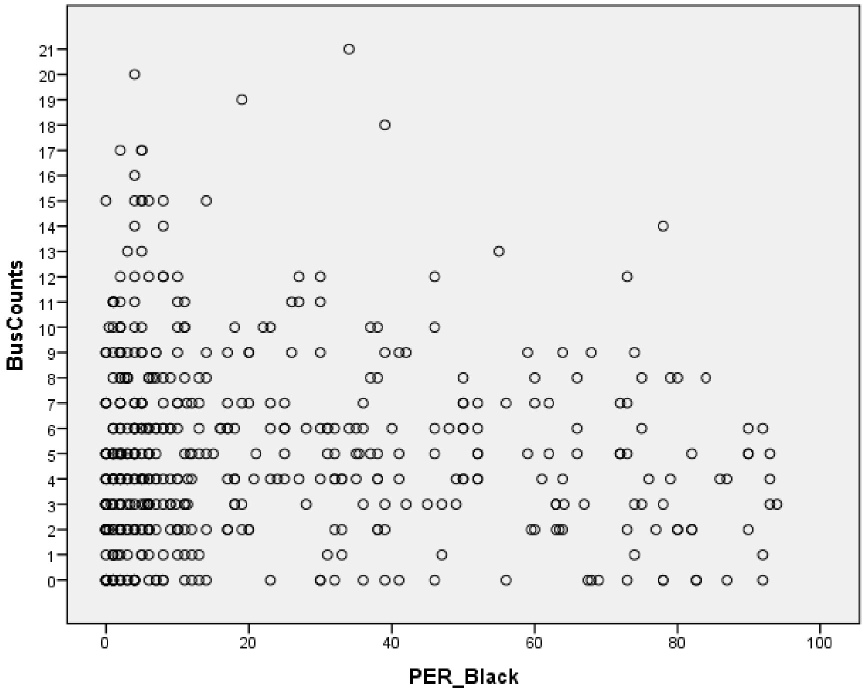


Figure 7. Scatter Plot of Bus Counts and Percent Hispanic or Latino

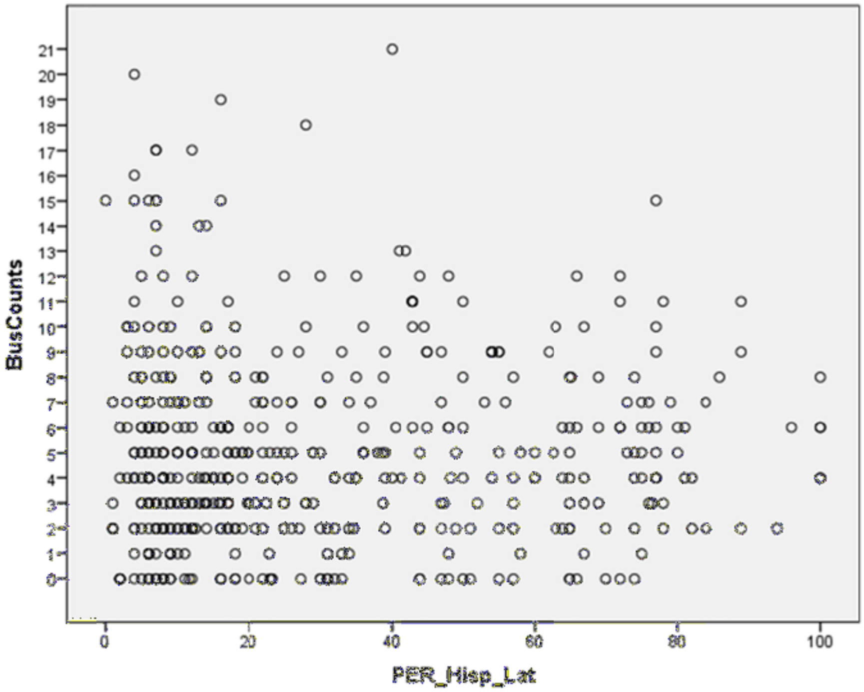
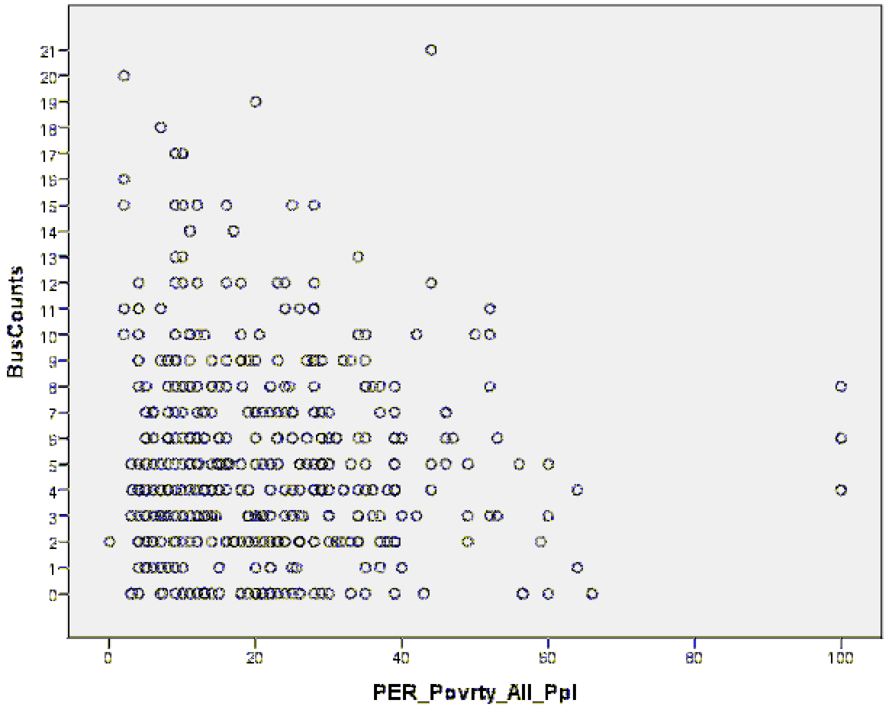
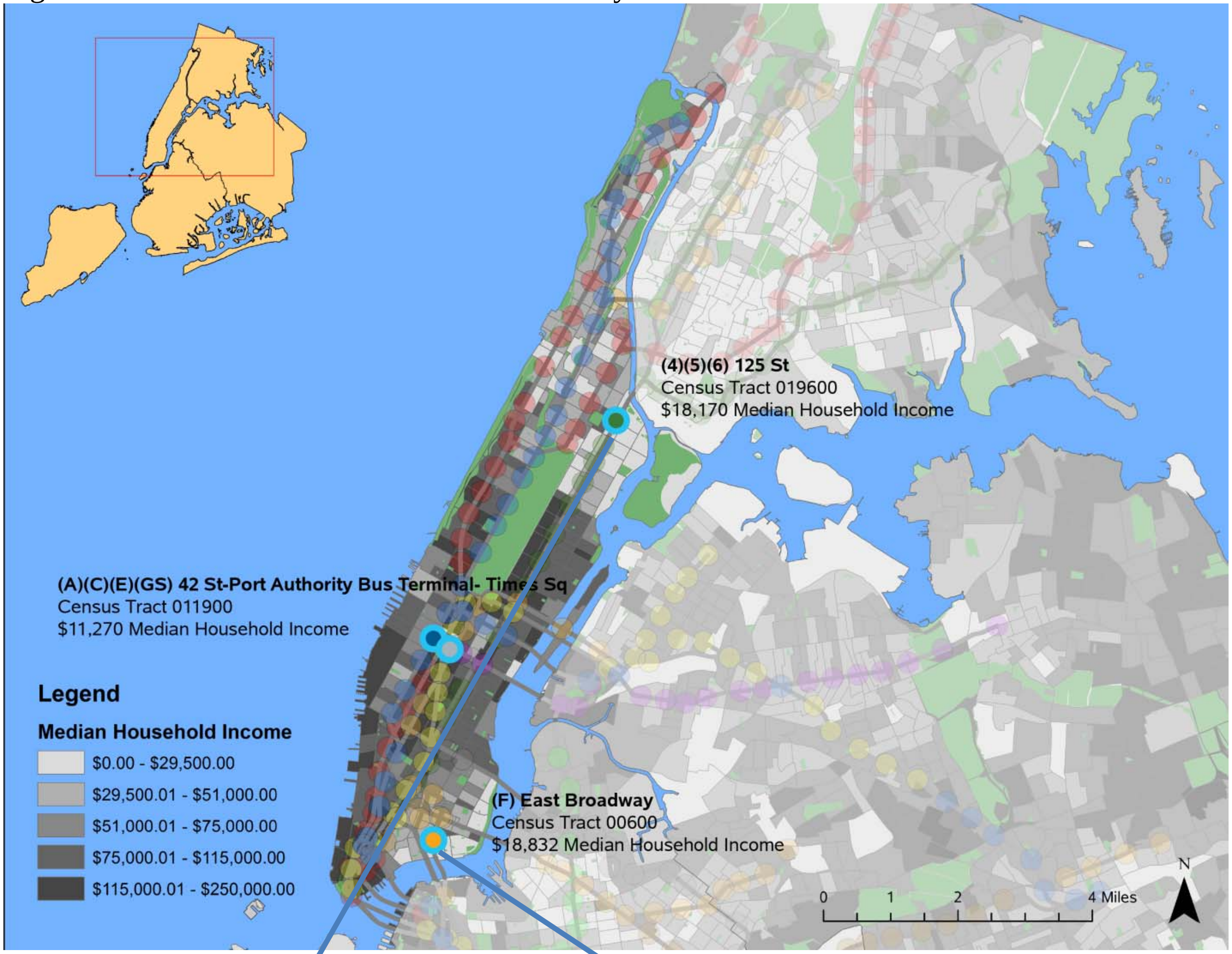


Figure 8. Scatter Plot of Bus Counts and Percentage of Individuals Below the Poverty Line



The association between the location of the subway stations with the buffers including bus stops and demographic variables were also explored visually using Geographic Information Systems. Figures 9-13 include maps that overlay information about median household income by census tract for each borough with the location of the city's subway stations. Income is defined for the single census tract where the station is located. These figures also show the location of selected subway stations in areas with relatively low median household income for residents based on the census tract where these stations are located. For illustration, below some of the borough maps are details for a few of the stations with among the lowest median household incomes. One can see from these detailed maps for Queens and Brooklyn that sometimes a station with low income has many connecting buses and sometimes very few or none, resulting in the relatively weak statistical relationship between median household income and bus connectivity.

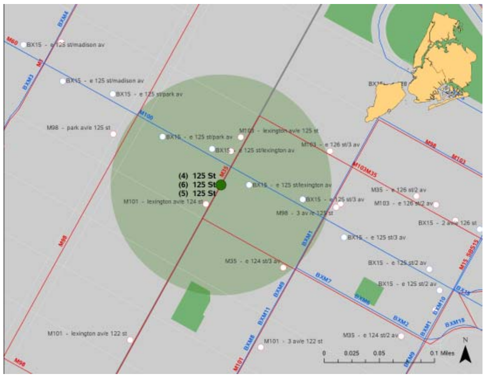
Figure 9. Median Household Income and Subway Stations in Manhattan



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See “Bus and Subway Connectivity and Demographic Characteristics” section for a description of the method.

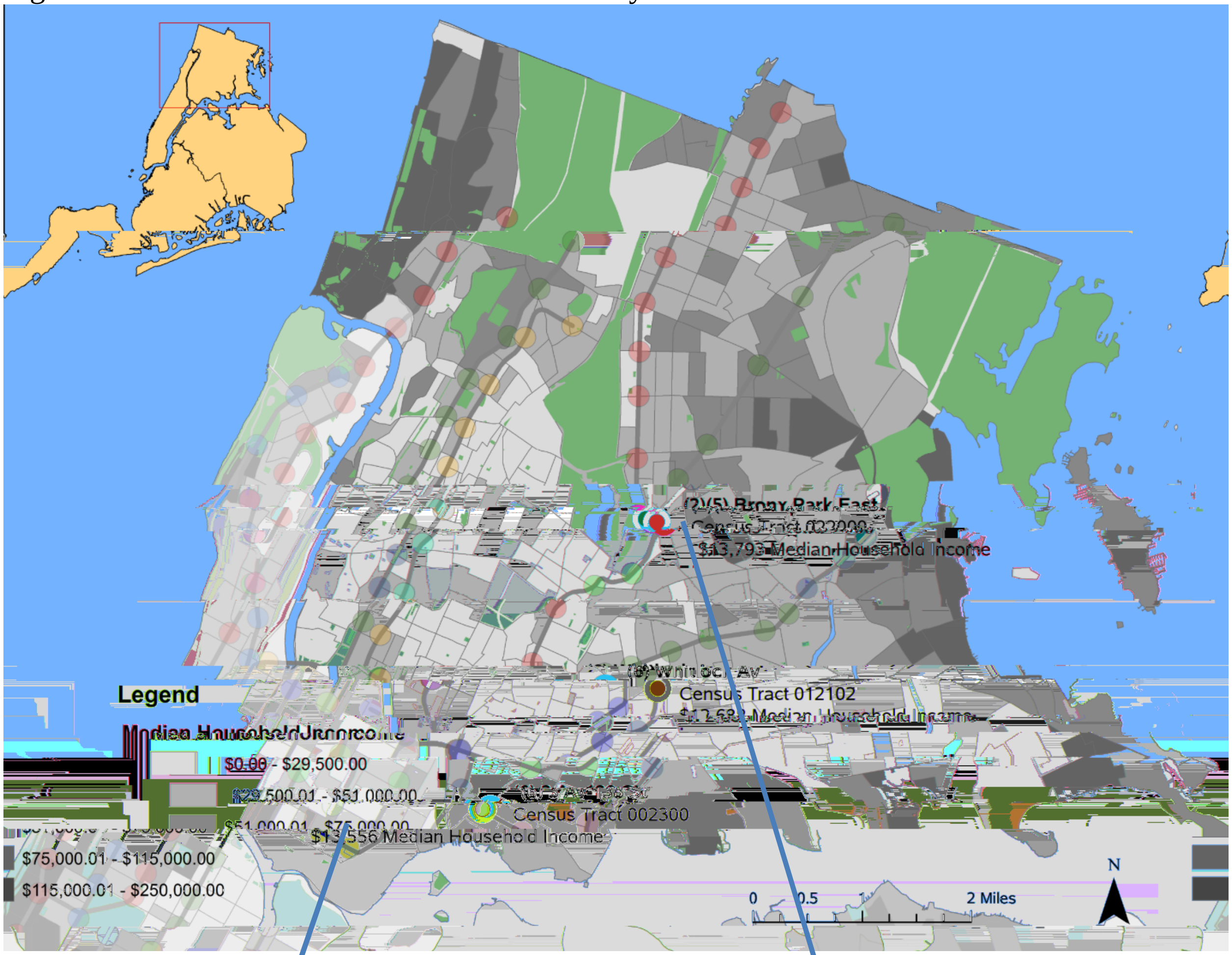
Detailed Subway Maps for Selected Low Median Household Income Subway Stations in Manhattan

125 Street



East Broadway

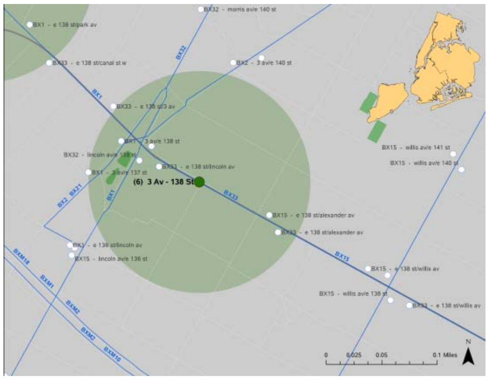
Figure 10. Median Household Income and Subway Stations in the Bronx



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See "Bus and Subway Connectivity and Demographic Characteristics" section for a description of the method.

Detailed Subway Maps for Selected Low Median Household Income Subway Stations in the Bronx

3 Av – 138 Street



Bronx Park East

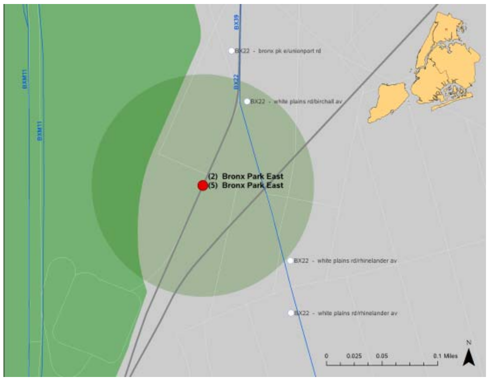
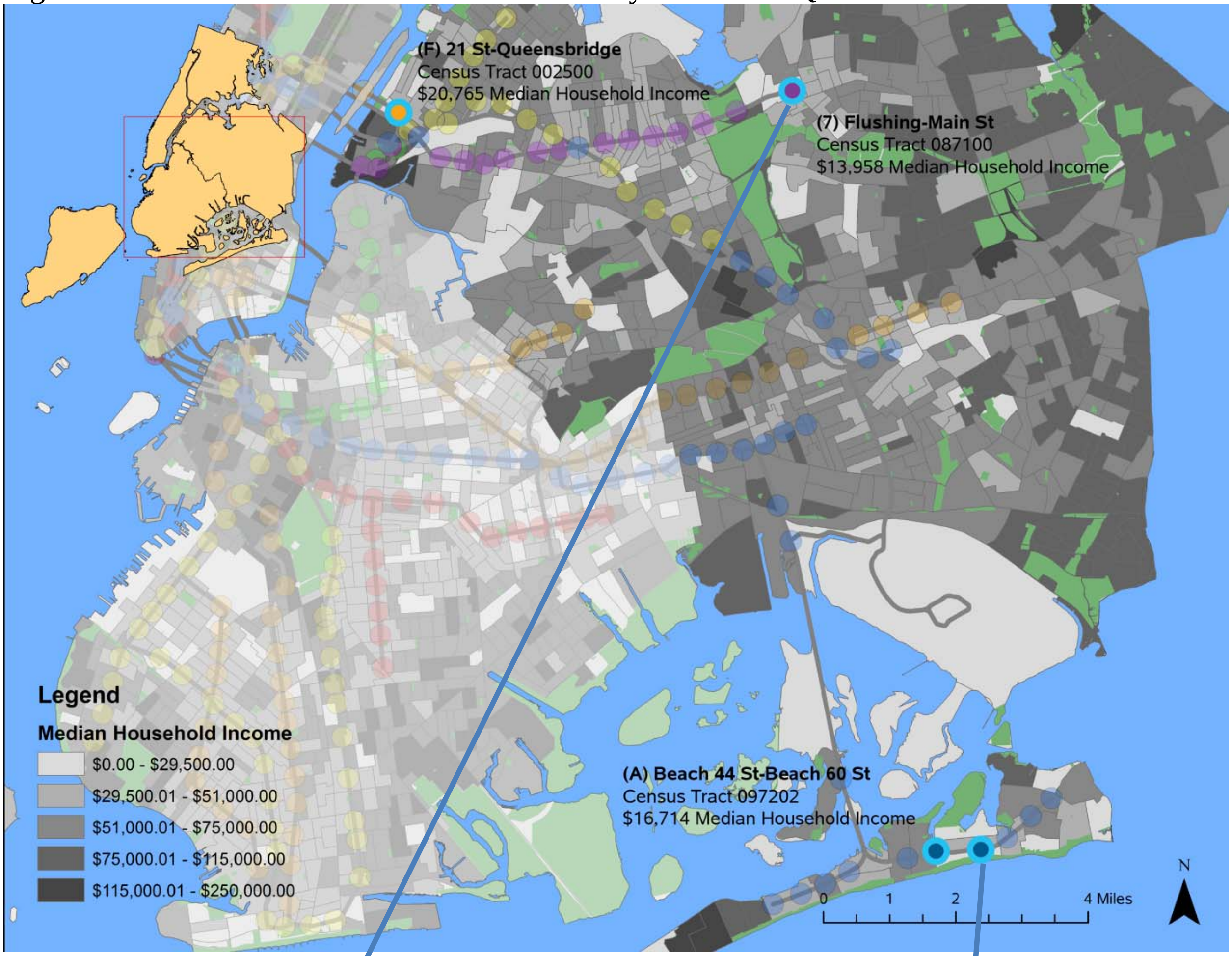


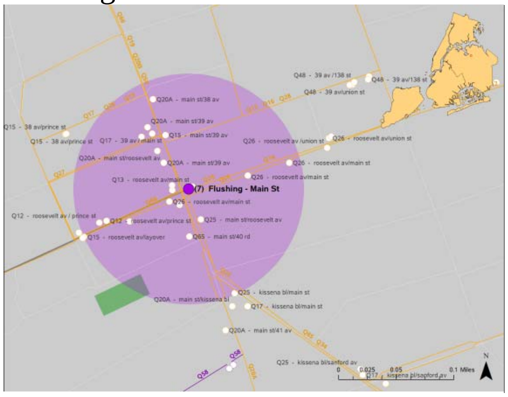
Figure 11. Median Household Income and Subway Stations in Queens



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See "Bus and Subway Connectivity and Demographic Characteristics" section for a description of the method.

Detailed Subway Maps for Selected Low Median Household Income Subway Stations in Queens

Flushing Main Street



Beach 60th Street

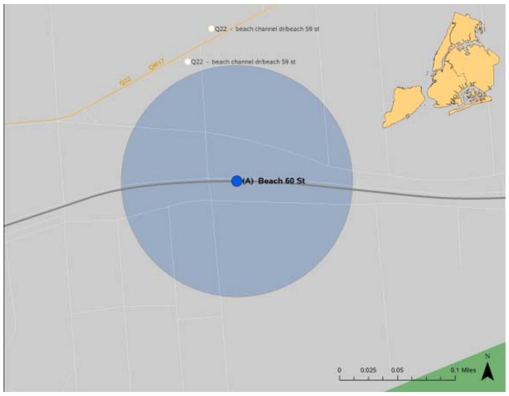
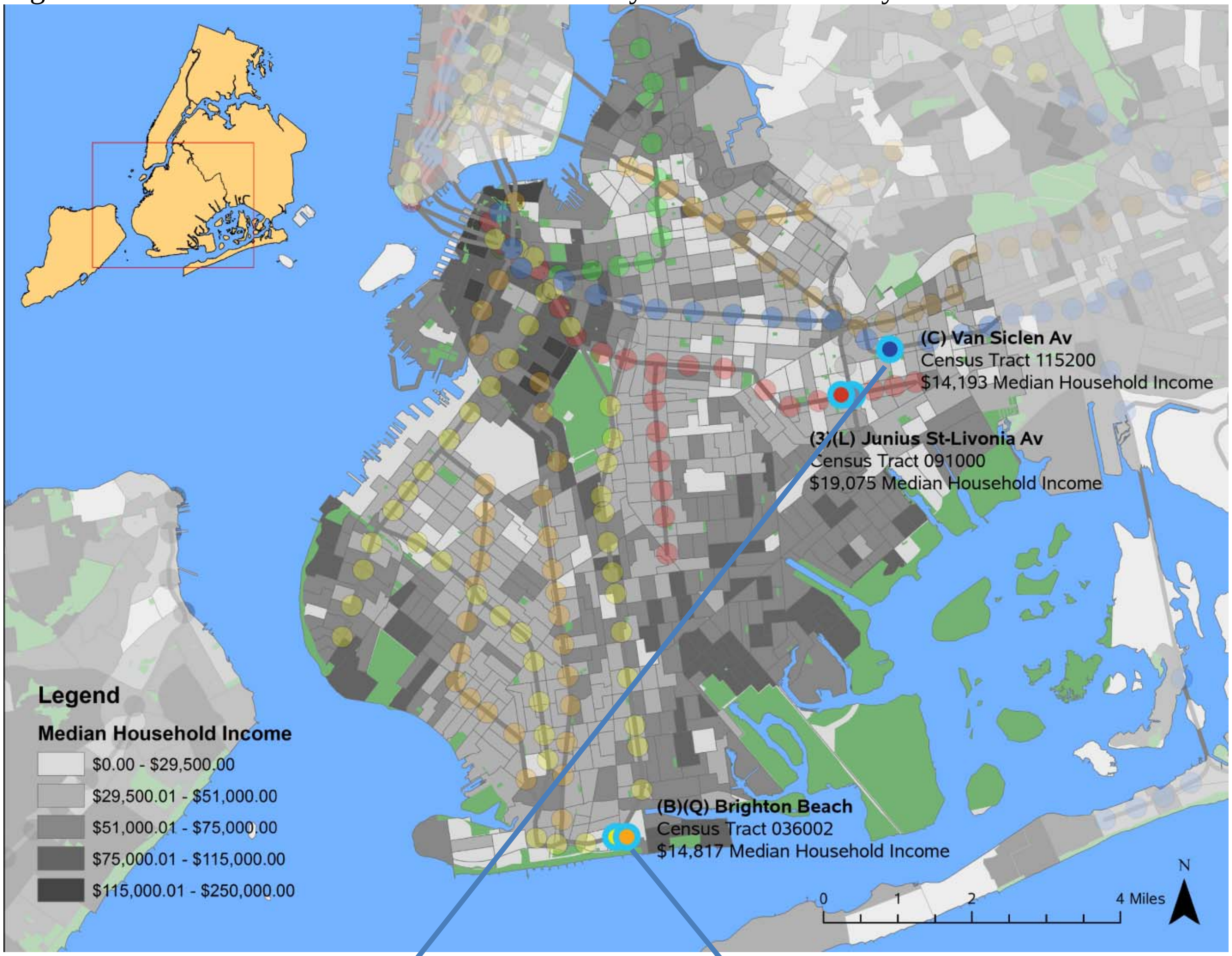


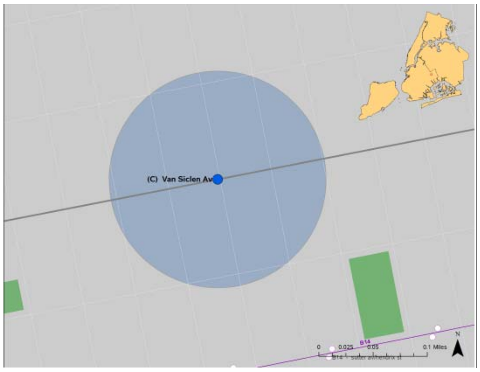
Figure 12. Median Household Income and Subway Stations in Brooklyn



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See “Bus and Subway Connectivity and Demographic Characteristics” section for a description of the method.

Detailed Subway Maps for Selected Low Median Household Income Subway Stations in Brooklyn

Van Siclen Avenue



Brighton Beach

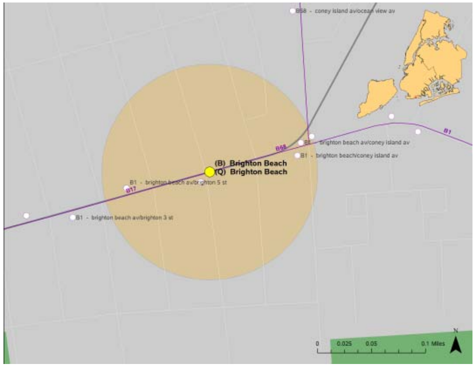
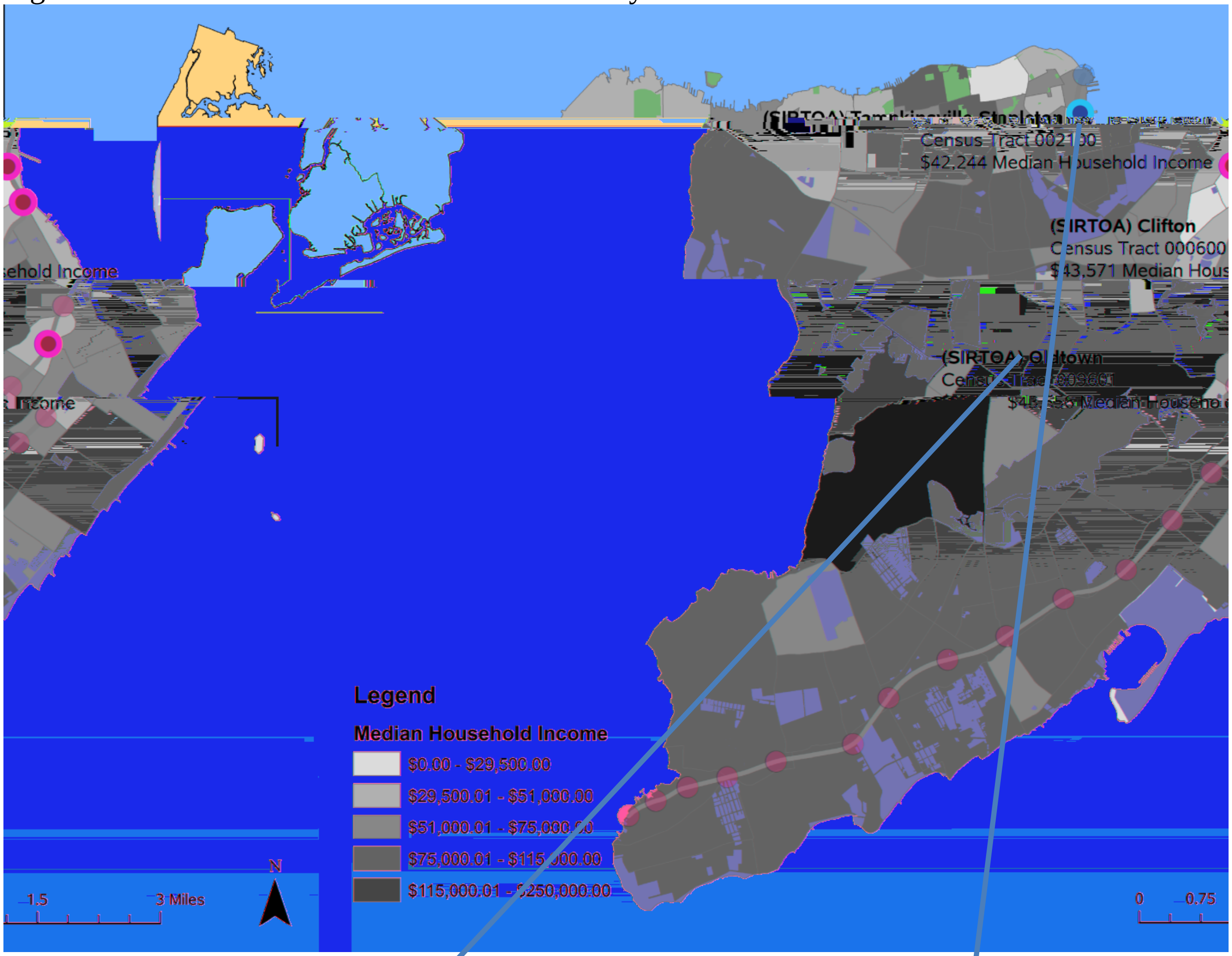


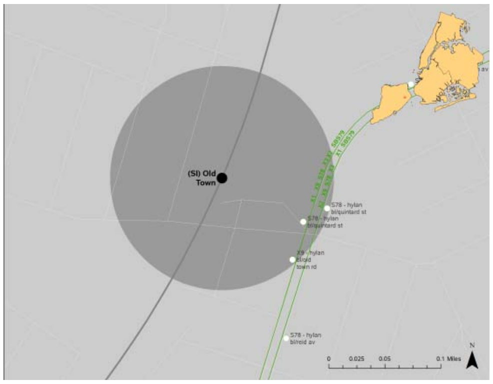
Figure 13. Median Household Income and Subway Stations in Staten Island



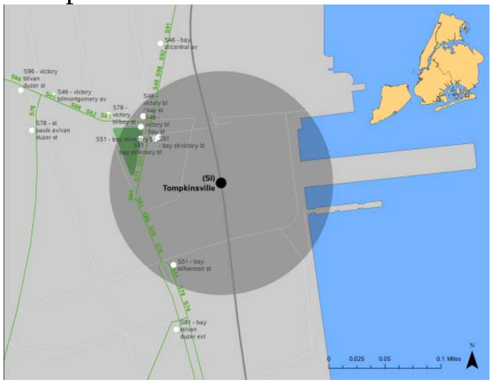
Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See "Bus and Subway Connectivity and Demographic Characteristics" section for a description of the method.

Detailed Subway Maps for Selected Low Median Household Income Subway Stations in Staten Island

Oldtown



Tompkinsville



Regression analysis:

In the last stage of the analysis a regression model was used to analyze whether any statistically significant associations could be found between the “bus counts” variable (number of buses stopping at stations) and some variables included in Table 16 above. After examining the data in Table 16 and the scatter plots it became apparent that five additional stations had unusual demographic data. These five stations were located in census tracts with a population of 2 individuals and 100% poverty rate. They were removed from the dataset for the regression models so the total number of stations in the dataset was 482. The dependent variable in all the models was “bus counts”. The negative binomial regression model was selected for this part of the analysis since the “bus counts” variable is a count variable with zero or positive integer values. Also, as Figure 3 shows it has a long-tailed right distribution. Negative binomial regression is considered appropriate for this kind of analysis (Simonoff 2004; Venables and Ripley 2002; Zwilling 2013). A number of single-predictor and multiple-predictor models (eight models) were run using Stata (StataCorp 2014). These analyses are summarized in Table 18 below.

The general formulation for the negative binomial regression equation for these models is as follows:

ln (bus counts) = Intercept (Constant in table below) + Coefficient(variable 1) + … + Coefficient (variable n)

For Model VIII in Table 18 for example the equation is:

ln (bus counts) = 1.4016 + .170(No. of Train Tracks) + 9.92e-07(Population Density) - .0006(% Black) + .0041(% Hispanic or Latino) - .0099(% Below Poverty Line)

Table 18. Results of Regression Analysis

Model	Prob > chi2	Predictor(s)	Coefficient	Std. Err.	z	P>|z|	[95% Confidence Interval]
I	0.0004	No. Train Tracks	.1585183	.0453097	3.50	0.000	.069713 .2473237
		Constant	1.381755	.0787226	17.55	0.000	1.227461 1.536048
II	0.1452	% Black	-.0020685	.0014137	-1.46	0.143	-.0048393 .0007022
		Constant	1.675429	.0464367	36.08	0.000	1.584414 1.766443
III	0.7189	% Hispanic or Latino	.0005204	.0014467	0.36	0.719	-.0023152 .0033559
		Constant	1.61656	.05466	29.57	0.000	1.509428 1.723692

Model	Prob > chi2	Predictor(s)	Coefficient	Std. Err.	z	P>|z|	[95% Confidence Interval]
IV	0.0178	% Below Poverty	-.0064066	.0026865	-2.38	0.017	-.0116719 -.0011412
		Constant	1.759603	.0645215	27.27	0.000	1.633143 1.886063
V	0.0006	No. Train Tracks	.1601761	.0452736	3.54	0.000	.0714415 .2489107
		% Black	-.002172	.0013936	-1.56	0.119	-.0049033 .0005594
		Constant	1.425185	.083471	17.07	0.000	1.261585 1.588786
VI	0.0012	No. Train Tracks	.1678124	.0460563	3.64	0.000	.0775438 .258081
		% Hispanic	.0015536	.0014519	1.07	0.285	-.001292 .0043992
		Constant	1.322188	.0961782	13.75	0.000	1.133683 1.510694
VII	0.0021	No. Train Tracks	.1696547	.0460325	3.69	0.000	.0794328 .2598767
		Population Density	7.59e-07	1.05e-06	0.72	0.469	-1.30e-06 2.81e-06
		% Hispanic or Latino	.0015156	.0015231	1.00	0.320	-.0014696 .0045007
		% Black	-.0024383	.0013993	-1.74	0.081	-.0051809 .0003042
		Constant	1.330752	.1057798	12.58	0.000	1.123428 1.538077
VIII	0.0001	No. Train Tracks	.1703068	.0455498	3.74	0.000	.0810309 .2595827
		Population Density	9.92e-07	1.04e-06	0.95	0.342	-1.06e-06 3.04e-06
		% Black	-.0005698	.0015365	-0.37	0.711	-.0035814 .0024417
		% Hispanic or Latino	.0040925	.0017621	2.32	0.020	.0006389 .0075461
		% Below Poverty	-.0099485	.0034815	-2.86	0.004	-.0167721 -.0031248
		Constant	1.401651	.1076923	13.02	0.000	1.190578 1.612724

The results of these models suggest that two variables have a statistically significant association with the dependent variable (bus counts): number of train tracks per subway station and percent of individuals below the poverty line ("poor"). The second column of Table 18, Prob > Chi2, is the p-value from the likelihood ratio (LR) test. Values below .05 suggest that at least one coefficient in the model is not equal to zero (IDRE 2014). All the models that include the variable 'number of train tracks per subway station' meet this criterion and the single parameter model that includes 'percent poor' also meets this criterion. Similarly, the P>|z| column shows similar results for the statistical significance of the predictor coefficients, again suggesting that these two variables are associated in a statistically significant way with the 'bus counts' variable.

The results for the variable 'number of train tracks per subway station' support the hypothesis stated earlier in this section that subway stations with more train tracks support greater ridership or transportation service users and that these stations are likely to have greater bus connectivity.

The sign of the 'percent below poverty' variable is negative which suggests an inverse relation with bus counts. This provides some evidence that poor neighborhoods might be associated with less effective connectivity between buses and subway stations than wealthy neighborhoods, holding other variables constant. The variables for 'population density,' 'percent black' and 'percent Hispanic or Latino' are not statistically significant in the single-predictor models. However, the variable for 'percent Hispanic or Latino' is significant in Model VIII, which is a multi-predictor model.

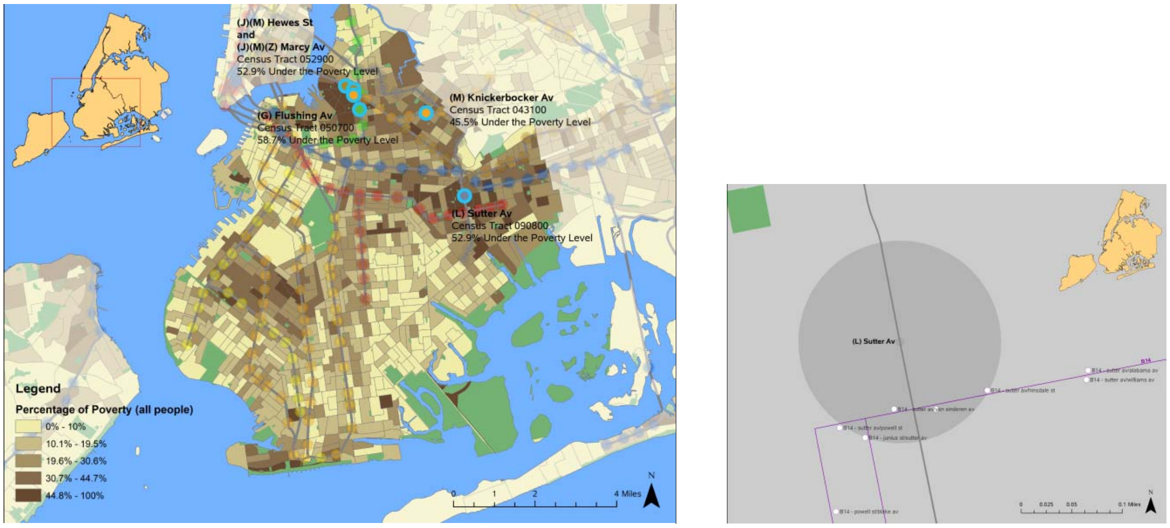
For a negative binomial regression model, the coefficients are interpreted as follows (IDRE 2014). In Model I shown in Table 18, increasing the number of train tracks per station by one is associated with a difference in the logs of expected bus counts by the coefficient shown in the fourth column: .1585. In Model VIII increasing the number of train tracks per station by one is associated with a difference in the logs of expected bus counts by .1703, while holding the other variables in the models constant.

In summary, the results of the regression analyses provide evidence that connectivity between subway stations and bus service provided by the MTA in New York City is associated with the number of train tracks per subway station and may also be associated (inversely) with the percentage of people below the poverty line in areas surrounding the subway station. This research could be extended to explore these associations in greater detail by conducting sensitivity analyses that could include varying the size of the buffer around each subway station; extending the reach of the demographic variables from the census tract where each subway station is located to a larger area that could coincide with the same size buffer as for the bus counts buffers or larger areas; and by exploring additional demographic variables and other measures of income and poverty. Given the relative significance of the percent below poverty variable, examples of stations with the highest percentages are given in Figures 14 and 15 below for the Bronx and Brooklyn, which have stations with the highest percent poverty. The stations with the highest percent poverty in each of those boroughs are also shown.

Figure 14 Selected Subway Stations with Highest Percent Population Below Poverty, Bronx and Bronx Park East station (64.4% Below Poverty)

Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See “Bus and Subway Connectivity and Demographic Characteristics” for a description of the method. The map to the right is a detail of the Bronx Park East station.

Figure 15 Selected Subway Stations with Highest Percent Population Below Poverty, Brooklyn and Sutter Avenue Station (52.9% Below Poverty)



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See “Bus and Subway Connectivity and Demographic Characteristics” section for a description of the method. The map to the right is a detail of the Sutter Avenue station.

Bus and Subway Connectivity and Subway Usage (Ridership)

To provide an initial evaluation of the relationship between bus counts (buses stopping at a given station) and ridership, bus counts and ridership were correlated in a separate analysis. Ridership by station was measured as Average Annual Weekday Ridership as provided in the MTA database (MTA circa 2014). The correlation coefficient for bus counts and ridership was 0.40 for the four boroughs (excluding Staten Island since ridership counts were not available in the way that they are for the other four boroughs), indicating a modest positive correlation. Thus, the analysis suggests bus connectivity increases with increasing station ridership.

Bus Connectivity in Special Rail Transit Locations: Subway Station Terminuses, New York City

Bus connectivity was evaluated in two separate areas within the NYC transit systems in the four boroughs operated by New York City Transit. One was outlying areas of the transit system where trains terminate, called terminuses. The other was highly dense areas where numerous train systems intersect. Staten Island was excluded in analyses with ridership since ridership is aggregated in ways that differ from ridership counts for the other four boroughs managed by the New York City Transit.

Subway lines terminate at different kinds of areas in New York City, and have a long history. Newman (2008) described the neighborhoods surrounding the terminal points in a colorful and anecdotal article. Many of these terminate at parks, business centers, borders between the city and other jurisdictions, or physical termination points such as the end of the borough boundaries or where the city meets waterways. Interconnectivity with other modes at these terminal points provides an interesting window into the role of multi-modal connections when rail transit no longer exists.

The 24 lines that constitute New York City’s subway system in the four boroughs of the City normally consist of about four dozen end points. Some lines divide serving a number of different end points, for example, the #5 train in the Bronx and the A train in Queens (Rockaways). Also, the end points of some trains coincide with other lines that continue further, but many simply terminate. The total number of terminuses is 52, however, for the purposes of calculating characteristics, duplicates have been eliminated to avoid double counting resulting in a total of 41. Each of the boroughs has approximately the same number of terminuses. Brooklyn, Manhattan and Queens each of have 11 and the Bronx has 8. Staten Island (not included in the analysis) has 2.

Table 19 contains a comparison of some of the characteristics of terminus stations in the four boroughs with stations system-wide (for the four boroughs), including the terminuses.

Table 19. Selected Characteristics of Terminuses Compared with Citywide Transit System Characteristics, New York City (Four Boroughs)

	Terminus Stations	Systemwide (including terminuses) (4 boroughs)
Number of stations	41*	493**
Average number of trains stopping	1.6	1.5
Average number of buses stopping	7.5	5.1
Population	162,391	7,730,847
Population density	52,701	31,644
Households	62,212	2,899,718
Population above the age of 16 years (surrogate for number of commuters)	132,474	3,481,786
Average percent of families below poverty****	18.3%	17.4%
Average mean household income*****	$80,457	$80,940
Average commute time in minutes******	39.4	38.9
Total Average 2013 Weekday Ridership (passenger trips)	1,137,446	5,465,034
Average Annual Weekday Ridership per Station	27,743	11,085

Note: Demographic characteristics pertain to the single census tract in which the station is located. Source of census tract information is the U.S. Census Bureau (2013) 2012 American Community Survey.

*Duplicates are eliminated to avoid double counting.

** For ridership, the MTA consolidates some of the stations where multiple train lines converge, totaling 421 stations.

***These are weighted by population at the census tract level.

****These are weighted by number of families at the census tract level

***** These are weighted by number of households at the census tract level

******Commute time is weighted by the number of workers 16 years old or older (surrogate for workers)

Bus Connectivity at Terminuses

The terminal points have interesting characteristics relative to subway stations citywide (defined as the four boroughs NYCT manages excluding Staten Island). The average number of buses stopping at subway stations system-wide (without duplication of stations) defined as buses stopping within a tenth mile of the station is substantially lower on average than the buses stopping at the terminus stations. This indicates that the terminus stations on average do rely on bus services to a greater extent than stations throughout the system in order to expand coverage to passengers beyond their terminus however, there are variations by station. At the upper extreme, Jamaica Center – Parsons/Archer has 23 buses stopping within the 0.1 mile radius. Other stations at the high end are Flatbush Avenue, World Trade Center, Flushing Main Street, and St. George shown in Figure 16. At the lower end of the range with very few buses stopping are Van Cortland Park – 242nd Street in the Bronx, Brooklyn Bridge – City Hall and 8th Avenue in Manhattan, and Far Rockaway Mott Avenue in Queens (not shown).

Figure 16. Terminuses with relatively high numbers of bus connections: Flatbush Avenue-Brooklyn College (Brooklyn), St. George (SI), World Trade Center (Manhattan), and Flushing Main Street (Queens)

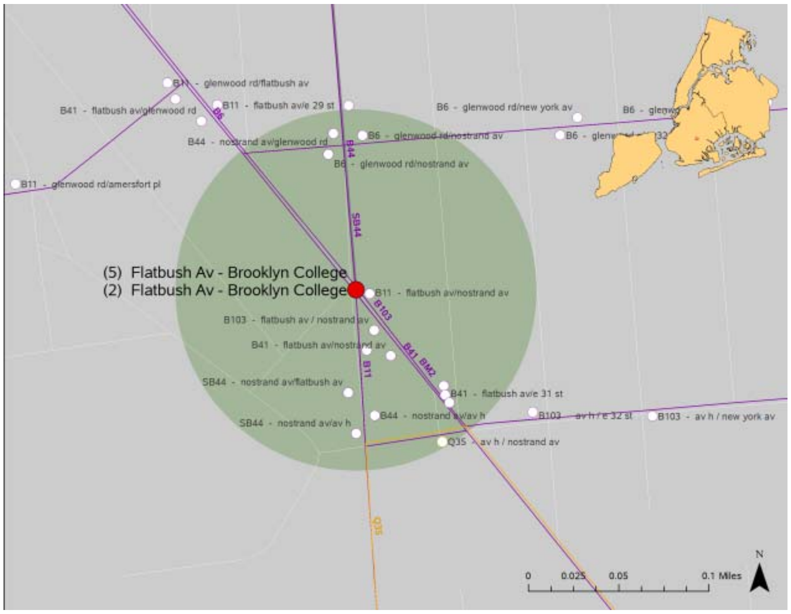
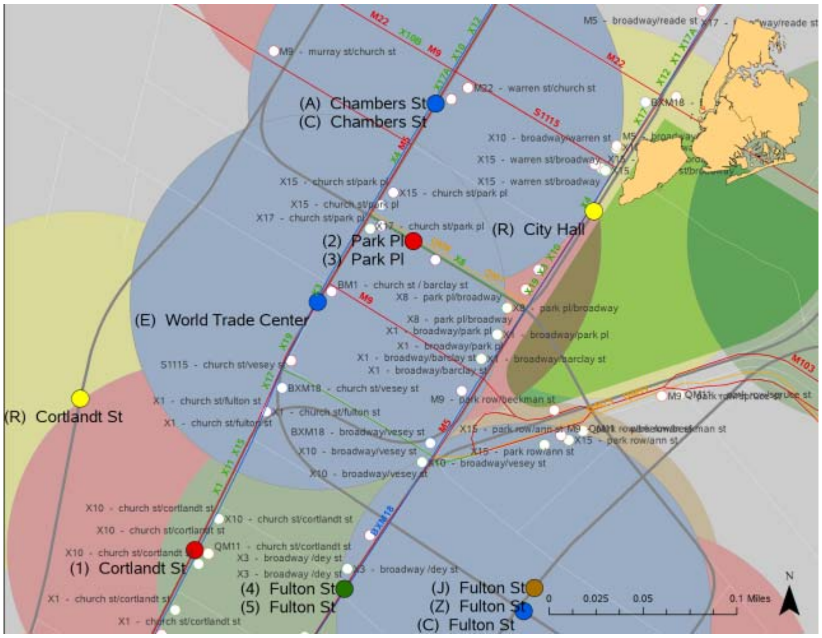
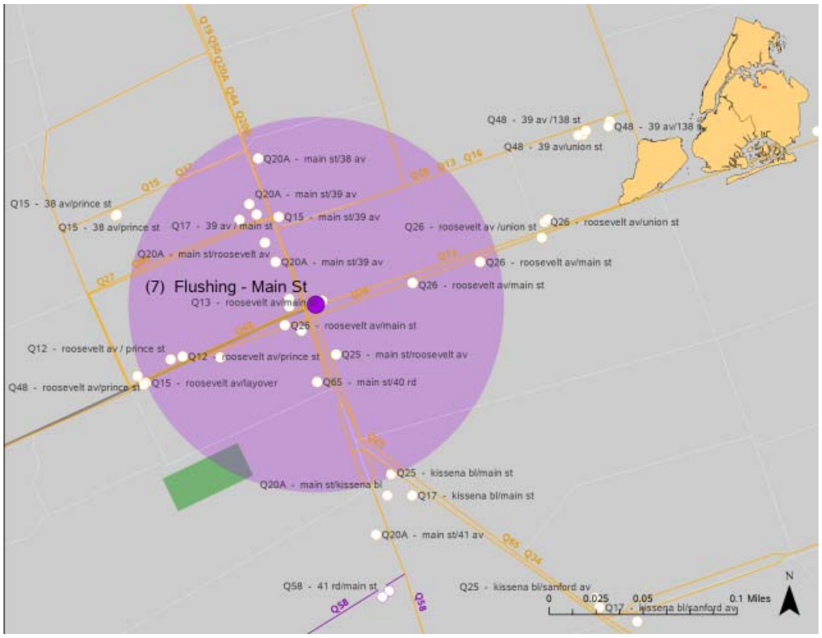


Figure 16 (continued)





Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See “Bus and Subway Connectivity and Demographic Characteristics” section for a description of the method.

Population Characteristics at Terminuses

Population characteristics for stations were identified as those for the census tract within which the station was located. The average population density at the terminus subway stations is 52,701, higher than the four borough average at stations of 31,644 people per station. The higher population density probably justifies the greater number of bus connections at these terminus locations. Measures of poverty and income do not show much difference between the terminus census tracts and the four boroughs as a whole.

Ridership Characteristics at Terminuses

The average annual weekday ridership per station for 2013 at the terminus stations was 27,743 almost three times the 11,085 system-wide (4 boroughs). The total number of riders across the 41 terminus stations was 1,137,446 and for the four boroughs it is 5,465,034. Thus, the percentage that average terminus ridership is of the 4 borough total ridership is 20.8%, which is a much greater share than the terminuses have of the population: 2.1% of the 4 borough population, 2.2% of the 4 borough total number of households, and 3.8%% of the 4 borough population 16 years or older. One needs to keep in mind that it is possible for a given passenger to be counted more than once if in a given day the person entered more than one terminus station, though for terminuses, given their distance from one another, this is probably not too likely.

The relationship between subway ridership and the extent of bus connections at terminuses is also somewhat supported by the correlation between the two, which is positive but low: r=0.3, which is slightly lower than the system-wide correlation cited earlier of 0.4 (which is also low).

For the small set of stations that are terminuses (about ten percent of the total number of stations), the relationship between subway ridership and number of trains stopping at terminus stations is unrelated and even weakly negative (-0.14).

In summary, outlying subway stations that are the terminus for at least one train, have characteristics that differ from those system-wide. While those terminuses have about the same number of trains stopping per station, they have a higher number of buses stopping and much greater ridership per station than the average for all stations in the 4 boroughs. The relationship between subway ridership and the extent of bus connections at terminuses is somewhat supported but weak and the number of trains stopping is not related to ridership at terminus stations.

Bus Connectivity and Commute Time at Terminuses

Combining census data on commute time for the census tracts in which the subway stations are located can provide some insight into the question of whether bus connectivity increases or decreases commute time. The average commuting time (weighted for population above 16 years of age) for terminus stations is 39.4 minutes vs. the 4 borough average of 38.4 minutes. Thus, on average it is very similar.

Summary

To summarize, the terminus stations on average have one and a half times the number of buses connecting to them within 0.1 mile of the station than the average station in the four boroughs even though the same average number of trains stop at both the terminus stations and the stations throughout the four boroughs. The terminuses have a higher population density and two and half times the average annual weekday ridership than the subway system in the four boroughs in general. The terminus stations also have a larger percentage of the four borough system ridership than they do of the population, number of households and population over 16 years old. Income measures do not differ for terminus stations vs. stations in the system as a whole across the four boroughs.

Bus Connectivity in Special Rail Transit Locations: Dense Rail Interconnection Points, New York City and northeastern New Jersey

Transit hubs that have dense interconnections among rail lines provide the opportunity for flexible interconnections among alternative transit routes. Depending on how they are designed, however, the concentration of multiple lines in the same place can also introduce a vulnerability if those areas are disabled by the same cause. Historically, however, those intersection points in the New York City Transit system have provided passengers the flexibility to seek alternative routes. In order to evaluate multi-modal connectivity at these transit hubs as an additional dimension of flexibility, the connectivity of buses to these transit hubs was analyzed.

New York City

For New York City, transit hubs were identified where there were three or more trains stopped, called “dense stations”. Bus stops within the tenth mile radius were tabulated. In addition, this characteristic of bus connectivity was related to a selected number of other transit system characteristics such as ridership. In all, 48 stations were identified with 3 or more trains stopping located in Brooklyn, Manhattan, Queens, and the Bronx.

Train connectivity. The number of trains stopping at these dense intersections was relatively highly correlated with 2013 ridership (r=0.62) using the number of trains that MTA (2014) indicates as those that stop at each station. The definition of ridership at a given station is defined as the number of people entering that station (“swiping”) but not leaving that station. Riders who are on the trains stopping at a given station can enter elsewhere and either stay on the train or disembark at those stations (but disembarking is not counted).

Bus connectivity with dense rail transit stations. In terms of buses stopping, those dense stations with the highest number of buses stopping (10 or more) within the 0.1 mile radius are given below. Several of these stations are shown with the buses stopping at them for illustration in Figure 17.

Brooklyn:
- Jay St. Metrotech

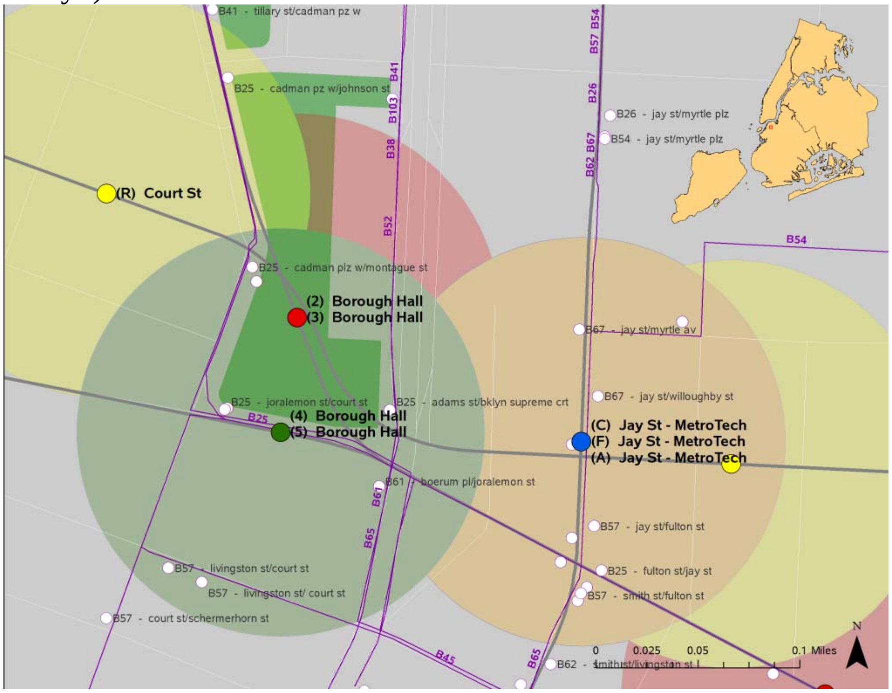
Manhattan:
- 125 St. Lexington Ave.
- 125 St. St. Nicholas Ave.
- 125 St (Lenox Ave)
- Chambers St (7 Av line)
- 34th St. Penn Station (7th Ave)
- 34th St. Herald Square (6th Ave.)

Queens:
- Jamaica Center - Parsons/Archer
- Sutphin Blvd - Archer Av - JFK Airport
- Queens Plaza

The number of buses stopping within 0.1 mile of the station was not correlated with 2013 ridership at all in fact the correlation was practically zero (r=0.08), probably because the relationship is not linear; people are transferring among the different lines within these stations which is not included in the ridership count, or given the density of the street networks near these stations, buses stopping were probably located beyond the 0.1 mile radius. The diagrams show this is the case for some of the stations (see maps in Figure 17). The white dots indicate the number of buses stopping within the 0.1 mile radius, and also show some buses stopping beyond that radius.

Figure 17. Selected Dense Subway Stations and Bus Connectivity, New York City

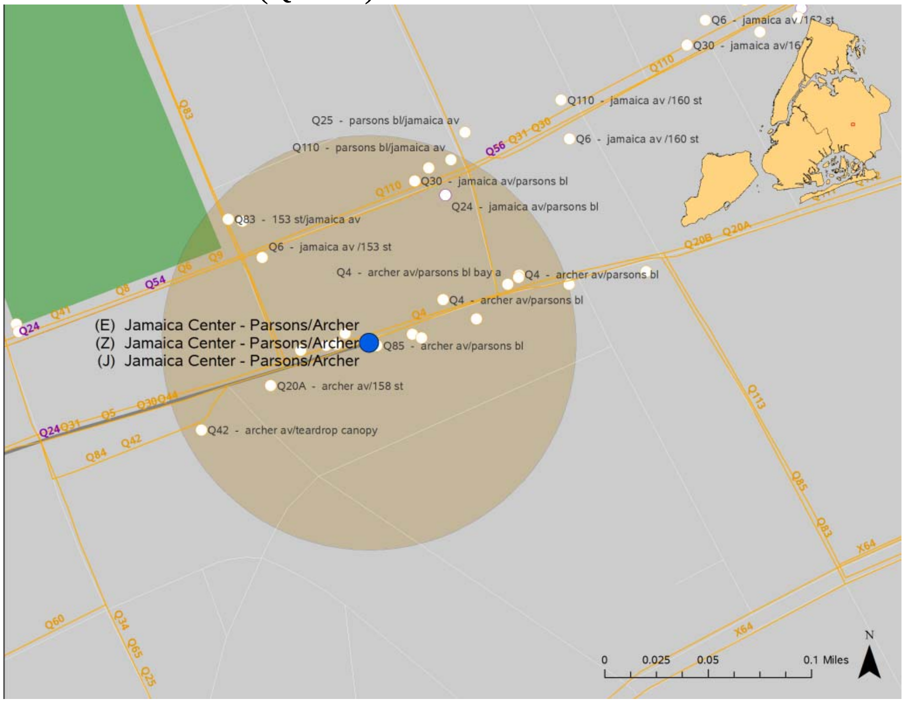
Metrotech (Brooklyn)



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See “Bus and Subway Connectivity and Demographic Characteristics” section for a description of the method.

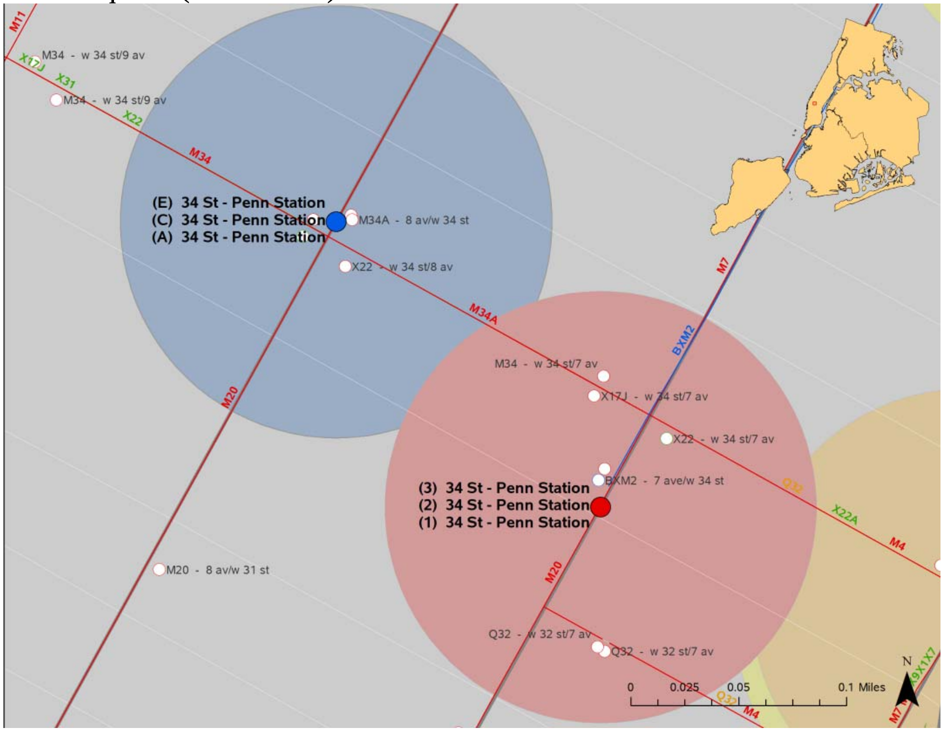
Figure 17 (continued)

Jamaica Center - Parsons/Archer (Queens)



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See "Bus and Subway Connectivity and Demographic Characteristics" section for a description of the method.

34th Street Herald Square (Manhattan)



Source: Maps were constructed by the research team using ARCGIS (ESRI 2014) from publicly available MTA data. See "Bus and Subway Connectivity and Demographic Characteristics" section for a description of the method.

Northeastern NJ

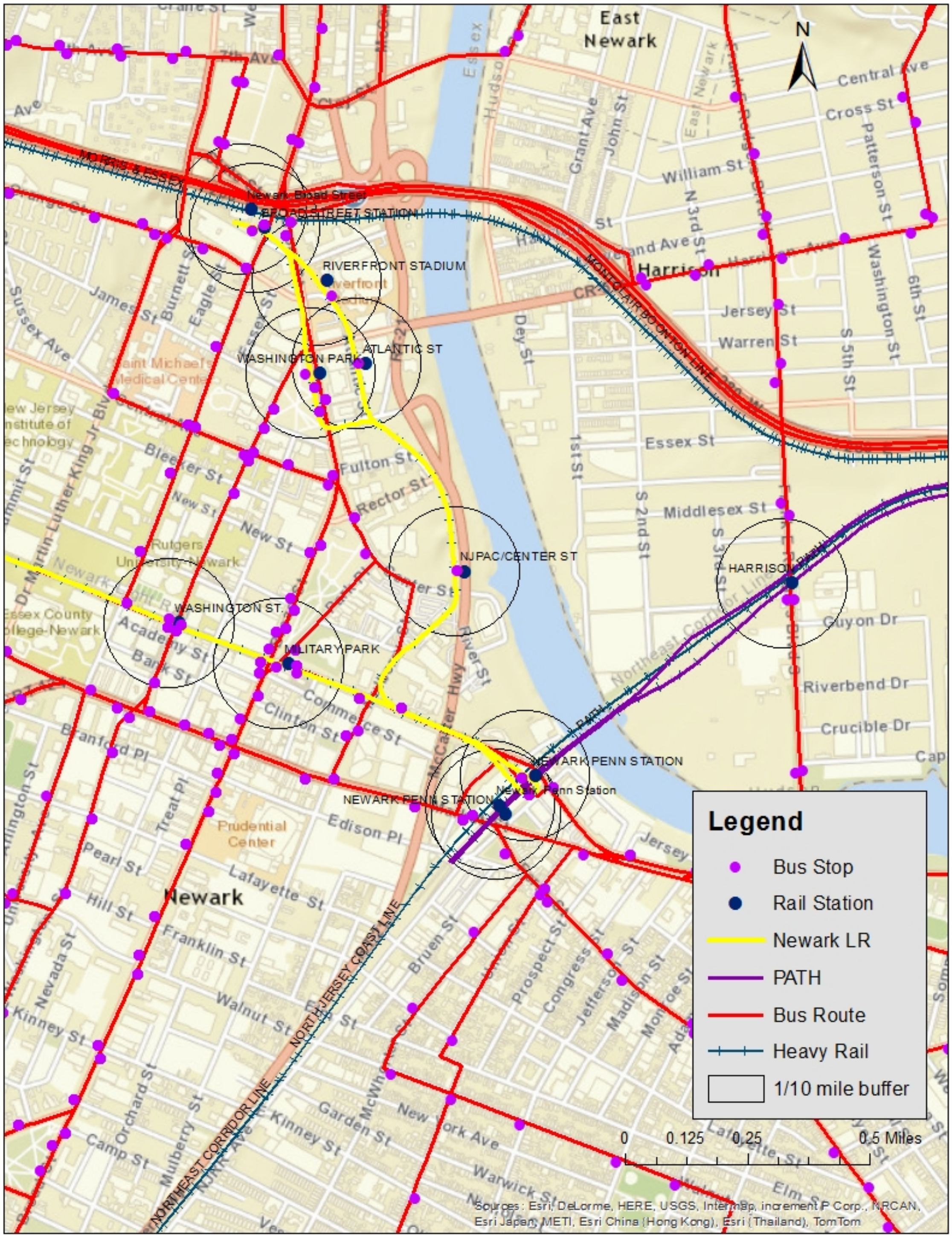
Selected northeastern New Jersey cities included in the study area were Newark, Jersey City, and Hoboken, and Newark and Jersey City have the highest city populations in the State of NJ. As in the case of New York City, those stations in northeastern NJ with 10 or more buses stopping sometime during a given day are listed below.

- Newark
  - Newark Penn Station
  - Atlantic Street
  - Military Park
  - Washington Park
  - Washington Street
  - Riverfront Stadium
  - Newark Broad Street
- Jersey City
  - Journal Square
  - Grove Street
- Hoboken
  - Hoboken Terminal

For the New Jersey stations, unlike New York City subway stations, bus stops were included in addition to the number of buses stopping at each train station. There are many more buses stopping at each bus stop than there are bus stops. The number of buses stopping at a given station was moderately correlated with the number of bus stops at that station (r=0.63). The number of buses stopping at a given station was moderately correlated with the number of rail lines converging at that station (r=0.50).

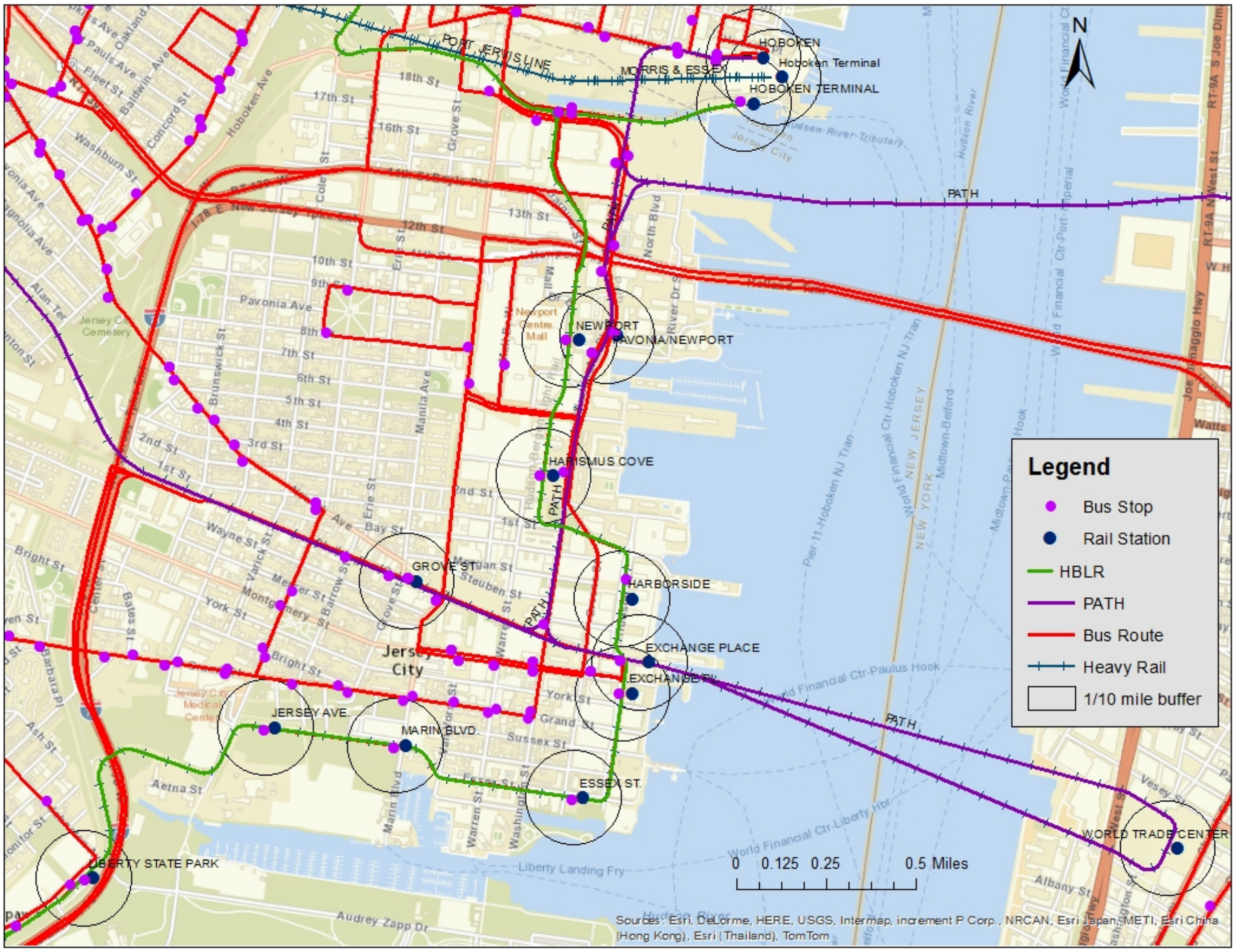
Figure 18 shows stations and bus connectivity for a number of the stations in the Newark Penn Station area and Figure 19 shows stations in both Hoboken and Jersey City.

Figure 18. Bus Stops Within 0.1 Mile of Train Stations, Newark, NJ



Note: Unlike the maps for New York City subway stations, only bus stops are indicated on this map not the number of buses that stop at each stop. There are many more buses stopping at each bus stop than there are bus stops.
Source: Maps were constructed by members of the research team using ARCGIS (ESRI 2014) from publicly available data sources.

Figure 19 Bus Stops Within 0.1 Mile of Train Stations, Jersey City and Hoboken, New Jersey



Note: Unlike the maps for New York City subway stations, only bus stops are indicated on this map not the number of buses that stop at each stop. There are many more buses stopping at each bus stop than there are bus stops.
Source: Maps were constructed by members of the research team using ARCGIS (ESRI 2014) from publicly available data sources.

IV. DISCUSSION AND IMPLICATIONS OF RESEARCH FINDINGS

The New York area depends on a flexible, well-connected transportation system. The system must be able to withstand the adverse effects of extreme events that have posed serious harm to its infrastructure. Transportation is vital for survival and the protection of social systems and the economy. In many extreme events, the impairment of transportation compromised the ability of society to recover or at the very least prolonged recovery.

The size of the New York area's population and its transportation infrastructure presents a unique opportunity to understand how flexibility is supported through the connectivity of its rail and bus transit systems. Rail and bus interconnections provide important multi-modal flexibility. Bus connectivity with rail transit in New York City and three cities in New Jersey (Newark, Hoboken, and Jersey City) indicates substantial variability in rail-bus connectivity among stations. A statistical analysis of the variations suggests a slightly inverse relationship between bus connectivity and the percent of the population below poverty in the single census tract within which the subway station is located. A positive relationship between number of train tracks and bus connectivity was also found. Future research in this area could include expanding the models presented to include variables related to land use and zoning that could also explain the association between subway lines at a subway station and bus connections. Two additional analyses were conducted for two subsets of the New York City transit system: stations that are terminuses within the four boroughs of New York City managed by NYC Transit and very dense portions of the system where numerous rail lines converge. Connectivity for the terminuses showed a higher level of bus connectivity than stations system-wide. For both New York City and three cities in northeastern New Jersey, connectivity is also higher for some of the very dense stations, measured in terms of the number of lines converging at a station.

Other forms of intermodal connectivity operate within the New York area including bikes, various privately operated vehicles, waterborne transit such as ferries, and street systems that support walking. These other modes vary considerably in energy intensity and commuting time. Future research could explore the interconnectivity of these other modes for passenger multi-modality with rail and buses to enhance transit flexibility.

Moreover, in order to characterize stations according to their demographics, only a single census tract was used in which the station was located. The defining characteristics of a particular station might extend far beyond that single census tract, but it is difficult to provide that information without origin and destination studies. Therefore, an area for future research is to characterize the demographics beyond a single tract based on how people travel.

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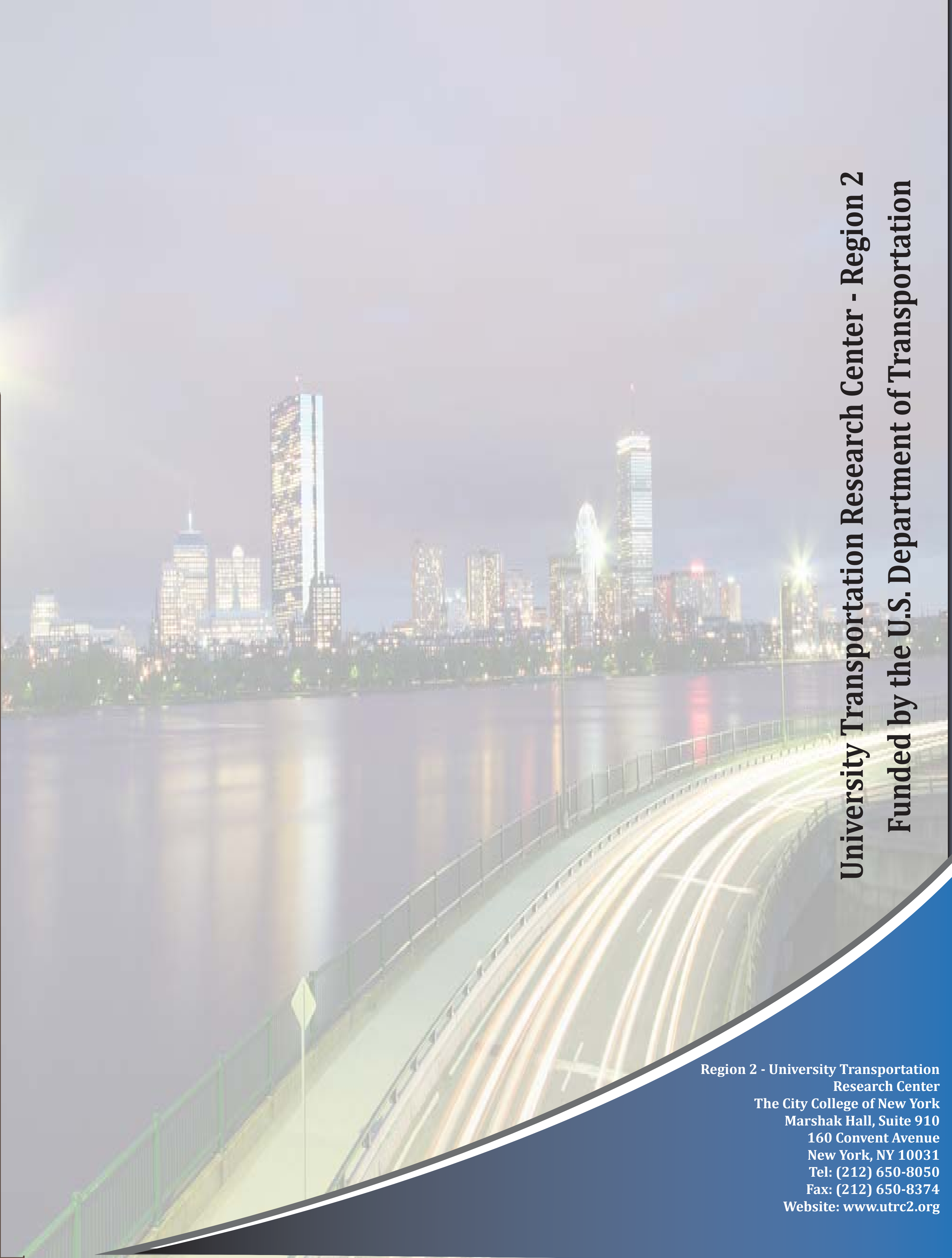

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