Quantifying Transit Access In New York City: Formulating an Accessibility Index for Analyzing Spatial and Social Patterns of Public Transportation

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Quantifying Transit Access In New York City: Formulating an Accessibility Index for Analyzing Spatial and Social Patterns of Public Transportation

by

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Submitted in partial fulfillment of the requirements for the degree of Master of Arts in Geography Hunter College of The City of New York

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ABSTRACT

This paper is aimed at analyzing the accessibility of New York City’s public transportation system through the creation of an appropriate and applicable accessibility index. The derivation of the index is detailed and then used to spatially analyze using Geographic Information Systems, where transit need is greatest and where access is lacking. A thorough regression analysis is performed to highlight relationships between certain demographic attributes and accessibility. Finally, recommendations for transit expansion are presented within a case study section, which highlights underserved neighborhoods.

KEY WORDS

Accessibility
Transit
Public Transportation
Subway
Bus
New York City
GIS
Spatial
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INTRODUCTION

Public transportation serves as the means for necessary and desired movement across time and space. Systems of public transit differ in size, coverage and modes, however each aims to serve the community by offering the most efficient and largest network possible. The resources available and landscape of a region as well as the paradigm employed by the planners, determine the extent and the nature of the public transportation network. New York City, as the largest city in the United States, possesses an impressive agglomeration of rail and bus services, which serve the population every day of the year at all hours of the day. Service however, differs neighborhood by neighborhood based on the existing infrastructure. This paper is aimed at quantifying the level of service for each census tract in New York City by the means of an accessibility index.

There are three goals of this paper which all stem from the concept of measuring “accessibility”. The first goal is to develop a thorough yet realistically implementable accessibility index through the identification of attributes of access in the form of quantifiable variables. The second goal is to use the index derived in the first goal to identify areas that are lacking access, by means of comparing transit offered with transit need. The final goal of the paper is to use the index to perform regression analysis through neighborhood case studies in an attempt to correlate patterns of accessibility with socioeconomic and demographic traits.
LITERATURE REVIEW

Transportation advancements in range and efficiency can be considered the marquee driving factor when looking at the push towards an ever globalizing world network. Cross continental travel has become a half-day affair and intra-nation city-to-city commutes have become accessible in multi-modal efficient fashion. Automobiles, trains, busses and airplanes have allowed for an ever increasingly connected world, economically, socially and politically. Transportation allows for increased communication, the distribution of wealth and goods and the ability for a higher quality of life. While increasingly important, long distance transportation is not the only form of critical human movement. In the urban environment intra-city transportation is the life and blood of a metropolitan area. There are public transportation systems and road infrastructure networks designed to serve society in the most efficient way possible, or at least that is the idea. This paper will serve as a means for analyzing New York City’s public transportation network and assessing the transportation accessibility of the neighborhoods within the city. Special emphasis will be placed on identifying underserved neighborhoods and disproportionately affected demographic groups within such vicinities.

In order to analyze the current transportation networks of New York City certain contexts must be identified, terminology defined, and paradigms discussed. The goal of this project is to identify the degree to which the public transportation system serves the New York City community. Although everyone benefits from an efficient and wide-spanning transit system, certain populations and certain neighborhoods need the
system more than others. Concepts regarding urban transportation systems must be reviewed in order to perform analyses that will rate the system spatially throughout the extent of the city and identify where access is lacking. This literature review will attempt to define the urban concepts of accessibility and mobility within the framework of public transportation as they pertain to assessing New York City’s transportation system. Once a thorough comprehension of the notion of accessibility is established, a quantification of the concept can be identified to best address the specific nuances of New York City. Existing accessibility indices will be reviewed and critiqued to set the stage for implementing an index specifically applicable to New York City in a geographic information system. The literature reviewed will lay a foundation for the second part of the GIS analysis which will attempt to identify any existing relationships between demographic attributes and geographic distribution of transportation access.

Urban Transportation

Urbanization, similar to globalization, has been continuously re-shaping the interaction networks within metropolitan areas of the world. To grasp the role of transportation systems within the urban context, an understanding of the urban form is a necessary foundation. There are two sources (among several others that will be referenced) that will serve as the basis for a theoretical framework in defining urbanism and the corresponding transport systems. “A Dictionary of Human Geography” is the most current “encyclopedia” of geographical concepts and terminology, and is published by the Oxford University Press (2013). “The Geography of Transport Systems”,
authored by Jean-Paul Rodrique et al. incorporates modern urban ideals geared specifically towards contemporary transportation theory and practice.

The purpose of transportation stated simply is to “overcome” space; essentially meaning that distance stands in the way of accomplishing something. Whether it be movement, communication, or a combination of the two. According to Rodrigue (2013) there are certain constraints that create the notion of a friction of distance. Constraints can come in the form of physical distance, duration of time, political barriers or boundaries or topography. Transportation attempts to combat the friction of distance at the lowest cost (in terms of time and money) possible to achieve a specific spatial goal. In this paper, the goal is the efficient movement of people through New York City, how they desire.

The necessity of transportation is almost so inherent in human nature that its importance is often overlooked and difficult to grasp. Rodrigue (2013) states that “transportation is an indispensible component of the economy and plays a major role in supporting spatial relations between people and the rest of the world”. Although almost overly concise, Rodrigue is essentially claiming that transportation is the driving factor of human activity. It is so ingrained in every person, and thus every action and desire of accomplishment. There are four core concepts of transport outlined in the Geography of Transport Systems. Modes, infrastructures, networks and flows, each represent a fundamental component of transportation.

Modes represent the means by which transportation is supported. Different modes are appropriate for transportation of different scales, at different times and
across different types of geographies. Rodrigue (2013) first breaks modes into 3 basic
categories representing the general geography through which the mode attempts to
facilitate movement. Water, land and air are the three major types of geographies and
each necessitates unique infrastructures and networks. For this paper, land
transportation will be the only set of modes analyzed, however it must be recognized
that both water and air travel play a huge role in the overall transport network of New
York City. There is a plethora of ferry service that provides access to and from
Manhattan from New Jersey, Staten Island and adjacent boroughs, which serves a huge
number of daily commuters (between 49,000 and 65,000) according to the New York
City Department of City Planning (2007). There are also three major international
airports within 10 miles of Manhattan, Newark Liberty International, LaGuardia
International and John F. Kennedy International servicing 37, 58 and 28 million
passengers annually respectively (Port Authority of New York and New Jersey, 2015).

As we focus on land transportation, by far the set with the most unique sub-
modes, specific application becomes the determining factor for which form is
appropriate. Land transportation modes can be broken down further into a dichotomy of
road versus rail. Road transportation according to Rodrigue has the lowest level of
physical constraints thus allowing for a diverse set of specific transportation activities to
take place. Roadways can take many specific forms, from limited access highways to
dirt trails, however they offer flexibility in terms of vehicle size, shape, speed and
personal decision-making. Roadways also facilitate both motorized and non-motorized
transportation including walking and biking, which are both major forms of travel in
urban areas.

Rail transportation is a “traced path on which wheeled vehicles are bound” (Rodrigue, 2013). Railways, unlike roads have a tremendous number of physical constraints, namely the rail itself and its compatibility with certain sized locomotives, electrical output needs and station locations. Constraints make for a more rigid mode of transportation with specific schedules, routes and vehicles and give individuals transporting, less control. Depending upon the needs of the individual and the location of the service, there are pros and cons to both rail and roadway transportation. Pros and cons are primarily measured in terms of cost, which can manifest in several forms.

Cost, defined by Rodrigue can be defined in terms of time and in terms of money. It may be cheaper to drive your automobile in New York City 35 blocks using, perhaps 50 cents of gasoline but the traffic of other vehicles may cause the trip to take 25 minutes instead of 6 minutes on a subway for 2 dollars and seventy five cents. These costs are the determining factors for which mode is chosen for a given trip. Some wealthier individuals may value their time more than the incremental money spent on a train ticket that saves them some of that time. On the other side of the spectrum there are those who may not be able to afford to take the more temporally efficient trip simply because they do not have the resources to afford such a luxury. These costs can begin to help inform planners regarding transit needs and where certain services should be implemented.
Defining Accessibility and Mobility

As noted several times already, transportation is aimed at efficiently serving the human population of a region at the lowest possible cost. Since there are numerous constraints that interfere with a hypothetically perfectly efficient system making stops at every point in space at all times, certain sacrifices must be made. There is a fixed amount of resources allotted to transportation systems, and there are physical barriers, which both play a role in preventing optimal service. Transportation and urban planners are tasked with taking the available resources and providing the highest level of service given the existing constraints and knowledge of the economic and social networks that exist within a city or metropolitan region.

Determining how to best allocate resources while creating the highest level of service becomes difficult without a clear notion of how to quantify “good” service. There are myriad attributes of transit service that can always be improved upon; the difficulty is assigning greater weight to some of those attributes to serve the best interest of the population. Several questions arise at this juncture however. Do different geographic tracts of a city require different service? Do certain populations need public transportation to a greater extent? How do we measure the benefits of increasing certain attributes of service such as time between trains versus expansion of a line to a new neighborhood? Planners of certain academic backgrounds may place emphasis on certain measures of transit efficiency, while others may completely disagree. A topic not
covered in this paper, but worth mentioning to provide food for thought is the intense
disparity between public and private public transportation service. For profit transit will
allocate service to maximize ridership and limit costs while public agencies are designed
to best serve the community. This paper focuses on the public transportation of New
York City, thus only government agencies and their practices will be of concern.

The intricacies involved in designing an efficient public transportation system can
be effectively evaluated through a thorough conceptualization of the two terms
accessibility and mobility. A large percentage of metropolitan planning agencies include
both accessibility and mobility in their “long term transportation plans”. From city to
regional to the federal level, planners consistently use accessibility and mobility to
explain and justify initiatives aimed at improving transit operations in their jurisdiction.
According to Susan Handy of the University of California at Davis (2002), the two terms
are often confused and very rarely defined in the aforementioned governing plans. Not
only are they rarely defined, but their definitions are often the subject of major
discrepancies between academics and professionals alike. This section of the literature
review is aimed at highlighting multiple definitions of the two terms from accredited
experts and agencies. Acknowledging certain biases and nuances of the origin of the
definition in terms of both the authoring individual, government or agency as well as
their geographic location is key in honing in on the appropriate definition for New York
City and for the purpose of this paper.

While this paper is aimed at measuring the accessibility of New York City’s public
transportation system, understanding mobility and its relationship with accessibility is
absolutely critical to contextualize the metrics associated with the efficiency of the network. Beginning with the broadest definition, mobility is the movement of people, ideas or goods across territory (Gregory et al, 2013). Refining that definition to the specific application of transportation geography, we read mobility as the movement of people or freight measured in terms of speed, capacity and efficiency (Rodrigue, 2013). According to the Victoria Transport Policy Institute of British Columbia (2011), mobility is the “movement of people and goods, recognizing both automobile and transit modes, but still assumes that movement is an end in itself, rather than a means to an end. It tends to give little consideration to non-motorized modes or land use factors affecting accessibility”. Handy (2002) quotes the American Heritage Dictionary, defining mobility as the ability to move or to be moved and the facility of movement. She also states that mobility is traditionally measured with level-of-service metrics which emphasize speed.

While each of these definitions differ in their exact terminology and level of specificity, the common thread is the notion of efficiency of movement, or the ease at which movement is facilitated. Mobility according to these definitions is a measure of how fast and easily movement can occur within a transport system. Increasing mobility is essentially creating greater efficiency in reaching accessible locations within the area served. Accessible locations are a function of where and how the transport network is arranged. Mobility is best conceptualized as an “efficiency” measure of accessibility.

Like mobility, accessibility has a multitude of definitions and an even greater divergent, inexact meaning. It can easily be argued that the definition of accessibility is never static, but is completely relative to the basis of the application. According to
Gregory et all, 2013 accessibility is “the ease with which goods and services in one location can be accessed by people living in another location. Transportation and communications media are key infrastructures in this regard, with availability, distance, time, and cost being principal constraints, along with structural barriers such as age, gender, disability, and class. Access to goods and services is often viewed as a key measure of social equity—that is, the greater access one has, the better off one is”. The Victoria Transport Policy Institute (2011) defines access as “the ultimate goal of most transportation, except a small portion of travel in which movement is an end in itself (jogging, horseback riding, pleasure drives), with no destination. This perspective assumes that there may be many ways of improving transportation, including improved mobility, improved land use accessibility (which reduce the distance between destinations), or improved mobility substitutes such as telecommunications or delivery services”. These two definitions create a lucid distinction between accessibility and mobility, essentially conferring that accessibility is a rudimentary measure of the ability to reach basic human necessities. Unlike mobility, access is the ability to move or be moved, rather than the speed at which such movement is facilitated. The dichotomy is tricky however, as there is certainly a difference in access between a hospital that can be reached in ten minutes versus one hour. Understanding the fundamental differences while acknowledging the interdependence is key before accurate measurement of accessibility and mobility can be performed.
Accessibility Indices

Now that the critical components of urban transportation have been outlined and definitions of accessibility and mobility have been qualitatively defined, the quantification of such measures must be tackled. Moving from a qualitative assessment of a measure, to something that can be empirically understood is difficult and involves a thorough review of previous research, studies and application. Understanding the context of specific research initiatives is equally important as measuring accessibility in one region may require different metrics and scales than another. This section of the literature review will highlight the findings of several research studies and academic papers attempting to quantify accessibility using “indices”. An index is a way of assigning empirical value as a means of rating an attribute, in this case, accessibility. The input of a given index will vary from instance to instance based on the researcher or agency’s exact definition of accessibility and their region’s specific needs and nuances. This paper will postulate the best possible accessibility index for New York City, however this literature review will encompass an analysis of several indices which have been assigned to rating transport systems of varying urban contexts. Understanding which attributes are valued and how they are weighted for a given city will help to form the basis for the index to be assigned to New York City.

The first measure of accessibility to be reviewed is an index developed by the government organization “Transport for London”. They released a study summary in 2010 titled “Measuring Public Transport Accessibility Levels”. This specific index was
chosen for reference here because they provide a concise synopsis of exactly what their index attempts to measure, and such is closely aligned with the goals of this paper. The agency states that the indexes they develop “are a detailed and accurate measure of the accessibility of a point to the public transport network, taking into account walk access time and service availability. The method is essentially a way of measuring the density of the public transport network at any location within Greater London”. This index is especially relevant to this paper because it measures accessibility to the public transportation network of the city and does not take into consideration accessibility to specific goods and services. This is evidence of a malleable definition of accessibility. In this case access is specifically defined in terms of the public transportation network itself *rather* than the offerings of the city, where as many define accessibility as the ability to reach those offerings.

According to the summary report, the index developed by Transport for London reflects:

- Walking time from point of interest to the public transport access points
- The reliability of the service modes available
- The number of services available within the catchment
- The level of service at the public transport access point “waiting time”

They specifically state that the index does not take into consideration the speed of the service, which would reflect a level of mobility. Interesting aspect to note, as they seem emphasize wait time, but not speed of service, even though each have the same net effect on the efficiency of access within the network. The difference here is access to
the network rather than efficiency once the network is accessed. This is one of the many subtleties between accessibility and mobility; one which the agency seems to thoroughly grasp, making it a credible reference of analysis.

Transport for London uses three modes of transportation to calculate their indices, busses, national rail and the London Underground. They calculate a level of accessibility for a given point of interest for each of the available modes, and then calculate the sum of the index for each mode into a final PATL (public transportation accessibility level). Important to note here is the use of even weighting for each mode of transportation. Because they have chosen to incorporate wait time into the accessibility level for each individual mode, there is no need to weight certain modes higher than others because it is already accounted for once summed. This index is extremely simple and uniformly applicable because of its ease of implementation. The data is retrievable from government agencies and easily quantified to form the index. They present their findings on a scale of 1 to 6 with 1 being very poor and 6, excellent. Level 1 is broken down into “1A” and “1B” and level 6 is broken down into “6A” and “6B” to further identify the worst of the worst and the best of the best.

The next accessibility measure is more complex in nature and breaks down accessibility into three methods of indexing. “A Composite Index of Public Transit Accessibility” prepared by Sha Al Mamun and Nicholas E. Lownes for the University of Connecticut reviews and presents three methods for measuring the accessibility of public transportation in Meriden Connecticut. This paper was chosen for reference because it highlights intricacies of public transit accessibility that are worth evaluating,
even if hyper specific or impossibly difficult to implement. It also provides an example of indexing for a much smaller urban area with a less sophisticated and expansive transportation network.

Mamun and Lownes present three components of accessibility, trip coverage, spatial coverage and temporal coverage. They define trip coverage as the ability to reach the desired definition. They refer to spatial coverage as the proximity to or from one’s home or point of interest. Finally they use the term temporal coverage referring to the times in which service is provided. Their methodology takes three forms which are then summed to form a composite score with a specific weighting scale. The first method is called the Local Index of Transit Availability (LITA). They state that this index is used to measure the transit service intensity of an area using census data as well as transit data to calculate a score for a given tract. Transit routes, capacity, stops and stations are the major metrics used to calculate the score per each unit of land area.

The second method they use is called the Transit Capacity and Quality of Service Manual. This method is especially relevant to this paper as it is calculating using Geographic Information Systems. They use a .25 mile buffer around stations and stops to identify areas with high access to the bus network of Meriden and calculate which geographic areas of the city are accessible based on a point distance from a bus stop along a given route. The third method, called the Time-of-Day Tool is also calculated using GIS and takes into consideration the temporal distribution of service availability and service demand. This method is used to measure the degree to which transit is provided and utilized throughout the day in a given tract of land.
While rather complex and not as relevant to this paper’s analysis of the accessibility of New York City’s transit system, Mamun and Lownes do provide insight to one aspect of accessibility indexing that is critical. The final part of this study discusses how scores are standardized for easily interpretable empirical measure of accessibility using each method. They present a standardization of each of their three scores which is calculated by taking “the difference between the raw score for a given tract and the mean of scores for all tracts, and then the difference was divided by the standard deviation of scores for all tracts”. Once each score was standardized, the three scores were summed to create the comprehensive index for each tract.

The next two accessibility indices to be explored each posit accessibility in terms of access to opportunities across the geographic space of a region. Before delving into the analysis of each of these indices, it is important to identify when it is appropriate to define accessibility as such, and when it is not. There are several different levels of cities in terms of size, opportunity and services provided. In the case of a small city surrounded by sparsely developed land, it may be important to include the location of jobs or hospitals or certain other important services which may only be located in specific areas in low density. In the case of large highly developed, dense cities (on the order of London, Tokyo and New York City) such destinations are so frequently present in both time and space that it may not serve the researcher any good to bother including them in the analysis of access.

Curtin University in Bentley, Australia released a study reviewing 41 different measures of accessibility in an attempt to create an index of accessibility to quantify
benefits of a new rail corridor in the area. They begin their analysis with a definition of accessibility as follows: “While mobility is concerned with the performance of transport systems in their own right, accessibility adds the interplay of transport systems and land use patterns as a further layer of analysis. Accessibility measures are thus capable of assessing feedback effects between transport infrastructure and modal participation on the one hand, and urban form and the spatial distribution of activities on the other hand. Some accessibility measures also include behavioral determinants for activity patterns in space and time, and the responses of transport users to physical conditions”.

Immediately it can be recognized that this research initiative is geared towards an area which falls into the category of regions which do not have uniform opportunities provided in a dense geographic area, and thus weighting specific destinations into the index is necessary.

This study breaks accessibility measures into a very detailed table of different approaches to quantifying accessibility. The first measure defines “catchment” which is essentially the travel impediment (or distance) to a given mode of transport or location. The second measure incorporates capacity constraints which help to portray regional differences in service availability and coverage. The third measure uses pre-defined time constraints to indicate clustering of trips with spatial-temporal clustering of activities. The next two measures incorporate societal benefits of certain attributes of the transit system which adds to the complexity of the index immensely. The final measure is used to index the route options by measuring centrality and intersection nuances of the network. Such an index is extremely complex and can only be
calculated by an agency who has access to tremendous amounts of data all available at the same scale and precision, which can utilize powerful Geographic Information Systems and data transformation software. As is the case with this specific study, such an index should be used when determining specific cost benefit analyses for an expensive project or new policy. This is not an index which would be used to paint a broad picture of the accessibility of a large city which is both easily interpretable and applicable to an entire region. Thus it will not be directly referenced to support the index this paper will assign to New York City, but simply as evidence of the differing views and application of measuring access.

The final example of an urban accessibility index is that of the Minnesota Department of Transportation, used to evaluate the accessibility of the Minneapolis-St. Paul region. The study was released in 2006 as part of the “Access to Destinations” project. The Department of Transportation provides a brief introduction to the study, again starting by clearly stating how they define accessibility for their own planning purposes. “The word “accessibility” has been around in the transportation planning field for more than 40 years, yet one often sees the term misused, so clarity in definition is important. Accessibility measures the ease of reaching valued destinations. Several cities use congestion levels and annual mobility reports to evaluate the performance of the transportation system, yet this misleads by looking only at the costs of travel while ignoring the benefits. This research demonstrates how accessibility can be used as a tool for evaluating the land use and transportation system in the Twin Cities region”.

Similar to the previous example, accessibility here is measured in terms of the
ability to reach desired destinations. This example is particularly interesting because of the methodology used to calculate the accessibility index. They implement an “accessibility matrix” that pins destinations with modes of transportation to such destinations. Figure 1 below shows their example, taken from the body of their report.

Figure 1: Accessibility Matrix (Minnesota Department of Transportation, 2006)

Such methodology seems like an appropriate way to calculate an accessibility index given the size and layout of the Minneapolis St. Paul region. While certainly a large city, it does not possess the density of goods and services that an international city like New York has, and thus requires a more segmented breakdown of accessibility measures. Calculating scores for each mode with each destination adds to the tedium of applying the index and also requires a greater amount of data.

DATA AND METHODS

The data and methods section of this paper will be broken down into the five following sections: New York City and Accessibility, Demographics and Accessibility,
Index Derivation (Transit Accessibility and Transit Need), Regression Analysis and Intersection of Need and Accessibility

The first two sections of the methodology aims to explain the nuances of New York City that make it a unique case study for accessibility. The geography, existing transit system and demographics of the city are highlighted through a series of maps and discussion. The result of the third section of methodology will be a “Transit Accessibility Index” and a “Transit Need Index”. The fourth part of the methods is aimed at locating the intersection of neighborhoods within New York City that possess a high level of transit need, yet a low level of transit access. The fifth section of methods is dedicated to correlating certain demographic attributes as indicators of transit accessibility. The results and discussion chapter which will follow presents the findings of each section of the methodology and will include a deeper look at the specific neighborhoods that were found to be most severely underserved.

New York City and Accessibility

Each of the four cases of accessibility index creation and implementation provides examples of unique geographies, requiring certain attributes or infrastructures to be included. From a large historical city like London, to small-town, Meriden Connecticut, there are established methodologies that create appropriate indices for measuring accessibility. When a specific research initiative calls for a measurement of accessibility, there may be specific destinations, modes or weights that need altering. For the purpose of this paper, a general analysis of accessibility to the public transportation system of New York City is the goal. That goal is aimed at providing
insight into two phenomena. Firstly a purely spatial, statistical analysis will serve as a means of illustrating census tracts (and thus, neighborhoods and boroughs) that have high, average and low levels of accessibility. The second phenomena that will be explored is the relationship between transit need and transit available. Transit need will be a function of automobile access, household income and housing density. Demographic attributes such as race and income will be explored for correlation to levels of transit accessibility in a given area using regression analyses.

Understanding the aims of the paper, a specific way of measuring accessibility will be more appropriate than others. The conceptualized index is a product of the reviewed literature and a contextual analysis of New York City’s transit system and demographic spatial profile. This part of the literature review will provide context to the intricacies of New York City’s geography, its transit system and its demographic profile as it pertains to the research interests of the paper. The information will be presented in the form of maps and summaries created using ESRI’s ArcGIS software and the spatial analysis application, GeoDa. Data was gathered from official U.S Government Census and American Housing Survey sources using American Factfinder as well as the New York City Department of City Planning’s website “Bytes of the Big Apple” and the Hunter College Center for Spatial Analysis (the Spatiality Blog).

The following map (Figure 2) presents New York City and the location of its four contiguous boroughs Manhattan, Brooklyn, The Bronx and Queens to set the regional context of the area of interest.
Figure 2: New York City with Census Tract Borders and Borough Labels
As seen in figure 2 above, New York City in the context of this research initiative will be defined as the four contiguous boroughs of Manhattan, Brooklyn, the Bronx and Queens. Staten Island was excluded for several reasons all relating to the suburban nature of the geography, demographics and transit system of the borough. The New York City Subway is a major component of the analysis performed for this paper, and because it does not extend to Staten Island, a different system for measuring accessibility would be necessary. The New York City Subway system operates 24 hours per day 365 days per year and is ridden by over 5.5 million people each week day according to the MTA (2016). Figure 3 below illustrates the extent of the New York City Subway System in 2015 (before the addition of the second avenue subway line. Express and local service are delineated through different coloring, with red symbolizing the option for express and local service and black symbolizing local service only. Important to note is that Manhattan is the nucleus of the subway system with almost every line running through the borough between either Queens and Brooklyn or the Bronx and Brooklyn. Express service can also be seen as extremely dense in Manhattan, yet non-existent in many neighborhoods in the three outer boroughs. Figure 4 on the following page shows the distribution of subway entrances throughout the city. This dataset is used extensively as a means for calculating subway access as a function of distance from a station.
Figure 3: New York City Subway Lines 2015
Figure 4: New York City Subway Station Entrances
In addition to underground and aboveground rail service the Metropolitan Transit Authority also runs public bus service throughout New York City which account for just over 2 million riders per average weekday (MTA, 2016). Bus service is also run in conjunction with subway service 24 hours per day, 365 days per year. The bus is a critical link for those living in more remote sections of the outer boroughs where subway service does not extend. Bus service is much more evenly spread out than subway service, however higher concentrations of stops and routes are still found in Manhattan.

Bus service will be the second mode of public transportation helping to comprise the accessibility index throughout the city, in conjunction with subway service. It is thus important to visually understand its distribution and level of service to appropriately weight its importance within the index. While both the bus and the subway operate at all hours of the day and all days of the year, higher efficiency is undoubtedly found riding rail. There are three ways in which the subway is of greater importance to New Yorkers. Wait time, speed of travel and ridership all favor subway service. Firstly there is less time between subways on an average weekday during rush hour than there is between busses. Local subways run on average every 4 to 6 minutes during peak hours while local busses run on average every 10 to 12 minutes (MTA, 2016). In some cases along the most heavily traveled subway line such as the Lexington Ave Local Line (6 train) subways run every 3 minutes. Quantifying exactly how much faster subway service is than bus service is difficult, however when viewing travel times from Eastern Queens to Midtown Manhattan comparing the F Subway Line, to corresponding Bus routes, the
subway proves to be more than 50 percent faster (30 minutes compared to 65 minutes) (Google Maps Estimate). While subway service does experience delays due to unforeseen events such as track fires, construction, and accidents, there is no influence of street traffic with which busses must constantly grapple. Lastly, the daily ridership of the subway system is 2.5 times higher than the bus system (MTA Factsheet). While the bus unquestionably serves an extremely important niche in public transportation, the subway network is preferred by New Yorkers for quick, dependable service, especially to and from places of employment. Many neighborhoods in outer boroughs depend on bus service to link to subway lines which offer quicker service for journeys of greater distance. Figures 5 and 6 highlight the official bus routes as of 2008 as well as every bus stop in the city. Figure 7 showcases the density of bus stops per mile, illustrating the areas that are best and least served by the New York City bus network.
Figure 5: New York City Bus Routes
Figure 6: New York City Bus Stops
Figure 7: New York City Bus Stop Density
Demographics and Accessibility

Now that the geographic distribution of the two main modes of public transportation within New York City has been established, the demographic distribution will be explored. Accessibility is a measure of a neighborhoods ability to reach the public transportation system of the city. Because the level of accessibility is obviously much different from neighborhood to neighborhood, one of the goals of this thesis is to parse out any existing relationships between certain demographics and levels of access.

New York City is an extremely interesting case study when it comes to demographics because of its anomalously high levels of diversity. While many “diverse” cities have very rigidly segregated neighborhoods (and these certainly do exist in New York), New York is home to the very clichéd “melting pot”. This essentially means that there are many sections of the city which are inhabited by many different ethnic and racial groups. Queens is considered to be one of the most diverse counties in the entire country, with 39.7% of the population being White, 19.1% Black, 22.9% Asian, 27.5% Hispanic and 13.7% other (2010 Census). The maps in this section will help to provide illustrative context for the demographic make up of New York City as it relates to the public transportation network, and ultimately the development of the accessibility index.

There are many variables that have been chosen for exploration, namely, income, vehicle ownership and race. Income and vehicle ownership were chosen as a means for assigning a degree of “need” for public transportation, while race was chosen
as a means for exploring inequalities experienced among individuals of different ethnic groups. This exploration was commenced because of a historical propensity of disadvantage among non-white groups, especially in urban America.

There are numerous modern works that cite such findings including examples of impoverished African American and Hispanic communities lacking access to both transit and super markets (the former of which influences the latter). Detroit, Michigan and Portland, Oregon, cities of very different history and demographic distributions are profiled in two studies, where it is concluded that there is a disproportionate burden placed upon minority race groups when it comes to urban access. Published in the American Journal of Public Health, Zenk et al. focus on the degree to which African American residents lack access to super markets in central Detroit. They concluded that there was an average of 1.1 extra miles between super markets within African American neighborhoods compared to neighborhoods that were primarily white with comparable economic demographic attributes (Zenk et al, 2004). Published by the American Sociological Society, Brian McKenzie of the U.S Census Bureau explored the lack of transit accessibility in impoverished neighborhoods of Portland Oregon and specifically concluded that Hispanic neighborhoods which have consistently possessed lower levels of access, had actually further declines from 2005 to 2009 (McKenzie, 2013). These two studies support the notion which has stood the test of time in America, that minority groups are constantly underserved in many ways. The regression analysis section of this paper will illuminate any relationships present within New York City. Figures 8 through 11 highlight in the form of quantile maps, the
geographic distribution of the aforementioned demographic variables that will be used in evaluating both transit need and racial inequities.
Figure 8: New York City Median Household Income
Figure 9: New York City Percent Black by Census Tract
Figure 10: New York City Percent Hispanic by Census Tract
Figure 11: Vehicle Ownership Percentage by Census Tract
Index Derivation

-Transit Accessibility

The accessibility index resulting from this paper is meant to be applicable to all areas of New York City (except Staten Island) by analyzing the two main modes of public transportation. Walking is inherently included within the index as a means of getting to and from station locations as a function of distance. Similar to the accessibility index created for London by Transport for London, in 2010, the index is intended to represent access to the public transportation system, rather than access to destinations. This was established because as a truly global city, New York- 8.55 million population (NYC.gov, 2016), like London- 8.53 million population (ONS.UK.gov, 2016), has a density of goods and services which is thoroughly spread throughout the contiguous 4 boroughs. In the case of a smaller city, there may be certain neighborhoods that do or do not provide certain basic human needs in the form of healthcare, recreation, grocery, or employment. In such cases, measuring accessibility in terms of ability to reach specific destinations is necessary, however for New York, it is not. The access to the transit system itself is the best indicator of accessibility as a measure for New Yorkers.

That being established, Transport for London recommended including four quantitative variables into their index of accessibility. Walking time to transport access point (distance), reliability of service mode (speed and traffic variables), number of service options, and the waiting time. They use commuter rail, subway and bus service
as the three modes of public transit. This model can be very similarly applied to New
York City as the same modes of service are available to the exact same sized
population.

The accessibility index will be comprised by a sum of a subway score, a bus
score and a disabled persons accessibility score. The bus score is comprised of only
one variable, and is the simplest score to calculate. The score is based entirely upon
bus station density per census tract. The density was calculated from a function of bus
stops per mile. The area geometry was calculated in ArcMap for each census tract, and
a count function was employed to find how many points fell within each census tract. A
new field was created titled “Bus_St_Den” representing the number of bus stop points
divided by the census tract area in miles to achieve a bus stop density. From the bus
stop density raw data, a bus score was developed on a scale of 1-10 to normalize the
density rates to later be combined with the other modal scores. Table 1, below shows
how the scale was derived using the following intervals with values ranging from 0 to 10.
The scale was cut off at 10 because once above 90 stops per square mile, additional
stops do not necessarily provide more access.

<table>
<thead>
<tr>
<th>Bus Stop Density (Stops/ Square Mile)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>.01-9.99</td>
<td>1</td>
</tr>
<tr>
<td>10-19.99</td>
<td>2</td>
</tr>
<tr>
<td>20-29.99</td>
<td>3</td>
</tr>
<tr>
<td>30-39.99</td>
<td>4</td>
</tr>
<tr>
<td>40-49.99</td>
<td>5</td>
</tr>
<tr>
<td>50-59.99</td>
<td>6</td>
</tr>
<tr>
<td>60-69.99</td>
<td>7</td>
</tr>
<tr>
<td>70-79.99</td>
<td>8</td>
</tr>
<tr>
<td>80-89.99</td>
<td>9</td>
</tr>
<tr>
<td>&gt;80</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1: Bus Service Score Derivation
The subway service score is comprised of multiple individual scores which together are combined to represent three attributes of subway access. The three individual scores represent the following three variables: distance to the nearest station, number of line options and express service option. Distance to the nearest station was calculated by using the “Near Analysis” function in ArcMap. The input features were the census tract polygons, and the near features were the station points. ArcMap grabs the nearest station and calculates a distance in feet for each census tract centroid. This represents the average distance a resident within a census tract must travel to reach the nearest subway entrance. Once the raw data was calculated in feet, the following scale (Table 2) was used to derive the score, again on a scale from 0-10. Census tracts more than 1 mile were given a score of 0 as a clean cutoff mark.

<table>
<thead>
<tr>
<th>Distance to Nearest Subway Entrance (Feet)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-500</td>
<td>10</td>
</tr>
<tr>
<td>500-1000</td>
<td>9</td>
</tr>
<tr>
<td>1-500</td>
<td>8</td>
</tr>
<tr>
<td>1001-1500</td>
<td>7</td>
</tr>
<tr>
<td>1501-2000</td>
<td>6</td>
</tr>
<tr>
<td>2001-2500</td>
<td>5</td>
</tr>
<tr>
<td>2501-3000</td>
<td>4</td>
</tr>
<tr>
<td>3001-3500</td>
<td>3</td>
</tr>
<tr>
<td>3500-4000</td>
<td>2</td>
</tr>
<tr>
<td>4001-5280</td>
<td>1</td>
</tr>
<tr>
<td>&gt;5280</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Subway Distance Score Derivation

Subway accessibility is about much more than just the distance from a station one must travel to access the rail network. In some areas of the city, there may be
several lines in close proximity, while in other areas there may only be one or even zero lines. The difference between having three of four lines to choose from rather than one, is quite large because different lines serve different destinations and different transfer hubs. The greater number of available lines, the greater access to the entire public transportation network. This score was weighted almost equally to the distance score because of how powerful options are in terms of accessing destination and for inter-borough trips. The best means for calculating the number of options one has, in terms of subway lines, is to count the number of lines intersecting a given census tract. This was performed in ArcMap using the “Intersect Analysis” tool. This tool calculated the number of polylines (subway lines) that intersected a given census tract. The score for this variable was simply equal to the raw number of intersecting lines which ranged from 0-15. The score was capped at 10 to remain standardized with the other scores. Thus, census tracts with greater than 10 intersecting lines still received a score of 10 for this index.

The final component of the subway accessibility score incorporates the speed of service. The best way for quantifying the speed of service is by differentiating express service from local service. Many subway lines were built with both local and express tracks (4 total tracks, two in each direction) to allow for quick service to “important” stops. The local tracks are on the outside (right side) which the express tracks operate on the inside. Express service skips local stops to provide the option for faster service to destinations further away. Having access to both local and express trains is a huge advantage for quick travel. An example of how much more efficient express lines can
be versus local is along the EFMR Lines in Queens (Figure 12).

Figure 12: Subway Map of EFMR Lines in Queens (MTA 2016)

Forest Hills is at the furthest east end of the M and R Lines which both operate locally in Queens. To get from Forest Hills to Manhattan along either of those local lines requires stopping at 12 stations along the way. However, the E and F lines are also available along the same line and require stopping at only three stations along the way, thus cutting the trip length in half. Having the option to choose between local and express service not only cuts down on the time you are on the train, but also cuts the wait time, as both trains are coming through the same station, with the option to take either. Express service was deemed a critical variable to consider within the accessibility index. Transport for London (2010) proposed including both service options as well as service speed within their index, both of which are a component of express service.

Express service can be quantified by taking the distance a census tract is
positioned from any point of access to an express line. Express lines were delineated in ArcMap and separated out from the Subway Line Polyline shapefile by creating a new field which marked a line as express or local in a given region. Using a near analysis each census tract was given a distance in feet from any of the express subway lines. The express service score was chosen to have a score ranging from 0-5 to essentially allot half the amount of weight of the distance score. The rationale here is that accessibility is more about access to the network rather than the actual speed of service, which would err more towards mobility. Express service provides greater access than local service, especially to those in the far reaches of the outer boroughs who are employed in Manhattan. For many a two hour commute is completely unreasonable, however an hour and 15 minute commute may be doable. Such a difference should be represented as increased access, but should not represent the same weight as one’s actual proximity to the service itself. The following scale (Table 3), based on distance from express subway access was used to derive the Express Service Score, the final component for the Subway Access Score, however it is only weighted 50 percent when added to the total subway score.

<table>
<thead>
<tr>
<th>Distance to Express Service</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1320</td>
<td>10</td>
</tr>
<tr>
<td>1320-2640</td>
<td>8</td>
</tr>
<tr>
<td>2640-3960</td>
<td>6</td>
</tr>
<tr>
<td>3960-5280</td>
<td>4</td>
</tr>
<tr>
<td>5280-10560</td>
<td>2</td>
</tr>
<tr>
<td>&gt;10560</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3: Express Subway Service Score Derivation
In addition to Bus and Subway Service Scores there is a third score, which will inform the final accessibility index. A major component of accessibility is found in the suffix of the word. The *ability* to access is embedded within the term and should not be forgotten. There is a large percentage of the population that is physically disabled and may not be able to climb stairs, go through doors, or step through turnstiles. In order for these individuals to access the public transportation system, certain features such as ramps or gates which allow for wheelchair access. New York City has installed such features and made certain stops and stations “accessible” to the physically disabled that depend on wheelchairs. The MTA has labeled on their website, which stations are wheelchair accessible. This data was already embedded in my point shapefile of station entrances with a field called “entrance_type”. An “access score” was derived by selecting all accessible station entrances and performing a near analysis to calculate how far each census tract was located from such an entrance. This score indicates the proximity to access to the subway network for those who rely on wheelchairs for movement and is the final component for the total accessibility index. This score was derived exactly the same as the express score was derived, using a scale of 0-10 with 10 representing census tracts within one quarter mile of an accessible station and 0 representing a tract further than two miles for an accessible station. This score was also weighted 50 percent when added to the total transit accessibility score. Since there are so few accessible stations, especially outside of Manhattan, using only distance to the nearest station, rather than a density provides the most relevant measure of accessing the network for disabled riders. Table 4 shows the distances and their
corresponding scores along the scale from 0-10.

<table>
<thead>
<tr>
<th>Disabled Access Score</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1320</td>
<td>10</td>
</tr>
<tr>
<td>1320-2640</td>
<td>8</td>
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<tr>
<td>2640-3960</td>
<td>6</td>
</tr>
<tr>
<td>3960-5280</td>
<td>4</td>
</tr>
<tr>
<td>5280-10560</td>
<td>2</td>
</tr>
<tr>
<td>&gt;10560</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4: Disabled Access Score Derivation

-**Transit Need**

The following subsection of the index derivation section addresses the idea of how much a region of New York City relies upon public transportation. This is a rather simple index derived from two variables. The two variables used are Median Household Income and Vehicle Ownership of a given census tract. These two variables were chosen because of how they affect a household’s reliance on the city’s public transportation. Income represents the ability to afford the most convenient forms of transportation such as cabs or commuter rail while automobile ownership symbolizes access to a direct means of transportation thus decreasing reliance on public transport.

The two variables are interestingly distributed because in some regions they are correlated with each other and in others they are not related at all. For example, in Manhattan cars are rarely needed for everyday use because of the high density of goods and services as well as the extensive subway network. Thus, higher income does not necessarily mean higher car ownership. However, in extremely wealthy areas, such as the Lenox Hill neighborhood of the Upper East Side, income is so high that
some households so indeed own automobiles because they can afford to keep them garaged. In the outer boroughs higher income sometimes does correlate to higher vehicle ownership, especially in neighborhoods of moderate density, such as Jackson Heights or Bushwick. Tables 5 and 6 show the scales used to index Household Median Income and Vehicle Ownership, respectively. The sum of these two scores creates the total need score, used in the regression analysis in the next section to locate the intersection of transit need and transit access.

<table>
<thead>
<tr>
<th>Household Median Income</th>
<th>Score</th>
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<tr>
<td>$0-10,000</td>
<td>10</td>
</tr>
<tr>
<td>$10,000-20,000</td>
<td>9</td>
</tr>
<tr>
<td>$20,000-30,000</td>
<td>8</td>
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<tr>
<td>$30,000-40,000</td>
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<tr>
<td>$40,000-50,000</td>
<td>6</td>
</tr>
<tr>
<td>$50,000-60,000</td>
<td>5</td>
</tr>
<tr>
<td>$60,000-70,000</td>
<td>4</td>
</tr>
<tr>
<td>$70,000-80,000</td>
<td>3</td>
</tr>
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<td>$80,000-90,000</td>
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<td>1</td>
</tr>
<tr>
<td>&gt;$100,000</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5: Income Score Derivation
Vehicle Ownership Score

<table>
<thead>
<tr>
<th>Vehicle Ownership</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10%</td>
<td>10</td>
</tr>
<tr>
<td>10-20%</td>
<td>9</td>
</tr>
<tr>
<td>20-30%</td>
<td>8</td>
</tr>
<tr>
<td>30-40%</td>
<td>7</td>
</tr>
<tr>
<td>40-50%</td>
<td>6</td>
</tr>
<tr>
<td>50-60%</td>
<td>5</td>
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<tr>
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</tr>
<tr>
<td>70-80%</td>
<td>3</td>
</tr>
<tr>
<td>80-90%</td>
<td>2</td>
</tr>
<tr>
<td>90-100%</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6: Vehicle Ownership Score

Regression Analysis

This section of methodology is aimed at exploring the patterns of accessibility across New York City and how they relate to other demographic and geographic characteristics of the urban land and social-scape. The goal of this initiative is to quantify the relationships between race and income with transit accessibility and to develop a model that predicts transit accessibility with the highest possible coefficient of determination (R-Squared). This value represents the degree to which independent variables help to explain the value of the dependent variable. In this case our dependent variable will always be the transit accessibility index which was derived in earlier sections of the paper, for each census tract in New York City. The independent variables to be modeled are:

- Race (Black and Hispanic) (2010 U.S Census)
- Income (Household Median Income) (2010 U.S Census)
Before performing the analysis it was hypothesized that the coefficient for both the Hispanic and Black variables would be negative, meaning that the higher the proportion of Black and Hispanic residents in a census tract, the lower the accessibility score should be. Income is predicted to have a positive coefficient, meaning that higher income neighborhoods should see a higher degree of access. Vehicle ownership is expected to have a negative coefficient, mainly because many of the neighborhoods with a high level of vehicle ownership such as Eastern Queens and Southeastern Brooklyn, possess much lower access to subway service. Lastly, residential housing density is expected to have a positive coefficient, meaning that the denser the residential housing in a neighborhood, the greater the degree of transit access. This is expected because Manhattan possesses such a high level of both housing density and transit accessibility.

The first part of the regression analysis will be to plot each variable individually to understand the individual relationships before combining them to create the most applicable model for predicting total accessibility. With each individual explanatory variable explored in terms of understanding its relationship with access, the next section of the methodology will lend itself to discovering which combination of the variables produce the highest coefficient of determination and will thus most appropriately model how to predict transit access. Each additional variable proved to better predict where...
greater transit access is located throughout New York City, providing evidence for the individual importance of each of them.

Once the entire model was formulated using the ordinary least squares regression, a test for spatial autocorrelation was applied to check for clustering or dispersion. This is necessary because if spatial autocorrelation is detected, a geographic weighted regression must be applied to correct for the clustering. A spatial autocorrelation test within ArcMap was conducted, and proved that clustering of the residuals did warrant a geographic weighted regression. The results of the ordinary least square regression, the spatial autocorrelation test and the geographic weighted regression are all presented and analyzed in the results and discussion chapter.

**Intersection of Need and Accessibility**

The final section of the methodology attempts to find where areas that need transit the most actually suffer from a lack of accessibility. The variables contained in the need index (vehicle ownership and income) will be plotted against the accessibility index (dependent variable) in a Geographically Weighted Regression helping to explain where transit accessibility is both needed and lacking. In a perfect world we would end up with an R-squared value of 1 where there would be no residual. This would mean that areas that need transit are provided transit accessibility to the exact degree they need. Obviously such a system does not exist, and there are undoubtedly areas that are underserved and overserved. This Geographically Weighted Regression (performed in ArcMap) assigns a predicted value in terms of transit accessibility based on transit need. This regression is extremely over-simplified and is only meant to
analyze the quantitative deviation in accessibility experienced by neighborhoods of differing need.

RESULTS AND DISCUSSION

This section will present the cartographic representations of each step of the methodology chapter and provide an analysis of the geographic patterns and relationships which are illustrated. It will be structured into the following five sections: Accessibility Index, Transit Need Index, Regression Analysis, Intersection of Need and Accessibility, Case Studies and Recommendations

Accessibility Index

Starting with the components of the transit accessibility index, the following set of maps illustrates the distribution of each part of the total index to highlight how the final score was derived. Figure 13 highlights the bus service score, derived purely from the bus stop density value assigned to each census tract. Figures 14, 15 and 16 represents the three components of the subway score: the distance score, the line intersection score and the express service score, respectively.
Figure 13: New York City Bus Service Score
Figure 14: New York City Subway Distance Score
Figure 15: New York City Subway Line Intersection Score
Figure 16: New York City Express Subway Service Score
As can be seen in the map on the previous page (Figure 16), there are many areas, especially in Brooklyn that received a low express service score while receiving a high distance score. There are several neighborhoods in Southern and Eastern Brooklyn that are well served in terms of their distance to service, but that service is only local and takes an extremely long time to connect with other lines from the furthest reaches of those local lines (namely, the D,F,N,B,Q and R Lines). This score helps illuminate issues in service which would be overlooked if one’s proximity to any type of service was the only indicator of access. Transit options and speed represent a large component of accessibility and must be incorporated into any accessibility index that will measure access to the transport network (Transport for London, 2010).

Figure 17 presents the total subway service accessibility score which represents the culmination (sum) of the three subway service component scores (Distance from Stop, Line Intersection and Express Service). The score thus ranges from 0 to 25; with 25 being a perfect score. There are some interesting things to note about the geographic distribution of this score which illuminates its usefulness. Firstly, at first glance it generally mirrors the subway lines with darker colors following the extent of the lines, however it highlights big differences in Queens and Brooklyn. Queens has a more narrow physical extent of service, with several lines concentrated along the same corridor, however the service is exceptional along that corridor. These areas’ (Jackson Heights and Forrest Hills) scores are higher than most of the neighborhoods in Brooklyn because of the number of lines accessible and the option of express or local service. Brooklyn has a smaller area than Queens that is completely unserved, but Queens has
higher scores where service is available. This subway service index paints a good picture not just of where service is available but also to what extent that service exists in terms of quality.
Figure 17: New York City Total Subway Service Score
Figure 18 on the following page highlights the geographic distribution of the disabled access score. Anywhere other than the blue colored census tracts (scores of 6+) there is extreme distance to any accessible stations. Taking into consideration that the individuals in need of these stations are getting around on a wheelchair, and it makes the score even more important. Traveling more than three quarters of a mile in a wheelchair is extremely difficult, and not possible for many disabled individuals. With the exception of the extreme lower east side, Manhattan (below 59th street) is entirely within one quarter mile of an accessible station. However, outside of that region, accessible stations are extremely isolated and make utilizing subway service quite difficult.
Figure 18: New York City Disabled Subway Access Score
Now that each component and sub-component of New York City’s accessibility has been quantified and illustrated we can sum the scores to create the total Transit Accessibility Score. The index will be a compilation in the form of a sum of the Bus Service Score, Subway Service Score and Disabled Access Score (50 percent weighting). The resulting scores fall within a range of 0-40. The resulting distribution (Figure 19) of the index across the city is nothing too surprising, with Manhattan proving to be highly accessible. A few exceptions to high accessibility in Manhattan are the extreme lower east side, the far western sections of the Meat-Packing District and Chelsea, and the Yorkville section of the Upper East Side, east of 2nd Avenue.

It is important to keep in mind that there are two subway projects that are currently in construction that will actively improve the accessibility of all three of the areas in Manhattan currently lacking service options. The 2nd avenue line is a multi-phase project which will open provide access progressively over the next decade along the entire east side of Manhattan. The 7 line has already been extended down to 34th street and 10th Avenue at Hudson Yards and is under study for further southern extension. Manhattan has been actively invested in over the last several years and will be more accessible in its entirety than any other section of New York City.

Turning attention to the outer boroughs it is easy to see where public transportation is highly accessible and where it is not. The northern half of Brooklyn has much better access than the southern half as there is a much greater density of subway lines with more express options. Queens experiences the highest of the high and the lowest of the low in terms of transit access, with the eastern third of the borough lacking
greatly. The subway lines simply do not extend far enough east to serve the far reaches of the borough bordering Nassau County. The Bronx, too, sees highly variable levels of transit accessibility with the Southern and Central portions of the borough experiencing high access and the Southeastern and Northwestern sections greatly lacking access. As was made obvious by the weighting of the index, the distribution is highly dependent on the level of subway service a neighborhood possesses. Bus service and disabled access play a vital role in supporting subway service and making the index more comprehensive and representative of the needs of all New Yorkers.
Figure 19: New York City Transit Accessibility Score
Transit Need Index

The next part of the methodology compiles a transit need index which was derived from the two variables highlighted in figures 20 and 21 by a simple raw summing. When summed, the Vehicle Ownership Score and the Income Score create a total Transit Need Score. The distribution of the resulting need index is highlighted in figure 22. Again, it is an interesting index because the two variables sometime work against each other (in opposite directions) to create a moderate need. There are wealthy areas that have low vehicle ownership, resulting in a moderate transit need. A large majority of Manhattan below 59th street has that type of pattern. Areas that are both poorer and possess low vehicle ownership, such as northern Brooklyn and the South Bronx end up with the highest Transit Need Score.
Figure 20: New York City Vehicle Ownership Score
Figure 21: New York City Income Score
Figure 22: New York City Transit Need Score
Regression Analysis

As noted in the final section of the methodology chapter, each explanatory variable; race, housing density, income and vehicle ownership, proved to increase the R-squared value of the model predicting transit accessibility. The resulting model produced the following regression report, seen in figure 23, with an R-Squared value of .47 (this is the result of the ordinary least squares regression). This figure signifies that 47 percent of the level of accessibility seen in a given census tract can be attributed to the explanatory variables included in this model. The coefficients for each variable here explain whether there was a positive or negative effect on accessibility.

As expected, housing density proved to be a positive indicator of accessibility, meaning that greater access was found within neighborhoods of higher housing density. Next, vehicle ownership, as expected, was found to indicate lower accessibility where higher figures were present. Median income had a slightly positive effect on accessibility, meaning wealthier areas were found to have greater access. Lastly, the variables indicating the percentage of minority residents (Black and Hispanic) had a positive effect on accessibility, yet only the Hispanic variable was significant. Although rather meaningless because of the extremely small coefficients, these results were the opposite of what is generally expected in terms of the relationship between race and accessibility (according to the literature cited). This can possibly be explained by the fact that minority residents live in areas with greater housing density (especially in the outer boroughs). As indicated by the regression, higher housing density is correlated with greater transit access, thus these two variables could be working in opposite
directions against each other.

Figure 23: Ordinary Least Squares Regression Summary

This regression analysis was performed using a standard ordinary least squares regression. OLS techniques however are limited when there are either of two “failure of assumptions” of spatial autocorrelation. What this means essentially is that the relationships between variables can be different across space, rather than uniform. Ordinary least squares regression can only be used when there is a (generally) uniform pattern of variable relationships across space. To quantify the degree of spatial autocorrelation, the “spatial autocorrelation” tool within ArcMap is employed. When performed on the data in the same manner the OLS was used, the tool reported a Z-Score of 67.47 indicating extreme clustering (shown in figure 24, below).
Given the z-score of 67.47, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

## Global Moran’s I Summary

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<table>
<thead>
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<tbody>
<tr>
<td><strong>Moran’s Index</strong></td>
<td>0.238298</td>
</tr>
<tr>
<td><strong>Expected Index</strong></td>
<td>-0.000487</td>
</tr>
<tr>
<td><strong>Variance</strong></td>
<td>0.000013</td>
</tr>
<tr>
<td><strong>z-score</strong></td>
<td>67.471088</td>
</tr>
</tbody>
</table>

Figure 24: Spatial Autocorrelation Report
When clustering is found to be significant a geographic weighted regression must be utilized to adjust for the variation in explanation across space. This is easily implemented within ArcMap as well using the “Geographic Weighted Regression” tool. The same variables are input into the regression tool and ArcMap generates an R-Squared value, as well as a layer within the map. The R-Squared value jumped all the way to .701 indicating the model (Vehicle Ownership + Black Percentage + Hispanic Percentage + Income + Housing Density = Transit Accessibility) correctly accounts for more than 70 percent of the variation in access. This result is very significant and highlights not only the accuracy of the model, but the power of the Geographic Weighted Regression tool and the impressive application of GIS in analyzing spatial modeling. Figure 25 below shows the distribution of the standard residuals, where the model under-predicted or over-predicted access based on the explanatory variables.
Figure 25: Geographic Weighted Regression
Intersection of Need and Accessibility

In order to quantify the degree to which certain neighborhoods are underserved, a Geographic Weighted Regression analysis between the variables contained in the Need index (Vehicle ownership and Income) and the Accessibility index (Dependent variable) was performed. The map which provides the clearest illustration of the results of the regression analysis is the quantile representation of the standard residual (Figure 26). Areas which are blue (a negative residual) on the map, experience less transit accessibility than they should based on their need (as defined by the two explanatory variables: vehicle ownership and income). There are three regions of New York City which possess a highly negative residual value. The South-Central Bronx, Eastern Williamsburg and Maspeth on the Brooklyn/Queens Border, and Southeastern Brooklyn in the neighborhoods of Canarsie, Flatbush and East New York. These areas will be highlighted in the following section of the paper, and recommendations for where transit expansion is suggested, will be discussed.
Geographically Weight Regression Transit Access Based on Need

Access Based on Need
- > 2.5 Std. Dev.
- 1.5 - 2.5 Std. Dev.
- 0.50 - 1.5 Std. Dev.
- -0.50 - 0.50 Std. Dev.
- -1.5 - -0.50 Std. Dev.
- -2.5 - -1.5 Std. Dev.
- < -2.5 Std. Dev.

Figure 26: Transit Accessibility as a Function of Need (Residual of GWR)
Case Studies and Recommendations

This section will be dedicated to honing in on the three regions of New York City identified in the methods section as being underserved by the public transportation system. There are two specific objectives of this section. The first is to highlight where additional transit service can be provided to increase the accessibility score of the deficient neighborhoods. The second is to analyze the demographics of the deficient neighborhoods to understand exactly who is bearing the burden of access deficit. Because regression analysis takes all 2000+ census tracts of New York City into consideration it can sometimes paint too broad a stroke when assigning a certain coefficient to each variable. The R-Squared and corresponding coefficients of the Black and Hispanic explanatory variables proved to be different than expected when looking at the city as a whole. Zooming in to specific neighborhoods which lack access the most severely should indicate if there is perhaps a relationship between race and access that may not be accurately represented when analyzing all of New York.

To begin, the three neighborhoods with the lowest residuals resulting from the Geographically Weighted Regression of vehicle ownership and income (Need) as a predictor of Transit Access will be presented in map form, zoomed in showing the extent within greater New York City. Three maps will be provided for each of the three underserved areas. The first will be the distribution of the standard residual, highlighting areas which are underserved compared to their need, in blue. The second and third maps show a backdrop of racial and income characteristics to contextualize the lack of service in the neighborhood.
The three neighborhoods to be explored are Southeastern Brooklyn (specifically Canarsie, Flatbush and East New York), The South-Central Bronx (Tremont, Belmont and Soundview) and the Williamsburg-Maspeth Border of Brooklyn and Queens. Starting with Southeastern Brooklyn, figure 27 highlights the underserved census tracts of the region.
Figure 27: Transit Access in Canarsie, Flatbush and East New York
As is evident by the figure above, there are several adjacent census tracts with residuals between -0.5 and -2.5 standard deviations that run in a line extending south-southeast from the junction of the 2,3,4,5 trains at Nostrand Avenue at the border of Crown Heights and Flatbush. The obvious cause of the lack of transit accessibility here is the distance away from the 2 and 5 lines to the west and the 3 and 4 lines to the east. Moderate levels of bus service prevent the accessibility score to drop to extraordinary low levels, however coupled with an absolute lack of subway service and a high level of need, the residuals are still solidly negative throughout the corridor.

Because of the negative residuals, the need for transit in this area is obviously substantial and the transit access, not adequate. A look at the demographics of this region can provide insight to which groups of people may be disproportionately affected by transit deficiencies which the regression models could not capture. Looking back to the coefficients for the Black, Hispanic and Income variables, we expect to see slightly higher (although negligible) transit access within highly black communities, slightly higher access within highly Hispanic communities and much better access within wealthier communities. Figures 28 and 29 below highlight the racial and income profiles (respectively) of the region in quantile map format to provide a contextual backdrop in determining the demographics of the underserved neighborhood.
Figure 28: Southeastern Brooklyn Transit Deficiency with Racial Backdrop
Figure 29: Southeastern Brooklyn Transit Deficiency with Income Backdrop
The regions highlighted by the Geographically Weighted Regression in Figure 27 almost entirely consist of census tracts which are 89-100 percent Black and Hispanic and possess Median Household Incomes of 20,000-40,000 dollars annually. While not necessarily strongly correlated in terms of the regression analysis, it is clear this underserved area of New York City is predominantly comprised of lower class Black and Hispanic residents.

The next region to be explored is that of the southern and central portions of the Bronx. Figure 30 highlights the distribution of the standard residuals, showing the area between the B,D and 2,5 subway lines to be extremely transit deprived, as well as a large chunk of Soundview, located to the east, just south of the (extremely local) 6 line. Figures 31 and 32 provide the racial and income characteristics of the neighborhood for analysis.
Figure 30: Transit Access in Tremont, Belmont and Soundview
Figure 31: Transit Deficiency in South-Central Bronx with Race Backdrop
Figure 32: Transit Deficiency in South-Central Bronx with Income Backdrop
In the Bronx, the communities affected by less than optimal transit service are of even lower annual income levels than those of Southeastern Brooklyn and still almost entirely Black and Hispanic. Notice too in figure 32, how the census tracts with greater income levels are generally found closer to intersecting subway lines, and even those tracts are still almost entirely below the 40,000 dollar level. Turning our attention to the final transit deficient region, figures 33 through 35 present East Williamsburg, Brooklyn and Maspeth, Queens.
Figure 33: East Williamsburg and Maspeth Transit Deficiency
Figure 34: East Williamsburg and Maspeth Transit Deficiency with Racial Backdrop
Figure 35: East Williamsburg and Maspeth Transit Deficiency with Income Backdrop
The example provided above of East Williamsburg, Brooklyn and Maspeth, Queens shows a very transit poor region even within census tracts that are intersected by subway lines. This is due to two specific reasons. Firstly there is a complete lack of express service and a limited number of lines, cutting down on the total subway score within the access score. Secondly, the area possesses moderate to low income and is populated by households with a low level of vehicle ownership, making their need greater. This region is not as entirely Black and Hispanic as Southeastern Brooklyn and the South-central Bronx, however it is still on average 50+ percent made up of Hispanic and Black residents. The income is slightly higher than seen in the Bronx example, but still is almost entirely below 40,000 dollars annually per household, with many census tracts greatly below that.

In each of these three neighborhoods (or agglomeration of multiple neighborhoods) there is a majority population of minority residents of low socio-economic status. While the entirety of New York City did not produce a correlative statistic that provides evidence for Hispanic and Black communities disproportionately lacking public transit access, there is indeed proof that they are the most underserved communities.

New York City has been working on projects that are extending subway service within neighborhoods of Manhattan including the Upper East Side (2nd Avenue Line) and the western portions of Midtown (7 Line extension) (MTA, 2016). The Second Avenue Line is a multiphase project which will initially provide service along second avenue between 63rd street and 96th street. Over the next decade it is projected that the line
will run all the way to 125th street to the North, and down to Hanover street in the Financial District to the south, split into two lines, the T and the Q (extension). The 7 line has already been expanded to the new Hudson Yards complex between 30th and 34th streets west of 10th Avenue.

Unfortunately, while investment in expanding the city’s most efficient form of transit is certainly beneficial to a large portion of the population, Manhattan is simply not the part of New York City that needs improved transit access. The 7 Line and Second Avenue Line provide those who already possess very adequate to even superfluous accessibility in some areas, increased mobility. Manhattan possesses conveniently placed express lines, the option of multiple inter-borough lines at many junctions and it rarely takes more than a 15 minute walk (3/4 of a mile) to a desired station entrance.

The three neighborhoods outlined above are the regions that would truly benefit from increased transit service, as it would increase the residents access. The last portion of this paper will be dedicated to identifying solutions to the lack of transit access in each of the three neighborhoods highlighted. Because of the extreme amount of time, money and resources needed to expand subway service, recommending implementation of new subway lines is rather illogical and would not serve any real benefit. However, providing links to nearby subway junctions that offer high levels of service (in the form of express service and multiple line options) with shuttle, bus or light rail is indeed feasible and is worth exploring.

Starting with Southeastern Brooklyn, there is a clear point of high access located at the junction of the 2,3,4 and 5 lines at the Nostrand Avenue Station. This station
offers four line options as well as the choice between local or express service. Creating a viable connection to this junction, for the tracts lacking access between the split of the subway lines, is key to improving access for this area. The question then becomes, which modes are most efficient and feasible.

When it comes to urban transportation, there are three modes most commonly found in the United States, subway (heavy rail), bus service and light rail (Rodrique, 2013). Subway service has proven to be the most efficient mode in New York City for a number of reasons discussed in previous sections of this paper. Unfortunately it is also by far the most expensive and difficult mode of transit to implement because it requires tunneling underground which is a multiyear (sometimes multi-decade in the case of the second avenue line) endeavor. If money and time were not important limiting factors, subway expansion would be the mode of choice for all three recommendations in this paper.

Accepting the fact that subway expansion is rather unreasonable in any form of short term plan, light rail and bus service remain as viable options. Bus service is already decently spread throughout the neighborhood in moderate density (according to figures 7, 8 and 9) and provides essentially as much access as it can. Bus service only contributes about one fourth of the total points to the accessibility index, thus even raising the bus score would have little effect in raising the residual between the need index and the accessibility index in the neighborhood.

What I propose is the implementation of a “linking” line which is specifically designed to quickly move passengers from outer stops to the transit junction. In the
form of either a light rail line or an express bus line, the goal is to allow riders to quickly access subway options at the junction. Figure 36 highlights the region, the existing subway lines and the proposed route for transit expansion. There is also a buffer placed around the proposed route (in pink) that shows all areas within ½ miles of accessing this transit line. The idea would be for stops to be placed every half mile along the 4 mile stretch so that all residents in the neighborhood would be within a 15 minute walk of the nearest stop. The area within that half mile buffer is correlated with the tracts which possessed the lowest residual and needed increased access most urgently.

Looking at the Bronx neighborhoods of Tremont Belmont and Soundview, there is a very concise, narrow corridor of limited access which can be easily addressed by a vertical north-south line with two east west off shoots to connect to each of the adjacent subway lines. Here too the goal is to provide expedient links to nearby subway lines which give riders the most options possible in terms of route and express choices. Figure 37 highlights the proposal for this region.

Finally, East Williamsburg, Brooklyn and Maspeth Queens require a three pronged line which takes riders from Maspeth and then forks to either offer a link to the Queens Lines to the north or the Brooklyn lines to the south. The Brooklyn lines (L and G) do not offer express service, but provide direct access to Downtown Manhattan while the Queens Lines (E,M,R, N and 7) provide express options and direct access to Midtown Manhattan. Figure 38 illustrates the proposed implementation for this area.
Figure 37: Proposed Transit Expansion in The Central Bronx
Figure 38: Proposed Transit Expansion in East Williamsburg and Maspeth
CONCLUDING REMARKS

The goals of this paper were three-fold. Firstly, the aim was to develop a means for quantifying the transit accessibility of an area within New York City in the form of an index. Secondly, an exploration regarding the relationships between variables affecting or affected by accessibility was undertaken, in an effort to expose inequalities among demographic groups and predict where access is abundant and where it is lacking. Lastly, recommendations for implementing transit expansion initiatives were given for three neighborhoods identified as sorely lacking access.

When developing a cumulative index, there are many complexities that render the index either valid and useful or perhaps biased and uninformed. Considering which variables to include in the quantitative measure of accessibility was the first challenge. The next was assigning correct weights to each variable to best represent the impact that variable has on accessibility in New York City. The weighting schema, which most significantly affected the index created in this paper, is that of favoring subway service over bus service. This decision was backed by three pieces of evidence, higher subway ridership, more efficient trips and more frequent service. Including access for disabled persons ensured the index was non-exclusionary and was weighted to reflect the relatively low but very much significant, population of such individuals.

Once implemented for analysis, the accessibility score of each census tract was used to analyze patterns in access between certain demographic groups. Although the regression analysis did not yield substantive results in terms of identifying significant relationships between demographics and lacking access by means of coefficient of
determination, a closer look at neighborhoods lacking access most greatly, did show a pattern in terms of resident characteristics. Each of the three neighborhoods which were categorized by dozens of contiguous census tracts with negative standard residuals (less transit accessible than needed) were inhabited by a large majority of low income (less than 40,000 annually per household) Black and Hispanic residents. The Central Bronx neighborhoods of Belmont and Tremont as well as the Southeastern Brooklyn neighborhoods of Canarsie, East New York and East Flatbush were almost exclusively inhabited by these individuals. While unfortunately this paper cannot serve as concrete evidence of accessibility inequality, it should hold enough credibility to spark further research on the issue. The combination of the regression coefficient for low income populations which shows a negative relationship with access, and the case studies of each poorly served neighborhood (in regards to race) do show that there are patterns worth further exploration.

The greatest strength of this paper is most certainly the coefficient of determination (R-Squared) that resulted from the agglomeration of all five explanatory variables which served as a model for predicting transit accessibility across New York City. The ordinary least squares regression was able to prove the model explains 47 percent of the variation of access, which is considered significant. The spatial autocorrelation test proved the residuals of the OLS were clustered and thus the model necessitated a Geographic Weighted Regression. The GWR yielded an R-Squared of .701, signifying a 70 percent explanation of transit access. This extremely significant value can help predict where transit access is most likely to be higher or lower across
urban space and can be applied to future urban planning studies in a variety of applications.

Building upon the methods and findings of this paper there is much room for further research. The accessibility index derived in this paper was meant to be simple, yet robust and easily quantifiable in a way that analyzed the average New Yorker’s needs. Additional variables can always be added to better model accessibility in New York City, including but not limited to a deeper analysis of bus service such as express and select bus routes and commuter rail service. Because time and data access were limited, these two sets of variables were omitted from the index, but could serve to benefit the index within future work on the topic.

A deeper exploration of transit expansion in the highlighted neighborhoods (as well as others) is certainly of use to city planners and academics alike who are constantly analyzing ways to improve the public transportation system of New York City. Weighing the benefits of certain modes over others and taking into consideration specific land use patterns to suggest exact route geometries would further this study to perhaps prompt a legitimate recommendation to the city.
REFERENCES


Zenk et al. (2004). Neighborhood Racial Composition, Neighborhood Poverty, and the