Where to go? Designing Bike Share Systems around High Frequency Transit and Separated Cycling Infrastructure

by

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Abstract

Bicycle share systems, by providing the opportunity for the automobile's spontaneous mobility without the destructive impacts, are seen as a low cost and critical tool for improving urban mobility while avoiding the problems of automobile oriented urban design.

Public transportation systems are often hindered with the "final mile" problem, where transit agencies cannot attract patrons to due to the lack of high quality, reliable feeder transit services. Bike share systems can potentially extend the reach of core quality transit services. The bicycle share system "final mile" solution is often cited by planners, but with little empirical evidence.

The planning industry also argues that separated cycling infrastructure encourages higher cycling rates. Existing literature indicates a positive relationship with general cycling, and between bicycle share systems and unseparated bicycle lanes. Minimal research has been undertaken using bicycle share system trip data to analyze the relationship between the number of trips and presence of separated cycling infrastructure.

Washington D.C.'s Capital Bikeshare system is a pioneering and successful system in North America, with over two million trips annually. A multivariable statistical analysis and visualization of the publicly available empirical trip data from Capital Bikeshare finds a statistically significant positive relationship between the rates of cycling trips and separated cycling infrastructure for most trips, and between the rates of cycling trips and Metrorail high frequency transit services during morning and evening peak trips.

Keywords: Bicycle Share System; Frequent Transit Services; Separated Cycling Infrastructure; Design; Rates of Cycling; Washington D.C. Capital Bikeshare

Dedication

I would like to dedicate this paper to my wife Meghan Proulx, who as always provided incredible support, and patience.

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Chapter 1.

Introduction

Transportation is often considered one of the most critical factors influencing the patterns, economies, land use and developments of cities. Historically as cities grew and developed they have been constrained in size respective to the era's available transportation technology. New trends are emerging that suggest we may be transitioning away from the twentieth century's transportation paradigm centered predominantly on accommodating the automobile in urban environments, as the costs of automobiles are seen as spatially, socially, economically and environmentally prohibitive (U.S. PIRG, 2013).

As a recent global phenomenon with over 500 worldwide systems, bicycle share systems are being seen by politicians and transportation planners as a critical piece of the mobility puzzle in providing cities (both large and small) and their inhabitants with new mobility options. It is necessary to develop a deeper understanding of the nuances of these systems in order to capitalize on potential quick, efficient and simple adjustments that can be implemented to sustain, improve and grow their accessibility and hence see a shift away from the personal automobile.

The concept behind the "3rd generation" bicycle share system is relatively simple; a large number of bicycles are distributed at stations throughout the city. Users can pick up a bicycle at one station and return it to another station. These bicycles are usually available for unlimited trips either through a low cost, one time use pass (e.g. $5) or an annual subscription (e.g. $90). A trip's first 30 minutes are usually free with a progressively increasing fee structure for longer trips to encourage short trips and the return of bicycles to maintain accessibility. These systems usually require prospective users to have a credit card to ensure a large deposit for damaged or stolen bicycles. One of the key features of these systems is that bicycle and user data for each trip can be collected.

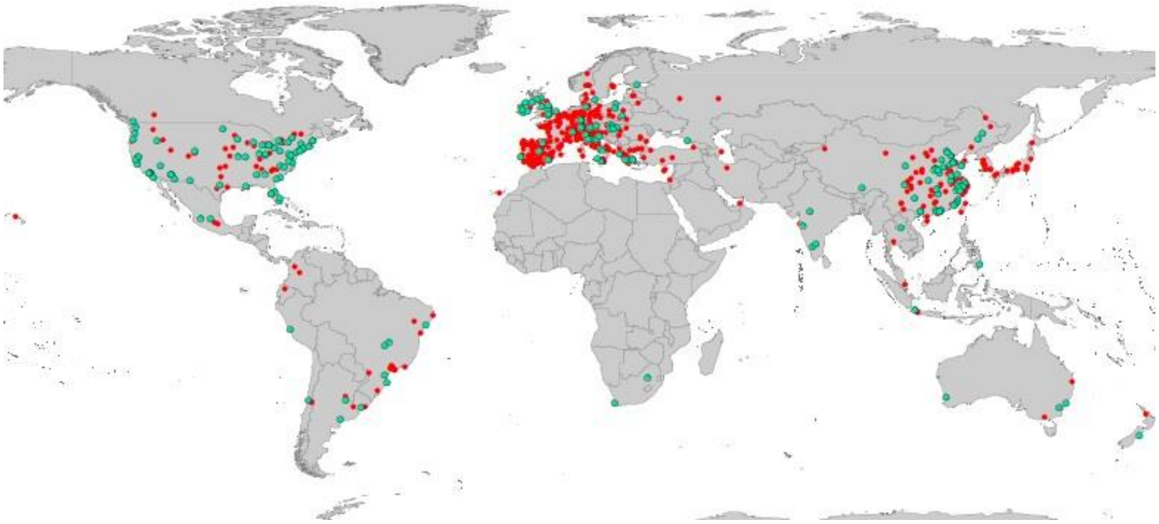


Figure 1.1 World Geography of Bicycle Share Systems
Note: Data Source (MetroBike, LLC, 2013) Red Dot-Existing as of Dec. 2013, Blue Dot – Proposed 2014 or Upcoming

Lyon's Vélo'V system which opened in 2005 was the first system of the current generation of bicycle systems; fast forwarding seven years later to 2013 has seen a worldwide proliferation with over 500 systems (EPI, 2013). These systems can vary in size from the largest in Hangzhou China with 80,000 bicycles to the smallest with 300 bicycles in Boulder, Colorado. Recently the bicycle share phenomenon has spread to North America in cities like Chicago, Montreal, New York City, Boston, San Francisco and Washington D.C. It was expected that the number of systems in the U.S. will double to over 50 systems in 2014 or 2015 with cities like Los Angeles, Austin, Portland, Seattle, and Vancouver opening their own systems (EPI, 2013).

Bicycle share systems bring increased exposure and accessibility to bicycles that may lead to increased rates of cycling. Meanwhile higher rates of cycling are shown to have significant impacts of city and personal finances, environmental pollutions, personal health and government health care costs ((Lindsay et al., 2010; Rojas-Rueda, et al., 2012; Saelensminde, 2003; Grabow et al., 2012).

Bicycle share systems are not without problems. Some systems experience funding problems, while others have been designed with too few stations. Most systems have the collective problem with bicycle imbalances that develop through typical system usage. Users wanting to avoid bad weather or uphill trips sometimes only make one way trips. In other cases specific stations are more popular than others, or system activities can be concentrated during specific times of the day. Therefore some stations become full, prohibiting users from returning bicycles and other stations become empty preventing users from taking out bicycles. These system imbalances require system operators to redistribute bicycles to maintain system accessibility and avoid losing customers. This demonstrates that there is a need to fine tune the design of these systems and better understand system trip patterns to maximize trips while minimizing bicycle redistribution costs and user disappointment.

1.1. Project Scope

In the planning industry there are two critical concepts involving bikeshare systems and cycling. First, higher rates of cycling are associated with separated cycling infrastructure. Secondly, bicycle share systems solve the "first and last mile" problem of public transportation systems.

Based on market research, transportation agencies have found that there is a 40% to 60% proportion of the population who are "interested but concerned" in starting cycling (Portland, 2013; TransLink, 2011). Respondents in this part of the population are typically "afraid to be in the roadway on a bicycle" and have a "fear of people driving automobiles" (Portland, 2013).

Separated cycling infrastructure physically separates people cycling from vehicular traffic with the use of a barrier or raised path. These are often cited by planners as one of the best tools for normalizing cycling by encouraging everyday people from 8 to 80 years old to cycle. There are numerous research studies that back up these findings (Rietveld et al., 2004; Hopkinson et al., 1996; Teschke et al., 2010; Winters et al., 2011; Buehler et al., 2012; McClintock et al., 1996; NITC, 2014). Only a few have tested this idea directly tested using bike share system trip data (Buehler, 2011a; Borgnat et al., 2011; Padgham, 2012; O'Brien et al., 2013; Nair et al. 2013).

It is also commonly assumed that bicycle share systems solve the "first and last mile" or "final mile" problem with transit. The assumption is that factors such as infrequent feeder transit services, or long walking distances to the nearest transit stop can deter people from using transit. There are many causes for these situations such as insufficient funding and demand, politics, or unsupportive urban built form. The argument is that by providing readily accessible bicycles for use getting to and from high quality transit services supports higher transit usage rates. There are few empirical studies to back up these assumptions.

Transit planning also involves the concept of high frequency transit services which Jarrett Walker defines as transit services with “15 minute or better” headways (Walker, 2012, p. 173) that allows for schedule free or spontaneous transit usage. This means that while waiting at a bus stop, a bus will arrive every 15 minutes or better.

This study takes these assumptions behind the transit “first and last mile” solution and separated cycling infrastructure being associated with higher cycling rates of bicycle share systems and put them to the test by analyzing the publicly available Washington D.C. empirical trip datasets (Capital Bikeshare, 2013) in relation to station locations.

Therefore this thesis will answer the question: **How does frequent transit service and separated cycling infrastructure affect the pattern of trips for Washington D.C.’s public bicycle share stations?**

The main objective for this study is to visualize, quantify and determine if there is a statistically significant relationship between high frequency transit services and separated cycling infrastructure in relation to higher rates of cycling trips at Capital Bikeshare stations.

It is the hope that this research will help the Capital Bikeshare or other system operators and planners by developing a better understanding of the typical usage patterns of bicycle share systems and the ways to fine tune the design and station locations of bikeshare systems. Developing the understanding of system usage patterns may provide planners and policy makers with evidence to justify extending the separated bike lane network into new areas.

If it is found that bikeshare members will opt to make trips in areas using separated cycling lanes, then this may provide justification for extending the separated cycling lane network to support more bikeshare trips.

Otherwise if it is found that bikeshare trips are being made to complete the final mile to frequent high quality transit services, this may provide justification to extend the separated bike lane network to connect to those frequent transit services. This may also provide justification for alternative bikeshare station placement at, or on routes that lead to frequent transit services.

While this research focuses on bikeshare systems, it also has the secondary goal of improving cycling for all. As new separated bike lanes can be used by any person cycling, if this research finds justification for extending separated bike lanes to support bikeshare use, this may support the call for safe, comfortable cycling for not only bikeshare users but non-users as well. New separated bike lanes can act as an equalizer for transportation networks, providing lower income households with inexpensive, spontaneous and safe access to mobility, employment and everyday services and goods.

1.2. Why Washington D.C.?

This thesis project focuses on the Washington D.C. Capital Bikeshare system which as of November, 2013 consists of over 300 stations and 2500 bicycles spanning over the Washington, D.C., Arlington and Alexandria, VA and Montgomery County, MD municipalities (Capital Bikeshare, 2013).

The system can be accessed through 1 day, 3 day, monthly, and yearly options as per Figure 1.2either directly through the station terminals or directly at the bicycle docking stations with the use of a system key. A credit card is required for all rentals, and membership is restricted to users aged 16 years and older. Users are granted unlimited trips for the duration of their membership. The first 30 minutes of each trip are free. Trips that run longer than 30 minutes become incrementally more expensive as per the duration-pricing structure in Figure 1.3.

Membership and Usage Fees

Membership Fee	
24-hour	$7
3-day	$15
Daily Key	$10 + $7/day
Monthly	$25
Annual	$75
Annual with Monthly Installments	$84 (12 monthly payments of $7)

Figure 1.2 Capital Bikeshare System Access Fees
Note: Source (Capital Bikeshare, 2013)

Usage Fees

Ride Time	Total Hourly Fee 24-hour and 3-day Members	Total Hourly Fee Daily, Monthly, Annual, and Annual with Monthly Installments Members
0 - 29:59 min	FREE	FREE
30:00 - 59:59 min	$2.00	$1.50
60:00 - 89:59 min	$6.00	$4.50
90:00 - 119:59 min	$14.00	$10.50
2:00:00 - 2:29:59 hours	$22.00	$16.50
2:30:00 - 2:59:59 hours	$30.00	$22.50
3:00:00 - 3:29:59 hours	$38.00	$28.50
3:30:00 - 3:59:59 hours	$46.00	$34.50
4:00:00 - 4:29:59 hours	$54.00	$40.50
4:30:00 - 4:59:59 hours	$62.00	$46.50
5:00:00 - 5:29:59 hours	$70.00	$52.50
5:30:59 - 5:59:59 hours	$78.00	$58.50
6:00:00 - 6:29:59 hours	$86.00	$64.50
6:30:59 - 23:59:59 hours	$94.00	$70.50

Figure 1.3 Capital Bikeshare Trip Pricing Structure
Note: Source (Capital Bikeshare, 2013)

The system also has a map user interface on the website as visualized in Figure 1.4, which allows users to see the station geographic locations and availability of bicycles of all stations for any given snap-shot in time.

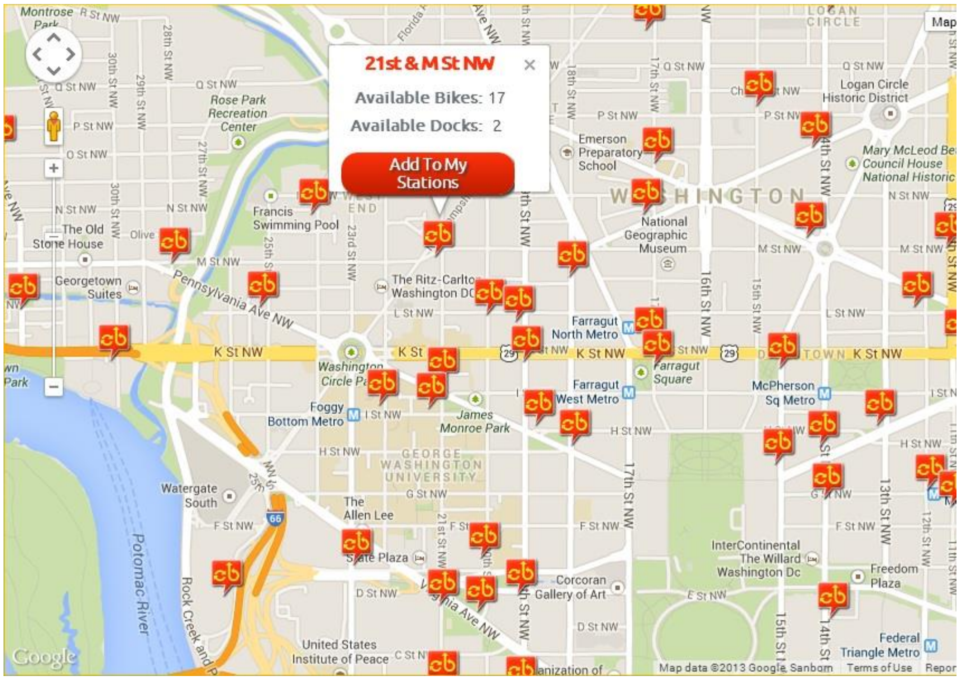


Figure 1.4 Capital Bikeshare Map User Interface
Note: Source (Capital Bikeshare, 2013)

The Washington D.C. system was chosen for this study topic for a number of reasons which include:

- It is a North American city, hence in a context which provides comparability to Canadian and other United States bicycle share system planning.
- Capital Bikeshare was a pioneering United States system established in 2010. There is a higher likelihood of stabilized system usage patterns unlikely to be affected by roll-out malfunctions or system start-up user uptake activity.
- With over 2,000,000 (Capital Bikeshare, 2013) trips generated by system users in the year 2013 alone, the Capital Bikeshare system is considered one the most successful 3rd Generation bikeshare systems in the world. It has been used as the basis for the designs of other United States systems.
- Capital Bikeshare provides a large publicly available secondary dataset of trips completed readily accessible on their company website.

This study consists of five chapters. Chapter 2 contains a literature review which is used to develop a conceptual framework of three main themes, enabling the definition and limitation of the thesis question, evaluating promising research methods, relating findings to previous knowledge and suggesting further research. Chapter 3 defines and operationalizes the study, methodology and key concepts. Chapter 4 consists of a five part analysis: trip visualization, univariate descriptive statistics, bivariate correlations, and multivariable linear regression analysis, and concludes with discussions of the findings. The final Chapter 5 summarizes the results and provides recommendations for further research.

Chapter 2.

Literature Review

A successful literature review enables the definition and limitation of the thesis question, the evaluation of promising research methods, the relation of findings to previous knowledge and the suggestion of further research. The conceptual framework that results from this literature review supports the interpretation of data and results and serves as the foundation for the methodology of the research project. This research project utilizes bivariate and multivariable methods in addition to descriptive statistics and visualization to discern the relationship between separated cycling infrastructure, high frequency transit and higher cycling trip rates for the Washington D.C. Capital Bikeshare system.

To achieve this conceptual framework, three main themes have been identified to categorize the potential literature:

1. Literature identifying potential social, economic and environmental benefits and drawbacks of cycling or bike-share systems.
2. Literature identifying the various factors that influence cycling trips.
3. Literature conducting analysis of bicycle share system patterns of activity.

2.1. Theme 1: Potential Social, Economic and Environmental Benefits and Drawbacks of Cycling or Bike-Share Systems

This section of the literature review highlights the importance and relevance of the research topic in the broader context of the literature and the socio-economic realities of society. This section will explain why readers should care about this research, and how the results and conclusions will be useful.

There are various studies that show that 30 minutes of brisk activity is associated with reduced Body Mass Index, lower risk of obesity and lower risk of type II diabetes which could see U.S. health care savings of $330 in 1987 dollars per person (Fan et al., 2013; Wei et al., 1999; Pratt et al, 2000).

Lindsay et al. and Rojas-Rueda et al. found that there are potentially large environmental benefits including reductions in air pollutants and greenhouse gases, personal health benefits due to increased physical activity and longer life expectancy if there was a 5% shift in vehicle kilometers or 40% increase in shares of short trips less than 5 to 7 km in an urban setting are completed by bicycle (Lindsay et al., 2010, p. 57; Rojas-Rueda, et al., 2012, p. 106). Grabow et al. found that replacing 50% of short car trips (less than 4 km) with bike trips would save $3.8 billion from avoided mortality and reduced health care costs annually for a city of 2 million people (Grabow et al., 2012).

There are also economic benefits due to the high benefit/low cost ratio of cycling infrastructure investment since it is easier to build and maintain more infrastructure to move more people by bicycle with less money and taxation (Saelensminde, 2003, p.604). Another study analyzing the Lyon bike share system has shown that trips over 500 meters can compete with automobiles for travel times and speed (Jensen et al., 2010, p. 522). Since transportation is often a space problem, the ability to fit more bicycles in the space as one car, can potentially move more people with no loss in economic activity.

Fuller et al. have shown that bike share systems lead to increased general population exposure to the access of bicycles which can lead to a greater likelihood of cycling (Fuller et al, 2013). With this information it is likely that an improvement in the bicycle share system design to generate more exposure would see an increase in the benefits associated with a higher cycling rate.

If a variable in this study is found to have a positive significant relationship with higher volumes of cycling trips, Section 2.1 has shown us that increased rates of cycling would see significant improvements in a population's life expectancy, personal health, as well as reductions in harmful pollutants, while moving more people and saving taxpayers money. Section 2.1 has also shown us that bikeshare systems are a suitable tool for increasing the likelihood of more people cycling and reaching their daily quota of 30 minutes of brisk physical activity per day.

2.2. Theme 2: Variables Influencing the Rate of Cycling Trips

This section identified the strongest variables affecting general cycling patterns. This research project will include a series of scaled variables (explained further in Chapter 3) to compare and control for the effects on the bicycle share patterns. This section provides the foundation of knowledge of the most important variables to consider when gauging the impact of separated bicycle lanes and high frequency transit on the rates of cycling.

Researchers are increasingly in agreement on a number of distinct variables related to cycling trip behaviour including land use, population density, minority populations, topography, age, occupation and education, gender, income, cycling infrastructure, public transportation, car ownership, and weather. Generally more mixed use, higher density, lower proportion of minority populations, lower elevation variation, higher proportions of under 25 years population, higher proportion of students, higher proportions of college education, higher proportion of males, higher proportions of household incomes below $15,000 annually, lower car ownership, non-precipitous and warm weather and a network of separated bicycle lanes are associated with higher cycling rates.

Land use & Population density

Comparing aggregate census data in the United Kingdom, Parkin's et al. analysis found that "an increase in population density… [increases] the likelihood of [people] cycling" to work (Parkin et al., 2008, p. 103). Another study analyzed aggregate information on seven American and Canadian cities showing that "high density environments tend to attract utilitarian cycling because more destinations are within easy cycling distance" (Pucher et al., 1999, p. 635).

Cervero et al. and Teschke et al. found that a more balanced mix of residential, commercial, entertainment, and office land uses than those with more single family residential or large commercial land uses around the trip origin was associated with a higher likelihood of cycling (Teschke et al., 2010; Cervero et al., 2003).

Other studies have found differences in the relationship of cycling to high density and land use. Reitveld et al. found that "bicycle use reaches a maximum in medium density areas…and falls… in high density areas" (Reitveld et al., 2004, p. 536). Moudon et al. (2005, p. 256-7) found that "cycling is only moderately associated with the... [built] environment." Moudon et al. (2005) also found that small areas with convenience stores, offices, fast food restaurants, hospitals or multifamily housing do see a relationship with higher rates of cycling. Winters et al. alternatively found that "population density [was] not [a] significant [determinant] of utilitarian cycling," however the authors also note the use of census tract boundaries instead of health authority geographic boundaries could be causing this difference (Winters et al., 2007, p. 56).

Cycling infrastructure and Transit

Several studies indicate that safety and collision risk is a significant factor considered in the cycling travel demand and route choices (Rietveld et al., 2004; Hopkinson et al., 1996; Teschke et al., 2010). The biggest incentive for increased cycling is the introduction of a network of separated cycle routes according to several studies (Teschke et al., 2010; Winters et al., 2011; Hopkinson et al., 1996; Buehler et al., 2012). Segregated cycling facilities had the greatest effect on the inexperienced, less confident, female, and young cyclists. (McClintock et al., 1996). Hopkinson et al. showed that after the completion of Copenhagen's "almost virtually continuous cycle network" the "journeys made by bicycle in Copenhagen increased by 50% over a five year period following construction" (Hopkinson et al., 1996, p. 242). A recent comprehensive study including 1,111 intercept surveys and 168 hours of video recordings from five U.S. cities found protected or separated bike lanes had 21 to 171% increases in usage one year after installation (Monsere et al., 2014, p. 6). The study also found that respondents preferred cycling lanes with the most physical separation for maximum comfort and perceived safety (Monsere et al., 2014, p. 10).

Meanwhile other studies state that the "provision of infrastructure alone appears insufficient to engender higher levels of cycling" (Parkin et al., 2008, p. 93). One study found that the presence of bicycle lanes or proximity to trails was insignificant; however the authors suggest that this could reflect the limited cycling infrastructure in place and does not rule out the relationship (Moudon et al., 2005, p. 245-6). In another study the "density of designated bicycle routes or off-road paths was not significant" (Teschke et al., 2010, p. 987).

One study did not find a significant relationship between cycling and public transportation. Buehler et al. concluded that "cities with more public transport supply per capital have higher cycling levels, but the correlation coefficient is not statistically significant" (Buehler et al., 2012, p. 419).

Car ownership levels

Often the strongest competing mode to the bicycle is the automobile; Parkin et al. (2008), Plaut (2005), Buehler et al. (2012), Herz (1985) all confirm that higher car ownership is strongly related to lower cycling rates.

Topography and Weather

Parkin et al. (2008), Reitveld et al. (2004), Winters et al. (2011) and Herz (1986) all concluded that there is a significant relationship between topography and cycling rates.

The results from Teschke et al. made the clear distinction between "hilly topography, as measured by variation in elevation" (Teschke et al., 2010, p. 986) and slopes in relation to cycling rates.

The studies were split if weather affected cycling rates. Parkin et al. (2008) and Winters et al. (2007) both found that precipitation has a relatively high negative impact on cycling rates. Otherwise Buehler et al. (2012) and Cervero et al. (2003) did not find a significant relationship between bike commuting and precipitation. These results may be varied due to the different climates of the cities analyzed.

Occupation, Education and Income

Parkin et al. has shown that "Higher professional" socio-economic classes reduce the levels of cycling (Parkin et al., 2008, p. 102). Plaut (2005) and Winters et al. (2007) also found that higher education, especially college education, could have a positive effect on bicycling rates. Another study found that education status does not "reveal a significant contribution to explaining [cycling] modal choice" (Herz, 1985, p.322).

Higher proportions of university or college students are also shown to cycle more than the non-students (Pucher, 1999; Winters et al., 2007; Buehler et al., 2012).

Several studies found that high household or personal incomes above $15,000-56,000 are related to lower utilitarian cycling rates (Parkin et al., 2008; Plaut, 2005; Winters et al., 2007).

One study found that income does not show a significant relationship to rates of cycling, however using the proportion of automobiles per households as a "proxy for income… [was] found significant" (Moudon et al., 2005, p. 257).

Winters et al. (2007) also noted that two surveys showed that higher cycling rates are positively related to an increase in household income, however it was suggested that there may have been some participation bias and low response rates. Additionally no multivariable modeling was completed to adjust for other key variables (Winters et al., 2007). Winters et al. also noted that the US National Household Travel Survey did not find an association between income and cycling modal share (Winters et al., 2007).

A literature review article conducted by Heinen et al. (2010) finds that the effects of income are ambiguous. Heinen et al. conclude that on the one hand "having a higher income enables a person to spend money on a bicycle, which in turn increases bicycle use" (2010, p.70), which tends to apply to those countries where people tend to not own bicycles in high numbers which includes the USA. Wealthier people may also be more conscious of their health and as a result may choose to cycle more to maintain their health (Heinen et al., 2010). Heinen et al. otherwise suggest that it could be that higher income implies that "one is able to spend more money on transport in general, including buying a car," (2010, p. 70) where higher rates of car ownership was found to be negatively related to higher cycling rates.

Age, Gender, and Minority Populations

Several studies also found that the proportion of young populations play a role on cycling rates (Rietveld et al., 2004). Plaut (2005) found that cyclists are more likely to be 25 years or under. Winters et al. (2007, p.54) found that "individuals aged 12-19 years were nearly three times more likely to cycle than those aged 20-29, and cycling decreased steadily with age."

One study found that middle-aged and young adults tend to bicycle more than older adults (Moudon et al., 2005), however on closer examination of the survey response rates and population sample may indicate potential sampling biases.

Parkin et al. (2008, p. 101) demonstrate that UK wards with "higher proportions of males demonstrate a greater level of cycling to work." Plaut (2005) and Winters et al. (2007) also confirm that females are less likely to walk or bicycle to work.

Three studies found that a higher proportion of immigrants or minority ethnic or racial population is related to a smaller proportion of non-motorized modes (Parkin et al., 2008; Plaut, 2005; Rietveld et al., 2004).

The variables that have been identified in this Chapter will guide the project conceptualization and operationalization in Chapter 3. In Chapter 4 once the bivariate and multivariable linear regression analyses have been completed, the findings will be compared to the literature in Chapter 2.2 to determine if there are divergent patterns. Any divergent patterns were verified to determine if there were errors in the analysis, or whether there are other factors that may be influencing the rates of cycling. It must also be noted that the literature in this section focuses on general cycling trends and there may be some differences from the behaviors of users completing trips using bicycle share systems. Since general cycling trips tend to be longer on average, the results for longer trips in Chapter 4 were used as a comparison point to ensure consistent results.

2.3. Theme 3: Previous Analysis methods and Conclusions of Bicycle Share System Patterns of Activity

This section reviews existing research focusing on bicycle sharing systems using operational data. This chapter identifies the various research methods used and the resulting conclusions and evaluate their applicability to this project. Each research method could be gauged based on their flaws, strengths, and resources required and as a result rejected or modified the methods to better suit the research project's needs.

This Chapter will also reveal how patterns of bicycle share system activities were previously analyzed, and as a result ensure that this project's research focus and analysis is not duplicating existing findings. Gaps or areas needing further study were identified and used to strengthen the research focus. The results from the literature in this Chapter were also used as a basis for the interpretation of the study results in Chapter 4.

Public bike share systems have been analyzed in a number of ways which are not particularly suitable to create a conceptual framework for this research project and include marketing (Haines & Skinner, 2005), technology challenges (DeMaio & Clifford, 2004; Shaheen & Guzman & Zhang, 2010), Growth trends (Shaheen & Guzman & Zhang, 2010), and political issues (DeMaio & Clifford, 2004).

Capital Bikeshare User Profiles

Buehler et al. (2011b) conducted a study using 340 intercept survey responses at bikeshare stations with the highest casual member usage to create a profile of casual users. The results found that the average Capital Bikeshare casual users can be described as well educated, white, female between the ages 25 to 34 that frequently cycle, is a domestic tourist and travels with a group (Buehler, et al., 2011b).

Capital Bikeshare (2013) conducted a Customer User and Satisfaction Survey in November 2012 of its subscriber members. The results from the Customer User and Satisfaction survey will be explained in further detail and compared to the findings from this study in Chapter 4.4.

Distance Patterns

Comparing bike share systems at a highly aggregate level, O’Brien et al. (2013, p. 15) “found there are very similar behaviors based on the distances people tend to travel.” Padgham (2012, p. 6) found that the number of trips decreased with smaller trip lengths and longer trip lengths: “The spatial and temporal variations in numbers of rides had a greater influence on observed mean distances than…variations in individual journey distances.”

Another study found that the driver of trip lengths was the pricing structure with the majority of trips under the free 30 minute pricing, peaking at 6 minutes (Jurdak, 2013, p. 2). Jurdak (2013) also finds that once a user knows they will incur a cost they will maximize their trip to match that cost-time range. Jurdak (2013) similarly found that higher trip volumes are not influenced as strongly by higher bikeshare station density. Jurdak (2013) also distinguishes that public bike share system user trips are more influenced by monetary factors, where private bicycle users are convenience driven. Therefore to increase bike-share usage Jurdak (2013) recommends that new bikeshare stations be appropriately separated to maximize the system the cost-free pricing period coverage.

Temporal Patterns

Many of the studies have identified that there are outgoing and incoming trip peaks that can vary between bike share systems and stations. O’Brien et al. (2013) and Nair et al. (2013) found that there are significant variations in flow volumes over the course of a weekday with strong morning and evening “rush hour” peaks while Borgnat et al. (2011) found three weekday usage peaks and weekend usage concentrated in the afternoon. Nair et al. (2013) studying Paris’ Velib found no weekend peaks.

O’Brien et al. (2013) and Kaltenbrunner et al. (2010) also found strong differences between the weekday and weekend patterns. O’Brien et al. found that for the Washington D.C. system in comparison to other systems had less change between weekend and weekday usage (O’ Brien et al., 2013).

Spatial Patterns

Several studies found consistent spatial trip behavior patterns within bike share systems. Borgnat et al. (2011) from their analysis found that clusters of bikeshare stations with similar trip behaviors form closely in space exchanging a large number of bicycles regularly.

Vogel et al. (2011) distinguished five distinct patterns in the temporal pickup and return activity at bikeshare stations which include morning bike returns and evening pickups at the inner-city, high all day activity bikeshare stations in the inner city and around tourist attractions, and night pickups at the edge of the network or in the inner city. Based on this it would be useful to operationalize the trip data evaluation based on similar trip destinations and times of day.

Froehlich et al. (2009) and Kaltenbrunner et al. (2010) show spatial dependencies with more active bikeshare stations closer to downtown. Downtown activities also increase as the day advanced (Froehlich et al., 2009; Kaltenbrunner et al. 2010). There was also a tendency for bicycles in the morning to leave from residential areas and arrive at areas close to Universities or commercial land use. This pattern reverses in the afternoon. Lathia et al. (2012) also found that patterns of activity formed concentric rings around the central London.

A few clusters were identified in the Washington D.C. system in the Arlington and Anacostia areas, “a southeastern cluster… sits within the Capitol Hill area” and another cluster appears on both weekday and weekends close to Georgetown and George Washington Universities, and may be related to student activity (O’Brien et al., 2013, p. 12). O’Brien et al. (2013, p. 12) also found central clusters but conclude that these cover “a range of residential and commercial areas, so it is difficult to speculate on its significance.” There are some “small clusters of reciprocal journeys suggesting some hyper local usage patterns”, with the Pentagon City/South Arlington being a “predominant weekday feature” (O’Brien et al., 2013, p. 14).

O’Brien et al. also found that there was a “consistency in the ratio between the popularity of the top 50 stands in each [bikeshare] system”, however the authors have noted this may be due to a small dataset (O’Brien et al., 2013, p. 15).

Transit and Cycling Lane Relationships

Buehler et al. (2011a) completed a bivariate and linear regression analysis of the impact of bike lanes on bikeshare usage, controlling for various population demographics and built environment variables within an 800m radius, finding a positive significant correlation with bike lanes and bikesharing usage. The study recommends siting bikeshare stations in locations with higher population densities, more retail destinations, and bike lanes (Buehler, 2011a).

A relationship between bicycle usage and transit was identified by some studies. Borgnat et al. (2011, p.421-2) found that bikeshare stations corresponding with major subways and buses experienced a “rush of activity at almost any time during the day” thus validating that the bicycle shares “are used as one part of an intermodal transportation system.” Borgnat et al. (2011) also found that unbalanced bikeshare stations generate near railway stations. Padgham (2012) noted that the London Tube is used to converge human movement towards the center before the bike share diverges it. Specifically for the Washington D.C. system another analysis also found concentrations of trips around commuter stations (O’Brien et al., 2013).

Nair et al. specifically analyzes the Paris’ “Velib” bicycle share system and determined a relationship between public transit and bicycle-sharing systems (Nair et al., 2013). Bikeshare stations with high utilization typically have “spatially proximate transit stops and services” and close correspondence to transit stops (Nair et al., 2013). Nair et al. (2013) also found that secondary bikeshare stations served as a buffer to major ones when they were full.

Other Patterns

From the previous theme of studies on general cycling variables, a number of these factors were also identified by bicycle share analysis studies. Borgnat et al. (2011) found that weather and holidays negatively influences bicycle usage. Topography was also verified as an influential variable by Froehlich et al. (2009), where bikeshare stations located in higher altitudes had lower usage.

Froehlich et al. (2009) confirmed a relationship with high density commercial areas and along arterial routes. Buehler et al. (2013) conducted an intercept survey study of the economic impacts from Capital Bikeshare users. The respondents were predominantly educated, higher income, annual member, males and under the age of 35. The survey found that 66% of respondents were travelling to a spending destination (Buehler, et al., 2013, p.13-14). 79% of respondents also said they would spend money within 4 blocks of the Capital Bikeshare station (Buehler, et al., 2013, p.13-14). Additionally the survey found that the Capital Bikeshare system was inducing trips with 16% of respondents making a trip they previously would not have made if the bikeshare station was not available (Buehler, et al., 2013, p.16).

Wood et al. (2013) using descriptive statistics analyzed the London bicycle share system and determined that females have different travelling preferences including areas associated with slower traffic streets. Females tend to use the system less overall, but more on the weekends and the morning peak hour (Wood et al, 2013)

Lathia et al. (2012) found that a policy change influenced the activity patterns for some bikeshare stations, sometimes reversing the activities. Therefore demonstrating that it is important to consider and control for policy changes that may occur within the system.

Chapter 2 explored existing literature, which was used to develop a conceptual framework of three main themes. Section 2.1 provided a framework for interpreting the impact of this study’s findings. Section 2.1 has shown us that increased rates of cycling would see significant improvements in a population’s life expectancy, personal health, as well as reductions in harmful pollutants, while moving more people and saving taxpayers money.

There may be many variables that influence the rate of cycling. This study is attempting to conduct a multivariable linear regression analysis. Therefore it is necessary to control for the strongest known variables influencing the rates of cycling and ensure a focus on measuring the influences from separated cycling lanes and high frequency transit services. Section 2.2 found that generally more mixed use, higher density, lower proportion of minority populations, lower elevation variation, higher proportions of under 25 years population, higher proportion of students, higher proportions of college education, higher proportion of males, higher proportions of household incomes below $15,000 annually, lower car ownership, non-precipitous and warm weather, and a network of separated bicycle lanes are associated with higher cycling rates. Based on the literature in Section 2.2 the consistency of this study's results can be evaluated against the larger body of literature. Any diversions of this study's results from the literature review can be used to gauge for errors in the study methodology or suggest further research.

Section 2.3 evaluated existing literature analyzing bikeshare system usage data. The literature generally found a spatial-temporal tendency for trips to leave residential areas in the morning commuting peak, arriving at areas with high commercial activity and reverse in the evening commuting peak. Additionally higher trip activity volumes typically occur downtown. Distinctions in trip patterns were also found between weekdays and weekends. While the literature found many of the same relationships as Section 2.2 between variables and the rates of cycling, a key driver of bicycle share usage may also result from the system pricing structure.

The literature from Section 2.3 provides a benchmark to gauge the consistency of this studies results and methodology within the larger body of literature. Section 2.3 has also allowed the identification of potential explanations for trip patterns which assist the interpretation of the results in Chapter 4. Finally, it is clear from Section 2.3 that no known study has attempted to answer the question outlined in Chapter 1 using bivariate correlation and multivariable linear regression analysis.

The next Chapter 3 will outline the conceptualization and operationalization used will satisfy the statistical analysis assumptions being used in this study.

Chapter 3.

Methodology

As outlined in Chapter 1 this is an exploratory study attempting to statistically evaluate over one million 2013 Capital Bikeshare trip data in relation to separated cycling lanes, and high frequency transit services. Since this study will be utilizing statistical univariate, bivariate correlation and multivariable linear regression analysis methods to evaluate the large trip dataset, there are a set of assumptions that require careful operationalization of the data collection to achieve optimal outcomes. Chapter 3 will address these requirements and the steps taken to ensure suitable study conceptualization and operationalization.

3.1. Timeframe

After an investigation of bicycle share systems around the world it was found that some bicycle share systems in the Northern hemisphere like Montreal's BIXI, Boston's Hubway, or Minneapolis' Nice Ride close over the winter months. To ensure maximum comparability to other systems and of other studies attempting to replicate the results generated from this study, a time frame from April 01, 2013 to September 30, 2013. This will help ensure that consistent weather and travelling patterns are being observed without requiring adjustments or controlling for adverse travel patterns caused by significantly different seasons. At the time of project conceptualization, this was also the timeframe that matched the most up to date trip dataset available. Since the trip dataset is set three years after the Capital Bikeshare roll-out, it is more likely that system usage patterns will be stabilized and largely unaffected by system start-up activity. Meaning that a significant proportion of the Washington D.C. population is more likely to be aware of the system, and that system usage patterns will remain relatively consistent over a short period of time (months).

The timeframe was also selected to ensure that there were at least 30 trips per bikeshare station to satisfy a rule of thumb with the Central Limit Theorem. This will ensure that the error for the estimated mean of the data for each bikeshare station approaches the normal distribution and ensure that noise in the data will not be significantly affecting the interpretation of the results. These parameters will also help ensure that the results will be generalizable to bikeshare stations within the system, and any theoretical findings will be generalizable to other systems.

3.2. Study Details

This study is analyzing the Capital Bikeshare operating in the Washington Metropolitan Area, which during study timeframe extended into Arlington, VA, Alexandria, VA and Montgomery County, MD. There was a lack of readily available or consistently measured environmental information (e.g. land use etc.) on the regions outside of Washington D.C. Therefore this project removed 95 bikeshare stations in Arlington and Alexandria, VA and Montgomery County, MD from the scope of study. For a full list of the 178 Capital Bikeshare stations included within the Washington D.C. boundary (see Appendix A).

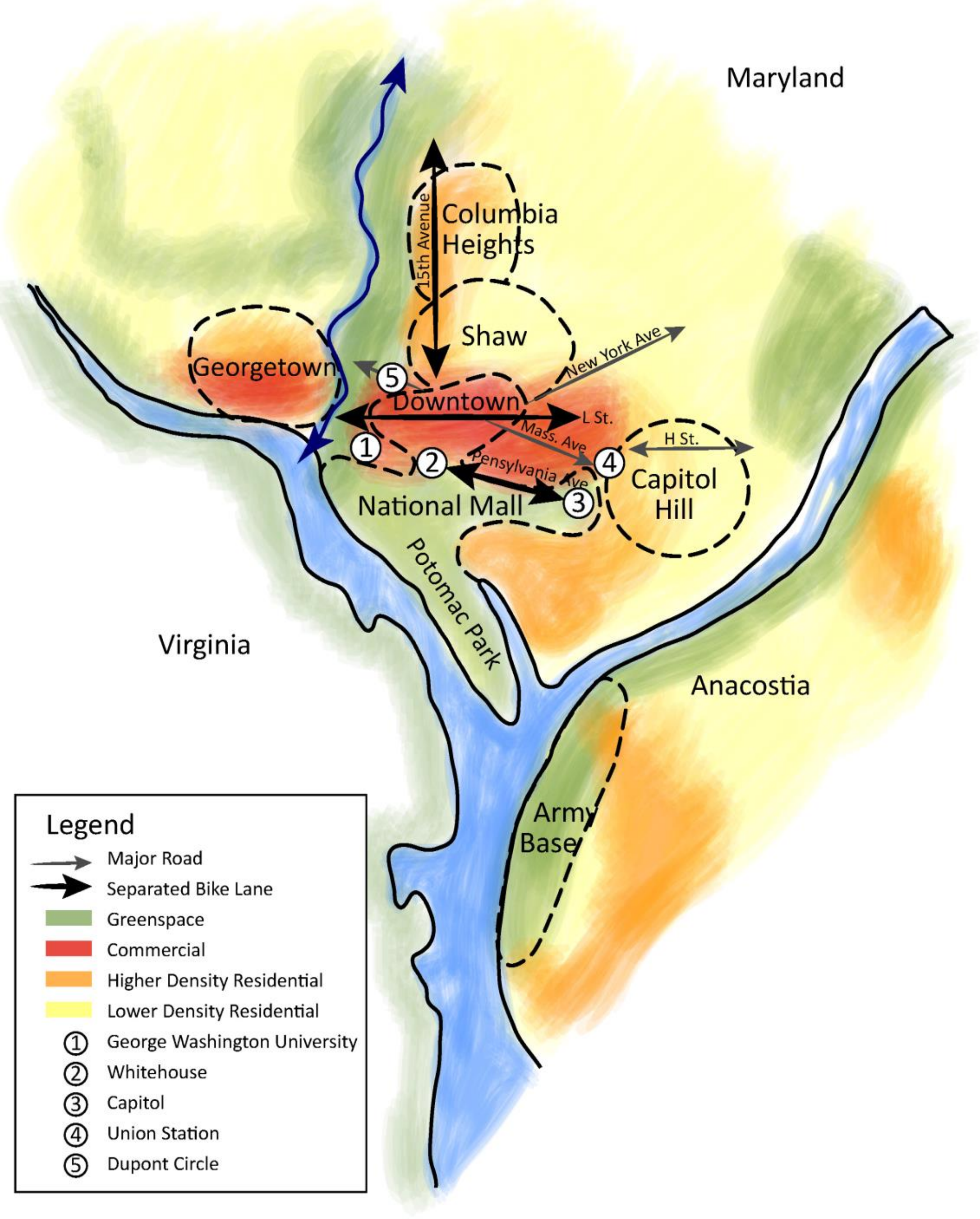


Figure 3.1 Washington D.C. Context Map

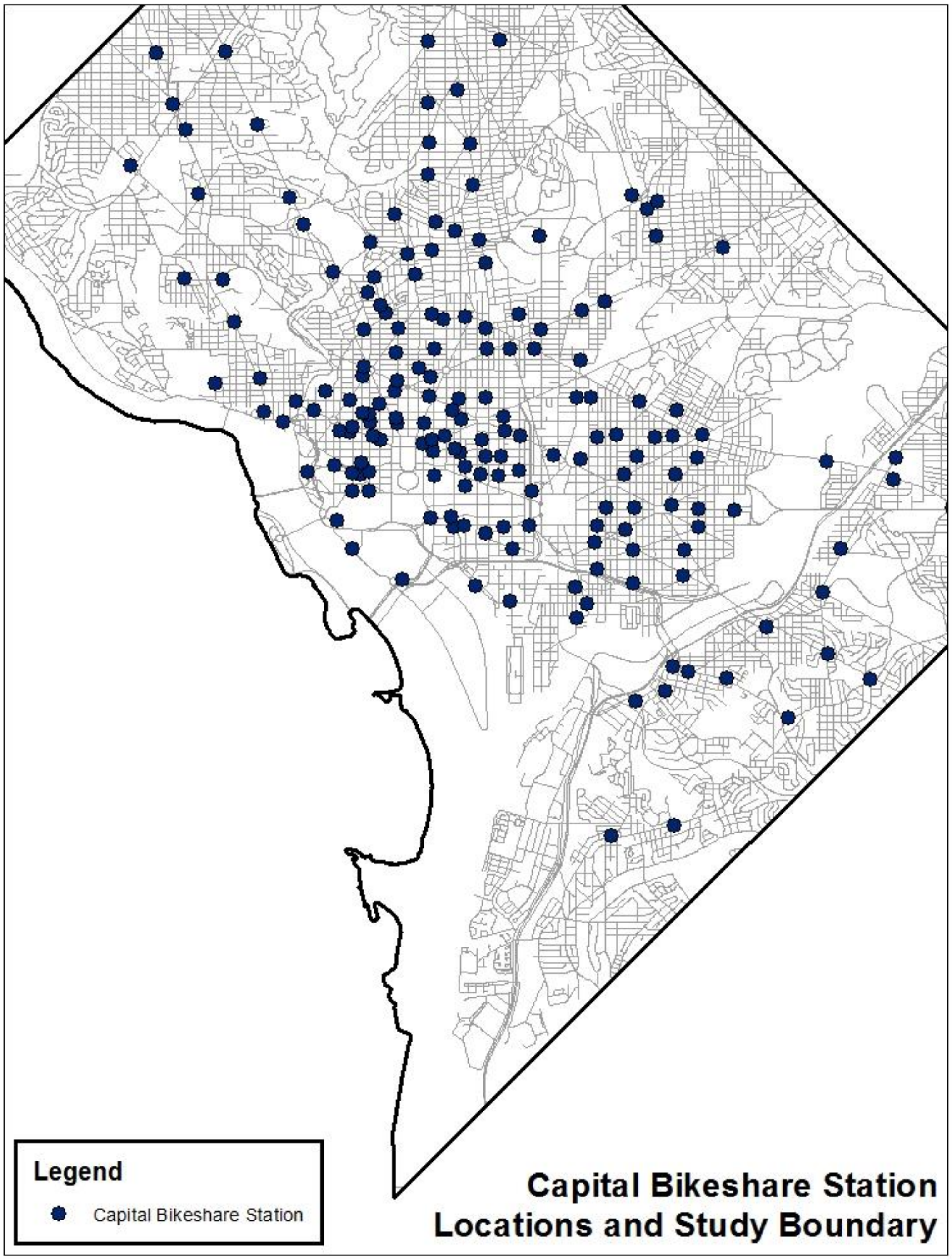


Figure 3.2 Capital Bikeshare Locations

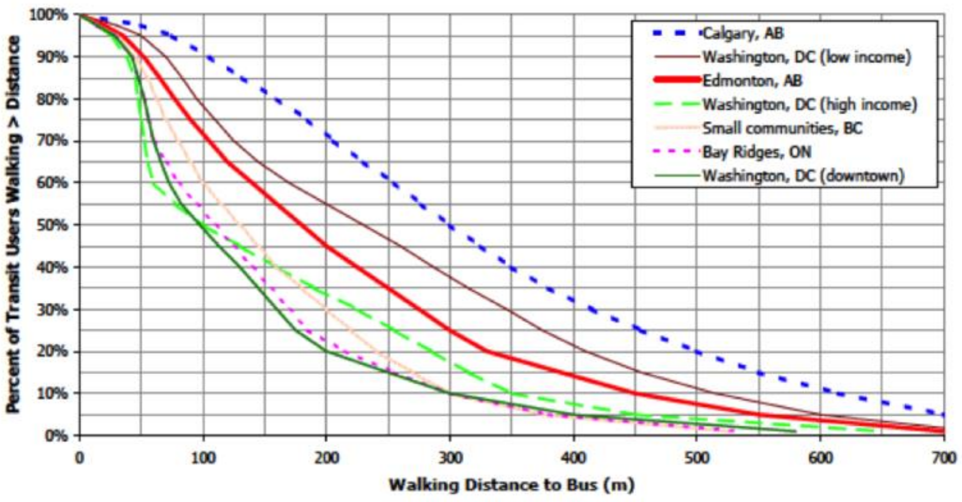


Figure 3.3 Average Percentage of People Willing to Walk to a Bus Stop at Various Distances
Note: Source (TRB, 2003, p. 3-10)

The study will be further confined within a set of varying radii around each bikeshare station at 20m, 50m, 100m, 200m and 400m. The 400m radius is important in the transportation planning industry as a "5 minute walking" distance that various studies have verified this is the maximum distance that people on average are willing to walk to access public transportation (TRB, 2003, p. 3-9). Analyzing the Capital Bikeshare station trips at the 400m radius will provide a sense of the ability of the bikeshare to provide a solution for the public transportation "final mile". The smaller radii will test the sensitivity of bikeshare trips with proximity to separated bike lanes and high frequency transit. Measurements of each of the variables outlined in Chapter 3.4 will be collected at each radius for each bikeshare station. These variables were measured in different ways to provide flexibility in the linear regression model building outlined in Chapter 4. For example in Figure 3.4 transit could be measured as high frequency, low frequency or no service at each radius for each bikeshare station.

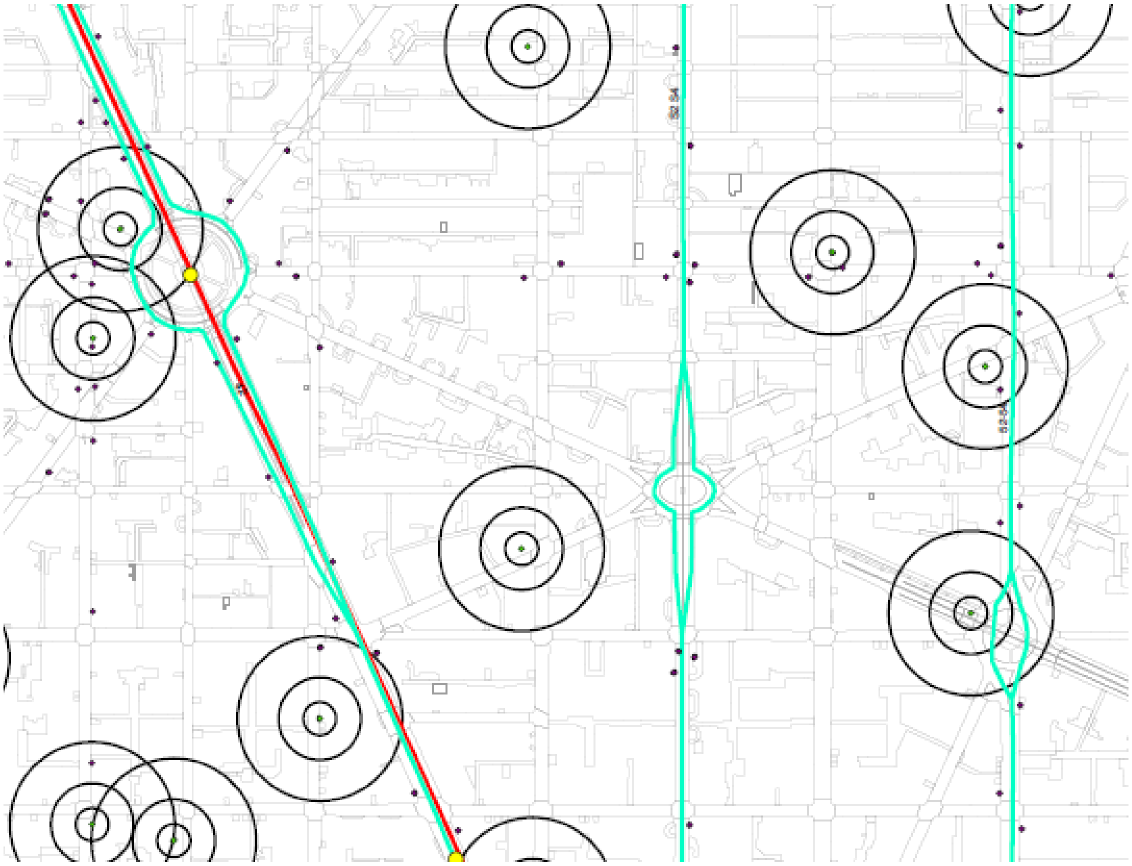


Figure 3.4 Example of Station Scoring for Proximity to High Frequency Transit
Note: Figure 3.4 shows several stations with concentric rings representing a 20m, 50m, and 100m proximity radius. In the scenario we can see that some stations have bus stops (purple dots) within different radii while others do not. In this scenario the total number of frequent network service, and non-frequent service bus stops were counted within each radius.

3.3. Bicycle Trip Data

This study will analyze large datasets of system trip histories publicly released by the Washington D.C. Capital Bikeshare system on their website. These were released in quarterly increments since the implementation of the program (Capital Bikeshare, 2013). The data is provided stripped of any information that could be used to identify system users and includes data on each trip's duration, trip start and end times, start and end bikeshare stations, as well as the member type (casual user - 1 or 3 day pass holders, or subscriber - annual or monthly members).

This research assumes that this data is the original system data and has not been altered in anyway. When downloaded from the website the data is provided in a ready to use excel format with a row for each trip and each trip attribute in its own column. It was confirmed through the interviews with the Capital Bikeshare staff that these publicly available datasets have been screened of any bicycle redistribution activity from Capital Bikeshare employees (removing bicycles from full bikeshare stations to move them to bikeshare stations with low volumes of bicycles).

The trip dataset was cleansed in order to remove any outlier system trip activity relative to the project scope that may distort the results. This was done using built-in recoding or filtering features of the SPSS software available through Simon Fraser University.

The dataset included trips to and from bikeshare stations located within (Washington D.C.) and outside (Arlington, VA, Alexandria, VA and Montgomery County, MD) the study scope. Since consistent data on the built environment for the Arlington, VA, Alexandria, VA and Montgomery County, MD trips was not available, trips that neither began nor ended inside the Washington D.C. boundaries were removed. This will capture the trips that started within Washington D.C. and ending outside and trips that started outside Washington D.C. and ending inside. It was decided that these trips should be retained as they do have an impact on the need to redistribute bicycles. The end result is that only 178 bikeshare stations within Washington D.C. are being analyzed, and those outside are not (see Appendix A).

All trips that started and ended at the same bikeshare station with trip durations less than two minutes were identified and removed, accounting for 1.2% of all trips. A user may have initiated taking a bicycle out of the system only to discover that the bicycle was broken. They also may have changed their mind on renting a bike, or there may have been a glitch in the system.

A closer examination of the trips in this timeframe determined that 41 bikeshare stations started operation in 2013, of that 33 started within the data timeframe. Nine stations started operation after July 23 accounting for 1.34% of the total trips. To provide a standard of comparison between Capital Bikeshare stations it was necessary to normalize the number of trips per bikeshare station by the number of days the bikeshare station was in operation over the timeframe. Visualizing the number of trips per day for the bikeshare stations that started operation within the data timeframe revealed that all stations took approximately two weeks to get past the initial ramp up activity before the usage approximately stabilized and extreme fluctuations dissipated. Therefore it was assumed for the purposes of this study that at least two weeks are needed to avoid extreme fluctuations in average trip usage per day. Based on this criteria two bikeshare stations (31106, 31514) were removed from the analysis accounting for 0.114% of all trips, bringing the total number stations being analyzed to 176 (see Appendix A).

The data cleansing results in 1,448,576 starting and 1,453,057 ending trips with a 1.314% loss of data.

3.4. High Frequency Transit Data

One main foci of this research is to determine if there is a relationship between high frequency transit services and the rate of bicycle share trips. To accomplish this research, information on the frequency and geographic location of high frequency transit services relative to the Capital Bikeshare station locations was required. This project defines high frequency transit as services with 15 minute or better frequency that operate at least 64% of the hours from 6:00 to 23:00 Monday to Friday, 6:00 to 21:00 Saturday, 7:00 to 20:00 Sunday. Services that only operated in the peak hours were excluded. Eighteen routes satisfied these conditions, three of which are Metrorail lines (See Appendix B). Eight of these routes do not satisfy these conditions on the weekends with frequencies exceeding 15 minutes. These routes were included in the analysis as these are some of the strongest services for Washington D.C.

The loss of frequency over the weekend could cause complications in the analysis; hence care was taken to compare the results between weekends and weekdays. If there are significant differences in the results, then the inclusion of these less frequent services will need to be adjusted.

It has been shown by previous studies that there may be a preference for the mode of transit, typically choosing rail style transit over bus transit services when rail services offer higher quality services (Ben-Akiva et al., 2002). Considering that WMATA fares between the Metrobus and Metrorail are not transferrable, this may further encourage this pattern. Therefore the bikeshare station proximity to Metrorail stations, which are the strongest, most reliable and frequent public transportation services in Washington D.C., will be considered separately to determine if it alters the results.

In 2012 the Washington Metropolitan Area Transit Authority (WMATA) created a 15 minute map which identifies services according to this definition (WMATA, 2012). A 2006 ArcGIS dataset of the transit service locations available from the Washington D.C. Data Catalog (Washington D.C., 2013) was also used. These sources were used as a basis for identifying potential high frequency routes, however since both resources were not created in the study timeframe, it was necessary to verify that there were no changes for these routes. The service frequencies were verified by looking up the WMATA route schedule information available from the WMATA website (WMATA, 2013). Care was taken to verify that there were no major service interruptions by scanning news articles and WMATA service notices (WMATA, 2013) and publications in addition by looking to see if there were any long term adjustments in the high-frequency network.

Since it is actually the bus stop or Metrorail station which is the key point of reference as a measure of transit, the number of bus stops or Metrorail stations within a radius for each bikeshare station was measured. The bus routes, bus stop locations, and Metrorail stop locations ArcGIS files were acquired from the Washington D.C. open data catalogue (Washington D.C., 2013).

The resulting Frequent Transit Network shown in Figure 3.5 loosely represents an optimal grid structure. However the transit services are predominantly radial, extending out from the downtown, and National Mall core. The area south of the Anacostia River displays the weakest grid structure of meandering non-legible routes.

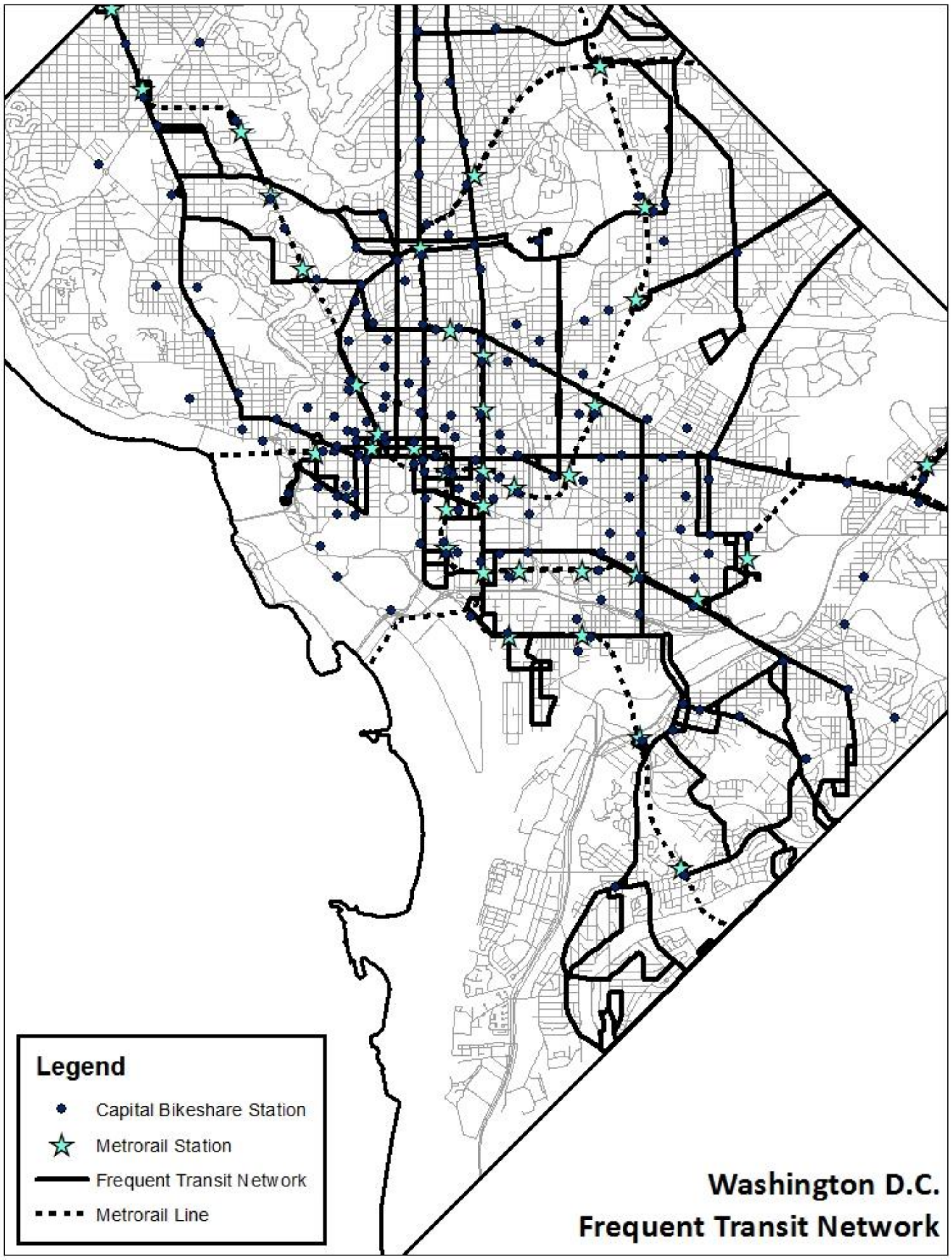


Figure 3.5 Map of All Day 15 minutes or Better Frequent Transit Network
Note: Source (Washington D.C., 2013)

3.5. Cycling Infrastructure Data

The other central purpose of this research intends to investigate the effect of the presence of automobile traffic separated cycling infrastructure on the pattern of bicycle share station trips. Automobile traffic separated bicycle lanes for the purposes of this study are defined as bicycle facilities that provide dedicated space physically separated from moving automobile traffic due to a physical barrier. This study includes both on-road and off-road facilities. A full list of automobile on-road separated bicycle lanes can be found in Appendix C.

The on-road separated bicycle lanes considered for this study do not offer true separation for their entire length, mainly with the Pennsylvania Ave mid-block sections and L St. bicycle lane mixing zones at intersections. However these were included as these are the truest separated bicycle lanes, which due to their design and placement would discourage vehicle travel in them. Information on the type and locations of Washington DC bicycle lanes was obtained from the Washington DC Department of Transportation (DOT) bicycle program map (Washington D.C. DOT, 2013) and the Washington DC open data catalogue (Washington D.C., 2013).

The quality of each applicable bicycle lane was verified using the Google Street View (Google Street View, 2013), Google Earth map histories feature (Google Earth, 2013) which are both time stamped, official planning documents and finally with an on the ground site visit. Care was taken to ensure that the separated cycling infrastructure existed during the time frame being studied, accomplished by looking at the Washington DC DOT planning documents, construction notices and news announcements.

Figure 3.6 shows that many of the low hanging fruit have already been capitalized with bike lanes along the waterfront edges or rail right-of-ways. Within the downtown the on-road separated lanes provide a bare minimum north-south and east-west cycling connections. The National Mall area makes up a large proportion of off-street cycling lanes. Generally the off-road network is well connected to the West, but has some disconnections within the city core and to the East.

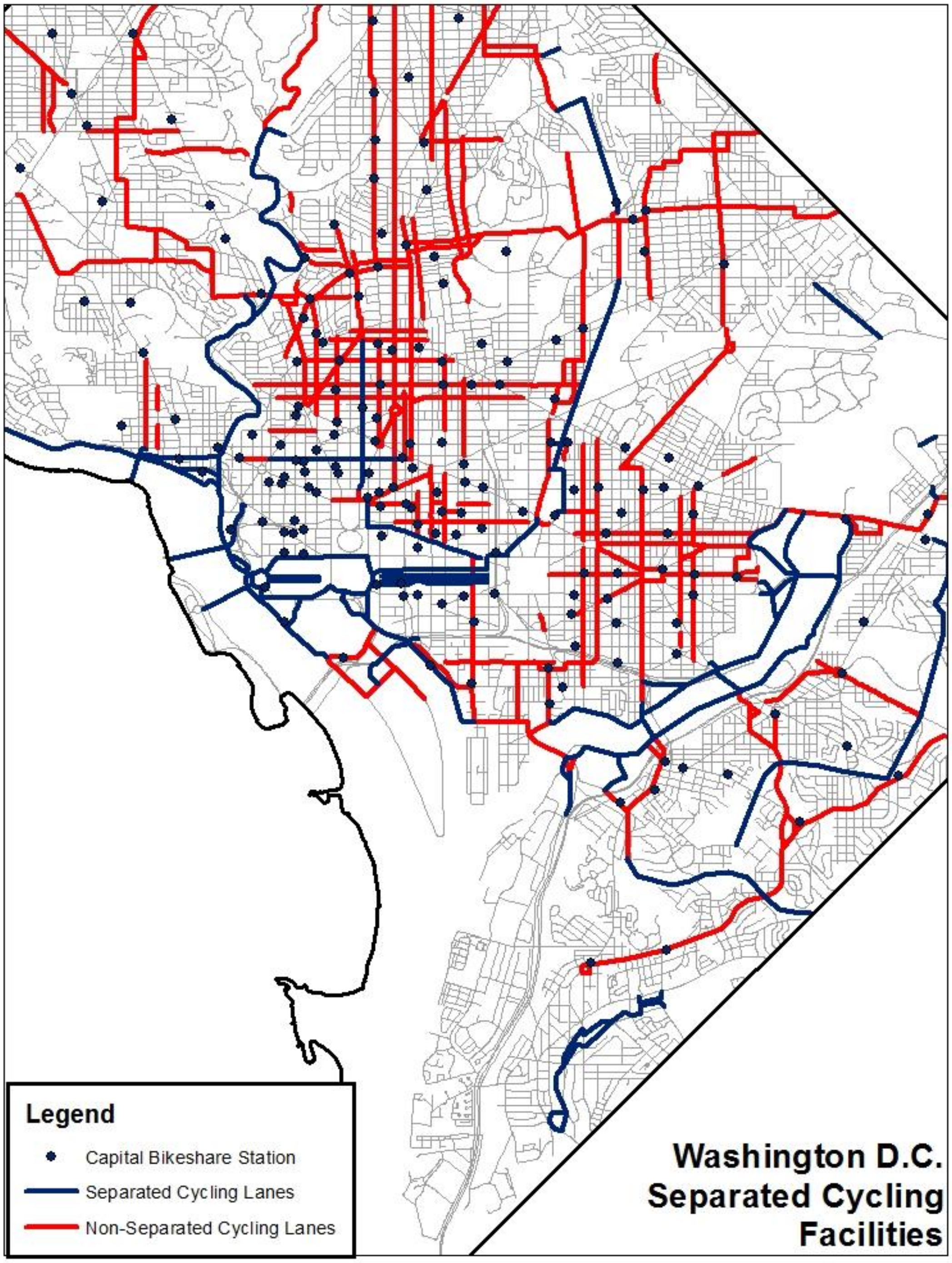


Figure 3.6 Map of Traffic Separated Cycling Lanes
Note: Source (Washington D.C., 2013)

3.6. Bicycle Share Station Attributes

The literature review (see Chapter 2.2) found a convergence of several key variables influencing the rates of general cycling. These variables must be considered in this study to determine if they are influencing the total number of trips at each bicycle share station. This is a critical step for attempting to control these variables and determine if the two test variables of high frequency transit and separated cycling infrastructure are statistically significant with higher trip rates. This chapter examines the data used for each variable to identify any patterns that may help guide the interpretation of the findings in Chapter 4.

There are hundreds of variables that could potentially affect the cycling trip rates; it is not possible to account for all of them in the scope of this thesis project. Therefore this research project will only attempt to control for the strongest known correlations between variables and higher cycling rates. This may introduce biases to the results as the true initial differences are not being controlled. Since the strongest effects are being accounted for, it was assumed these biases will be negligible.

The literature review did not identify employment as an important factor, after further reflection, employment was included as an additional factor. In the interviews with the Capital Bikeshare staff, employment density was revealed as one of the four criteria in gauging the system implementation suitability mapping, which also included population density, cycling to work rates and Proximity to Metrorail (Capital Bikeshare Staff, Personal Communication, March, 2014). Employment is also considered by other transportation planning agencies such as TransLink when gauging the suitability for transit services (TransLink, 2011a).

The literature review also did not find any studies that addressed the impact of tourist attractions on the rates of cycling. Washington D.C. has a large volume of museums, historical buildings, monuments and other tourist attractions that could have potential impacts on the rates of cycling. Therefore it would be prudent to include tourist attractions as a variable influencing the rates of cycling. The final list of variables that have been included in this analysis can be broken into two distinct groups 1) Variables that describe the socio-economic population demographics and 2) Variables that describe the physical built environment.

Socio-Economic Population Demographic Variables:

1. Population density
2. Proportion of minority populations
3. Proportion aged 25 years or younger
4. Proportion of students
5. Proportion of post-secondary education
6. Proportion of males
7. Proportion of income
8. Proportion of car ownership
9. Proportion of employment

Built Environment Variables:

10. Land use
11. Tourist attractions
12. Bikeshare Station Density
13. Intersection Density
14. Elevation Change

According to Babbie et al. for bivariate analysis and multivariable analysis it is necessary for these variables to be measured dichotomously, categorically, or continuously (Babbie et al., 2002, pp.410-462). Some demographic variables e.g. proportion of males will need to be transformed from a nominal value to a proportion of the bikeshare station's respective Washington D.C. census tract. This project is also attempting to utilize multivariable linear regression analysis (see Chapter 4.3). Since this is an exploratory study it is uncertain which measure will best indicate the variables underlying behavior. Therefore to ensure maximum flexibility in the model building it is necessary to quantify these variables in as many ways as possible. To determine the presence of these variables, each bikeshare station will be given a score at each radius as outline in Chapter 3.2 (20m, 50m, 100m, 200m, and 400m) for each of the 14 variables listed above.

Information was gathered from several data sources to accurately depict and account for these variables as closely as possible. Each variable was measured by building an ArcGIS file consisting of each of the respective features, and the bikeshare station location data. A buffer was created for the bikeshare station locations representing the various radii (20m, 50m, 100m, 200m, and 400m) around each station. The ArcGIS Intersect feature was then used to capture any overlap between the features and the buffer.

Information on the socio-economic population demographics including density per square mile, proportions of race, gender, age, level of education, level of income, level of employment and car ownership were collected through the American Community Survey (ACS) 2012 5-year estimates using the U.S. Census Bureau Fact Finder tool (U.S. Census Bureau, 2013). In a perfect world the data from the same year as the data time frame would be used; however such a dataset is currently not available. The data time frame could have been adjusted to better suit the census data, however the system opened in 2010, so earlier timeframes may risk being affected by implementation usage patterns. In addition the majority of separated cycling lanes were installed in 2012 so a shift in the time frame could see a loss in the comparison data. The dataset that best matches the data timeframe was used, with the assumption that significant demographic shifts do not occur over such a short time frame. Any anomalies that appeared in the results were investigated to determine if there were any rapid neighbourhood demographic shifts that may have occurred.

This project used the U.S. ACS data according to the census tract geographical areas since this is the smallest geographical scale of the census data that doesn’t experience the potential data loss caused by privacy measures associated with the smaller U.S. block groups.

Population density is measured as persons per square mile. From Figure 3.7 below it can be seen that a high proportion of bikeshare stations (41) are located in the downtown and National mall census tracts. The census tracts immediately north and the east of the downtown have the highest densities, consisting of small to large apartment blocks and mostly row houses. Georgetown to the west also increases in density. The outer perimeter census tracts are generally the least dense.

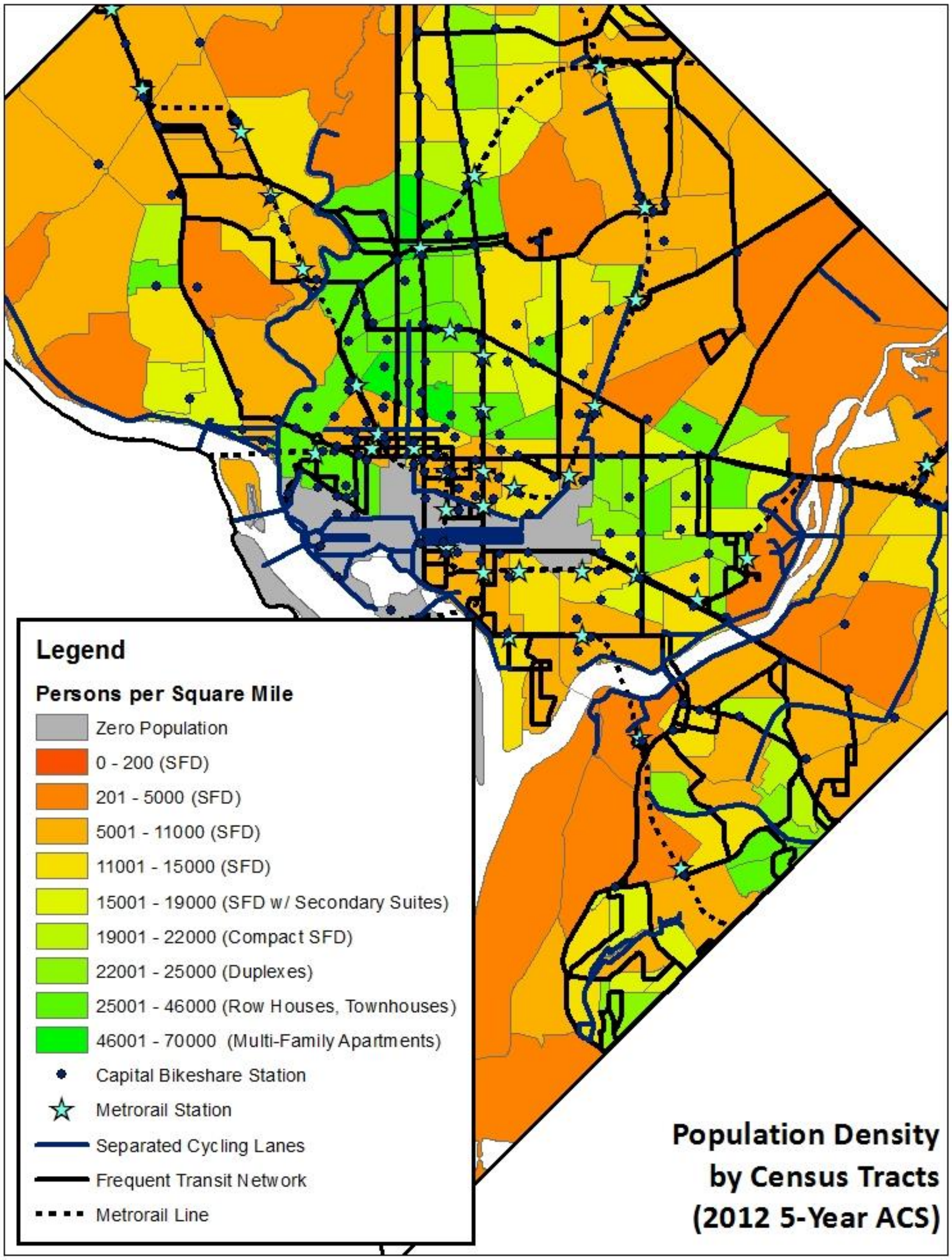


Figure 3.7 Map – Population Density by Washington D.C. Census Tract
Note: Source (ACS. 2012), SFD stands for Single Family Dwelling

The ACS provided a count of the number persons of various races. From the literature review in Chapter 2 it was found that the proportion of minority populations had a significant relationship with rates of cycling. Therefore the race data for each census tract was expressed as a proportion of the total census tract population in three different groups: White, African American, and Minorities which consists of all other races. From the 2012 ACS the minority classification consists of American Natives, Asian, Hawaiian, and other races which accounts for an average 9% of all census tracts per bikeshare station.

Table 3.1 Washington D.C. Racial Statistics

	White	African American	Minority (Other Races)
Mean (% of tract)	35	56	9
Standard Deviation (% of tract)	32	36	6

Note: Source (ACS. 2012)

From Figure 3.8 and Figure 3.9 below it can be shown that the census tracts to the west of 16th St NW, areas surrounding the National Mall and downtown and the H St. area to the east of the downtown are predominantly White, with lower proportions south of the Anacostia river and to the north-east. Meanwhile the census tracks with higher proportions of African Americans are generally opposite of census tracts with high proportions of whites. Higher proportions of African American are located south of the Anacostia River and east of 16th St NW. Overall a large number of the bikeshare stations are located in areas in the downtown and just north of the downtowns which also have higher proportions of whites. If the results from the analysis in the next chapter find a higher representation of whites using the Capital Bikeshare, it may be a symptom of a high number of stations located in areas with higher proportions of white population. Figure 3.10 also shows that the highest proportions of minority populations are located north of the downtown and west of the Anacostia River.

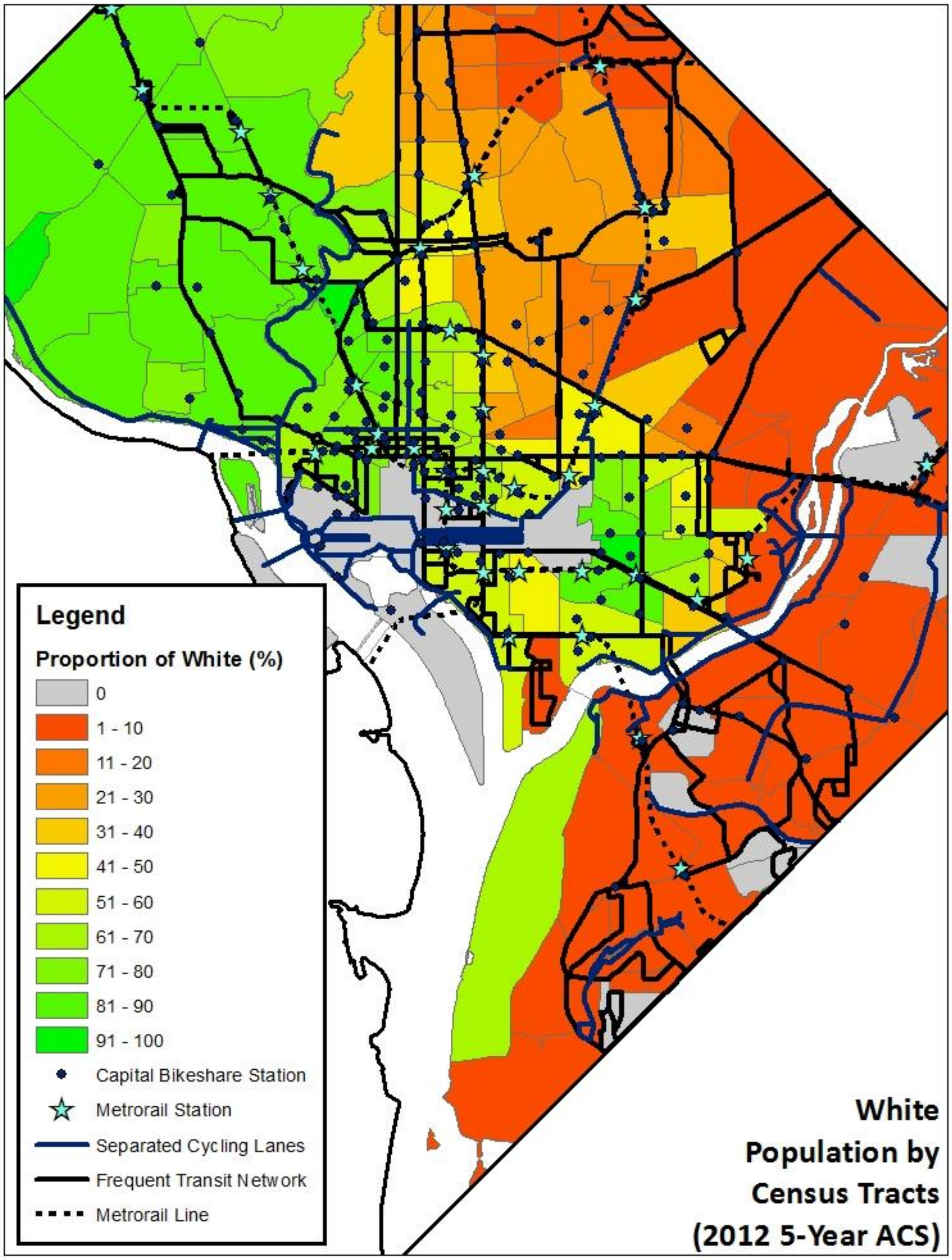


Figure 3.8 Map – Proportion of White population by Washington D.C. Census Tract
Note: Source (ACS. 2012)

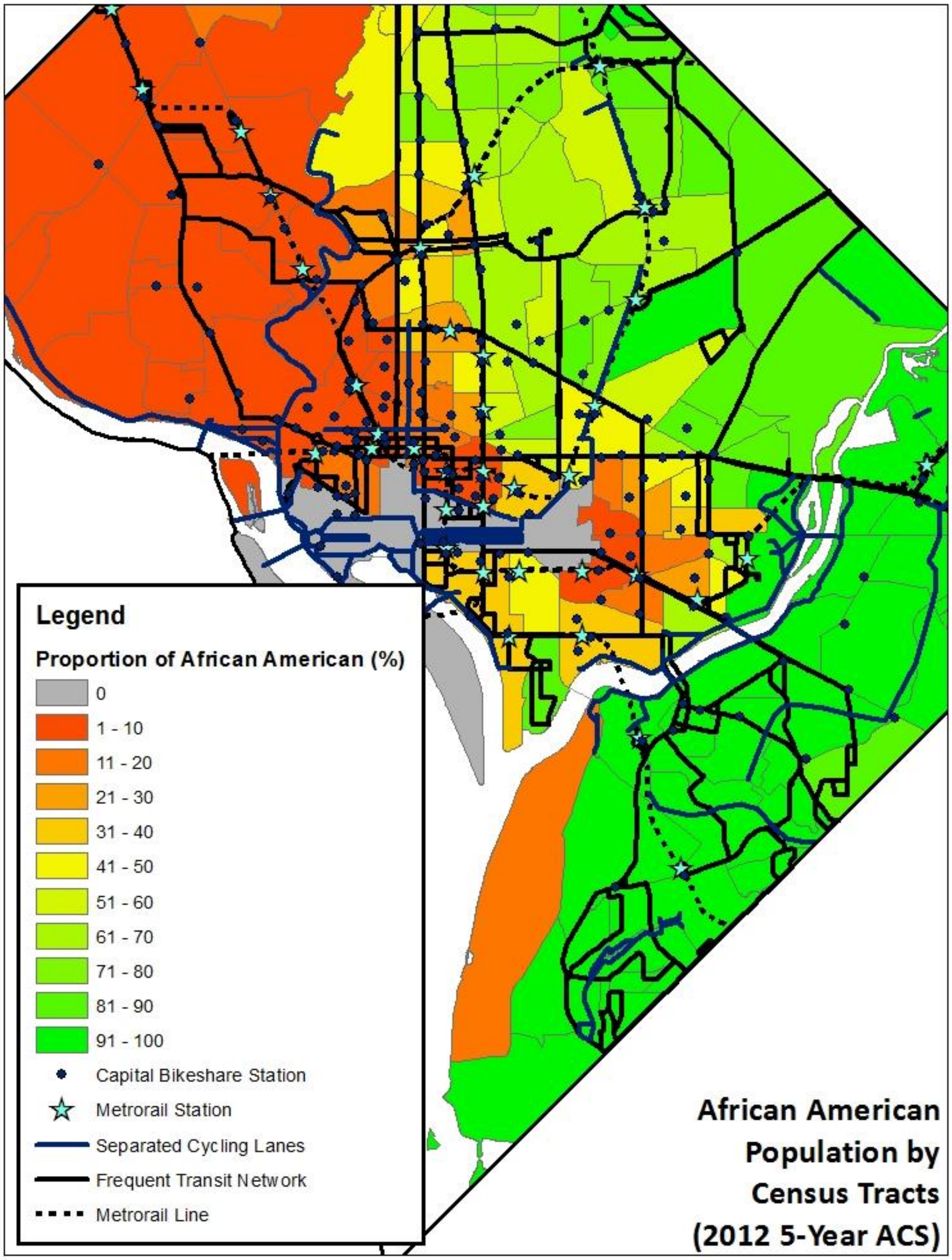


Figure 3.9 Map – Proportion of African American population by Washington D.C. Census Tract
Note: Source (ACS. 2012)

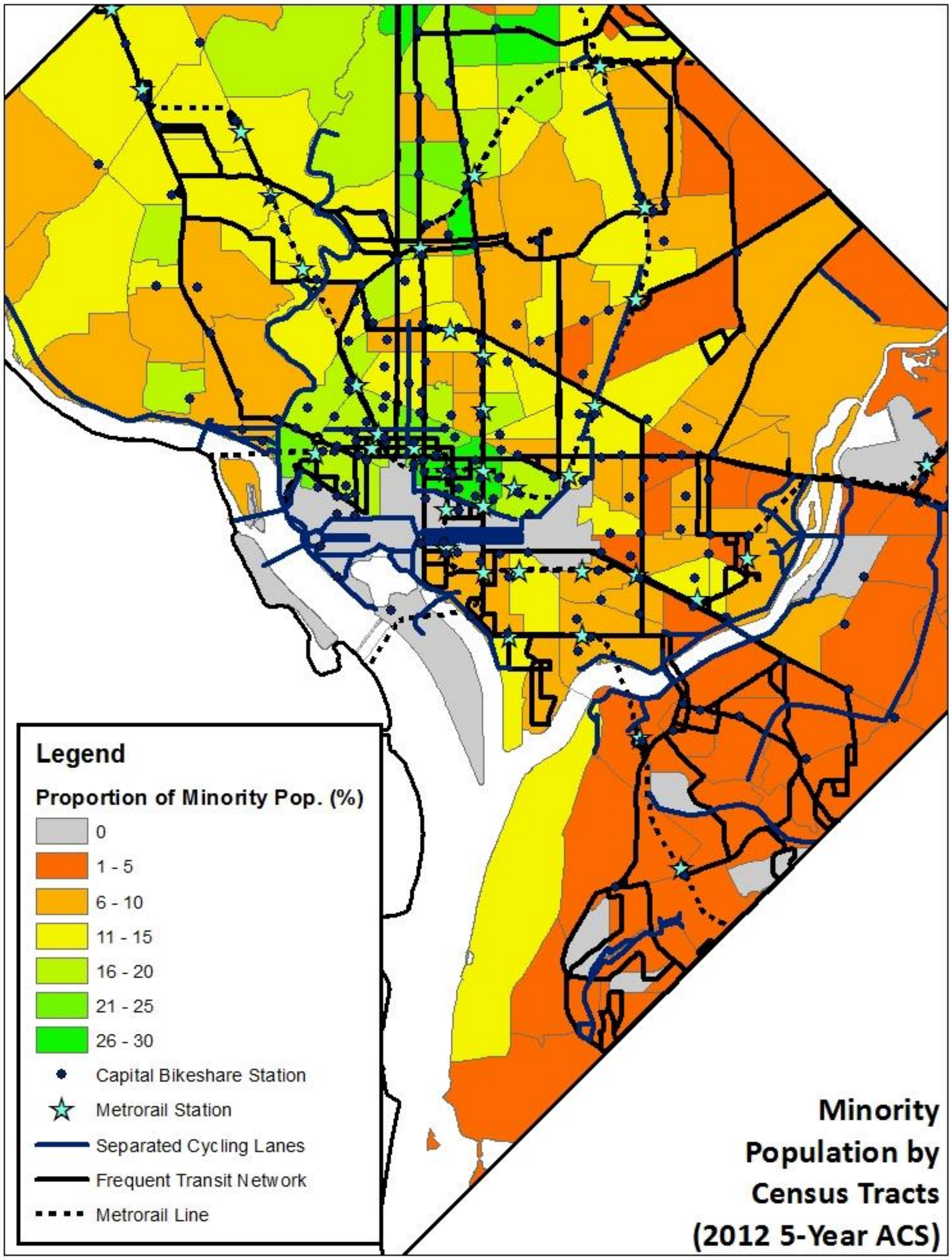


Figure 3.10 Map – Proportion of Minority population by Washington D.C. Census Tract
Note: Source (ACS. 2012)

From the literature review in Chapter 2 it was found that the proportion of youth aged less than 25 years old had a significant relationship to cycling. To best control for the age, this study included all age brackets defined in the ACS 2012 5-year census tract estimates. The age brackets were organized into a variable represented as a proportion of the census tract.

The literature review in Chapter 2 found that the proportion of males had a significant relationship with the rate of cycling. This data was organized into a variable represented as the proportion of males per census tract.

The literature review in Chapter 2 found that there was a relationship with the level of education, more specifically with the proportion of bachelor degrees and the rate of cycling. Therefore the ACS 2012 5-year estimates were organized into a variable representing the number of bachelor degrees as a proportion of the census tract population. Figure 3.11 shows that this variable closely aligns with the white statistics in Figure 3.8, with higher proportions immediately surrounding the downtown, to the west of 16th St NW and north of the Anacostia River.

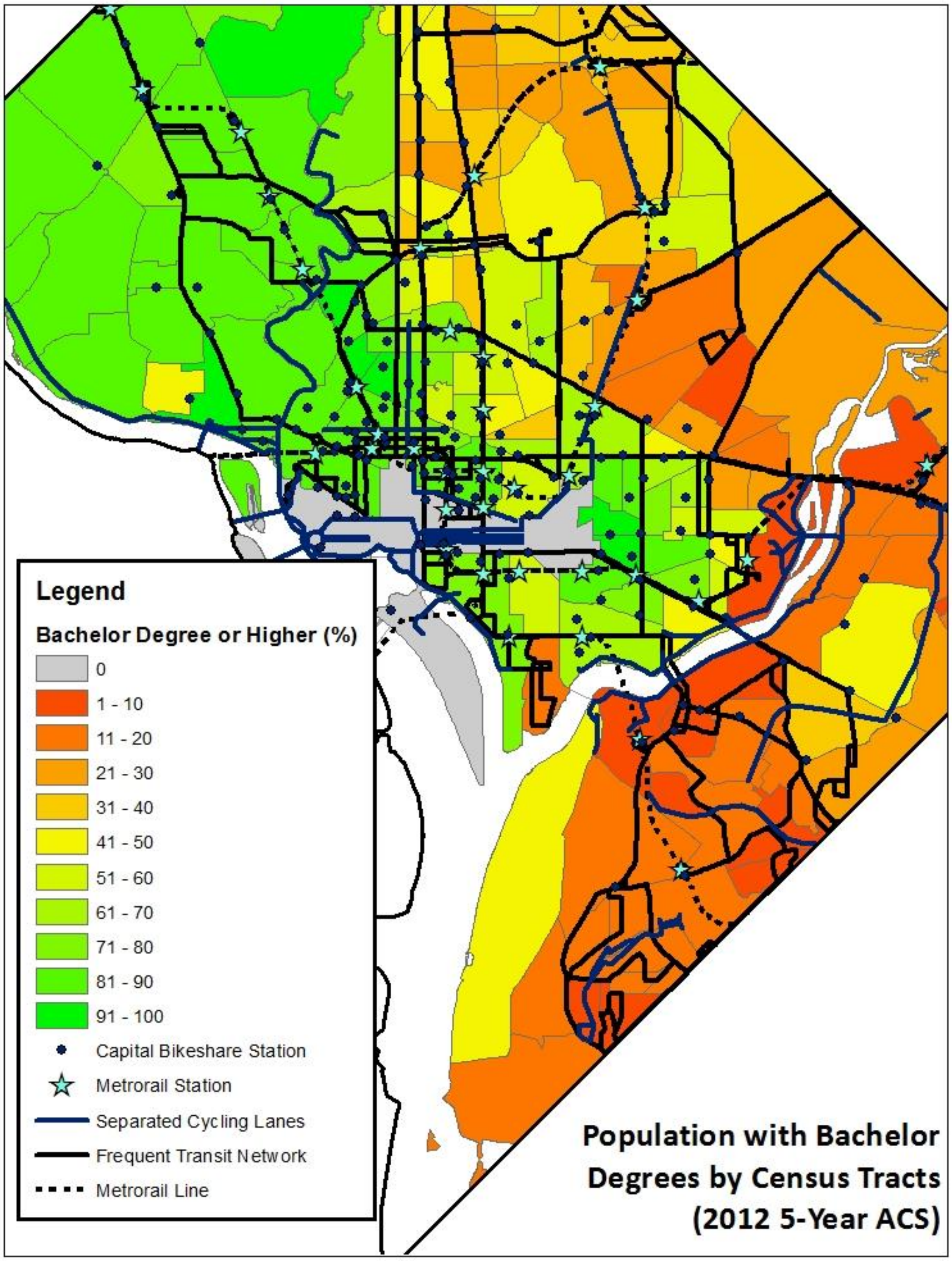


Figure 3.11 Map – Proportion of Population with Bachelor Degrees by Washington D.C. Census Tract
Note: Source (ACS. 2012)

The literature review in Chapter 2 found that the level of household income, specifically higher household income, was related to lower rates of cycling. To best control for household income, similarly to the age variable, this study will include all income brackets defined in the ACS 2012 5-year estimates by census tract. This information was organized into a variable of the household income as a proportion of the total census tract households. According to the 2012 U.S. Department of Health and Human Services the poverty threshold was $23,050 per year for a 2 parent, 2 children household (U.S. Department of Health & Human Services, 2012). This poverty threshold was also used to approximate the income brackets for this study in Chapter 4.

Figure 3.12, Figure 3.13, and Figure 3.14 show that the highest proportions of low income households are located east of 16th St. NW, and particularly south of the Anacostia River. The areas surrounding the downtown and West of 16th St NW are predominantly higher income. Middle class income households earning $25,000 to $100,000 per year are fairly evenly distributed with the highest proportions to the North-East and south of the Anacostia River. Higher proportions of high income households above $100,000 are generally located opposite to areas with high proportions of low income households. The largest proportions of high income households are located to the North-West and immediately east of the downtown.

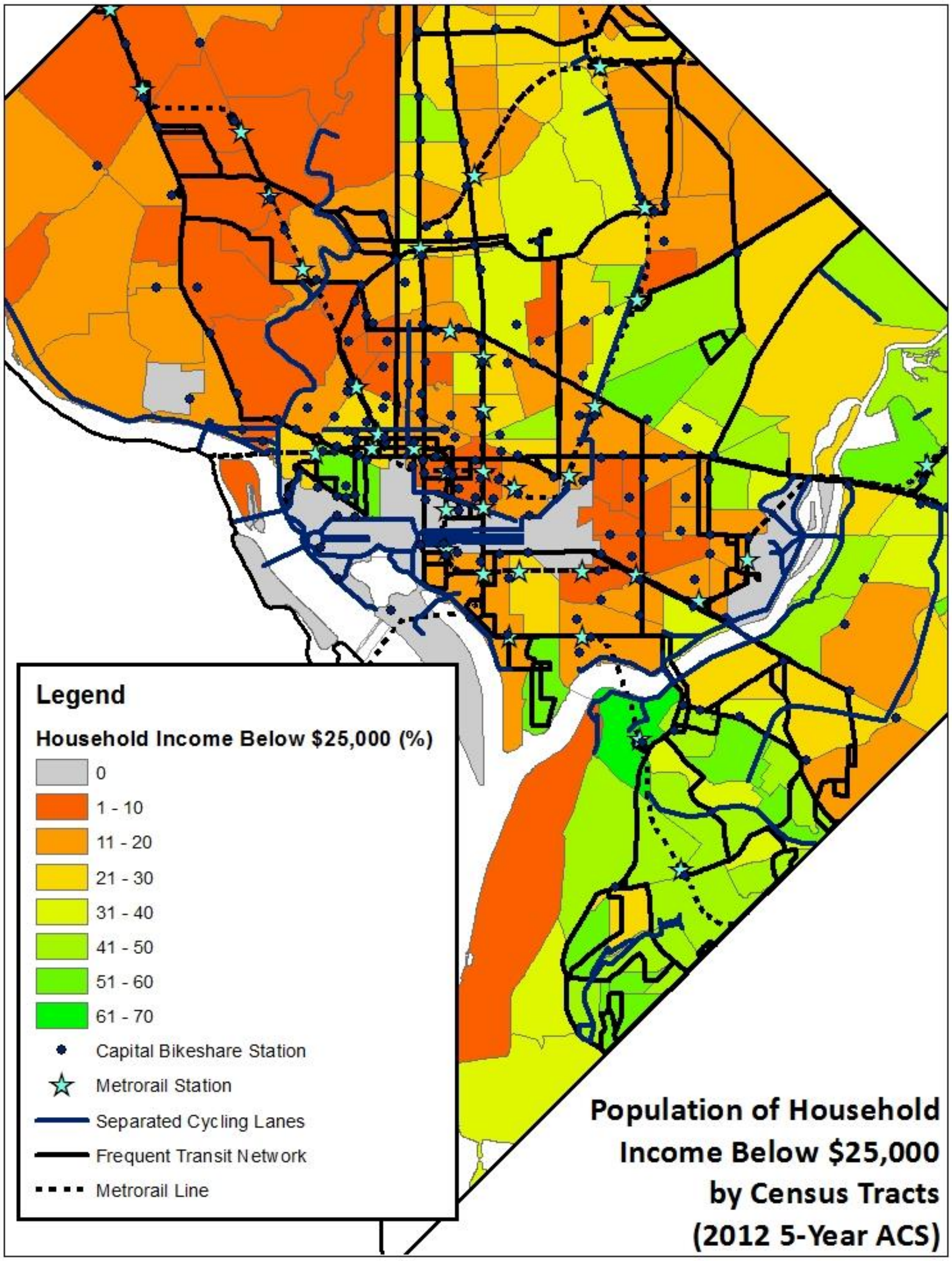


Figure 3.12 Map – Proportion of Household Incomes Below $25,000 by Washington D.C. Census Tract
Note: Source (ACS. 2012)

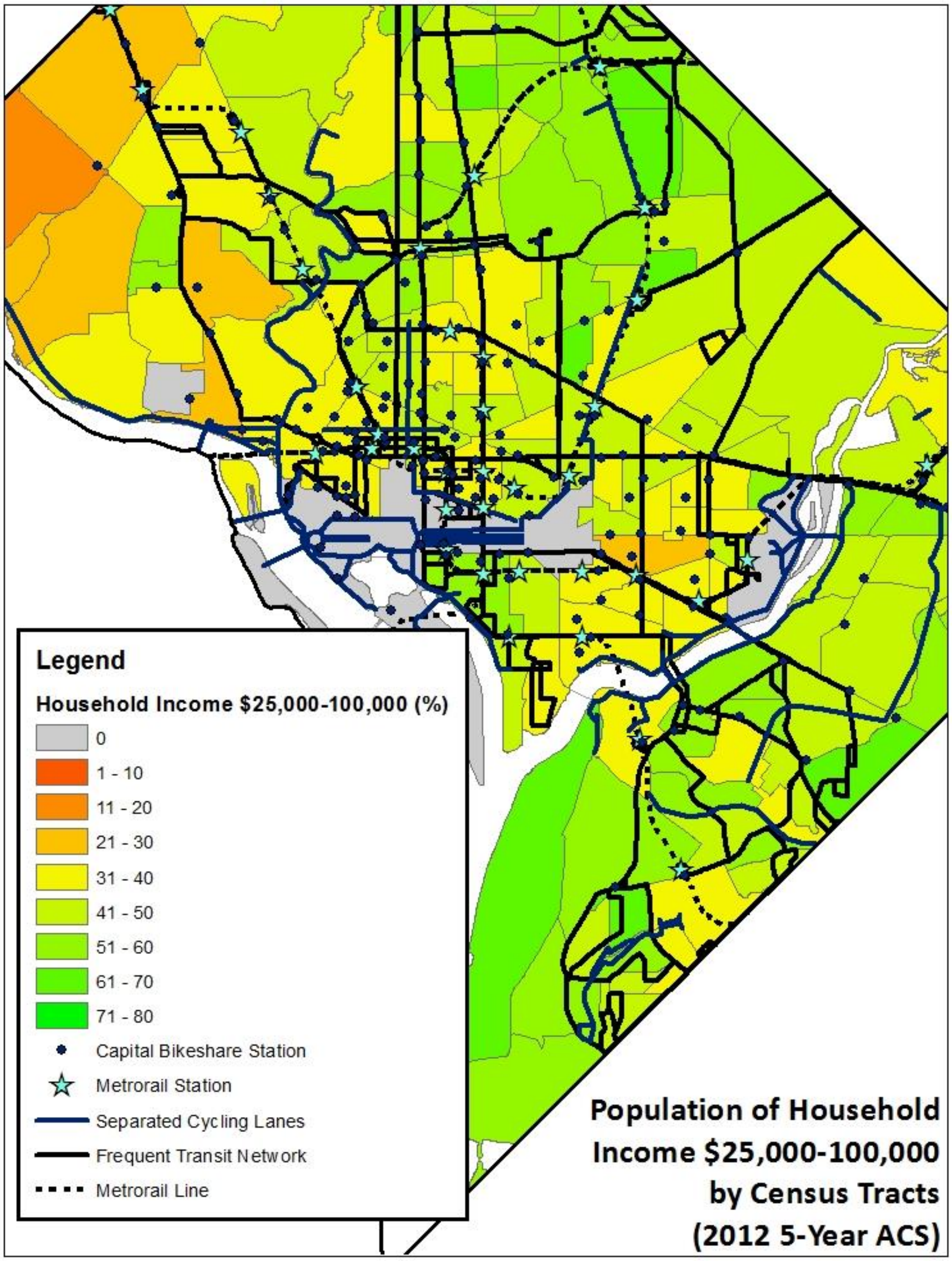


Figure 3.13 Map – Proportion of Household Incomes Between $25,000 and $100,000 by Washington D.C. Census Tract
Note: Source (ACS. 2012)

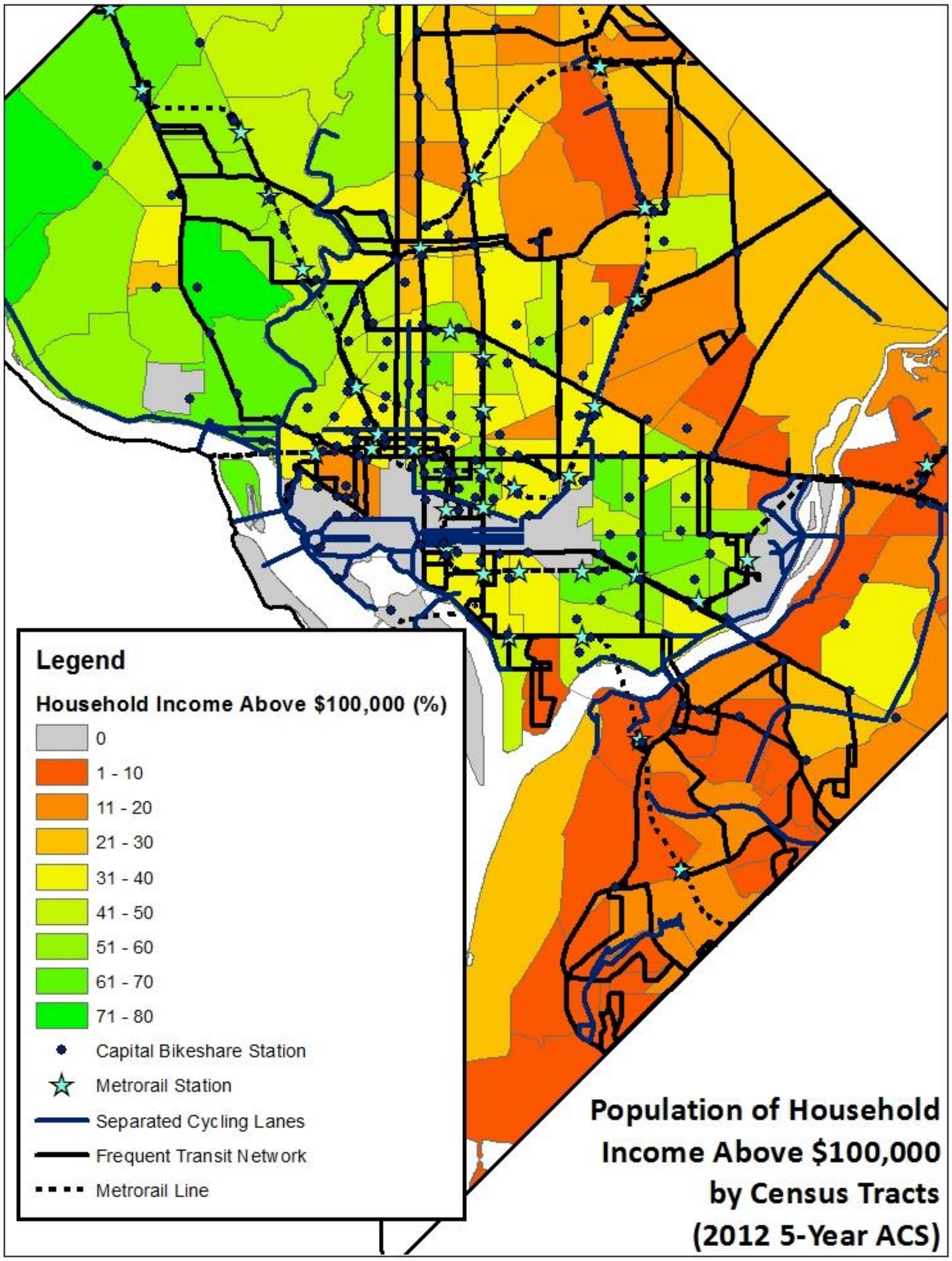


Figure 3.14 Map – Proportion of Household Incomes Over $100,000 by Washington D.C. Census Tract
Note: Source (ACS. 2012)

The literature review in Chapter 2 found that higher car ownership was related with lower rates of cycling. The 2012 5-year ACS information was organized into a variable of the car-free households as a proportion of the overall census tract households. From Figure 3.15 it is shown that generally the higher proportions of car-free households are located to the north of downtown, and south of the Anacostia River. The areas south of the Anacostia River could have low car-ownership due to lower income levels as shown in Figure 3.12. Whereas the areas north of downtown could be a result of good walkability and close proximity of necessary everyday services and goods as the land-use map shows in Figure 3.17.

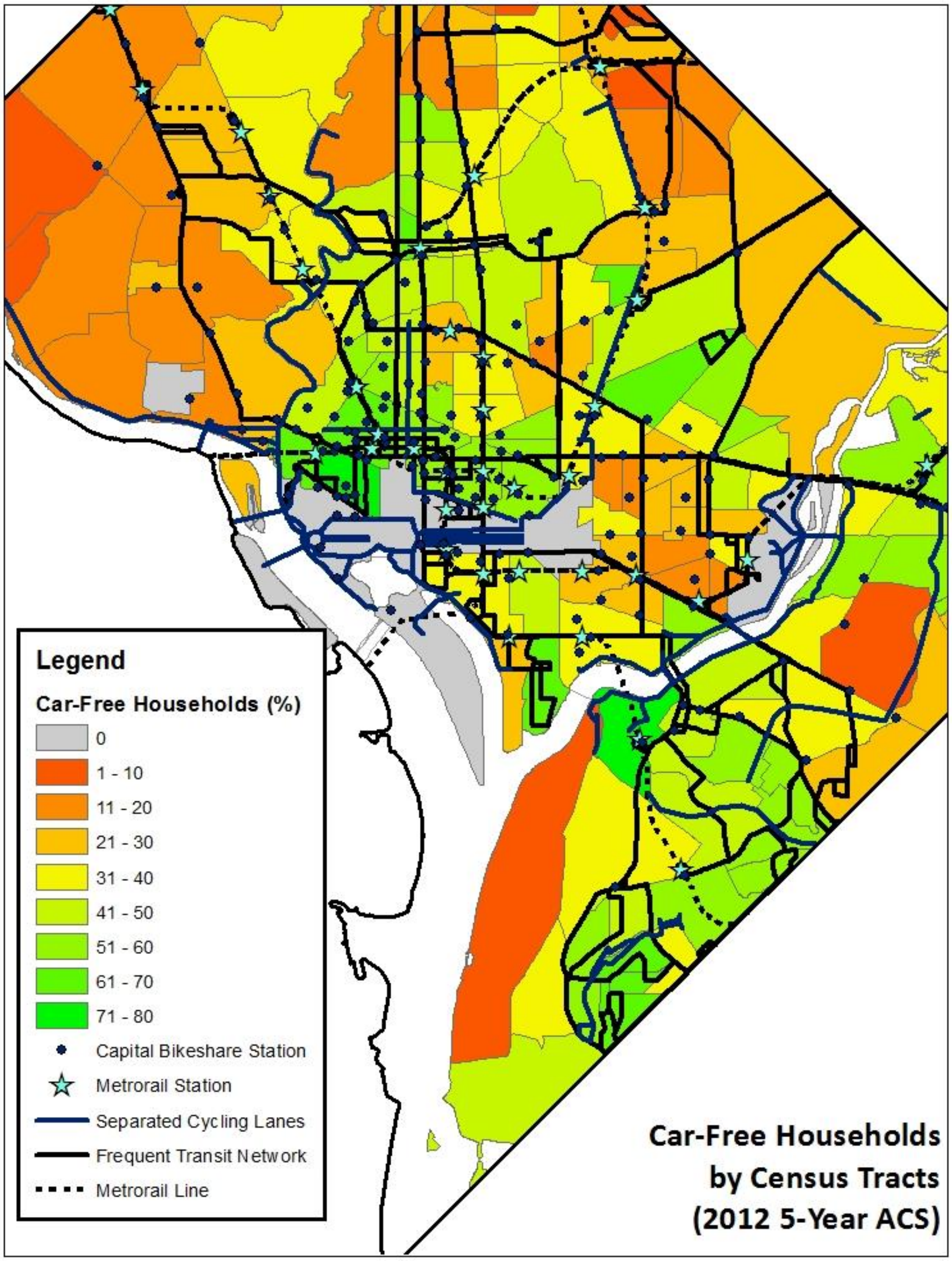


Figure 3.15 Map – Proportion of Car-Free Households by Washington D.C. Census Tract
Note: Source (ACS. 2012)

Additionally the proportion of those persons 16 years of age and older employed as a proportion of the overall census tract population were used to measure the level of employment. Figure 3.16 shows the highest proportions of people that are employed are located west of the Anacostia River, in the vicinity of the H-Street, surrounding and north of the downtown.

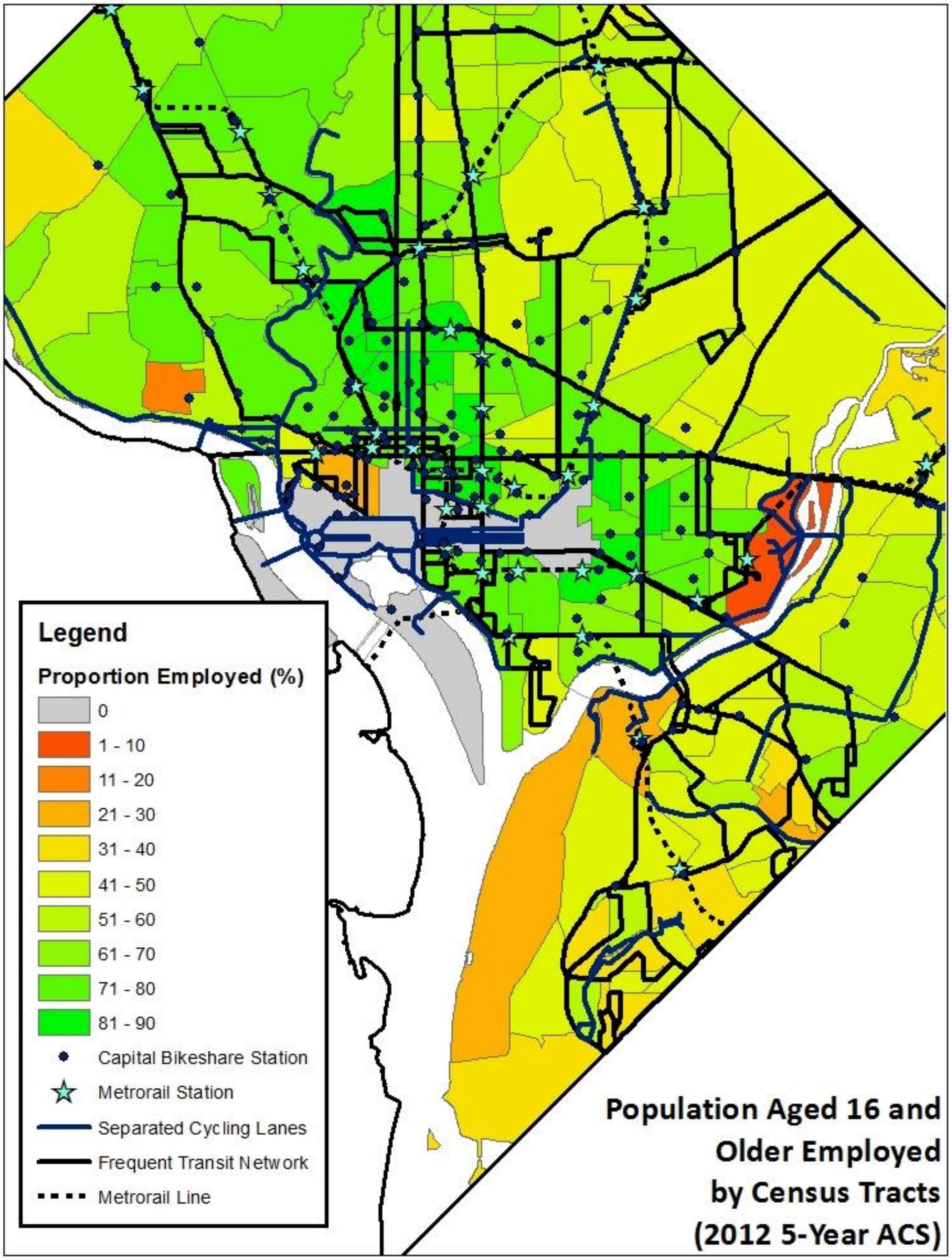


Figure 3.16 Map – Proportion of Employed Population Aged 16 years or Older by Washington D.C. Census Tract
Note: Source (ACS. 2012)

The literature review in Chapter 2 revealed that mixed land use was related to the rates of cycling. Land use data was acquired from the Washington D.C. municipal resources; specifically a 2006 map of existing land uses (Washington D.C., 2013). While the existing land use data is seven years old it is not expected that the land use would be drastically different from the data time frame. To verify the validity of this land use information, a combination of site visits, Google Street View (Google Street View, 2013) and the Google Earth map histories feature (Google Earth, 2013) was used to examine the land use and built environment surrounding both randomly and purposely selected bikeshare stations. This verification process found that the land use data was consistent, with the exception that this study has the inability to distinguish commercial uses into two distinct categories of offices, and shops/services which may generate different mobility requirements.

It was not possible to find a 2006 definition of land uses; therefore the 2011 Comprehensive Land Use Plan (The District of Columbia, 2011) definitions were used. The 2006 existing land use map and the planned 2011 comprehensive were developed as part of the same process. A comparison of the 2006 and the 2011 maps confirms no drastic changes and that the 2011 definitions are suitable for the 2006 data. The land use categories are measured for each bikeshare station as the proportion of the total area at each radius. There are a total of ten land use categories defined as below:

- **Low density residential –** "Housing development primarily consisting of single family detached or semi-detached homes." (The District of Columbia, 2011)
- **Low-medium density residential (moderate density residential)** – "Row house neighbourhoods, garden apartment areas, and areas characterized by a mix of single family homes, row houses, and small apartments." (The District of Columbia, 2011)
- **Medium density residential** – "Areas of mid-rise (typically 4-7 storey) apartment development, although may also identify areas with a mix of high rises and row houses or high-rises surrounded by large open spaces." (The District of Columbia, 2011)
- **High density residential –** "Areas characterized by multi-family housing of 8-stories or more." (The District of Columbia, 2011)

- **Mixed use –** “A development type in which various uses such as office, retail and residential are combined in a single building or on a single property.” (The District of Columbia, 2011)
- **Commercial** – which includes:
- **Heavy commercial –** “Retail commercial use with some of the same characteristics and external impacts as industrial uses, such as noise, dust, vibration, and large open storage areas. Examples would be auto-body shops, auto parts shops, lumber yards, building supply wholesalers, plumbing contractors etc.” (The District of Columbia, 2011)
- **Medium density commercial –** “Areas of mid-rise (4-7 storey) office and retail development.” (The District of Columbia, 2011)
- **Moderate density commercial** – “Areas of retail, office, and service uses generally 3-5 stories in height.” (The District of Columbia, 2011)
- **Low density commercial –** “Commercial development characterized by one and two storey buildings, often with off-street surface parking lots.” (The District of Columbia, 2011)
- **Institutional –** “Property owned and operated by a college, university, hospital, society, religious order, house of worship, foundation, non-profit entity, or other organization with similar characteristics.” (The District of Columbia, 2011)
- **Industrial** – “Relating to companies engaging in the manufacture of products or processing of materials.” (The District of Columbia, 2011)
- **Parks and Open Space –** “Tract of land set aside for public use, aesthetic enjoyment, recreation, or the conservation of natural resources. Any parcel of land which is essentially unimproved, farmed or devoted to a public or private recreational use. Includes the federal and district park systems, including the national parks, the circles and squares of the L’Enfant city and district neighbourhoods, the national mall, settings for significant commemorative works, certain federal buildings such as the White House and the US Capitol grounds and museums, and district-operated parks and associated recreation center. It also includes permanent open space uses such as cemeteries, open space associated with utilities such as the Dalecarlia and McMillan Reservoirs, and open space along highways such as Suitland Parkway. This category includes a miss of passive open space (for resource conservation and habitat protection and active open space (for recreation).” (The District of Columbia, 2011)
- **Public –** which combines:
- **Federal public** – “the portion of Washington D.C. under federal ownership, especially the area around the national mall, tidal basin and US Capitol. Includes land and facilities owned, occupied and used by the federal government, excluding parks and open space. Uses include military bases, federal government buildings, the International Chancery Center, federal hospitals, and similar federal government activities. The federal category

generally denotes ownership rather than use. Land with this designation is generally not subject to zoning." (The District of Columbia, 2011)

- **Public, quasi-public, institutional** – "Any space owned and maintained by the District of Columbia government and used by the public particularly streets, alleys, and sidewalks." (The District of Columbia, 2011)
- **Local public** – "Any building used to deliver local government services, such as a police or fire station, a school, a senior center, a library, city hall, or a wastewater treatment plant. Includes land and facilities occupied and used by the District of Columbia government or other local government agencies (WMATA), excluding parks and open space. Uses include public schools including charter schools, public hospitals, government office complexes, and similar government activities." (The District of Columbia, 2011)

The land use map in Figure 3.17 shows that a majority of the bikeshare stations are located in the downtown core where there is predominantly commercial land use. The area immediately north of the downtown is a mix of commercial, higher density apartments and low-medium density row-houses. The area immediately west of the Downtown core consists predominantly of low-medium residential density land use with a dispersed mix of smaller scale commercial. From this map it can be shown that the high frequency transit routes typically follow corridors of commercial and medium to high density land uses.

The data from this map aligns with the more recent 2012 5-year ACS population density data in Figure 3.7. This suggests that generally there have been minor changes in the eight years since this 2006 land use data was published.

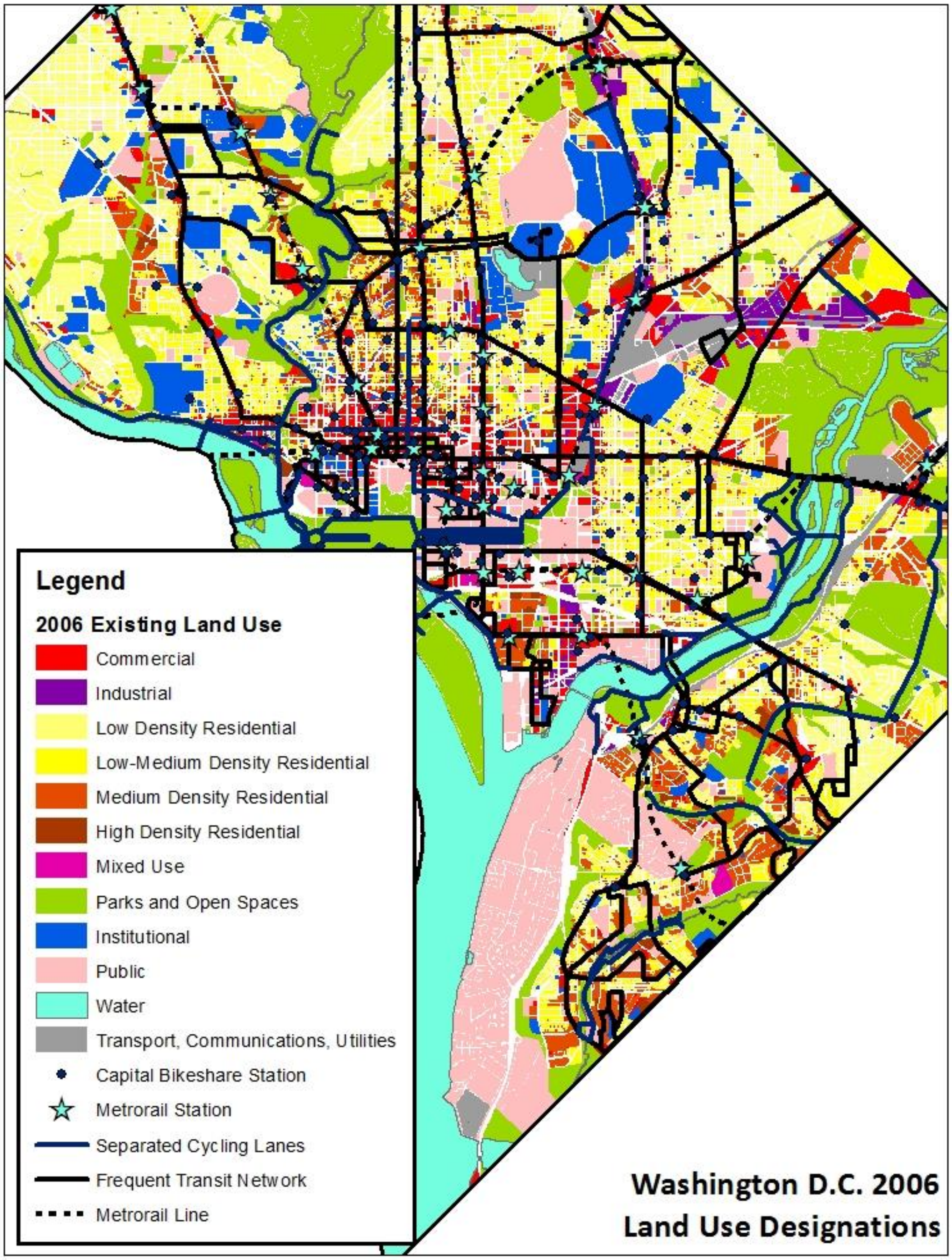


Figure 3.17 Map –Washington D.C. 2006 Existing Land Uses
Note: Source (City of Washington. 2013)

The topographical information was collected using an ArcGIS dataset available from the Washington D.C. open data catalogue (Washington D.C., 2013). The literature review in Chapter 2 found that the variation in elevation had a relationship with the number of trips. Therefore the elevation change (the difference between the maximum and minimum elevation) for each bikeshare station for each radius was determined. Despite the variable measuring the change in elevation, only the absolute elevation per geographical point was able to be visualized as shown in Figure 3.18. Based on Figure 3.18 below the lowest elevations are located in the National Mall and Downtown core. The elevation levels increases slightly to the north and west of the Downtown. The areas to the far north and south of the Anacostia River have the largest elevations. The majority of bikeshare stations are located in the lowest elevation areas in the national mall, downtown and areas immediately north and west of downtown.

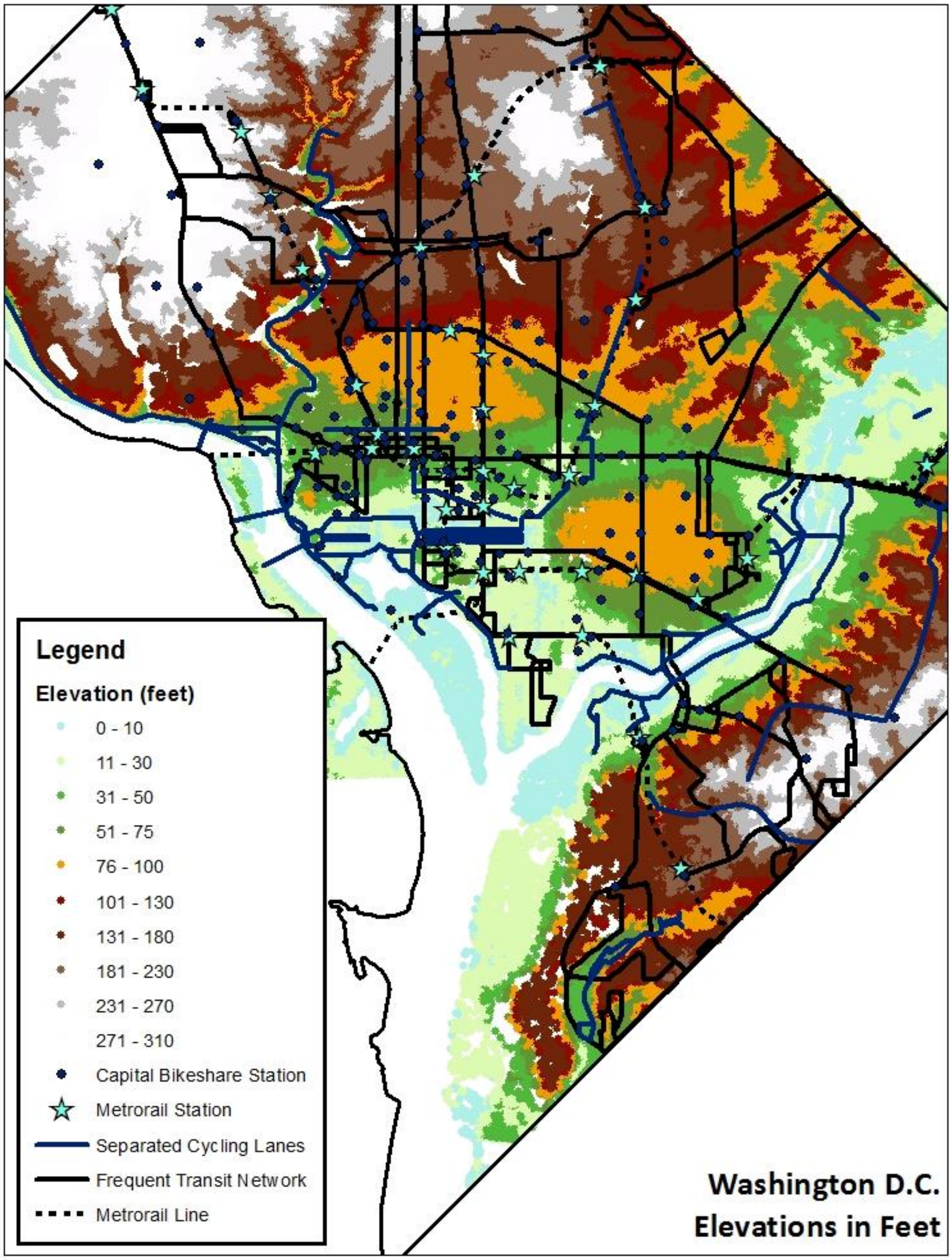


Figure 3.18 Map –Washington D.C. Elevations
Note: Source (City of Washington. 2013)

The literature review in Chapter 2 did not find a relationship between cycling and tourist attractions. However given the large presence of tourism in Washington D.C. it would be prudent to account for and control for these as they could influence bikeshare ridership levels, therefore the geographical locations of major tourist attractions were also required. A list of attractions in Washington D.C. was obtained from an ArcGIS file (City of Washington D.C., 2013). For the purposes of this study major tourists attractions are being defined as attractions or venues that attract large volumes of domestic, national, and international visitors.

Since there are potentially hundreds of attractions in Washington D.C., this study only focuses on the top visited attractions. Information on the most visited attractions was acquired from the Smithsonian Institute (Smithsonian, 2013). The Smithsonian Institute provides information on the number of visits for the thirty-one attractions that it manages and operates in Washington D.C. The number of visits range from 38,000 to 8 million for 2013 (see Appendix D) over an entire year. Considering that this is a year's worth of visits, and that the Capital bike share only saw 1.5 million trips for the six month data timeframe, it is very likely that only a small proportion of these visits would have been associated with Capital Bikeshare trips. Therefore only attractions with more than 600,000 visits per year were considered.

After examining this list against a search of attractions being advertised by tourism and travelling websites it was also decided to include the Washington Monument, The White House, the U.S. Capitol, and the Verizon Center. All of these attractions are also within 400 meters of a Capital Bikeshare station. The Verizon Center is a 20,000 seating capacity sports arena that is host to two professional NBA basketball teams, and one NHL hockey team and numerous concerts throughout the year (Verizon Center, 2013). It is easy to estimate that this attraction will have more than 600,000 visits per year. The Washington Monument, The White House, and the U.S. Capitol are famous American attractions with close proximity to many of the other high visitation attractions. While official numbers of the total number of visitors are not available, this study will assume that these attractions have at least 600,000 visitors per year. Figure 3.19 shows that the top attractions within 400m of a bikeshare station are all located in a relatively small geographically constrained area within the Downtown core and National Mall.

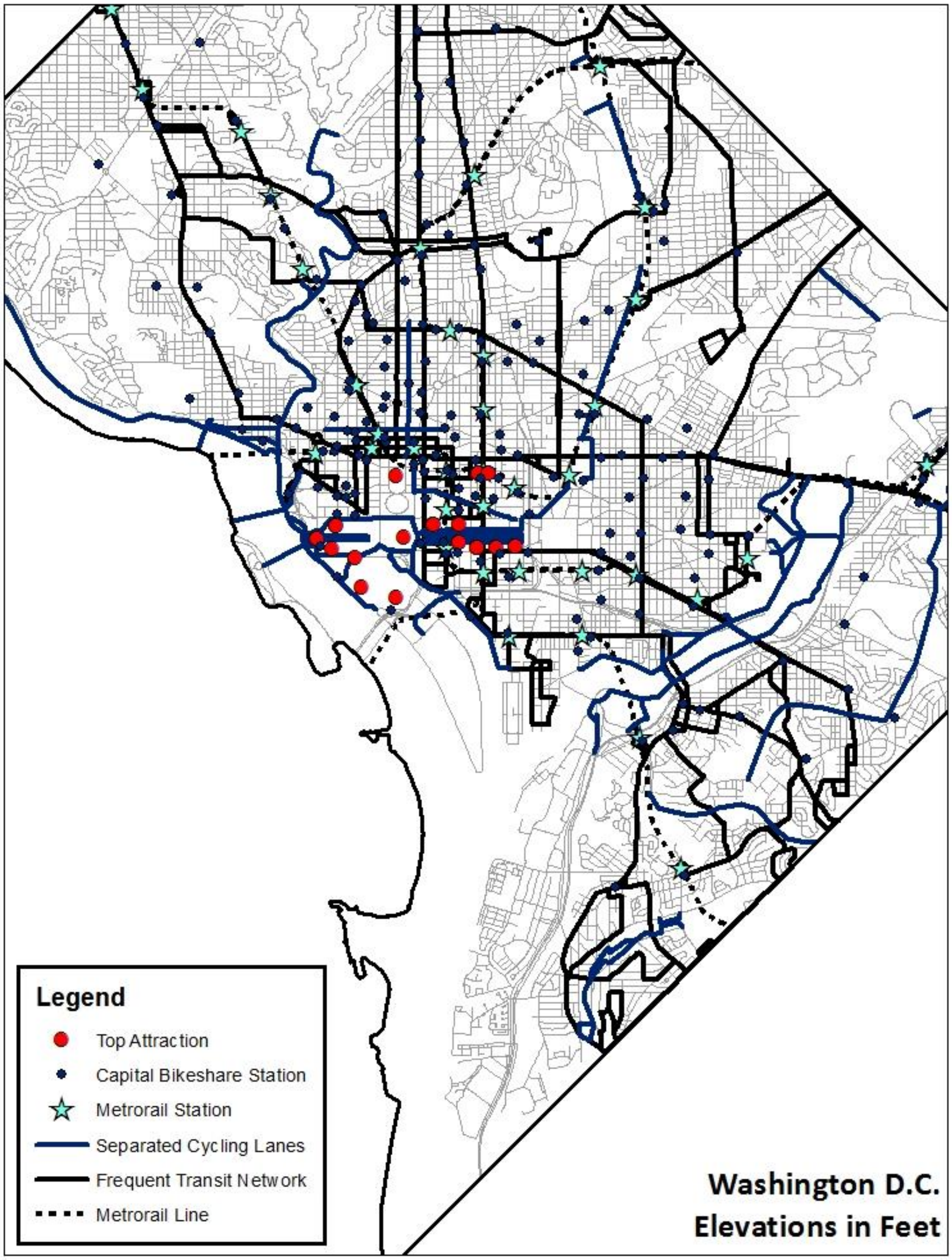


Figure 3.19 Map –Washington D.C. Top Attractions
Note: Source (Smithsonian. 2013)

Bikeshare station density and the intersection density combined provide a measure of the walkability and permeability of the bikeshare system, and potentially the grid layout which is important for mobility. The fewer intersections there are the further someone may have to walk, cycle to get to their destinations. Since post-World War II suburban style developments tend to be arranged with long meandering roads with few intersections, destinations are farther to reach than they physically are. Higher intersection densities more closely represent the true travelling distance between two points, which fosters greater transit performance efficiencies. The assumption is that the higher the permeability of the built form, the more supportive the built environment is for allowing people to walk to a bikeshare station and use the bikeshare bicycle for their trip.

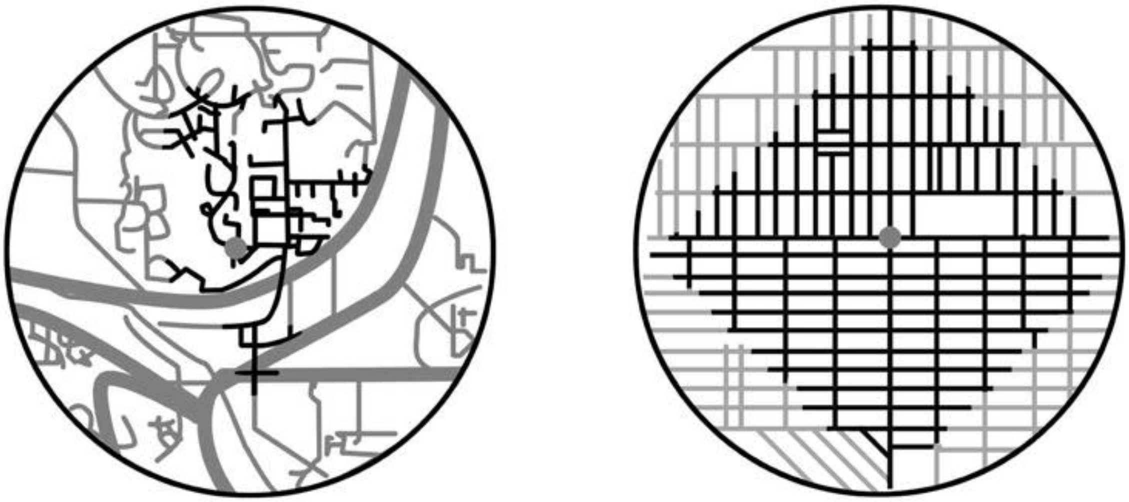


Figure 3.20 400m Walkability with Different Urban Built Forms
Note: Dark lines show how far people can walk within 5 minutes. Source (Walker. 2012, p.62)

The literature review in Chapter 2 found that higher intersection density was related to higher volumes of bikeshare trips. An ArcGIS intersection dataset identifying each intersection was acquired from the Washington D.C. open data catalogue (Washington D.C., 2013). This dataset included intersections such as overpasses, underpasses, and highway entry and exit ramps. These intersections were excluded because it is unlikely that an underpass indicates increased permeability in the built form for cycling or walking. Secondly, environments like a highway entry ramp are not environments conducive and may actually act as barriers for cycling or walking. Therefore the assumption is that these intersection types would not induce volumes levels of trips.

The bikeshare density variable was determined for each bikeshare station as a total count of the number of bikeshare stations within each radius defined in Chapter 3.2.

Since all bikeshare stations are being analyzed during the same timeframe it was assumed that time dependent variables such as the weather or holidays will have affected all bikeshare stations similarly, and do not need to be controlled.

The accuracy of the information in this chapter was further verified with visit to Washington D.C. in March, 2014 conducting site observations of the built environment and interviews with Capital Bikeshare employees. The site observations entailed visiting a combination of bikeshare stations with the highest trips, outliers from the linear regression model analysis, irregular geospatial/trip quantities and randomly chosen stations. The bikeshare stations were evaluated based on their immediate environment for the type and scale of commercial, residential and institutional land uses, the presence of separated bike lanes and transit stops. These evaluations were compared against their station ratings as completed in this chapter, and found no major discrepancies.

Other ArcGIS datasets such as the Washington D.C. boundary, street and road networks, bikeshare station locations were also required for visualization and analysis acquired from the Washington D.C. open data catalogue (Washington D.C., 2013).

3.7. Site Visits and Interviews

Since this study uses datasets that are not as recent as the 2013 study time frame (e.g. the land use data is from 2006), it was necessary to use interviews and site visits to verify the accuracy and validity of both my data and results. A week-long trip was made to Washington D.C. in mid-March 2014 to conduct site visits and prearranged interviews with the Capital Bikeshare planning staff. At this point the initial multivariable and bivariate analysis had been completed and there was a solid understanding of the general findings.

The visit initially consisted of obtaining a three day casual membership so that the system could be used and observed for its operational qualities. While travelling around the city it was important to note key characteristics of the Washington D.C.'s built environment including the scale of buildings and general layout of land use. Both the Metrobus and Metrorail services were used to obtain observations of their operations and experiences. Finally the three on-road separated cycling facilities were cycled on to obtain observations of their operations and experiences. Over the course of the week the Downtown, Columbia Heights, Shaw, Capitol Hill, H St., National Mall / Potomac Park, and Georgetown areas were visited.

The visit to Washington D.C. also consisted of conducting site visits at various bikeshare stations to verify that the built environment characteristics matched the datasets beings used. The twenty stations that were visited were selected based on three main categories:

1. Bikeshare stations with the highest and lowest usage
2. Bikeshare stations that have been identified as outliers in the multivariable linear regression analysis
3. Bikeshare stations chosen randomly

The built environment and transportation infrastructure around these stations were verified against a check list as seen in Appendix I. Details on the surrounding scale and type of land uses, the presence and type of cycling infrastructure, and the presence and type of transit infrastructure were recorded. Photos capturing the bikeshare station and the immediate built environment were taken. These photos and observations were later verified against the dataset per station to uncover any major discrepancies. No significant differences were found except for the inability of my research to differentiate between office and retail land use types.

The interviews took place after using the bikeshare system across the city for a few days. Observations from the system usage and on the ground experiences in Washington D.C. in conjunction with my findings were crucial for gaining a contextual understanding of Washington D.C. Interviews were conducted with three Capital Bikeshare planning staff. The interviews were casual and loosely structured and consisted of presenting the research methodology, findings and potential explanations for the results. To help further my understanding of the system and its operational limitations, afterwards I asked the interviewees about certain operational features of the Capital Bikeshare, specific ambiguous findings from the research, or information that was shared over the course of the interviews.

3.8. Data & Study Limitations

Besides the limitations already mentioned in Chapter 3 above, there are further data and study limitations that are outlined below.

Since this project is removing bikeshare stations located outside of the Washington D.C. boundary but including trips that started within Washington D.C. and ending outside the study boundary and trips that started outside Washington D.C. and ending inside the study boundary it was necessary to consider how the number of trips originating or ending in the other regional municipalities will affect the results. In the preliminary analysis in Chapter 4 the influence of regional trips on the analysis was tested by removing trips with connections outside Washington D.C. to determine their impact on the statistics. This study does not undergo a complete edge effect analysis. Since it very likely that there are trips not destined to end or start within the Washington D.C. boundaries, there are bound to be some biases. It is assumed that these biases are negligible.

Since each bicycle has an identifying code, it was planned to ensure that no bicycle was being counted twice at any given point in the dataset. Similarly since each bicycle share station has a known number of available docking points, it was also planned to verify that at any given point in the timeframe the number of bicycles did not exceed the maximum allowable docking points for all bikeshare stations. It was found due to the large scale of the data, these tasks were quite complex and would have required significant time and resources outside the scope of this thesis project. Therefore due to the inability to verify these qualities, there is potential for bias and irregularities in the study results.

This study is using a 400m radius to assume a 5 minute walking distance from the bicycle share stations. This is the known distance people are on average willing to walk to high quality transit services. This project is using a series of ArcGIS buffers to measure the variables within each radius. These “as the crow flies” buffer distances mean that the results are not path dependent and cannot account for the true journey paths following roads and connections between bikeshare stations. Since this project will not be determining the true paths of Capital Bikeshare trips, there will be biases and irregularities with this study’s results as the actual trips may have been longer within the 400m buffer.

It was also revealed from the interviews with the Capital bikeshare staff that the station selection criteria involves locating bikeshare stations as close as possible to bicycle facilities and Metrorail stations, areas with higher proportions of cycling to work modal shares, and higher density employment/population (Capital Bikeshare Staff, Personal Communication, March, 2014). This may introduce biases for the study results since the bikeshare stations will have a built-in relationship with these variables. The results have been evaluated to ensure that this is not the case.

There may be many other external factors either unknown or known that are not being controlled for. Accommodating for the largest known influences on the rates of cycling should minimize the complications from excluded variables.

Chapter 3 outlined the suitable study conceptualization and operationalization required for the three-part analysis and visualization in Chapter 4.

Chapter 4.

Analysis

Chapter 1 introduced the project, Chapter 2 reviewed the existing literature, and Chapter 3 completed preliminary conceptualization and operationalization of this study. Chapter 4 consists of a four-part statistical analysis and visualization of the data outlined in Chapter 3. Chapter 4 will outline the statistical analysis tools used and the respective limitations, assumptions and results. Chapter 4 will end with a discussion of the analysis findings and their placement within the literature review.

This first section of Chapter 4 explores basic characteristics, behaviors and patterns of the trip data.

The unit of analysis for this research project is the Washington Capital Bikeshare system. Since the research is also looking at the patterns at the bikeshare station level within the system, these are embedded units of analysis. Each bikeshare station is being treated as an individual observation by analyzing the respective trips that flow into and out of selected bikeshare stations over a 24 hour period. In this project the dependent variable is the number of trips at each Capital Bikeshare stations. There are two test independent variables: separated cycling infrastructure, and high frequency transit. There are potentially other independent variables according to the literature review in Chapter 2.

From the literature review (Chapter 2.3) it is apparent there are different ways to analyze the rich datasets available from public bike share systems, including network analysis (O’Brien et al., 2013), state prediction using spatiotemporal characteristics (Borgnat et al., 2010; Kaltenbrunner et al., 2010), using data mining methods to cluster bikeshare stations into communities (Froehlich et al., 2009), analyzing the spatial tides across the city (Padgham, 2012), and bikeshare station stand occupancy analysis (Vogel et al., 2011).

There are benefits and draw backs to each method. For example disaggregate studies of bike share systems pose a danger with the “disappearance of meaningful data in the noise of small numbers” (O’brien et al., 2013, p. 16; Lathia et al., 2012).

Some studies used bicycle share system stand occupancy data to conduct their analysis. These studies however do not incorporate real time bicycle share system behavior and only look at the overall availability of bikes (Vogel et al. 2011). These studies also do not consider flows, and only describe the net changes.

From the literature review it was clear that no known research has been completed conducting bivariate and multivariable analysis on the Washington, D.C. Capital Bikeshare system to examine the relationship between separated cycling infrastructure, high frequency transit and the patterns of bicycle share station trips.

Table 4.1 below shows the summaries of the study trips measured in various ways. All trip statistics were positively skewed with a higher proportion of low trip bikeshare stations.

For the purposes of this study subscriber users are classified as trips made by members with an annual pass and monthly pass, while casual users are classified as trips made by members with a daily pass or 3-day pass. For the purposes of this analysis A.M. Peak trips have been defined from 6-11a.m., while P.M. Peak trips have been defined from 3-9p.m. representing 22% and 45% respectively of the total system data. The peak times were chosen by evaluating Figure 4.4 to select the hours between when the peak starts and which hour it returns to approximately same starting level of trips per hour.

From Table 4.1 it can be shown that the differences between starting trips and ending trips are minor, indicating that the data is fairly consistent and there are no major differences caused by the inclusion of trips starting within the study area and ending outside set out in Chapter 3.

There are minor differences between the average trips per weekday versus average trips per weekend day. This potentially confirms that the inclusion of Frequent Transit Network routes without frequent weekend services had minimal influences on the results.

There is a higher mean of evening peak trips than morning peak trips, which is due to a longer peak period with larger volumes of trips.

The mean trip durations of 28 minutes closely aligns with the 30 minute maximum free time limit per trip allowed by the Capital Bikeshare system pricing. This suggests that monetary factors may have a large role in influencing the behaviour of Capital Bikeshare users as suggested by Jurdak (2013).

Table 4.1 Capital Bikeshare Trip Statistics April to September 2013

Description (n = 176)	Mean	Standard Deviation	Median	Maximum	Minimum
Total Starting Trips	8231	6723	7498	40258	28
Total Ending Trips	8256	7126	7326	43590	35
Average Start Trips per Day	47	36	43	220	0.24
Average End Trips per Day	47	38	44	238	0.24
Average Start Trips per Weekday	46	35	45	220	0.18
Average End Trips per Weekday	48	43	39	265	0.15
Average Start Trips per Weekend Day	46	37	45	228	0.18
Average End Trips per Weekend Day	49	45	40	264	0.15
Average Start AM Peak Trips per Weekday	12	10	9	75	0.01
Average End AM Peak Trips per Weekday	11	12	7	87	0.02
Average Start PM Peak Trips per Weekday	21	18	20	101	0.01
Average End PM Peak Trips per Weekday	21	18	19	106	0.02
Average Start Trips by Subscribers Users per Day	35	28	31	170	0.14
Average End Trips by Subscriber Users per Day	35	29	31	186	0.14
Average Start Trips by Casual Users per Day	12	18	6	145	0.02
Average End Trips by Casual Users per Day	12	18	6	139	0.02
Average Trip Duration (min)	28	58	19	1441	2.00

Note: Source (Capital Bikeshare. 2013)

Figure 4.1 shows approximately consistent system trip volumes per day over the entire study timeframe. This is further confirmed with an approximately linear relationship shown in Figure 4.2 with the cumulative summation of trips per day for the entire system. There appears to be divergence in the patterns with abnormally low usage on June 7, June 10, May 7 April 29, and April 30. After checking for events on these days, climatic conditions and verifying with Capital Bikeshare staff for major operational or software glitches (Capital Bikeshare Staff, Personal Communication, March, 2014), the only potential conclusion is that there was excessive rain and abnormally lower temperatures on these dates. The approximately linear growth in trips possibly supports the assumption that the weather is influencing all bikeshare stations in the system similarly. This also shows that climate is consistent enough across the data timeframe that the Capital Bikeshare is experiencing approximately the same number of trips per day.

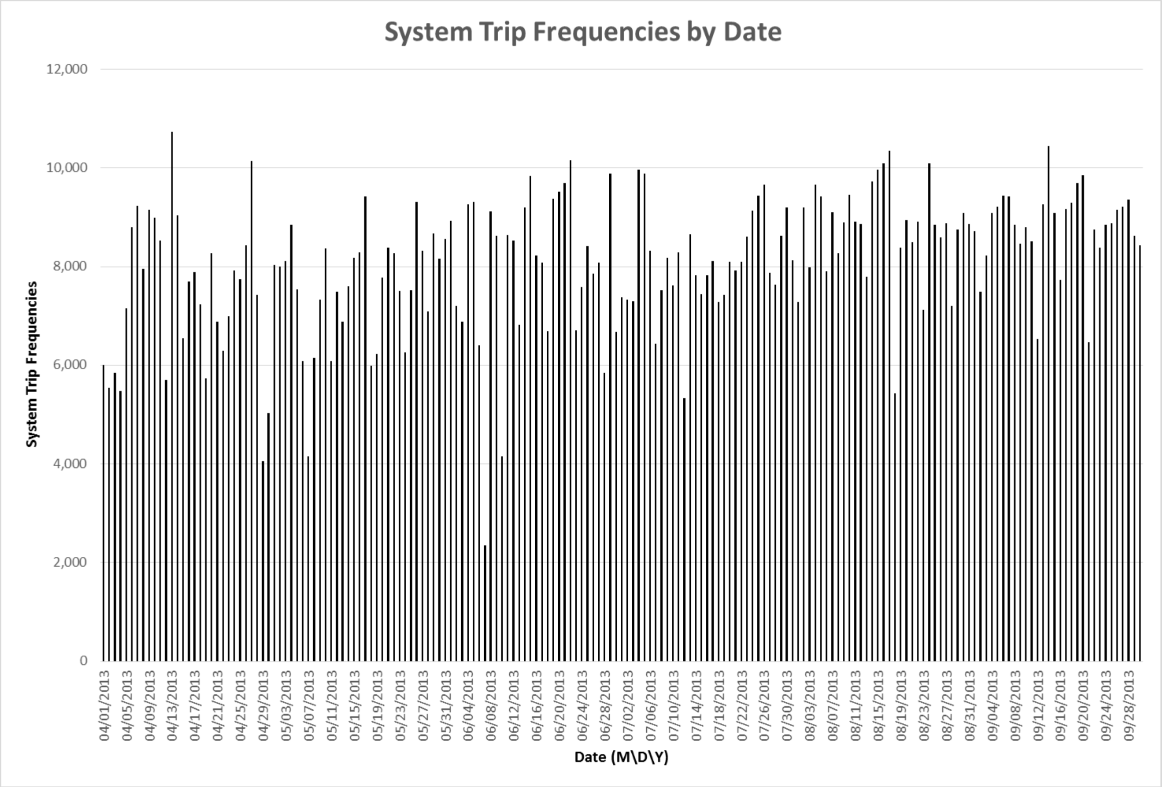


Figure 4.1 Graph – System Trip Frequencies per Date over Study Timeframe
Note: Source (Capital Bikeshare. 2013)

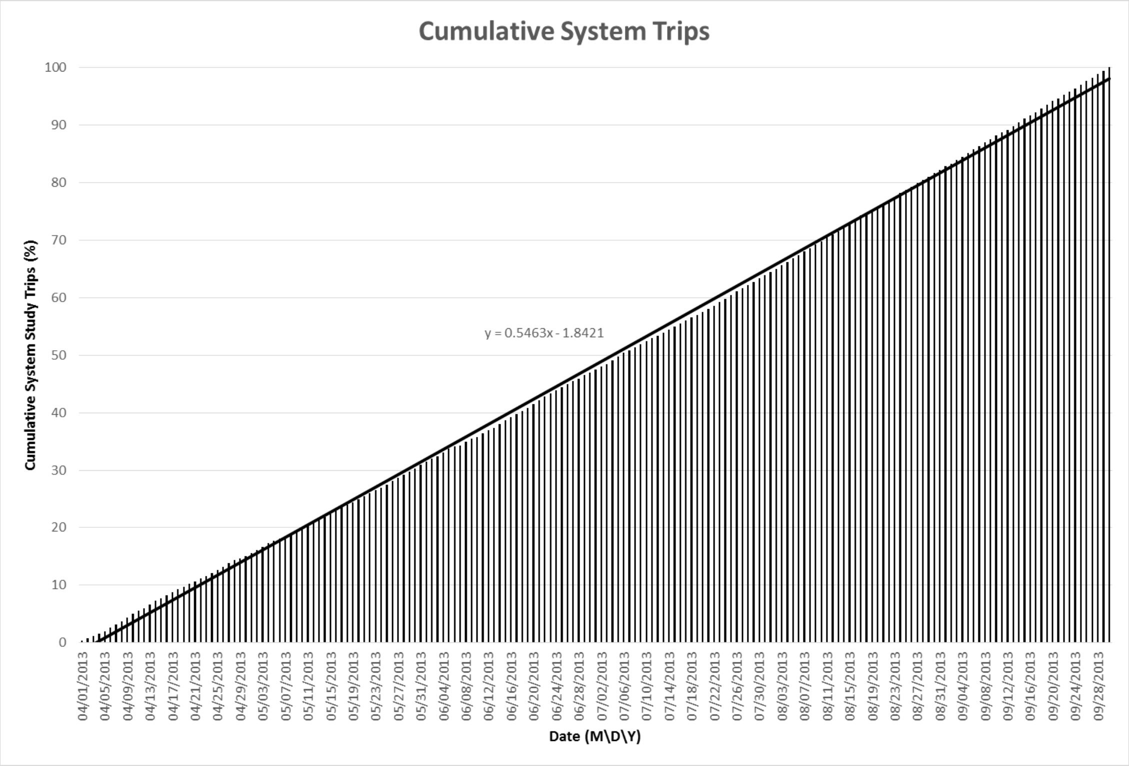


Figure 4.2 Graph – Cumulative System Trips per Date for Study Timeframe
Note: Source (Capital Bikeshare. 2013)

Figure 4.3 shows an inverse log-linear pattern, with a few bikeshare stations that exhibit significantly higher use while a large majority of stations exhibit low usage. This reflects Zipf's Law log linear pattern that occurs with population size distribution of cities in a country. Zipf's Law states that "for most countries the size distribution of cities strikingly fits a power law: the number of cities with populations greater that S is proportional to 1/S." (Gabaix, 1999, p. 739). Gabaix attributes this to larger cities generally having higher quality and quantities of amenities that can further support shocks to the regional activity (Gabaix, 1999). This could also be compared to airline networks, where specific airports due to a more central position in the network operate as a hub with more direct and frequent connections to other airports (Wang et al., 2011).

It is possible that bikeshare stations in the downtown areas, specifically the "Massachusetts Ave & Dupont Circle NW" bikeshare station with the highest trips, have a succession of higher quality and proportion of amenities including retail, offices, services, recreational destinations. This in addition to a stronger and more central placement within the network of both bikeshare stations, separated bike lanes, and the Frequent Transit Network, contributes to a stronger ability to accommodate the shocks of variations in everyday economic activity. Bikeshare stations in lower density residential neighbourhoods would exhibit the opposite, since a greater degree of land use mixture, multipurpose travelling and strong network connections are typically absent.

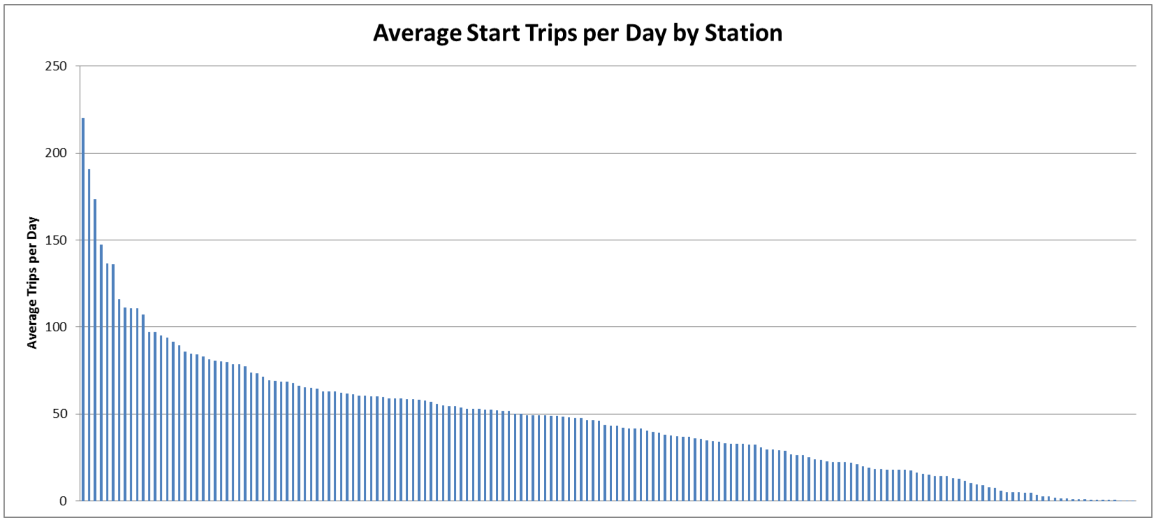


Figure 4.3 Graph – Capital Bikeshare stations Arranged by Decreasing Average Trips per Day
Note: Source (Capital Bikeshare. 2013)

In Figure 4.3 the absence of self-evident groups of bikeshare stations with similar trip activities could indicate there is a different combination of variables for each bikeshare station is contributing to a different level of usage. This could also indicate that the summation of the variables cumulatively work to increase bikeshare station trip activity. Some bikeshare stations present very limited trip activity which could potentially demonstrate the opposite relationship, where the absence of variables cumulatively leads to little or no activity.

Analyzing the peak trip patterns of the system-wide data in Figure 4.4 and Figure 4.5 exhibits a surprising consistency. Throughout the week the morning, afternoon and evening peaks regularly occur at 8 a.m., 12 p.m. and 5 p.m. with the only exception that the Friday lunch time peak shifts to 1 p.m., and the Saturday and Sunday both only have one peak at 2 p.m. The weekday morning peak is less pronounced and more abrupt, occurring over a shorter amount of time. Afterwards there is a gradual rise in the number of trips until a minor lunch peak, building up to the evening peak which is more pronounced, occurring over a longer period. The weekend peaks see a more gradual rise and decay over the entire day. The Saturday night trips do not fully diminish until 4 a.m. suggesting the Capital Bikeshare is being used for nightlife and social activities. Despite the weekday and weekend pattern differences, all weekdays and weekend days individually account for 14.1%, and 14.8% of all trips respectively. Saturday accounts for the largest proportion of trips with 15.5% of all trips. Overall weekdays and weekends account for 70%, and 30% of all trips respectively

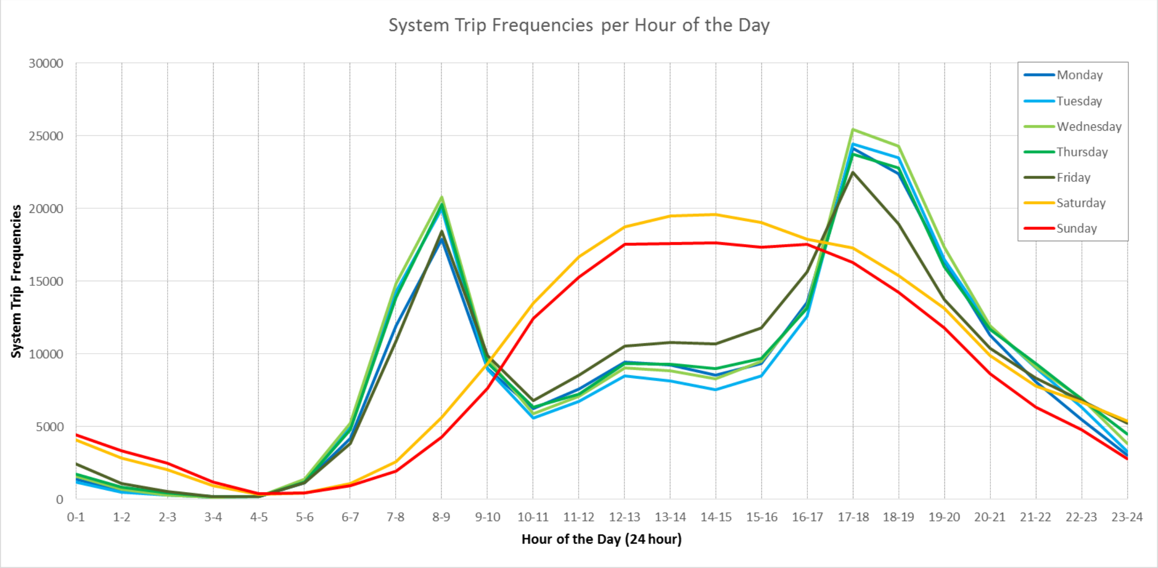


Figure 4.4 Graph – Total System Trips per Hour of the Day
Note: Source (Capital Bikeshare. 2013)

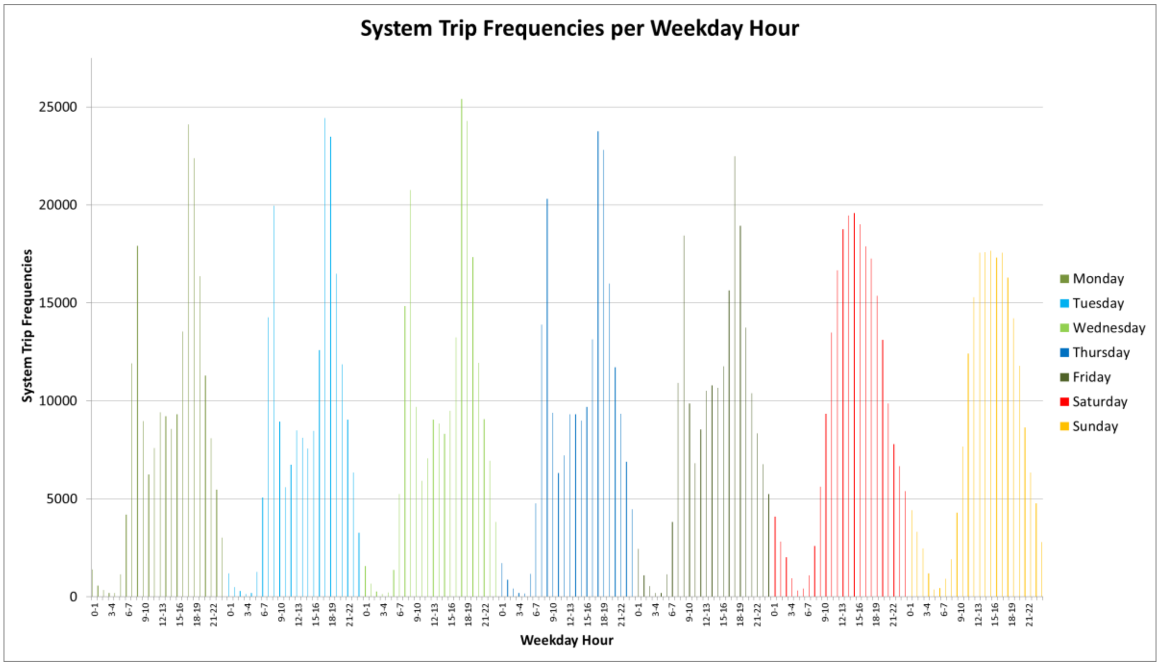


Figure 4.5 Graph – Total Capital Bikeshare System Trips per Weekday Hour
Note: Source (Capital Bikeshare. 2013)

Figure 4.6 and Table 4.2 show that the Capital Bikeshare is dominated by short trips under 30 minutes as found by Jurdak (2013). The mean and median trip lengths were 28 and 19 minutes respectively. Overall, 41.5%, 73.2%, and 88.7% of all trips were 10 minutes or less, 19 minutes or less and 30 minutes or less respectively. Table 4.2 demonstrates that casual riders make longer trips, where only 63% of all trips were 30 minutes or less versus 97% for subscribers. Put another way 37% of all casual trips are longer than 30 minutes versus 3% of subscriber trips.

Table 4.2 Capital Bikeshare Trip Duration Statistics

Duration (min)	Overall	Casual	Subscriber
2 or less	0.5%	.04%	.7%
5 or less	12.5%	2.1%	15.9%
10 or less	41.5%	12.3%	51.2%
19 or less	73.2%	37.0%	85.1%
30 or less	88.7%	63.0%	97.2%
60 or less	95.2%	82.0%	99.5%
120 or less	97.4%	90.0%	99.8%
360 or less	98.6%	98.9%	99.9%

Note: Source (Capital Bikeshare. 2013)

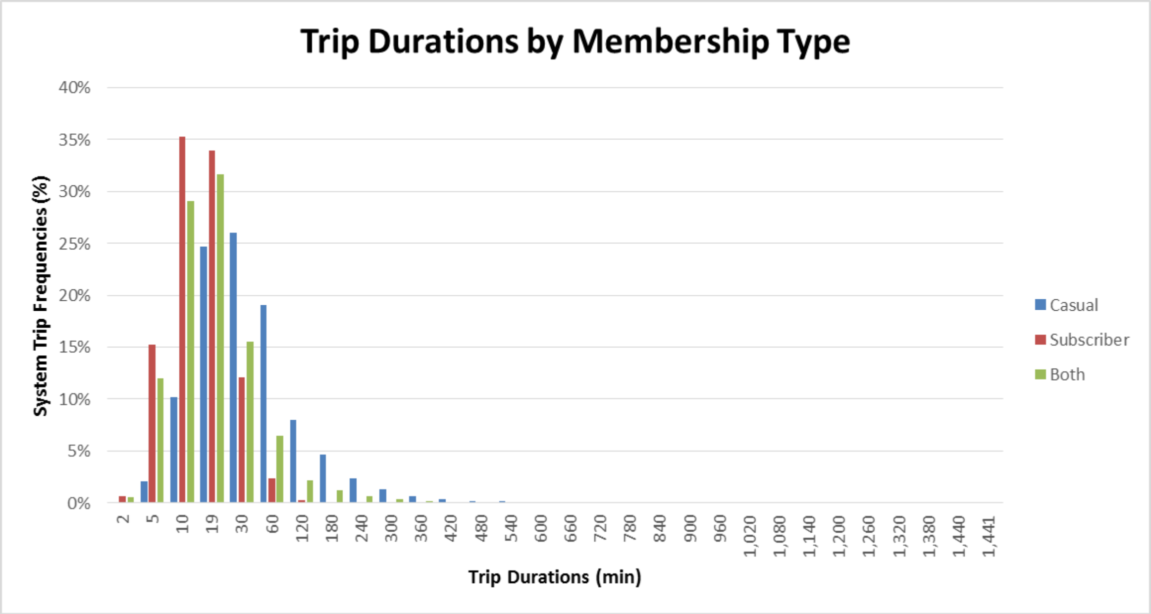


Figure 4.6 Graph – Total Capital Bikeshare System Trip Duration Counts
Note: Source (Capital Bikeshare. 2013)

Figure 4.7 below shows that the longest trips start from the bikeshare stations surrounding the National Mall. The bikeshare stations in the traditional mixed use residential neighbourhoods to the north and east of downtown show the shortest trip durations. The bikeshare stations in the downtown and far outer residential neighbourhoods to the north and in Anacostia have moderately longer trip lengths (20-40 minutes). Interestingly Figure 4.7 also demonstrates that there are no bikeshare stations with average trip duration lower than 10 minutes. Therefore per bikeshare station basis trips are typically 10 minutes or longer.

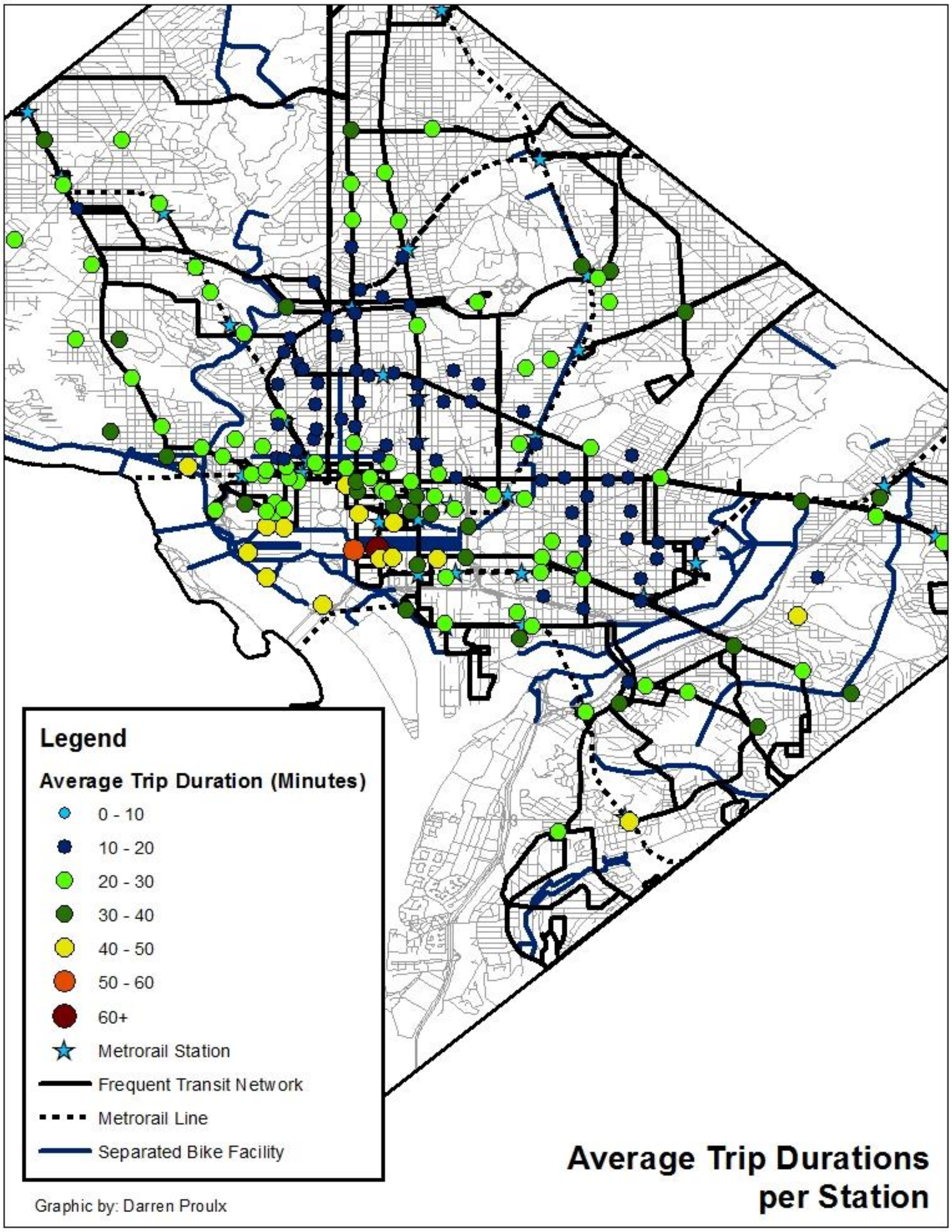


Figure 4.7 Map –Average Durations (Minutes) per Bikeshare Station
Note: Source (Capital Bikeshare. 2013)

The system use is dominated by subscriber users, comprising 75.2% of all trips. This suggests that the system is used predominantly by locals that have the ability to purchase an annual pass. From Table 4.2 and Figure 4.6, 51.2% and 97.2% of all subscriber trips are under 10, and 30 minutes respectively, reflecting the overall system pattern more closely than 12.3% and 63% respectively for casual users. The casual user trips are strongest on the weekend making up 40% and 38% of the Saturday and Sunday trips respectively as opposed to 17-22% during a typical weekday. Figure 4.8 further demonstrates the differences between casual and subscriber users. Subscribers show comparable usage patterns to Figure 4.5 which considers all trips, with two significant a.m. and p.m. peaks, and one minor lunch peak each weekday. The casual users only see one peak for the weekday which is significantly lower than the casual weekend peaks. These divergent casual user trip peak and duration patterns suggest that subscribers have the strongest influence in shaping the overall system trip patterns on weekdays.

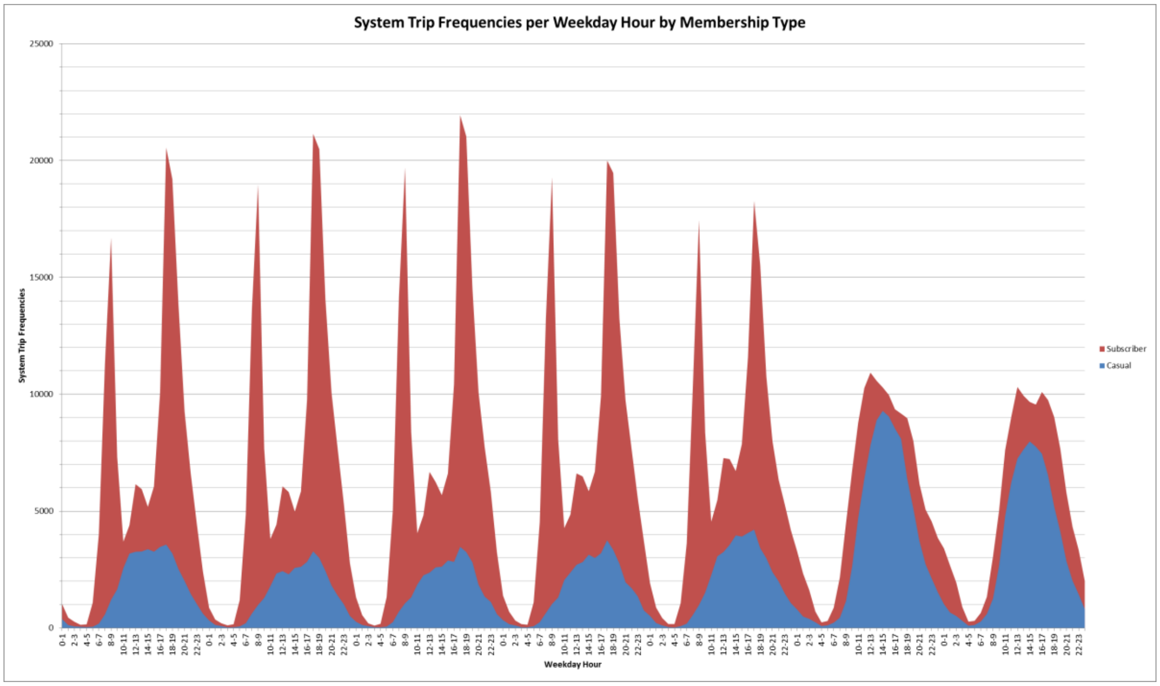


Figure 4.8 Graph – Total Capital Bikeshare System Trips per Weekday Hour by Membership Type
Note: Source (Capital Bikeshare. 2013)

Figure 4.9 shows that there are ten bikeshare stations with the highest average usage over 100 trips per day. Five are located just north of the downtown in the Shaw neighbourhood, two are located east of the downtown at the Union Station, and at the Eastern Market, and the final three bikeshare stations are located in the National Mall/Potomac Park. The stations south-east of the Anacostia River, and far north-east see some of the systems lowest usage.

Figure 4.10 shows that the top three bikeshare stations used by casual members are located within the National Mall. These bikeshare stations also correspond with higher overall use. Therefore is likely that casual users strongly influence the trip patterns at these bikeshare stations. Otherwise, generally bikeshare stations with higher casual trips are located in close vicinity to the National Mall and immediately north of the downtown.

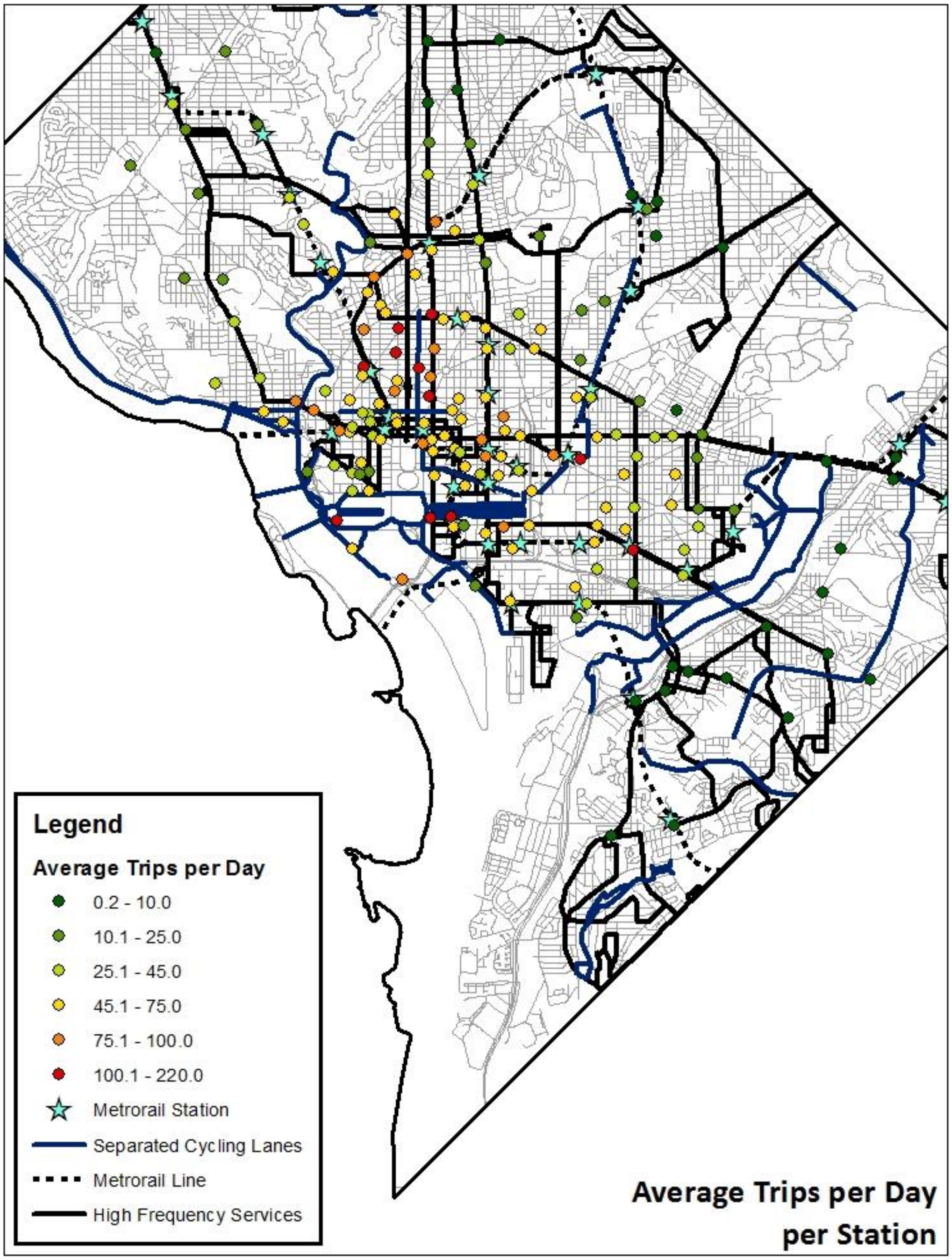


Figure 4.9 Map –Average Starting Trips per Day per Bikeshare Station
Note: Source (Capital Bikeshare. 2013)

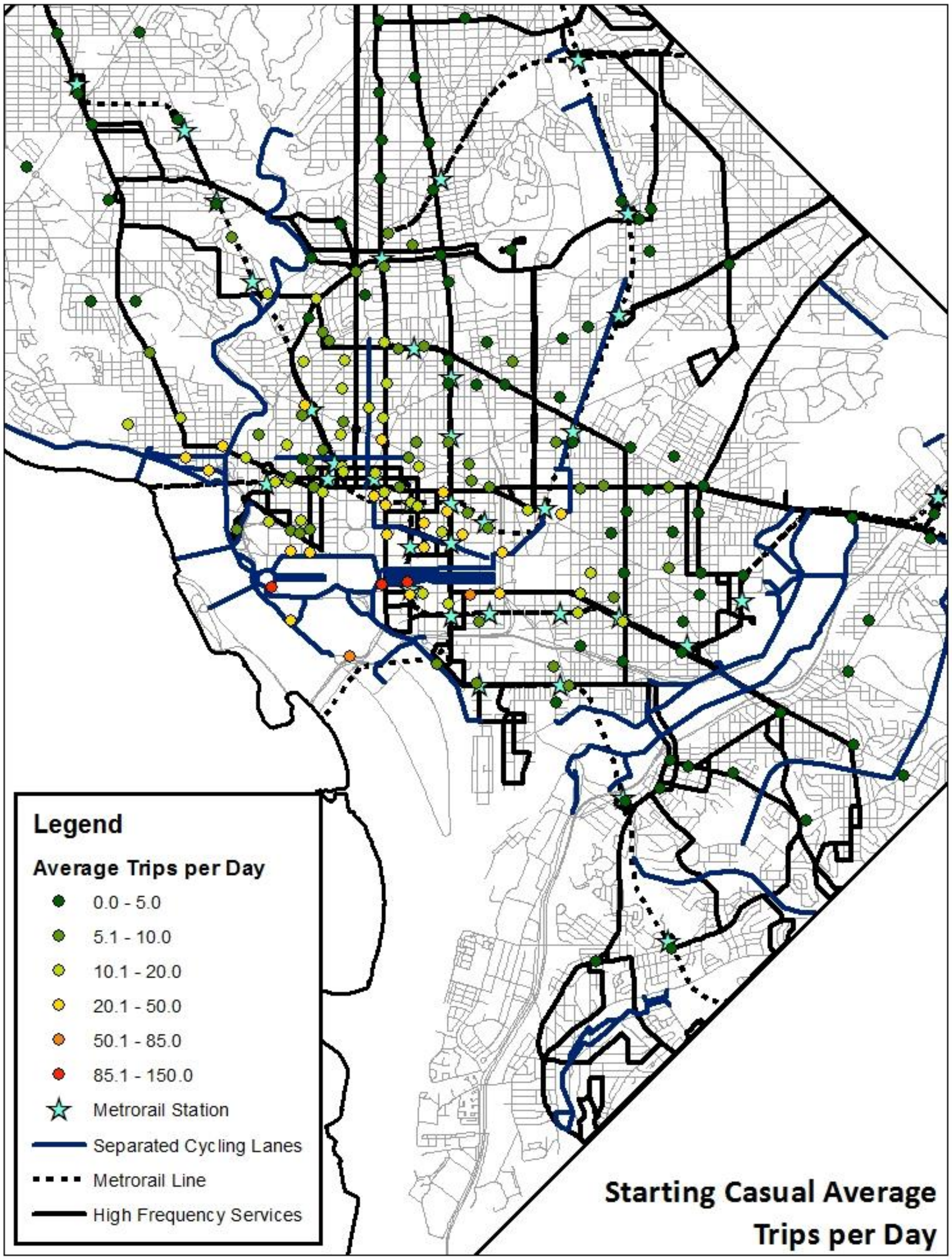


Figure 4.10 Map – Average Starting Casual Member Trips per Day per Bikeshare Station

Note: Source (Capital Bikeshare. 2013)

This first section of Chapter 4 explored the higher level characteristics, behaviors and patterns of the Capital Bikeshare trip data including the predominant trip memberships, peak times, trip durations and geographic distribution of trips. The results from this chapter have revealed 75% of trips are made by subscriber users, 88% of trips are less than 30 minutes, and peak trips times are consistent throughout the weekdays. This potentially demonstrates that the system is dominated by locals using the system for short trips for commuting to and from work. Additionally casual user trips are predominantly constrained within the National Mall. The following sections of Chapter 4 will explore these relationships in greater detail.

4.1. Bikeshare Station Variable Descriptive Statistics and Visualization

This chapter examines the descriptive statistics of the variables in an aggregate bikeshare station basis. This chapter will also geographically visualize the basic relationship between frequent transit services, separated cycling lanes and Capital Bikeshare trips.

Based upon a review of the descriptive statistics and the data structure for all variables at the various radii outlined in Chapter 3 it was decided to only use the 400m radius data. It was found that smaller radii had insufficient variability in the data. Since this project is also measuring population demographics at the American Community Survey census tract scale, a 400m radius best aligns with this geographic scale.

The corresponding census tract for each bikeshare station was chosen based on the immediate bikeshare station location relative to the census tracts. When a census tract shape file was overlaid over the bikeshare station location data, the ArcGIS intersect tool was used to match the bikeshare station with the overlapping census tract. This may introduce bias into the results as this study will not account for the full geographic variation of demographic statistics within the full 400m radius. However, with

85 out of 178 total census tracts included in this study, this is sufficient variability and representation for the analysis.

From Table 4.3 the mean population density for the census tracts surrounding bikeshare stations is 23.7 persons per acre (approximately 8.17 dwelling units per acre, considering an average 2.9 persons per unit) which is considered a low density residential neighbourhood consisting of single family houses, secondary suites and duplexes. This is surprising since the site visit found that the neighbourhoods surrounding the Washington D.C. downtown core were quite densely structured consisting mainly of row houses.

The population density map (Figure 3.7), shows that there are 41 bikeshare stations located in the downtown and national mall census tracts accounting for 23% of the total study bikeshare stations. The thirty downtown bikeshare stations have a similar maximum population density of 23.4 persons per acre while the eleven National Mall bikeshare stations have zero population. These bikeshare stations could be significantly contributing to the lower mean population density

Access to frequent transit services within 400m of bikeshare stations varies widely with some bikeshare stations having 37 stops on the high end and zero on the low end. There are also large variations relative to the type of frequent transit service ranging from a mean 10 frequent bus stops to 0.5 Metrorail stations. .

Despite the scarcity and dispersion of only 5.856 kilometers (km) on-road separated bike lanes in Washington D.C., and 94.256 km total on and off road separated bike lanes, a 0.428 kilometer mean length of separated bike lanes within 400m of a bikeshare station is relatively high.

The mean bikeshare station density of 2.5 bike share stations within 400m is considered low compared to other systems. O’Brien et al. in a comparison of bikeshare systems found that the Capital Bikeshare had an average 529m distance between bikeshare stations while 50% of the 38 systems compared had an average 300-400m between bikeshare stations (O’Brien et al., 2013, p.6).

Otherwise on average most bikeshare stations are located in areas with moderate changes in elevation, high intersection density, and 400m away from a top attraction. The top three land uses are commercial, low-medium density residential, and public and recreational land uses. The bikeshare stations are also generally located in areas with high proportions of employment, education, people aged older than 25, and household incomes over $25,000. Bikeshare stations also have a tendency to be located in areas with higher proportions of Whites than African Americans or other minorities. With a 10.9% mean proportion of minority population bikeshare stations are also generally located in areas with relatively high other minorities representation, considering that other minorities only account for 9% of Washington D.C.'s total population.

Table 4.3 Bikeshare Station Variable Statistics within 400m Radius

Description (n = 176)	Mean	Standard Deviation	Median	Maximum	Minimum
Built Environment					
Frequent Transit (# of Stops)	10.1	7.1	9	37	0
Non-Frequent Transit (# of Stops)	7.7	5.7	7	26	0
Metrorail Stations (# of Stops)	0.5	0.6	0	2	0
Separated Bike Lanes (length in meters)	428.9	655.6	0	3427.5	0
All Bike Lanes (length in meters)	1277	1075	1079	3919	0
Elevation Change (ft)	68	40.4	55.5	207.3	12.1
Bikeshare Station Density (# of Stations)	2.5	1.7	2	8	1
Intersection Density (# of Intersections)	31.5	9.8	32	52	3
Top Attractions	0.2	0.6	0	3	0
Land Use (Percentage of 400m Area)					
Commercial Land Use	13.9	12.5	9.7	53.9	0
Low Density Residential Land Use	3.8	8.2	0.4	39.2	0
Low Medium Density Residential Land Use	12.8	13.1	9.3	49.4	0
Medium Density Residential Land Use	4.2	5.6	2	35.4	0
High Density Residential Land Use	2	3	0.5	15.6	0
Mixed Land Use	0.6	1.7	0	11.1	0
Industrial Land Use	0.7	2	0	15	0
Institutional Land Use	5.4	9.4	2.3	64	0
Public and Recreational Land Use	8.4	12.1	3.3	67.9	0
Public Land Use	9	11.2	4.1	51.2	0
Demographics					
Population density (persons per square mile)	15172	11819	11818	67900	0
0 to 14 Age (% of Census Tract)	8.2	6.4	7.3	28.7	0
15 to 24 Age (% of Census Tract)	17.7	17.7	13.0	98	0
25 to 39 Age (% of Census Tract)	32.3	15.5	36.2	59.1	0
Over 40 Age (% of Census Tract)	35.6	15	36.6	67.7	0
Males (% of Census Tract)	32.0	16.3	0.3	74.7	0
White (% of Census Tract)	50	29.5	56	94.6	0
African American (% of Census Tract)	33.2	31	19.9	99.8	0
Minority (% of Census Tract)	10.9	7.2	10.3	28.3	0
No Car Households (% of Census Tract)	37.7	18	38.9	74.4	0
Bachelor Degree or Higher (% of Census Tract)	59.2	28.1	69.6	94.6	0
Students (% of Census Tract)	3.1	2	2.6	11.3	0
Employment (% of Census Tract)	61.3	22.2	71.8	88.2	0
Below $25,000 Household Income (% of Census Tract)	19.1	14.1	16.2	64.8	0
$25,000 to 100,000 Household Income (% of Census Tract)	38.3	13.7	39.9	61.5	0
Above $100,000 Household Income (% of Census Tract)	35.2	18.9	37.6	77.9	0

Note: Source (Capital Bikeshare. 2013)

For the purpose of convenience, this study will focus on explaining the results using the average trips per day statistic. All major deviations from this statistic will be explained.

Table 4.4 shows the percentage and average trips when filtering bikeshare stations by 400m proximity to the frequent transit network, metro stations and separated bike lanes. The Capital Bikeshare system is well served by the Frequent Transit Network, with 92% of bikeshare stations within 400m of a frequent transit service with all-day 15 minutes or better frequency. Bikeshare stations within 400m of Metrorail stations account for 50% of all trips for the study.

Table 4.4 Bikeshare Station Trip Statistics Filtered by 400m Proximity to Frequent Transit Services and Separated Bike Lanes

	Number of Stations	Percentage of Total Start Trips	Percentage of Total End Trips	Average Start Trips per Day	Average End Trips per Day	Average Start Trips per Weekday	Average End Trips per Weekday	Average Start Trips per Weekend	Average End Trips per Weekend	Average Start Trips per Weekday AM Peak	Average End Trips per Weekday AM Peak	Average Start Trips per Weekday PM Peak	Average End Trips per Weekday PM Peak
All bikeshare stations	176	100%	100%	46.57	46.66	45.85	45.90	48.38	48.55	11.53	11.27	21.37	21.46
Bikeshare Stations within 400m proximity of:													
Frequent Transit Network	162	93.6%	93.8%	47.15	47.35	46.79	46.98	48.06	48.28	10.69	10.35	19.40	19.65
Metrorail Stations	73	50.3%	50.7%	56.39	56.98	57.03	57.24	54.75	56.30	10.36	15.43	25.61	21.33
Separated Bike Lanes	85	57.1%	59.5%	55.03	57.48	54.56	56.84	56.19	59.08	9.07	15.04	25.01	21.06

Note: Source (Capital Bikeshare. 2013)

The mean starting and ending trip statistics remain approximately unchanged when considering only bikeshare stations within 400m proximity of the frequent transit network, but increases when considering bikeshare stations within 400m proximity of Metrorail stations or separated bike lanes. When considering peak trips, the mean morning peak start and evening end trips decreases for frequent transit, Metrorail stations and separated bike lanes. On the other hand the mean morning peak end and evening peak start trips for bikeshare stations within 400m proximity of Metrorail and separated bike lanes increases. This may just be an indication that there are Metrorail stations, frequent transit services, or separated bike lanes where people work, and shop but not where they live. Secondly this may also indicate that Capital Bikeshare users are commuting to and from bikeshare stations within 400m of Metrorail stations and separated bike lanes.

Figure 4.11 to Figure 4.19 visualize the average starting trips per day per bikeshare station in various ways, where both the size and color represent different ranges of trip amounts.

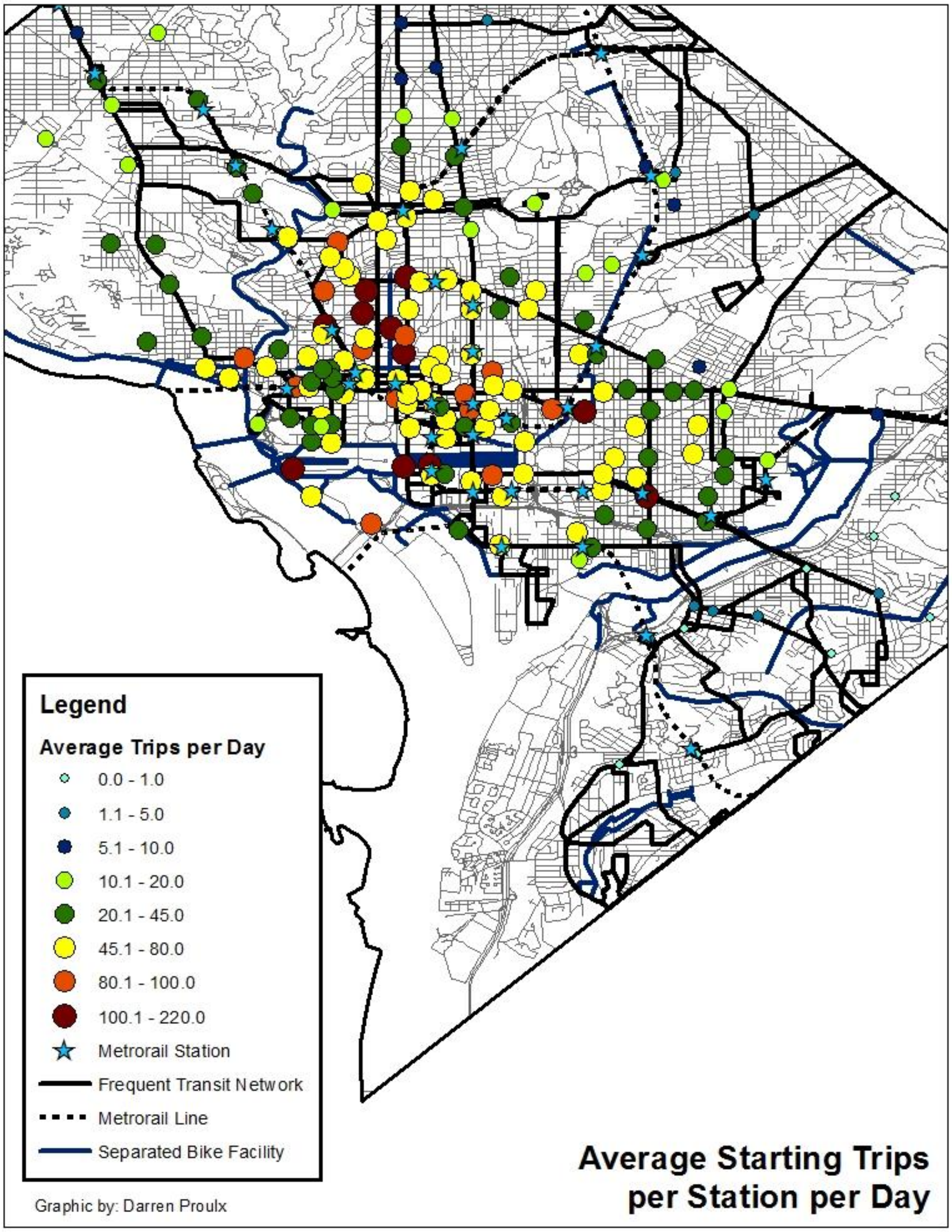


Figure 4.11 Map – Average Starting Trips per Bikeshare Station per Day
Note: Source (Capital Bikeshare. 2013)

Figure 4.12 below shows that the Capital Bikeshare stations within 400m of a separated bike lane generally have higher use accounting for 57.1-59.5% of the starting and ending trips respectively. Despite that 93.7% of the separated bicycle facilities are off-road, Figure 4.12 clearly demonstrates a significant proportion of the trips are more closely associated with bikeshare stations located within 400 m of the 15th St, L St. and Pennsylvania Ave on-road separated cycling lanes and not the National Mall off-road separated cycling lanes.

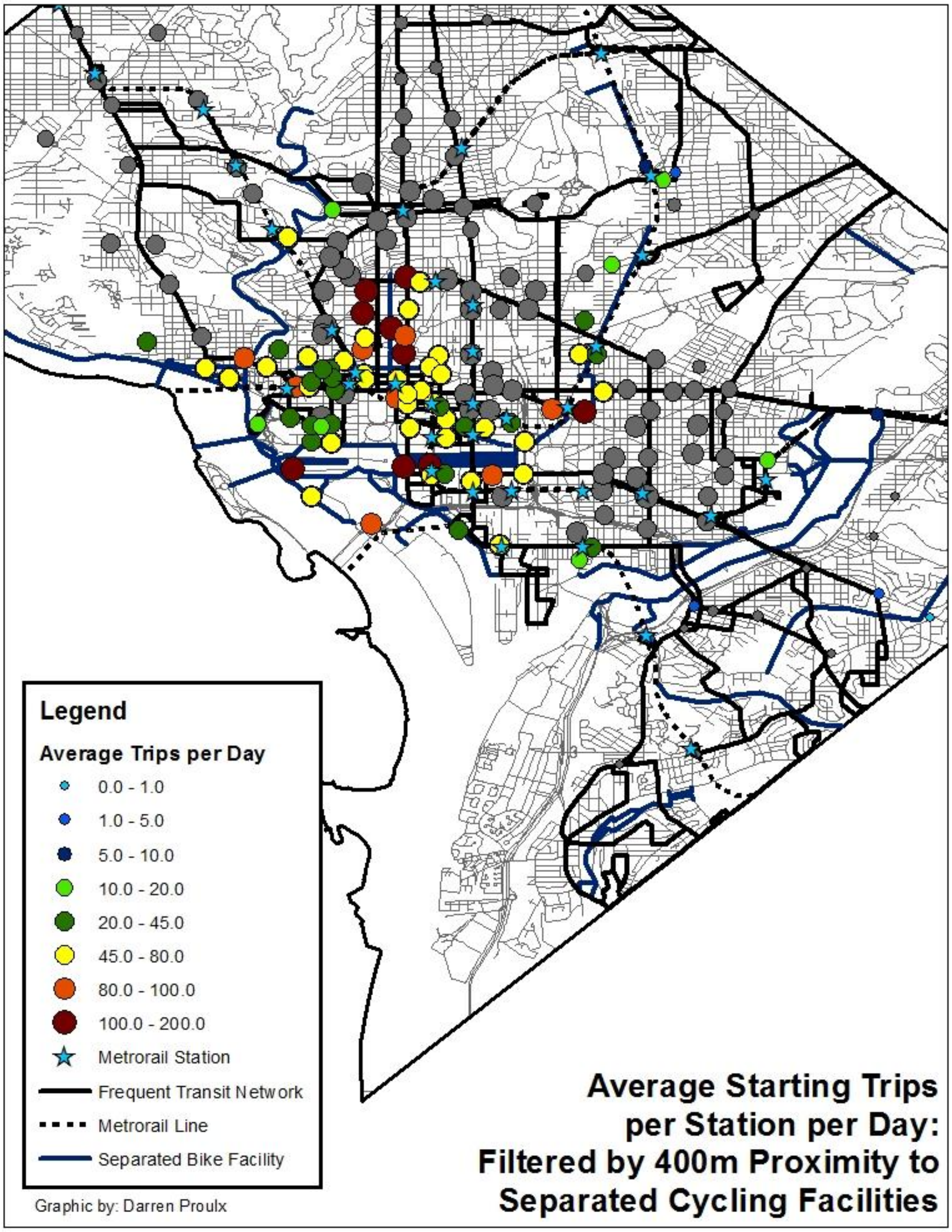


Figure 4.12 Map – Average Starting Trips per Day per Bikeshare Stations within 400m Proximity of Separated Bike Lanes
Note: Source (Capital Bikeshare. 2013). Grey circles represent bikeshare stations outside of the 400m proximity at the same scale of average trips per day as indicated on the Legend.

Figure 4.13 below shows that while almost all bikeshare stations are within 400m of frequent transit services, accounting for 93.6-93.8% of the starting and ending trips respectively, there is no discernable pattern of bikeshare station trips. Based on this, the analysis of relationships to the Frequent Transit Network will have to predominantly rely on the statistical analysis in Chapters 4.2 and 4.3.

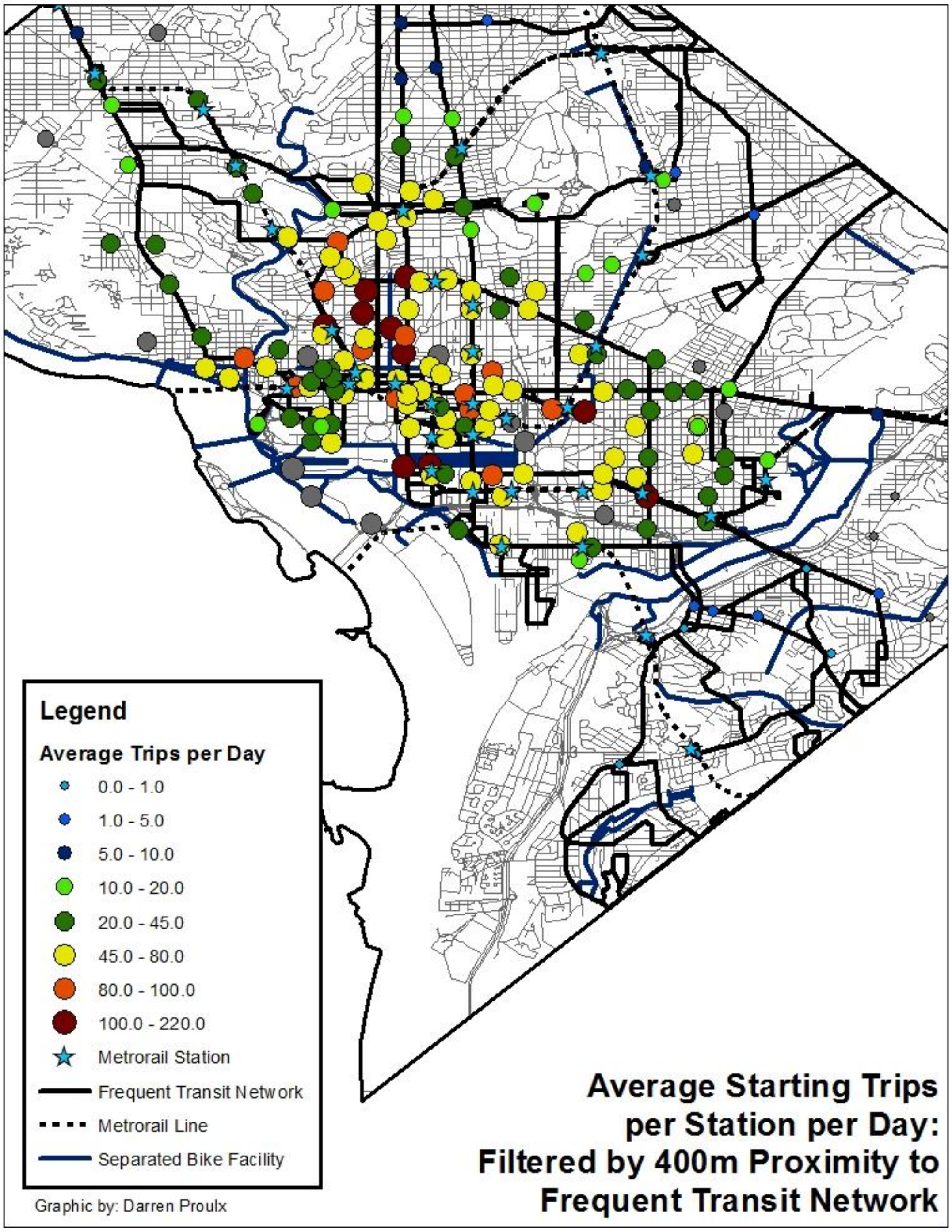


Figure 4.13 Map – Average Starting Trips per Day per Bikeshare Stations within 400m Proximity of the Frequent Transit Network
Note: Source (Capital Bikeshare. 2013). Grey circles represent bikeshare stations outside of the 400m proximity at the same scale of average trips per day as indicated on the Legend.

Figure 4.14 below shows that bikeshare stations within 400m proximity of a Metrorail station account for 50.3-50.7% of all starting and ending trips respectively. Several of the highest use bikeshare stations are not within 400m of a Metrorail station, specifically the “Lincoln Memorial”, “Jefferson Memorial”, “Ohio Dr & West Basin Dr SW / MLK & FDR Memorials” bikeshare stations on the south-west edge of the Potomac Park. This indicates that there are certainly variables other than 400m proximity to the Frequent Transit Network contributing to higher use. Investigating the trip characteristics of these bikeshare stations reveals that a high proportion of trips are made by casual users, with the top trip destinations and origins remaining within the National Mall area. Buehler et al. (2011b) similarly found that over half of casual user’s trips were made by domestic tourists (from 14 U.S. states), for tourism, site seeing typically contained within the National Mall area. The tourism pattern is possibly further confirmed since these three bikeshare stations are also within 400m proximity to the Lincoln memorial, FDR Memorial, and Thomas Jefferson Memorial which according to the Smithsonian Institute statistics saw 5,400,000, 2,300,000, and 1,900,000 visits in 2013 respectively (Smithsonian, 2013).

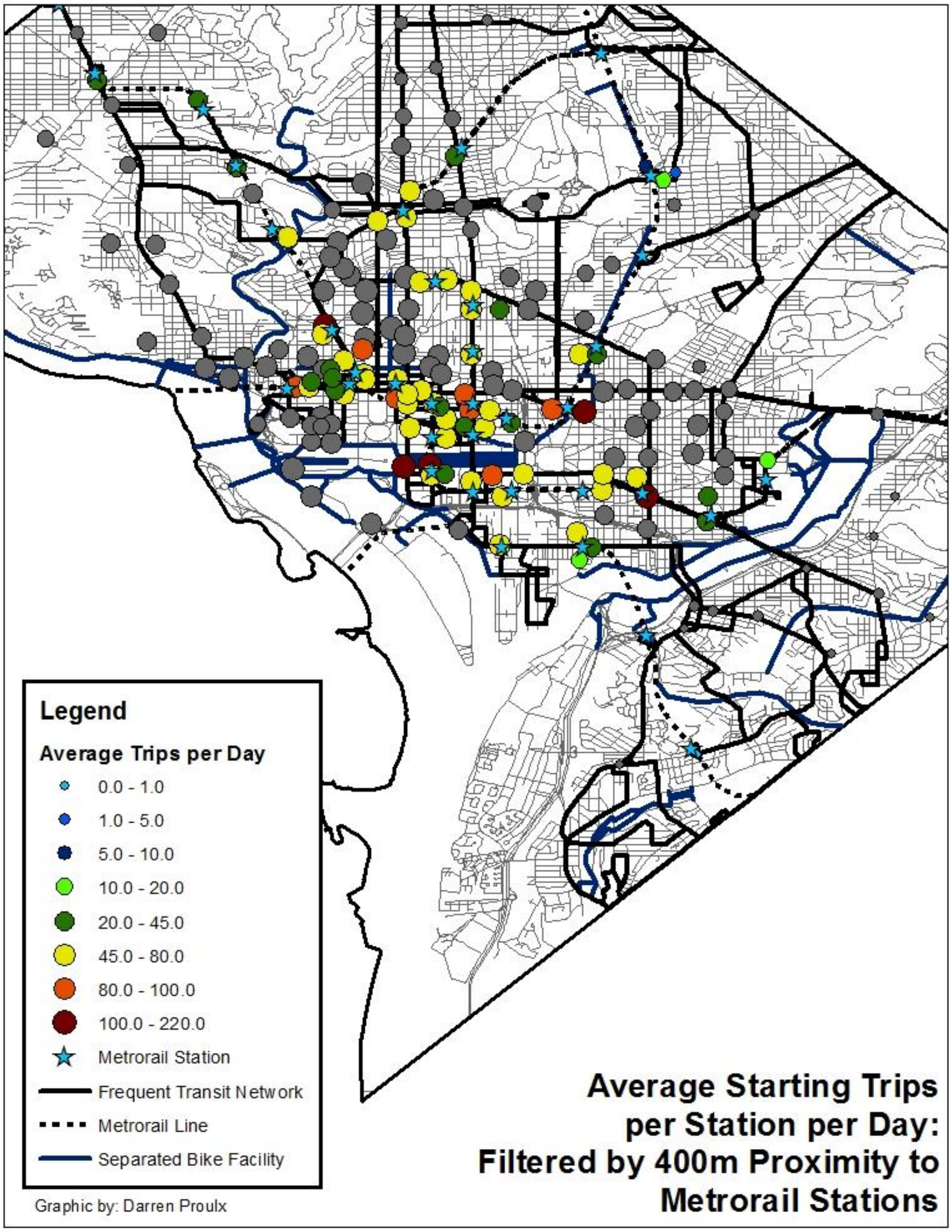


Figure 4.14 Map – Average Starting Trips per Day per Bikeshare Stations within 400m Proximity of Metrorail Stations

Note: Source (Capital Bikeshare. 2013). Grey circles represent bikeshare stations outside of the 400m proximity at the same scale of average trips per day as indicated on the Legend.

The following Figure 4.14Figure 4.18 demonstrate a clear commuting pattern with a high proportion of trips starting at bikeshare stations further than 400m away from Metrorail stations in the morning and ending at stations within 400m of Metrorail stations. The evening peaks show the opposite pattern with a high proportion of trips starting within and ending outside of 400m proximity from Metrorail stations.   Figures 4.14-8 are consistent with the findings in Table 4.4.

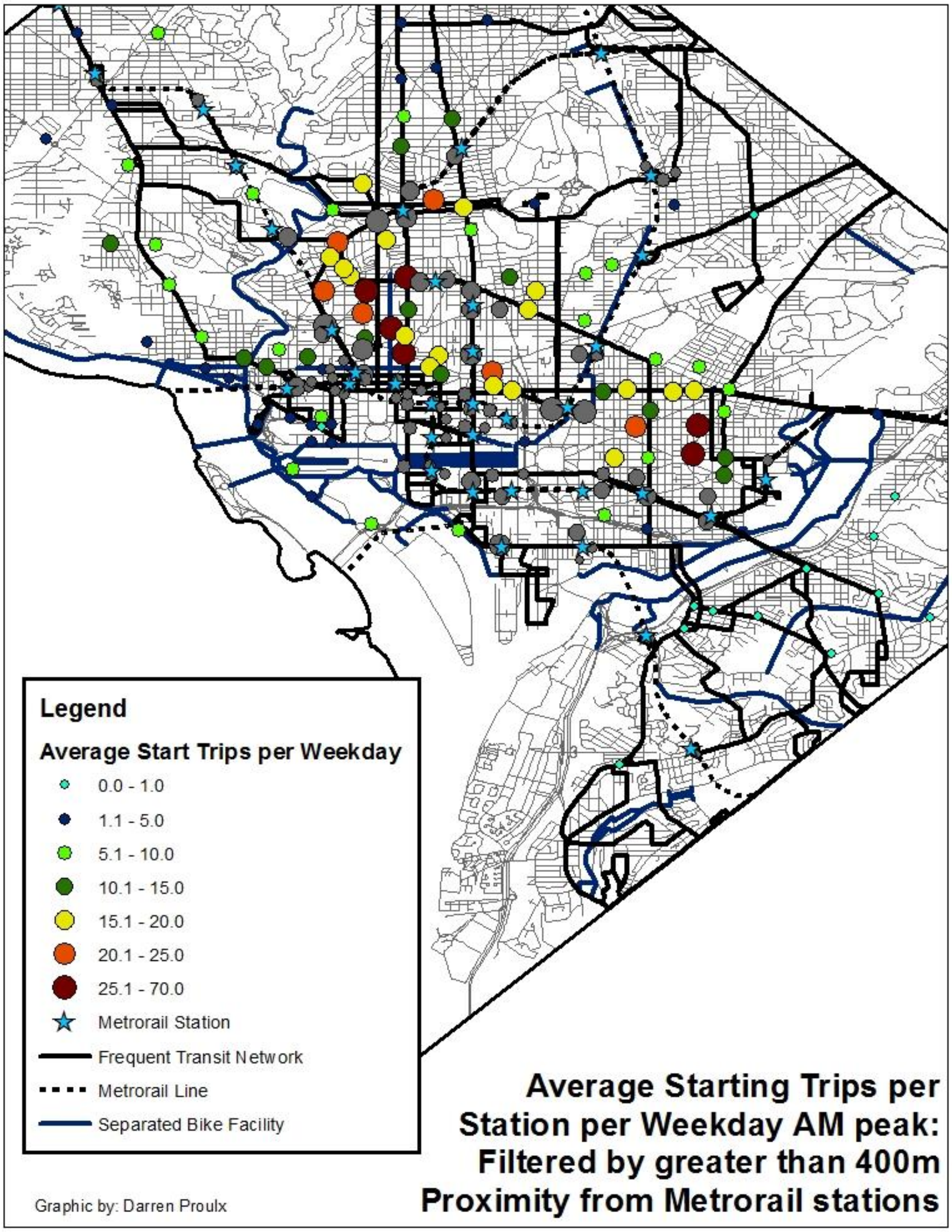


Figure 4.15 Map – Average Starting Trips per Weekday AM Peak per Bikeshare Stations with greater than 400m Proximity of Metrorail Stations

Note: Source (Capital Bikeshare. 2013). Grey circles represent bikeshare stations within 400m proximity at the same scale of average trips per day as indicated on the Legend.

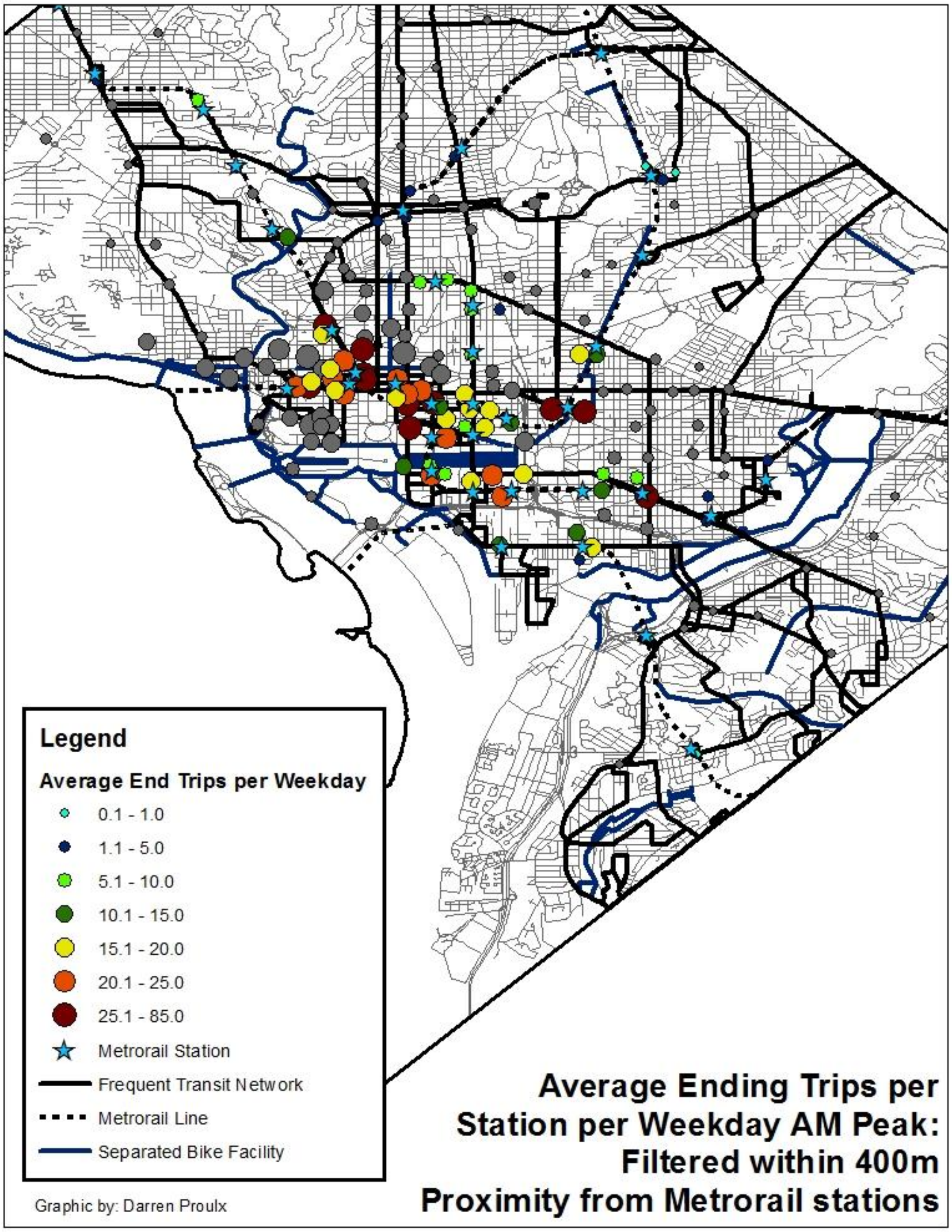


Figure 4.16 Map – Average Ending Trips per Weekday AM Peak per Bikeshare Stations within 400m Proximity of Metrorail Stations

Note: Source (Capital Bikeshare. 2013). Grey circles represent bikeshare stations outside of the 400m proximity at the same scale of average trips per day as indicated on the Legend.

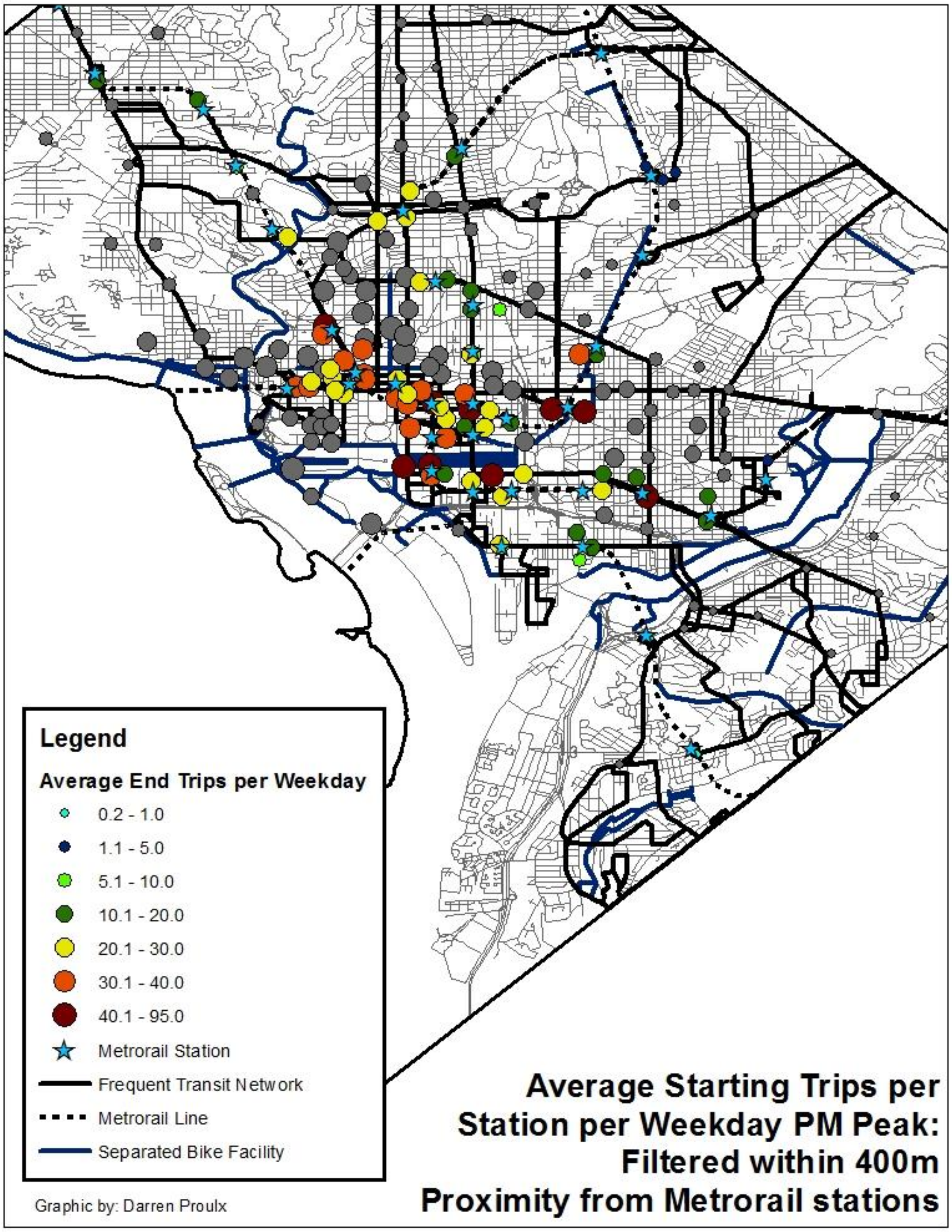


Figure 4.17 Map – Average Starting Trips per Weekday PM Peak per Bikeshare Stations within 400m Proximity of Metrorail Stations
Note: Source (Capital Bikeshare. 2013). Grey circles represent bikeshare stations within 400m proximity at the same scale of average trips per day as indicated on the Legend.

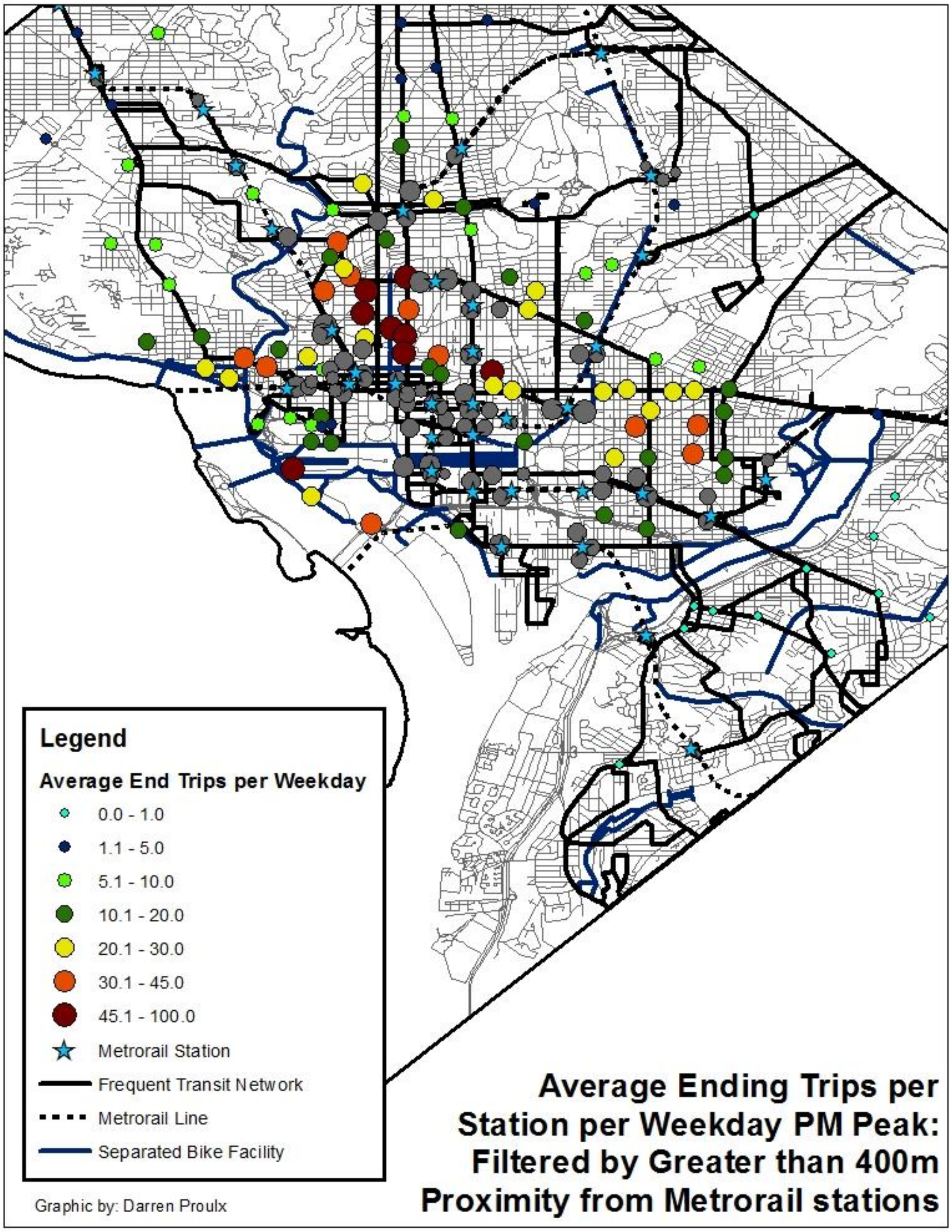


Figure 4.18 Map – Average Ending Trips per Weekday PM Peak per Bikeshare Stations with greater than 400m Proximity of Metrorail Stations
Note: Source (Capital Bikeshare. 2013). Grey circles represent bikeshare stations outside of the 400m proximity at the same scale of average trips per day as indicated on the Legend.

Figure 4.19 below shows the connections between all trip origins and destinations. Four distinct groups of bikeshare stations with higher use can be identified. To the North-West a group of the most popular origin-destination bikeshare stations involve the “Massachusetts Ave & Dupont Circle NW” bikeshare station. Another group to the west involves the “Columbus Circle / Union Station”. The third interrelated group of high bikeshare station trips involves the “Eastern Market / 7th & North Carolina Ave SE” bikeshare station. Finally the last group of bikeshare stations are located in the National Mall involving the “Lincoln Memorial” bikeshare station. Otherwise areas of higher trip connections are located predominantly in the downtown, the National Mall, and the mixed use residential neighbourhoods to the east and north of downtown. The highest trip connections generally involve the bikeshare stations of the highest trips, particularly with the group to the north. The lowest volume trip connections are generally located in the periphery regions.

No strong patterns in relation to frequent transit services and separated cycling infrastructure are discernible from Figure 4.19.

The highest trip connections in the National Mall area, an area relatively lacking bikeshare stations with 400m proximity to Metrorail stations may suggest the importance of the off-road cycling facilities for the predominantly casual users for the purposes of tourism.

The connections with the Union Station bikeshare station predominantly link bikeshare stations located to the east in the traditional mixed use residential neighbourhood. This suggests there may be a commuting relationship between bikeshare stations and intercity public transportation.

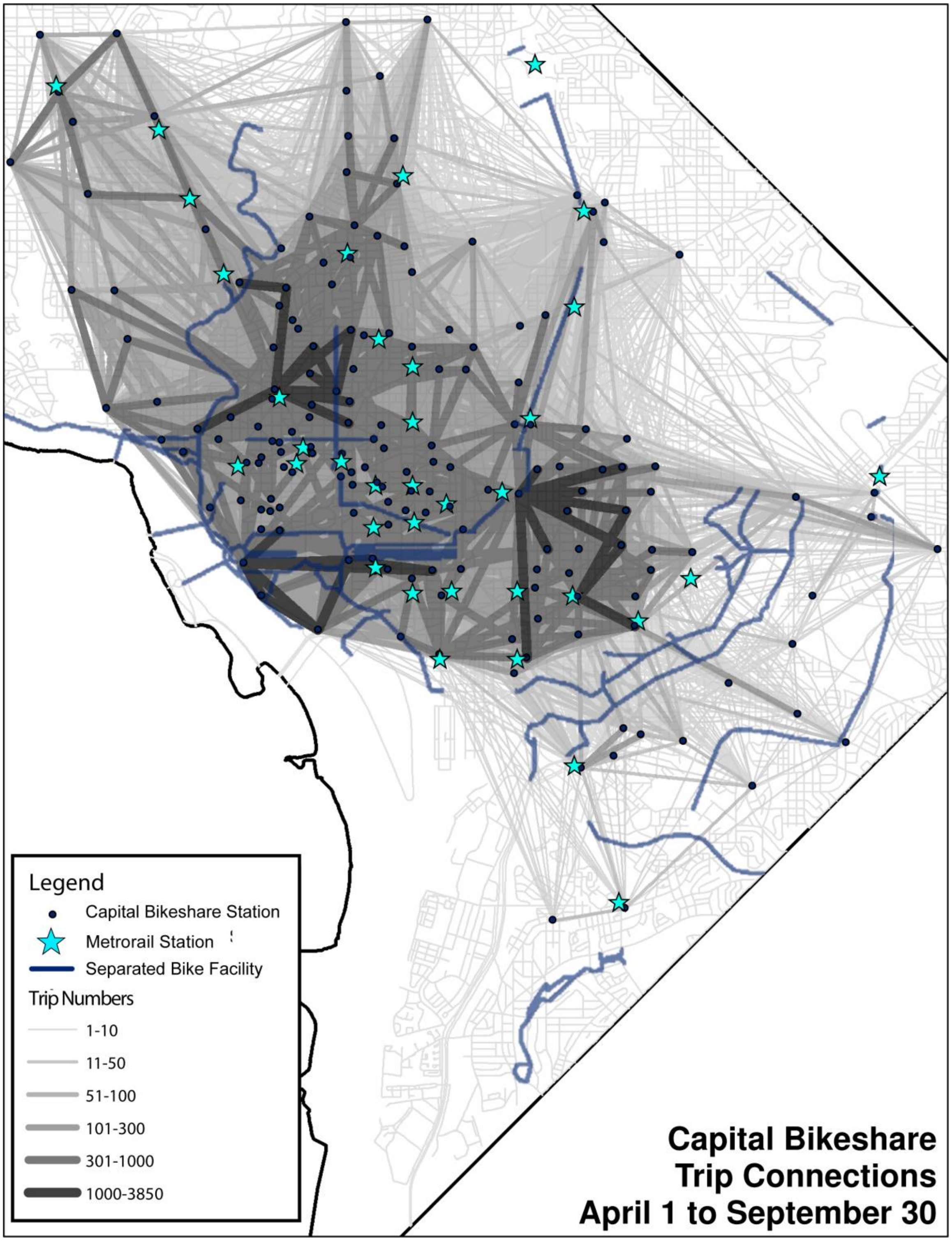


Figure 4.19 Map – Spider Diagram Showing Connections between All Trip Origins and Destinations

Note: Source (Capital Bikeshare. 2013)

Chapter 4.1 examined the aggregate descriptive statistics of the variables influencing bikeshare station trips and geographically visualized the trip relationships with frequent transit services, and separated cycling lanes. Initial findings from this chapter suggest a pattern exists between higher trip rates at bikeshare stations within 400m proximity of separated bike lanes and high frequency transit. Furthermore the findings from this section potentially suggest that a significant proportion of members are using the bikeshare system to commute from residential neighbourhoods to Metrorail stations. Chapter 4.2 will develop this preliminary evaluation of the trip patterns with a bivariate analysis.

4.2. Summary of Bivariate Analysis

Chapter 4.1 examined the aggregate descriptive statistics of the socio-demographic and built environment variables for all bikeshare stations. Visualizing the trips suggests that there is a relationship between separated cycling lanes, high frequency services and higher trip rates. Otherwise a pattern of users using the bikeshare system for commuting within 400m of Metrorail station and back was observed. The following Chapter 4.2 will build on these findings using a bivariate correlation analysis to examine the statistical relationship between all variables and the number of trips at each bikeshare station.

Two main statistical bivariate analysis methods were considered for this study: two-tailed Pearson’s correlation and Spearman’s rank correlation. The Pearson’s bivariate correlation is a statistical measure of the strength of a linear relationship between paired data. To use the Pearson’s correlation this requires three main assumptions:

1. The data is measured in an interval or ratio level
2. The data is linearly related
3. The data is normally distributed

On the other hand the Spearman's rank correlation is a statistical measure of the strength of a monotonic relationship between paired data. The Spearman's correlation requires two assumptions:

1. The data is measured in an interval, ratio or ordinal level
2. The data is monotonically related

The key difference between the two methods is that the Pearson's correlation assumes normally distributed data while the Spearman's correlation does not. However both methods describe the direction and magnitude of a linear relationship (Nelson, E., et al., 2000).

After investigating the trip and bikeshare station variable statistics it became clear that most variable data in this study was not normally distributed. Various data transformations were considered in an attempt to normalize the data, including the exponential, and square root functions. Due to the presence of a high volume of true zero data, these transformations proved ineffective. As a result of the inability to normalize the data, the Spearman's correlation was used to analyze the bivariate correlation relationships.

From the literature review in Chapter 2.2 it was found that income had an ambiguous relationship with higher rates of cycling. Income is a complex variable and the societal or cultural context could play an important role in determining the relationship between income and higher rates of cycling. From the literature it is clear that income will have some influence, but the direction is unclear. Therefore the analysis will analyze the relationship with all of the ACS income brackets to ensure that the income relationship that is prevalent in this context does come forward.

Table 4.5 below displays the final Spearman's rank correlation coefficients. Green highlighting represents positively statistically significant (±0.05) spearman correlation coefficients and a direct relationship with the volume of trips. Red highlighting represents negatively statistically significant (±0.05) spearman correlation coefficients and an inverse relationship with higher volumes of trips. The closer the spearman coefficient is to ±1 the stronger is the correlation. The age and household income variables were collapsed from the ACS defined brackets to more manageable ranges maintaining the same representation of positive and negative correlations. For the complete ACS defined age and household income correlation breakdown please refer to the addendum in Appendix E.

For this study it is important to remember that correlation does not mean causation, rather that a relationship exists between the two variables.

From Table 4.5 separated bicycle lanes and non-separated bike lanes are statistically significantly related to higher volumes of trips for most trip measurement variables. The peak, member type, and duration trip measurements have a tendency to to eliminate or flip the significance.

Basic non-frequent transit services were found not to be significant with any trip measurement variable. Frequent transit services are statistically significant for most trip measurements, except for casual user trips ending in the A.M. Peak, starting P.M Peak, and starting or ending on the weekend. This could suggest that the service is being used as a commuter manner in order to extend the reach of the core, high quality transit services. The Metrorail is Washington D.C.'s strongest frequent transit service since it operates in its own grade separated right of way with high frequency, larger stop spacing, and direct routing. Metrorail stations within 400m were found to be statistically significant for almost all trip measurement variables except for Peak A.M. trips. This could indicate that bikeshare systems should be planned around frequent transit services exhibiting the same qualities as the Metrorail.

Evaluation of the overall starting and ending trips, weekday and weekend average trips per day measurements finds that variables behave consistently with the significance and direction of variables. The only exception occurs with overall average ending trips per day and average ending weekend trips per day which are negatively correlated with institutional land uses.

Generally average trips per day are positively correlated with Capital Bikeshare stations within 400m of separated bike lanes, frequent transit, Metrorail stations, top attractions, commercial, high density residential, and mixed land uses with higher system bikeshare station density. Areas with higher population density, youths aged 25-

39, whites and other minorities, Bachelor degrees, employment, and high income are also all positively correlated with higher use. This suggests that areas with mature youths who are educated, white and other minorities, employed with high income are using the system to make trips between dense residential neighbourhoods and commercial nodes close to high quality, frequent transit services.

Comparing these results to the literature review in Chapter 2 finds many similarities and a few differences. Areas with bike lanes, bikeshare station density, mixed land use, high density, higher proportions of whites, no car households, and bachelor degrees were all found to be positively correlated with higher bike share usage as suggested from the literature review. The results also match the literature review with negative correlation to areas with elevation changes and low density urban built form.

Differences from the literature review include:

- The literature review stated that those aged 25 and under were the most likely to cycle. From this analysis it shows that areas with high proportions of those aged 25 to 39 years old were the most strongly correlated with bicycle share use. This may be explained by the 16 year old minimum age operation restriction imposed by Capital Bikeshare. Another explanation may be the system requirement of a credit card to access the bicycles.
- The literature review predicted that minorities would be negatively correlated with higher rates of cycling. However the results from this section find a positive correlation with areas of higher proportions of minorities.
- The literature review found that higher household income would be negatively correlated with higher trips. The results from this section found the opposite, with a positive correlation to areas with high household incomes over $100,000.
- One study had confirmed intersection density having a significant relationship. The preliminary results in this section however suggest minor correlations.
- The literature review suggested that students were positively correlated with higher trip rates. The results from this section demonstrate the opposite. This could be a result of the system's credit card requirement for rentals. Students may also consider owning bicycles a less expensive alternative to an annual Capital Bikeshare membership.

Intersection density was negatively correlated with casual users. This potentially indicates that casual users are not necessarily travelling in the city or neighbourhoods but rather in the National Mall and downtown areas. This is confirmed by examining the average starting trips per day filtered by casual users in Figure 4.10. Buehler et al.'s study of Capital Bikeshare casual users also found that 53% of casual users were domestic tourists from 14 U.S. States and were mainly using the Capital Bikeshare for tourism/sight-seeing and social/personal purposes (Buehler, 2011b, p. 11-12). Buehler et al.’s research also found that bikeshare stations with high casual member use outside of the National Mall had little to no international tourist respondents, suggesting that international tourists were primarily using the Capital Bikeshare to tour the National Mall instead of Washington D.C.’s neighbourhoods (Buehler, 2011b).

Variable	Start	End	Start Weekday	End Weekday	Start Weekend	End Weekend	Start Weekday AM	End Weekday AM	Start Weekday PM	End Weekday PM	Start Casual	End Casual	Start Sub-scriber	End Sub-scriber	Start Duration up to 10 min	End Duration up to 10 min	Start Duration 10 to 30 min	End Duration 10 to 30 min	Start Duration over 30 min	End Duration over 30 min
Built Environment																				
Non-Frequent Transit	0.005	0.024	0.029	0.046	-0.041	-0.019	0.071	0.093	0.036	0.019	0.007	0.006	0.068	0.084	0.058	0.076	-0.011	0.002	-0.06	-0.059
Frequent Transit	.191*	.158*	.236**	.195**	0.105	0.087	0.096	.252**	.238**	0.103	0.142	0.122	.263**	.220**	.283**	.246**	.176*	.148*	0.118	0.091
Metro Stations	.273**	.273**	.306**	.296**	.197**	.219**	0.02	.447**	.369**	.177*	.308**	.316**	.250**	.250**	.232**	.233**	.265**	.264**	.307**	.332**
Non-Separated Bike Lanes	.231**	.200**	.214**	.187*	.280**	.247**	.438**	-0.084	0.058	.343**	-0.015	0.004	.391**	.342**	.398**	.353**	0.143	.150*	-0.062	-0.031
Separated Bike Lanes	.292**	.345**	.298**	.356**	.230**	.294**	-.155*	.518**	.454**	.164*	.526**	.520**	0.051	0.14	0.044	0.102	.317**	.356**	.511**	.506**
Elevation Change	-.544**	-.573**	-.549**	-.575**	-.494**	-.529**	-.370**	-.509**	-.549**	-.546**	-.477**	-.500**	-.508**	-.546**	-.511**	-.518**	-.475**	-.544**	-.428**	-.456**
Station Density	.428**	.443**	.470**	.479**	.339**	.363**	0.115	.615**	.560**	.310**	.524**	.509**	.402**	.426**	.421**	.422**	.413**	.441**	.465**	.446**
Intersection Density	0.116	0.095	0.112	0.096	0.139	0.113	.422**	-0.12	-0.034	.247**	-.153*	-0.136	.336**	.298**	.355**	.329**	0.015	0.03	-.191*	-.180*
Top Attractions	.295**	.313**	.266**	.283**	.333**	.350**	-0.13	.303**	.361**	.203**	.507**	.503**	-0.016	0.035	-0.058	-0.034	.329**	.332**	.447**	.461**
Land Use																				
Commercial Land Use	.332**	.366**	.389**	.423**	.200**	.255**	.170*	.531**	.440**	.284**	.310**	.321**	.446**	.472**	.445**	.476**	.334**	.363**	.297**	.298**
Low Density Residential Land Use	-.586**	-.620**	-.604**	-.639**	-.520**	-.564**	-.326**	-.676**	-.661**	-.537**	-.631**	-.649**	-.520**	-.565**	-.534**	-.551**	-.546**	-.604**	-.586**	-.611**
Low Medium Density Residential Land Use	-.172*	-.211**	-.221**	-.249**	-0.045	-0.109	.351**	-.575**	-.431**	0.036	-.477**	-.457**	0.046	-0.014	0.043	0.004	-.221**	-.238**	-.493**	-.468**
Medium Density Residential Land Use	-0.054	-0.099	-0.081	-0.11	0.013	-0.052	.350**	-.398**	-.262**	0.077	-.347**	-.341**	0.14	0.087	0.115	0.082	-0.076	-0.108	-.335**	-.342**
High Density Residential Land Use	.265**	.223**	.281**	.241**	.243**	.202**	.459**	0.113	.194*	.279**	0.101	0.082	.407**	.360**	.408**	.387**	.245**	.201**	0.117	0.07
Mixed Land Use	.307**	.320**	.289**	.314**	.311**	.324**	.172*	.296**	.301**	.297**	.313**	.321**	.297**	.324**	.259**	.275**	.305**	.316**	.265**	.277**
Industrial Land Use	-0.109	-0.079	-0.145	-0.094	-0.051	-0.04	-0.023	-.181*	-.181*	-0.005	-.218**	-.195**	-0.038	-0.007	-0.056	-0.034	-0.113	-0.074	-.233**	-.199**
Institutional Land Use	-0.114	-.158*	-0.097	-0.145	-0.138	-.180*	0.042	-0.103	-0.116	-0.139	-.169*	-.196**	0	-0.057	0.014	-0.037	-0.103	-0.136	-.157*	-.211**
Public and Recreational Land Use	-0.043	-0.053	-0.057	-0.071	-0.029	-0.032	-.282**	0.038	0.026	-.163*	.155*	0.132	-.260**	-.248**	-.249**	-.244**	-0.049	-0.066	.188*	.171*
Public Land Use	0.015	0.023	0.04	0.037	-0.015	-0.001	-.160*	.208**	0.109	-0.074	.189*	.189*	-0.084	-0.075	-0.074	-0.086	0.015	0.017	.160*	.192*
Demographics																				
Population density per square mile	.239**	.183*	.233**	.178*	.270**	.207**	.565**	-0.092	0.069	.333**	-0.047	-0.051	.455**	.377**	.457**	.398**	0.136	0.109	-0.091	-0.096
0to14 Age	-.470**	-.484**	-.515**	-.517**	-.355**	-.389**	-0.117	-.683**	-.634**	-.317**	-.640**	-.618**	-.326**	-.361**	-.340**	-.351**	-.474**	-.487**	-.632**	-.600**
15 to 24 Age	-.220**	-.210**	-.160*	-.158*	-.337**	-.299**	-.165*	0.074	-0.09	-.267**	-.192*	-.189*	-0.089	-0.108	-0.08	-0.079	-.202**	-.205**	-.162*	-.182*
25to39 Age	.505**	.476**	.524**	.496**	.465**	.450**	.584**	.355**	.427**	.533**	.318**	.323**	.688**	.641**	.685**	.651**	.412**	.410**	.270**	.279**
Over 40 Age	-.458**	-.439**	-.473**	-.453**	-.390**	-.387**	-.266**	-.467**	-.499**	-.375**	-.446**	-.433**	-.389**	-.393**	-.404**	-.386**	-.453**	-.451**	-.443**	-.419**
Males	0.034	0.017	0.025	0.017	0.054	0.03	.161*	-0.073	-0.022	0.077	-0.087	-0.091	.159*	0.131	.152*	0.147	-0.008	-0.034	-0.06	-0.082
Whites	.347**	.332**	.372**	.348**	.303**	.306**	.350**	.418**	.390**	.303**	.355**	.337**	.474**	.435**	.501**	.484**	.298**	.282**	.384**	.351**
African American	-.524**	-.520**	-.521**	-.510**	-.500**	-.509**	-.199**	-.596**	-.612**	-.391**	-.684**	-.658**	-.369**	-.386**	-.383**	-.390**	-.539**	-.521**	-.709**	-.674**
Minority	.297**	.275**	.351**	.317**	.206**	.206**	.239**	.420**	.387**	.218**	.312**	.295**	.419**	.364**	.420**	.402**	.302**	.260**	.323**	.290**
No Car Households	0.122	0.118	.196**	.179*	-0.025	0.004	0.057	.313**	.244**	0.031	0.119	0.113	.238**	.212**	.260**	.246**	0.081	0.086	0.105	0.082
Bachelors Degree or Higher	.349**	.348**	.373**	.366**	.302**	.318**	.300**	.440**	.403**	.305**	.390**	.372**	.456**	.439**	.472**	.472**	.299**	.299**	.405**	.378**
Students	-.220**	-.236**	-.228**	-.239**	-.189*	-.204**	0.033	-.343**	-.312**	-0.137	-.360**	-.350**	-0.068	-0.097	-0.081	-0.097	-.266**	-.263**	-.395**	-.379**
Employment	.464**	.444**	.468**	.447**	.468**	.453**	.525**	.303**	.383**	.497**	.345**	.350**	.611**	.569**	.598**	.574**	.393**	.387**	.296**	.306**
Household Income Below $25,000	-.393**	-.401**	-.348**	-.355**	-.472**	-.472**	-.177*	-.283**	-.365**	-.375**	-.487**	-.484**	-.237**	-.269**	-.224**	-.244**	-.407**	-.406**	-.484**	-.494**
Household Income $25,000 to $100,000	-.227**	-.262**	-.197**	-.233**	-.258**	-.287**	0.01	-.295**	-.265**	-.201**	-.345**	-.342**	-0.101	-.163*	-0.107	-.151*	-.245**	-.269**	-.351**	-.347**
Household Income Above $100,000	.271**	.276**	.258**	.262**	.305**	.311**	.343**	.198**	.210**	.336**	.202**	.212**	.408**	.395**	.400**	.408**	.207**	.213**	.189*	.203**

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive statistical significance. Red highlighting indicates negative statistical significance, No color indicates no significance. ** Indicates correlation is significant at the 0.01 level. * Indicates correlation is significant at the 0.05 level.

Weekday trips are very similar to the system-wide trip patterns, potentially due to the domination of subscriber trips which make up 75% of all trips and 81.2% of all weekday trips. The only exception occurs with car-free households becoming positively correlated.

Weekends, which are heavily saturated with casual users making up 39.0% of all weekend trips, still finds positive significant relationships with Metrorail stations and separated bike lanes, but not frequent transit routes.

The starting morning peak trips present the most inconsistent results accounting for 17.9% of all trips opposed to 32.9% starting evening peak trips. A negative relationship was found with separated bike lanes, but also a positive correlation with non-separated bike lanes. Meanwhile no relationship was found with high frequency transit. This could potentially be explained due to the positive statistical significance of low-medium density and medium density residential neighbourhoods, suggesting that many of the morning peak trips originate in the Shaw, Columbia Heights, U-Street, and H-Street neighbourhoods, which have few separated bike lanes and high frequency transit services.

Interestingly when examining the peak period set of trip data finds that starting morning peak trips are closely related with lower density residential land use. Ending morning peak trips are closely related with high frequency transit services including Metrorail stations, and commercial land uses. Starting evening peak trips exhibit patterns of the post-work commute towards home. Similarly ending evening peak trips are a reflection of the starting morning peak trips, with the distinction that it does not see the same relationship to lower density residential uses. This suggests more diversified trip destinations in the evening peak.

Comparing subscriber versus casual member trips finds that high frequency transit is more closely related to subscribers, while separated bike lanes are more closely related to casual users. A possible explanation for this could be that most casual trips are located in the vicinity of the National Mall (Figure 4.10), which has a high volume of separated bike lanes. This is further supported by casual user’s stronger relationship with park land uses in Table 4.5.

Surprisingly subscribers do not find a strong relationship with separated bike lanes but rather with non-separated bikes lanes. This could be that the separated bike lanes, which are located primarily in the downtown core, are not within close proximity to where subscribers live.

Both subscriber and casual trips find a strong relationship with high density residential areas. This could indicate that a large proportion of subscribers live in higher density areas. It also indicates that both member types are making trips predominantly in the more densely structured areas of Washington D.C.

Trips of durations less than ten minutes are strongly related with frequent transit including Metrorail Stations, non-separated bike lanes but surprisingly not separated bike lanes. It could be that people are making short “final mile” trips to the reliable and further reaching Metrorail system that users cannot justify making a detour to the dispersed and limited separated bike lanes. Trips up to 30 minutes are strongly related to all types of frequent transit, but trips over 30 minutes are only strongly related with Metrorail stations. Trips over 10 minutes are also strongly related with separated cycling lanes. As trip durations grow the relationship to residential land uses weakens, reflecting the behaviors of casual users who tend to use the system for longer trips mainly for tourism in the National Mall area.

Chapter 4.2 presented and evaluated the results from a Spearman’s bivariate correlation analysis. This chapter found strong positive relationships with separated bike lanes and Metrorail stations. Bus based frequent transit services were only positively correlated during the peak times. Subscribers show a stronger relationship with Metrorail stations, while casual users show strong relationships with separated cycling lanes. Similar to Chapter 4.1 these results indicate that patterns of subscriber users using the Capital Bikeshare system to commute to and from Metrorail stations. The next Chapter 4.3 will build on these results by completing a multivariable linear regression analysis.

4.3. Summary of Multivariable analysis

Chapter 4.2 provided an examination of the relationship between each individual variable and the number of trips per bikeshare station. However it is now necessary to take this analysis further by attempting to evaluate how all of these variables interact together and estimate their combined effect on the number of trips on each bikeshare station.

Since the number of trips at bicycle share stations are being influenced simultaneously by several independent variables it is necessary to try and model this by using a multiple variable linear regression analysis. It is possible to visualize the relationship between these variables in the form of a function expressed below:

$Y= b_0 + b_1X_1 + b_2X_2 +b_iX_i + e$

Where

Y = number of trips at the bicycle share station

$B_{0,1,2,3...}$ = regression weights

$X_{1,2,3...}$= test variables and the variables listed in Chapter 4.1

e = residual

Various “Enter” models were constructed using SPSS based on the results in Chapter 4.2, composed of different combinations of the dependent trip statistics and independent built environment, land use and demographic variables. This process relies on the diverse measurements for each variable as described in Chapter 3 and 4.1. This will serve as a secondary step in confirming the statistically significant relationships between high frequency transit services, separated cycling infrastructure and higher rates of cycling found in Chapter 4.2.

According to the IBM Knowledge Center, linear regression “estimates the coefficients of the linear equation, involving one or more independent variables, that best predict the value of the dependent variable” (IBM, 2014).

There are six assumptions associated with linear regression analysis (Chen, X, et al. 2003):

1. There are no significant outliers.
2. Both dependent and independent variables are intervals, ratios, or dichotomous.
3. Normality - For each value of the independent variable, the distribution of the dependent variable must be normal.
4. Independence of observations – All observations errors are independent from other errors.
5. Linearity – The relationship between the dependent variable and each independent variable should be linear.
6. Equal Variance (Homoscedasticity) – The variance in error should be constant.

Initially the distribution, mean and standard deviation were examined for every variable using a histogram plot. If there were major deviations from normal distribution such as outliers or positive skewedness of the data, transformations were used. Due to the presence of true zero data, in many cases the square root function was used to normalize the data. For several variables, an inflection point was observed using a Q-Q plot indicating different behaviours in the data within the same variable. In this case the variable was transformed into a categorical or dichotomous dummy variable, separating the variable at the inflection point.

The data has true zero population statistics resulting from the 11 bikeshare stations in the National Mall census tract. These could have a significant influence on the results. A second linear regression model was analyzed removing the 11 National Mall bikeshare stations to determine whether this influences any of the resulting coefficients.

To ensure that the distribution of every dependent variable in every model was normally distributed a histogram of the standardized residuals was examined for every model.

The linearity of each model was tested by using a normal P-P plot of the standardized residuals.

The equal variances of the model were tested using a scatter plot of the standardized predicted values against the standardized residuals to ensure that the variances were approximately equal relative to changing standardized predicted value.

The initial models included all variables to determine if there were any strong collinearity tendencies between any independent variables. Collinearity was defined as variables with a collinearity VIF statistic greater than two. This identifies any variable which is measuring similar characteristics of another socio-economic demographic or built form variable. It was found that some variables had strong collinearity problems such as the various household income classifications. The under $25,000 household income bracket was found to be strongly interacting with the above $100,000 household income bracket. Hence the under $25,000 household income bracket was removed from the model.

After this there were still a few demographic and built form variables with collinearity statistic violations. This was addressed by using the SPSS Principal Component Analysis tool. This is a variable reduction technique which maximizes the amount of variance explained by grouping these variables together and creating a set of underlying factors from the collinear variables. The results from the Principal Component Analysis can be found in Appendices G & H. Focusing on the rotated component matrix in Appendix G three factors were extracted from this process accounting for 77.1% of the total variable variance which can be summarized generally as:

1. Wealthy, educated whites and minorities
2. High population density locations with male students in car free households
3. Lower population density locations with families

Focusing on the rotated component matrix in Appendix H the models with the national mall bikeshare stations removed, two factors were found accounting for 75.6% of the total variance amongst the variables which can be summarized generally as:

1. Wealthy, educated whites
2. Low population density locations with families

For a summary on the variable definitions used in this chapter's models please refer to Appendix F.

A Durbin-Watson statistic was used to verify an independence of residuals. A Durbin-Watson statistic of two indicates no residual correlation, zero indicating a strong positive correlation and four indicating a strong negative correlation. From the results in Tables 4.6-4.17 the linear regression model Durbin-Watson statistics range from 1.385-1.856. Therefore the models exhibit moderate to strong independence of residuals.

All models also reveal an ANOVA statistic of 0.000, signaling that all models can statistically predict the dependent variable.

Bikeshare stations 31200 "Massachusetts Ave & Dupont Circle NW" and 31623 "Columbus Circle / Union Station" were often outliers in most models. In specific situations other bikeshare stations such as 31101 "14th & V St NW", 31243 "Maryland & Independence Ave SW", 31247 "Jefferson Dr & 14th St SW", 31258 "Lincoln Memorial", 31600 "5th St & K St NW" and 31613 "Eastern Market Metro / Pennsylvania Ave & 7th St SE" are also outliers. The "Massachusetts Ave & Dupont Circle NW" and "Columbus Circle / Union Station" bikeshare stations have the highest system use in this study with 40,000 and 35,000 trips respectively.

Examining the top five trip destinations and origins for the "Massachusetts Ave & Dupont Circle NW" bikeshare station reveals that the top trip connections are to other high trip volume bikeshare stations in close vicinity such as bikeshare stations 31101 "14th & V St NW", 31201 "15th & P St NW", 31214 "17th & Corcoran St NW", 31229 "New Hampshire Ave & T St NW", and 31241 "Thomas Circle".

For the “Columbus Circle / Union Station” bikeshare station the strongest trip connections exist with bikeshare stations in the mixed use residential neighbourhood immediately to the east.

It could be that there are additional factors outside of the variables examined in this study that also contribute to significant increases in trips. One possible explanation could be that their location within the Capital Bikeshare network makes them important hubs or exchange points for other activities similar to a network of airports that have busier hub airports. For example since the “Columbus Circle / Union Station” bikeshare station’s strongest connections are to the east, it could be this bikeshare station is the most conveniently located bikeshare station for connections to other bikeshare stations, intercity trips and the Metrorail system. These are aspects of the trips that are not being considered and are outside the scope of this study.

Table 4.6 below shows the VIF correlation coefficients of the final model. All other models generally follow the same VIF patterns.

Tables 4.6, 4.7 and 4.8 below show that separated bike lanes are positively statistically significant for the general system trip statistics accounting for 62.8-77% of the total variance explaining bikeshare station trips. Non-separated bike lanes are also significant; however the linear regression coefficient is extremely small. This means that large addition of bike lanes is required to support a small increase in cycling trips.

Non-frequent transit services are not statistically significant with higher bicycle share trips. Including the National Mall bikeshare stations found that frequent transit services were negatively related to higher trips. Excluding the National Mall bikeshare stations finds frequent transit services become not significant. A potential explanation for this could be that in certain cases transit is competing with the bicycle share system. Frequent transit services were only found to have a positive significant relationship with Metrorail Stations during the weekday when National Mall bikeshare stations were excluded.

The data evaluation from the beginning of Chapter 4 found that weekday trips predominantly consisted of subscriber users. The results below also demonstrate that there are no significant differences between the measurement of weekday and weekend relationships caused by including frequent transit services with non-frequent weekend services as assumed in Chapter 3.

Table 4.6 General Trip Statistics Linear Regression Coefficients

	Start Trips						End Trips					
	Mall			No Mall			Mall			No Mall		
R	0.824			0.855			0.850			0.878		
R Square	0.679			0.731			0.723			0.770		
Durbin-Watson	1.612			1.571			1.387			1.580		
ANOVA	0.000			0.000			0.000			0.000		
Outliers	31200, 31623			31200, 31623			31623			31623		
Variable	**Coefficient**	**Sig.**	**VIF**	**Coefficient**	**Sig.**	**VIF**	**Coefficient**	**Sig.**	**VIF**	**Coefficient**	**Sig.**	**VIF**
Metrobus Frequent Transit	-0.055	0.023	1.785	-0.015	0.528	1.979	-0.012	0.021	1.785	-0.005	0.317	1.979
Metrorail Station	0.468	0.152	1.587	0.544	0.079	1.616	0.088	0.204	1.587	0.112	0.094	1.616
Metrobus Not Frequent Transit	-0.018	0.524	1.512	0.019	0.446	1.431	-0.006	0.326	1.512	0.002	0.768	1.431
Separated Bike Lanes Under 1000m	-0.386	0.294	1.885	-0.480	0.119	1.503	-0.106	0.178	1.885	-0.122	0.065	1.503
Separated Bike Lanes Over 1000m	1.755	0.002	2.370	1.572	0.004	1.635	0.341	0.006	2.370	0.308	0.008	1.635
Non-Separated Bike lanes	0.001	0.000	1.919	0.001	0.000	1.758	0.000	0.003	1.919	0.000	0.005	1.758
Small Scale Commercial Land Use (<7% Area)	-0.779	0.028	1.796	-0.948	0.007	1.907	-0.110	0.143	1.796	-0.173	0.022	1.907
Low Density Residential Land Use	-0.240	0.535	2.250	-0.437	0.218	2.162	-0.076	0.356	2.250	-0.105	0.170	2.162
Medium Density Residential Land Use	0.021	0.458	1.585	0.003	0.899	1.618	0.002	0.750	1.585	-0.002	0.790	1.618
High Density Residential Land Use	0.151	0.005	1.612	0.133	0.009	1.726	0.033	0.003	1.612	0.031	0.005	1.726
Institutional Land Use	0.117	0.724	1.394	-0.138	0.673	1.511	0.037	0.598	1.394	-0.024	0.735	1.511
Industrial Land Use	-0.380	0.327	1.537	-0.452	0.209	1.567	-0.028	0.738	1.537	-0.052	0.504	1.567
Parks and Recreation Land Use	0.191	0.569	1.677	0.063	0.843	1.66	-0.017	0.811	1.677	-0.033	0.633	1.660
Public Land Use	-0.332	0.252	1.289	-0.159	0.554	1.256	-0.048	0.431	1.289	-0.02	0.731	1.256
Top Attractions	0.642	0.221	1.923	0.243	0.661	1.658	0.136	0.224	1.923	0.048	0.688	1.658
Intersection Density	0.036	0.079	2.399	N/A	N/A	N/A	0.009	0.400	2.399	N/A	N/A	N/A
Change in Elevation	-0.017	0.000	2.163	-0.013	0.004	2.405	-0.004	0.000	2.163	-0.003	0.001	2.405
Factor 1: High Income - Educated, White	0.740	0.000	1.478	0.967	0.000	1.944	0.217	0.000	1.478	0.252	0.000	1.944
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-0.222	0.159	1.521	N/A	N/A	N/A	-0.056	0.097	1.521	N/A	N/A	N/A
Factor 3: Low Population Density Areas with Families	-1.004	0.000	2.446	-0.906	0.000	2.311	-0.251	0.000	2.446	-0.239	0.000	2.311
Males	N/A	N/A	N/A	0.004	0.713	1.587	N/A	N/A	N/A	-0.001	0.552	1.587
Students	N/A	N/A	N/A	-0.079	0.331	1.778	N/A	N/A	N/A	-0.018	0.312	1.778
Minorities	N/A	N/A	N/A	0.001	0.968	2.456	N/A	N/A	N/A	0.006	0.298	2.456
Car-Free Households	N/A	N/A	N/A	-0.011	0.349	2.653	N/A	N/A	N/A	-0.004	0.100	2.653

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Table 4.7 Weekday Trip Statistics Linear Regression Coefficients

	Start Weekday				End Weekday			
	Mall		No Mall		Mall		No Mall	
R	0.832		0.860		0.793		0.812	
R Square	0.692		0.739		0.628		0.659	
Durbin-Watson	1.44		1.534		1.453		1.653	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31200, 31623		31200, 31623		31200		31200	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.044	0.057	-0.013	0.586	-0.052	0.003	-0.016	0.357
Metrorail Station	0.558	0.077	0.631	0.039	0.467	0.550	0.529	0.466
Metrobus Not Frequent Transit	-0.005	0.860	0.025	0.313	0.000	0.200	0.030	0.701
Separated Bike Lanes Under 1000m	-0.329	0.354	-0.416	0.169	-0.027	0.540	-0.188	0.215
Separated Bike Lanes Over 1000m	1.653	0.003	1.543	0.004	2.024	0.001	1.756	0.006
Non-Separated Bike lanes	0.001	0.002	0.000	0.002	0.000	0.001	0.000	0.000
Small Scale Commercial Land Use (<7% Area)	-0.802	0.019	-0.957	0.006	-1.045	0.030	-1.196	0.010
Low Density Residential Land Use	-0.305	0.413	-0.466	0.183	-0.510	0.577	-0.704	0.184
Medium Density Residential Land Use	0.012	0.661	-0.006	0.828	0.015	0.255	-0.005	0.525
High Density Residential Land Use	0.149	0.004	0.132	0.008	0.117	0.062	0.095	0.114
Institutional Land Use	0.119	0.712	-0.103	0.749	-0.122	0.767	-0.387	0.252
Industrial Land Use	-0.496	0.185	-0.585	0.100	-0.389	0.923	-0.487	0.901
Parks and Recreation Land Use	0.168	0.604	0.058	0.852	0.171	0.530	0.003	0.909
Public Land Use	-0.233	0.404	-0.089	0.736	-0.297	0.089	-0.222	0.190
Top Attractions	0.215	0.670	-0.061	0.911	0.250	0.003	0.109	0.058
Intersection Density	0.033	0.088	N/A	N/A	0.042	0.048	N/A	N/A
Change in Elevation	-0.016	0.000	-0.013	0.004	-0.017	0.001	-0.014	0.016
Factor 1: High Income - Educated, White	0.763	0.000	0.948	0.000	0.713	0.000	0.962	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-0.159	0.296	N/A	N/A	-0.163	0.111	N/A	N/A
Factor 3: Low Population Density Areas with Families	-1.010	0.000	-0.921	0.000	-0.977	0.000	-0.886	0.001
Males	N/A	N/A	0.001	0.903	N/A	N/A	0.007	0.200
Students	N/A	N/A	-0.084	0.296	N/A	N/A	-0.070	0.606
Minorities	N/A	N/A	0.006	0.813	N/A	N/A	-0.011	0.486
Car-Free Households	N/A	N/A	-0.008	0.496	N/A	N/A	-0.006	0.348

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Table 4.8 Weekend Trip Statistics Linear Regression Coefficients

	Start Weekend				End Weekend			
	Mall		No Mall		Mall		No Mall	
R	0.8		0.831		0.830		0.853	
R Square	0.641		0.690		0.690		0.728	
Durbin-Watson	1.424		1.642		1.452		1.560	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31258		31200		31200, 31623		31200, 31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.082	0.003	-0.023	0.392	-0.090	0.033	-0.027	0.524
Metrorail Station	0.249	0.507	0.326	0.344	0.240	0.158	0.278	0.105
Metrobus Not Frequent Transit	-0.050	0.120	0.004	0.893	-0.044	0.991	0.012	0.255
Separated Bike Lanes Under 1000m	-0.551	0.193	-0.668	0.052	-0.277	0.943	-0.470	0.559
Separated Bike Lanes Over 1000m	2.002	0.003	1.593	0.008	2.375	0.001	1.844	0.002
Non-Separated Bike lanes	0.001	0.000	0.001	0.000	0.001	0.004	0.001	0.003
Small Scale Commercial Land Use (<7% Area)	-0.701	0.085	-0.921	0.019	-0.950	0.004	-1.125	0.001
Low Density Residential Land Use	-0.069	0.877	-0.353	0.371	-0.266	0.194	-0.582	0.061
Medium Density Residential Land Use	0.046	0.168	0.028	0.354	0.04	0.595	0.021	0.861
High Density Residential Land Use	0.157	0.010	0.138	0.015	0.121	0.029	0.098	0.075
Institutional Land Use	0.112	0.771	-0.234	0.521	-0.122	0.718	-0.462	0.260
Industrial Land Use	-0.076	0.865	-0.113	0.777	-0.046	0.322	-0.055	0.200
Parks and Recreation Land Use	0.221	0.567	0.049	0.891	0.259	0.613	0.045	0.992
Public Land Use	-0.540	0.107	-0.322	0.284	-0.609	0.311	-0.436	0.433
Top Attractions	1.77	0.004	1.103	0.075	1.95	0.637	1.303	0.851
Intersection Density	0.043	0.066	N/A	N/A	0.049	0.040	N/A	N/A
Change in Elevation	-0.018	0.001	-0.013	0.010	-0.019	0.000	-0.014	0.004
Factor 1: High Income - Educated, White	0.689	0.000	1.007	0.000	0.723	0.000	1.067	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-0.355	0.052	N/A	N/A	-0.310	0.309	N/A	N/A
Factor 3: Low Population Density Areas with Families	-0.960	0.000	-0.870	0.000	-0.894	0.000	-0.763	0.000
Males	N/A	N/A	0.011	0.358	N/A	N/A	0.017	0.533
Students	N/A	N/A	-0.061	0.501	N/A	N/A	-0.052	0.414
Minorities	N/A	N/A	-0.013	0.680	N/A	N/A	-0.023	0.701
Car-Free Households	N/A	N/A	-0.020	0.133	N/A	N/A	-0.014	0.649

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Tables 4.9 and 4.10 show a positively statistically significant relationship between Metrorail stations, morning peak ending trips and evening peak starting trips. This suggests that typical a day of Capital Bikeshare usage for the majority of users consists of trips starting away from and ending near Metrorail stations in the morning peak, and starting near and ending away from Metrorail stations in the evening peak.

A positively statistically significant relationship was also found between separated bike lanes and ending morning peak trips and starting/ending evening peak trips only when there was over 1000m lengths of bike lanes within 400m. Basic non-separated bike lanes were also significant for all peak periods except the morning ending trips. The linear regression coefficients were again extremely small, similar to the general trip statistics in Table 4.6.

While the bikeshare stations with high proportions of separated bike lanes and Metrorail stations are heavily used, this research is not path dependent and it is not clear whether people are actually using these facilities. However this study can indicate that they are heavily using stations near Metrorail stations and separated bicycling facilities.

Table 4.9 AM Peak Trip Statistics Linear Regression Coefficients

	Start Weekday AM				End Weekday AM			
	Mall		No Mall		Mall		No Mall	
R	0.759		0.79		0.866		0.873	
R Square	0.576		0.623		0.749		0.761	
Durbin-Watson	1.542		1.631		1.856		1.748	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31623		31623		31200, 31623		31200, 31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.041	0.005	-0.025	0.114	0.003	0.827	-0.001	0.920
Metrorail Station	0.192	0.332	0.208	0.298	0.582	0.002	0.671	0.001
Metrobus Not Frequent Transit	0.001	0.963	0.022	0.191	0.025	0.115	0.018	0.253
Separated Bike Lanes Under 1000m	-0.519	0.021	-0.595	0.003	0.430	0.040	0.400	0.036
Separated Bike Lanes Over 1000m	0.507	0.145	0.476	0.169	1.488	0.000	1.544	0.000
Non-Separated Bike lanes	0.000	0.000	0.000	0.000	0.000	0.470	0.000	0.589
Small Scale Commercial Land Use (<7% Area)	-0.351	0.103	-0.629	0.006	-0.632	0.002	-0.538	0.013
Low Density Residential Land Use	0.007	0.978	-0.007	0.977	-0.390	0.076	-0.425	0.053
Medium Density Residential Land Use	0.013	0.441	0.005	0.796	-0.023	0.157	-0.031	0.063
High Density Residential Land Use	0.132	0.000	0.140	0.000	0.011	0.702	0.001	0.982
Institutional Land Use	0.052	0.797	-0.083	0.694	0.075	0.690	-0.014	0.943
Industrial Land Use	-0.302	0.200	-0.411	0.079	-0.404	0.067	-0.460	0.040
Parks and Recreation Land Use	-0.070	0.729	-0.053	0.798	0.368	0.053	0.258	0.191
Public Land Use	-0.168	0.339	-0.132	0.450	0.112	0.494	0.116	0.484
Top Attractions	-0.565	0.077	-0.592	0.100	-0.410	0.168	-0.361	0.292
Intersection Density	0.024	0.050	N/A	N/A	0.009	0.455	N/A	N/A
Change in Elevation	-0.009	0.001	-0.009	0.004	-0.006	0.016	-0.005	0.073
Factor 1: High Income - Educated, White	0.270	0.005	0.292	0.008	0.522	0.000	0.612	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-0.071	0.457	N/A	N/A	0.054	0.545	N/A	N/A
Factor 3: Low Population Density Areas with Families	-0.283	0.021	-0.526	0.000	-0.566	0.000	-0.316	0.006
Males	N/A	N/A	-0.008	0.247	N/A	N/A	0.002	0.754
Students	N/A	N/A	0.005	0.925	N/A	N/A	-0.037	0.465
Minorities	N/A	N/A	-0.002	0.895	N/A	N/A	0.010	0.560
Car-Free Households	N/A	N/A	-0.020	0.012	N/A	N/A	0.016	0.040

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Table 4.10 PM Peak Trip Statistics Linear Regression Coefficients

	Start Weekday PM				End Weekday PM			
	Mall		No Mall		Mall		No Mall	
R	0.855		0.875		0.799		0.828	
R Square	0.732		0.766		0.638		0.685	
Durbin-Watson	1.496		1.598		1.421		1.622	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31200, 31623		31200, 31623		31623		31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.019	0.248	0.000	0.979	-0.062	0.001	-0.024	0.216
Metrorail Station	0.455	0.037	0.525	0.014	0.196	0.434	0.207	0.400
Metrobus Not Frequent Transit	0.003	0.886	0.017	0.338	-0.018	0.402	0.017	0.413
Separated Bike Lanes Under 1000m	0.012	0.961	-0.003	0.989	-0.267	0.345	-0.422	0.085
Separated Bike Lanes Over 1000m	1.381	0.000	1.325	0.441	1.153	0.009	0.768	0.072
Non-Separated Bike lanes	0.000	0.043	0.000	0.000	0.001	0.000	0.001	0.000
Small Scale Commercial Land Use (<7% Area)	-0.632	0.008	-0.630	0.005	-0.774	0.005	-0.990	0.000
Low Density Residential Land Use	-0.329	0.204	-0.465	0.200	-0.242	1.542	-0.416	0.141
Medium Density Residential Land Use	-0.001	0.938	-0.012	0.077	0.029	0.759	0.014	0.506
High Density Residential Land Use	0.071	0.045	0.052	0.797	0.103	0.576	0.090	0.026
Institutional Land Use	0.110	0.620	-0.041	0.001	-0.133	0.603	-0.356	0.171
Industrial Land Use	-0.362	0.163	-0.407	0.050	-0.150	0.615	-0.211	0.461
Parks and Recreation Land Use	0.293	0.190	0.162	0.021	-0.022	0.932	-0.121	0.635
Public Land Use	-0.092	0.633	0.014	0.457	-0.333	0.136	-0.298	0.166
Top Attractions	0.297	0.396	0.112	0.978	0.427	0.290	0.273	0.536
Intersection Density	0.015	0.265	N/A	N/A	0.039	0.963	N/A	N/A
Change in Elevation	-0.011	0.000	-0.008	0.729	-0.013	0.005	-0.011	0.003
Factor 1: High Income - Educated, White	0.620	0.000	0.767	0.103	0.407	0.001	0.585	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-0.060	0.567	N/A	N/A	-0.195	0.109	N/A	N/A
Factor 3: Low Population Density Areas with Families	-0.754	0.000	-0.559	0.339	-0.548	0.000	-0.622	0.000
Males	N/A	N/A	0.006	0.000	N/A	N/A	0.007	0.404
Students	N/A	N/A	-0.061	0.145	N/A	N/A	-0.038	0.557
Minorities	N/A	N/A	0.006	0.021	N/A	N/A	-0.020	0.365
Car-Free Households	N/A	N/A	0.003	0.332	N/A	N/A	-0.017	0.087

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Tables 4.11 and 4.12 below show the linear regression models based on membership type. A positively statistically significant relationship exists between Metrorail Stations and starting subscriber trips. A positively statistically significant relationship also exists between ending casual user trips and frequent transit services. Separated bike lanes over 1000m length within a 400m radius are also positively statistically significant except for subscriber starting trips.

The results from Tables 4.6-4.11 similar to the bivariate analysis in Chapter 4.2 generally support the findings from the literature review in Chapter 2. Changes in elevation and small scale retail (less than 7% of a 400m radius area) are negatively statistically significant with higher Capital Bikeshare trips. Males, higher education and high density residential land uses are positively statistically significant with higher Capital Bikeshare trips. The statistically insignificant relationship with students and car-free households diverges from the literature review, which found positively statistically significant relationships with higher rates of cycling. Besides high density residential and commercial land uses, other land uses were seldom found statistically significant.

Table 4.11 Subscriber Trip Statistics Linear Regression Coefficients

	Start Subscribers				End Subscriber			
	Mall		No Mall		Mall		No Mall	
R	0.835		0.858		0.829		0.816	
R Square	0.689		0.736		0.688		0.667	
Durbin-Watson	1.454		1.545		1.665		1.8	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31101, 31623		31623		31200, 31258		31200	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.035	0.079	-0.015	0.480	-0.043	0.028	-0.019	0.656
Metrorail Station	0.507	0.064	0.613	0.027	0.399	0.629	0.504	0.695
Metrobus Not Frequent Transit	-0.004	0.853	0.013	0.559	0.003	0.345	0.020	0.459
Separated Bike Lanes Under 1000m	-0.475	0.124	-0.609	0.027	-0.189	0.457	-0.385	0.381
Separated Bike Lanes Over 1000m	0.833	0.083	0.673	0.158	1.250	0.000	0.895	0.000
Non-Separated Bike lanes	0.001	0.000	0.001	0.000	0.001	0.187	0.001	0.143
Small Scale Commercial Land Use (<7% Area)	-0.747	0.012	-0.956	0.002	-0.979	0.118	-1.176	0.132
Low Density Residential Land Use	-0.330	0.309	-0.392	0.215	-0.499	0.764	-0.603	0.220
Medium Density Residential Land Use	0.018	0.443	0.002	0.930	0.020	0.771	0.001	0.995
High Density Residential Land Use	0.168	0.000	0.157	0.001	0.135	0.896	0.119	0.516
Institutional Land Use	0.077	0.782	-0.198	0.495	-0.115	0.935	-0.447	0.837
Industrial Land Use	-0.265	0.413	-0.408	0.204	-0.170	0.259	-0.315	0.316
Parks and Recreation Land Use	0.004	0.990	-0.106	0.710	0.016	0.136	-0.151	0.202
Public Land Use	-0.257	0.290	-0.250	0.298	-0.324	0.603	-0.381	0.542
Top Attractions	-0.662	0.132	-0.495	0.316	-0.559	0.000	-0.349	0.001
Intersection Density	0.032	0.057	N/A	N/A	0.042	0.355	N/A	N/A
Change in Elevation	-0.014	0.000	-0.012	0.003	-0.015	0.025	-0.013	0.172
Factor 1: High Income - Educated, White	0.749	0.000	0.818	0.000	0.697	0.002	0.852	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-0.048	0.718	N/A	N/A	-0.074	0.127	N/A	N/A
Factor 3: Low Population Density Areas with Families	-0.684	0.000	-0.859	0.000	-0.695	0.000	-0.809	0.032
Males	N/A	N/A	0.001	0.902	N/A	N/A	0.006	0.243
Students	N/A	N/A	-0.056	0.440	N/A	N/A	-0.041	0.362
Minorities	N/A	N/A	-0.004	0.876	N/A	N/A	-0.018	0.727
Car-Free Households	N/A	N/A	-0.014	0.210	N/A	N/A	-0.010	0.561

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Table 4.12 Casual Trip Statistics Linear Regression Coefficients

	Start Casual				End Casual			
	Mall		No Mall		Mall		No Mall	
R	0.841		0.832		0.829		0.85	
R Square	0.707		0.693		0.687		0.722	
Durbin-Watson	1.619		1.793		1.46		1.573	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31200, 31258		31200		31101, 31623		31200, 31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.034	0.033	-0.005	0.740	-0.037	0.042	-0.007	0.412
Metrorail Station	0.064	0.764	0.059	0.742	0.109	0.168	0.077	0.088
Metrobus Not Frequent Transit	-0.016	0.384	0.013	0.373	-0.018	0.914	0.012	0.401
Separated Bike Lanes Under 1000m	0.127	0.597	0.139	0.433	0.190	0.562	0.171	0.188
Separated Bike Lanes Over 1000m	1.791	0.000	1.756	0.000	1.882	0.014	1.848	0.079
Non-Separated Bike lanes	0.000	0.135	0.000	0.111	0.000	0.000	0.000	0.000
Small Scale Commercial Land Use (<7% Area)	-0.300	0.196	-0.258	0.200	-0.384	0.002	-0.335	0.001
Low Density Residential Land Use	-0.003	0.990	-0.198	0.333	-0.081	0.147	-0.277	0.075
Medium Density Residential Land Use	0.006	0.767	0.000	0.985	0.006	0.433	0.000	0.968
High Density Residential Land Use	0.003	0.919	-0.011	0.702	-0.005	0.004	-0.021	0.013
Institutional Land Use	0.084	0.702	0.041	0.829	-0.019	0.696	-0.043	0.152
Industrial Land Use	-0.302	0.235	-0.238	0.252	-0.304	0.620	-0.230	0.358
Parks and Recreation Land Use	0.325	0.140	0.244	0.185	0.348	0.958	0.260	0.620
Public Land Use	-0.100	0.597	0.122	0.433	-0.104	0.207	0.105	0.138
Top Attractions	1.866	0.000	1.153	0.000	1.894	0.229	1.228	0.509
Intersection Density	0.012	0.372	N/A	N/A	0.013	0.021	N/A	N/A
Change in Elevation	-0.007	0.028	-0.003	0.197	-0.007	0.000	-0.004	0.003
Factor 1: High Income - Educated, White	0.329	0.001	0.554	0.000	0.339	0.000	0.541	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-0.206	0.047	N/A	N/A	-0.168	0.598	N/A	N/A
Factor 3: Low Population Density Areas with Families	-0.657	0.000	-0.286	0.007	-0.590	0.000	-0.251	0.000
Males	N/A	N/A	0.006	0.355	N/A	N/A	0.008	0.518
Students	N/A	N/A	-0.049	0.298	N/A	N/A	-0.047	0.600
Minorities	N/A	N/A	0.009	0.552	N/A	N/A	0.006	0.485
Car-Free Households	N/A	N/A	0.004	0.580	N/A	N/A	0.005	0.391

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Tables 4.13-4.15 below show the linear regression models based on three main trip duration measurements: under 10 minutes, between 10 and 30 minutes, and over 30 minutes. A positively statistically significant relationship with frequent transit services was only found with Metrorail stations and starting trips under 10 minutes. Separated bike lanes were only positively statistically significant with ending trips under 10 minutes, and are strongly related to trips over 10 minutes. This follows the patterns observed previously with casual users generally taking longer trips in the National Mall area which has a high concentration of separated off-road cycling facilities.

One objective of this study is to explore the assumed phenomenon that bikeshare systems are being used as the “final mile” solution to access frequent transit services. Therefore it would be prudent to add an additional linear regression model that represents the characteristics of a final mile trip as closely as possible by using the typical 400m commuting time while using a bicycle. This represented using a linear regression model analyzing peak trips under 10 minute durations as shown in Tables 4.16 and 4.17. Tables 4.16-4.17 show the only positively statistically significant relationships with frequent transit services occur between Metrorail stations and ending morning and starting evening peak trips. These results are similar to the peak trip models in Tables 4.9-4.10. On the other hand separated bike lanes were only positively statistically significant with peak ending trips. Since peak trips are predominantly subscribers these results potentially demonstrate that subscribers are using the Capital Bikeshare system to complete the “final mile” to a Metrorail station.

With a positive significant relationship with separated cycling lanes only occurring after the morning peak and since users in the morning peak are more likely to be subscribers this suggests that the majority of subscribers live in areas with no separated bike lanes within 400m of a bikeshare station and are making short trips to the nearest bikeshare station that is within 400m of a Metrorail station.

In Table 4.16 it can be shown that separated bike lanes are only positively statistically significant with higher evening peak trips when including the National Mall bikeshare stations. This suggests that generally evening peak trips are more likely to occur between bikeshare stations within 400m proximity of a separated bike lane, with a sizable volume of trips occurring within the National Mall. The evening peak trip characteristics could be due to a combination of casual trips occurring later as per Figure 4.8, and the commute home typically taking more time, possibly involving trip chains for errands, and social functions, etc.

Table 4.13 Under 10 Minutes Trip Statistics Linear Regression Coefficients

	Start Under 10 Minutes Duration				End Under 10 Minutes Duration			
	Mall		No Mall		Mall		No Mall	
R	0.840		0.860		0.823		0.840	
R Square	0.706		0.740		0.677		0.705	
Durbin-Watson	1.472		1.514		1.433		1.499	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31200, 31623		31623		31101, 31623		31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.041	0.250	-0.030	0.904	-0.335	0.177	-0.098	0.716
Metrorail Station	0.192	0.102	6.386	0.049	4.014	0.234	5.054	0.146
Metrobus Not Frequent Transit	0.001	0.738	0.060	0.820	0.011	0.970	0.140	0.622
Separated Bike Lanes Under 1000m	-0.519	0.095	-8.092	0.012	-3.481	0.359	-6.129	0.077
Separated Bike Lanes Over 1000m	0.507	0.136	4.252	0.445	11.826	0.046	6.600	0.271
Non-Separated Bike lanes	0.000	0.000	0.008	0.000	0.007	0.000	0.007	0.000
Small Scale Commercial Land Use (<7% Area)	-0.351	0.000	-13.992	0.000	-14.299	0.000	-15.160	0.000
Low Density Residential Land Use	0.007	0.220	-5.710	0.124	-6.086	0.129	-7.463	0.062
Medium Density Residential Land Use	0.013	0.588	-0.128	0.649	0.094	0.752	-0.166	0.583
High Density Residential Land Use	0.132	0.000	1.829	0.001	1.686	0.002	1.424	0.012
Institutional Land Use	0.052	0.949	-3.416	0.316	-1.553	0.652	-5.141	0.162
Industrial Land Use	-0.302	0.197	-6.393	0.090	-3.738	0.351	-4.925	0.224
Parks and Recreation Land Use	-0.070	0.237	2.014	0.545	3.372	0.330	1.196	0.738
Public Land Use	-0.168	0.228	-3.667	0.193	-4.798	0.110	-5.645	0.063
Top Attractions	-0.565	0.004	-11.547	0.047	-12.951	0.018	-9.922	0.112
Intersection Density	0.024	0.045	N/A	N/A	0.449	0.033	N/A	N/A
Change in Elevation	-0.009	0.000	-0.148	0.002	-0.166	0.001	-0.137	0.008
Factor 1: High Income - Educated, White	0.270	0.000	8.883	0.000	7.185	0.000	9.029	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-0.071	0.502	N/A	N/A	-0.864	0.595	N/A	N/A
Factor 3: Low Population Density Areas with Families	-0.283	0.000	-9.704	0.000	-7.398	0.000	-8.355	0.000
Males	N/A	N/A	0.031	0.773	N/A	N/A	0.115	0.327
Students	N/A	N/A	-1.005	0.239	N/A	N/A	-0.975	0.288
Minorities	N/A	N/A	-0.336	0.238	N/A	N/A	-0.297	0.333
Car-Free Households	N/A	N/A	-0.058	0.651	N/A	N/A	-0.013	0.925

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Table 4.14 10-30 Minute Trip Statistics Linear Regression Coefficients

	Start 10-30 Minutes Duration				End 10-30 Minutes Duration			
	Mall		No Mall		Mall		No Mall	
R	0.785		0.809		0.798		0.813	
R Square	0.616		0.654		0.636		0.661	
Durbin-Watson	1.339		1.421		1.385		1.479	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31623		31200, 31623		31200, 31623		31200, 31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.422	0.075	-0.196	0.409	-0.519	0.036	-0.204	0.419
Metrorail Station	2.649	0.408	3.655	0.233	2.005	0.548	3.095	0.342
Metrobus Not Frequent Transit	-0.156	0.565	0.095	0.705	-0.167	0.555	0.135	0.614
Separated Bike Lanes Under 1000m	-5.336	0.141	-3.543	0.244	-2.554	0.498	-1.635	0.613
Separated Bike Lanes Over 1000m	12.132	0.032	14.457	0.007	15.977	0.007	16.349	0.004
Non-Separated Bike lanes	0.004	0.009	0.003	0.064	0.004	0.010	0.003	0.040
Small Scale Commercial Land Use (<7% Area)	-8.919	0.011	-10.575	0.003	-11.523	0.002	-13.332	0.000
Low Density Residential Land Use	-1.941	0.610	-3.550	0.313	-4.046	0.309	-5.999	0.109
Medium Density Residential Land Use	0.230	0.416	0.247	0.355	0.316	0.285	0.263	0.354
High Density Residential Land Use	1.044	0.045	0.930	0.063	0.819	0.130	0.702	0.185
Institutional Land Use	2.074	0.527	1.118	0.730	-0.428	0.900	-2.212	0.520
Industrial Land Use	-2.073	0.586	-2.597	0.467	-1.240	0.755	-2.040	0.590
Parks and Recreation Land Use	-0.595	0.856	-0.696	0.826	-0.060	0.986	-0.837	0.803
Public Land Use	-3.236	0.256	-0.782	0.769	-3.753	0.207	-1.727	0.543
Top Attractions	8.412	0.104	1.020	0.852	8.124	0.132	2.355	0.686
Intersection Density	0.090	0.651	N/A	N/A	0.210	0.312	N/A	N/A
Change in Elevation	-0.113	0.014	-0.096	0.034	-0.144	0.003	-0.119	0.014
Factor 1: High Income - Educated, White	6.082	0.000	7.261	0.000	5.301	0.001	7.784	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-2.945	0.058	N/A	N/A	-3.153	0.052	N/A	N/A
Factor 3: Low Population Density Areas with Families	-10.414	0.000	-7.011	0.000	-10.366	0.000	-7.297	0.000
Males	N/A	N/A	-0.039	0.708	N/A	N/A	-0.016	0.887
Students	N/A	N/A	-0.576	0.477	N/A	N/A	-0.340	0.692
Minorities	N/A	N/A	0.577	0.034	N/A	N/A	0.257	0.371
Car-Free Households	N/A	N/A	-0.193	0.112	N/A	N/A	-0.159	0.217

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Table 4.15 Over 30 Minutes Trip Statistics Linear Regression Coefficients

	Start Duration Over 30 Minutes				End Duration Over 30 Minutes			
	Mall		No Mall		Mall		No Mall	
R	0.815		0.797		0.806		0.774	
R Square	0.664		0.636		0.650		0.599	
Durbin-Watson	1.576		1.759		1.598		1.731	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31200, 31247, 31258, 31623		31200, 31243		31200, 31258, 31623		31200, 31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.314	0.039	-0.042	0.737	-0.323	0.041	-0.070	0.617
Metrorail Station	1.046	0.610	0.847	0.600	2.032	0.341	1.447	0.425
Metrobus Not Frequent Transit	-0.321	0.066	-0.072	0.585	-0.336	0.064	-0.089	0.549
Separated Bike Lanes Under 1000m	0.477	0.837	1.630	0.309	1.080	0.653	2.037	0.258
Separated Bike Lanes Over 1000m	14.095	0.000	13.788	0.000	14.793	0.000	14.644	0.000
Non-Separated Bike lanes	0.001	0.318	0.000	0.553	0.001	0.343	0.001	0.562
Small Scale Commercial Land Use (<7% Area)	-4.018	0.072	-4.074	0.026	-4.160	0.073	-4.349	0.034
Low Density Residential Land Use	0.797	0.744	-1.297	0.484	0.115	0.964	-1.825	0.380
Medium Density Residential Land Use	0.085	0.639	0.090	0.521	0.050	0.792	0.068	0.668
High Density Residential Land Use	-0.043	0.895	-0.158	0.547	-0.181	0.599	-0.294	0.317
Institutional Land Use	1.149	0.584	0.955	0.575	0.144	0.947	0.203	0.915
Industrial Land Use	-3.284	0.180	-2.782	0.140	-3.113	0.221	-2.573	0.224
Parks and Recreation Land Use	3.005	0.155	2.488	0.136	3.701	0.092	3.227	0.086
Public Land Use	-1.772	0.331	0.342	0.808	-0.869	0.646	0.968	0.540
Top Attractions	14.690	0.000	6.577	0.024	14.724	0.000	7.143	0.029
Intersection Density	0.052	0.686	N/A	N/A	0.060	0.650	N/A	N/A
Change in Elevation	-0.057	0.051	-0.034	0.156	-0.061	0.045	-0.041	0.130
Factor 1: High Income - Educated, White	2.222	0.024	4.496	0.000	2.274	0.026	4.179	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	-2.640	0.008	N/A	N/A	-2.299	0.027	N/A	N/A
Factor 3: Low Population Density Areas with Families	-6.225	0.000	-1.605	0.094	-5.327	0.000	-1.391	0.195
Males	N/A	N/A	0.049	0.374	N/A	N/A	0.047	0.445
Students	N/A	N/A	-0.216	0.612	N/A	N/A	-0.159	0.739
Minorities	N/A	N/A	0.195	0.172	N/A	N/A	0.199	0.213
Car-Free Households	N/A	N/A	-0.011	0.865	N/A	N/A	-0.028	0.697

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Table 4.16 Under 10 Minutes AM Peak Trip Statistics Linear Regression Coefficients

	Start Weekday PM Under 10 Minute				End Weekday PM Under 10 Minute			
	Mall		No Mall		Mall		No Mall	
R	0.840		0.864		0.825		0.840	
R Square	0.706		0.746		0.680		0.705	
Durbin-Watson	1.569		1.644		1.538		1.683	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31613, 31623		31623		31101, 31600, 31623		31600, 31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Metrobus Frequent Transit	-0.009	0.429	0.000	0.994	-0.030	0.019	-0.010	0.460
Metrorail Station	0.481	0.003	0.573	0.001	0.080	0.646	0.086	0.633
Metrobus Not Frequent Transit	0.003	0.820	0.006	0.672	-0.001	0.939	0.014	0.346
Separated Bike Lanes Under 1000m	-0.140	0.441	-0.236	0.143	-0.203	0.300	-0.430	0.017
Separated Bike Lanes Over 1000m	0.618	0.030	0.420	0.133	0.661	0.031	0.220	0.478
Non-Separated Bike lanes	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Small Scale Commercial Land Use (<7% Area)	-0.498	0.005	-0.518	0.005	-0.659	0.001	-0.749	0.000
Low Density Residential Land Use	-0.271	0.158	-0.324	0.082	-0.276	0.182	-0.361	0.082
Medium Density Residential Land Use	-0.005	0.718	-0.020	0.155	0.013	0.392	-0.003	0.835
High Density Residential Land Use	0.080	0.002	0.070	0.009	0.093	0.001	0.079	0.008
Institutional Land Use	0.002	0.989	-0.219	0.201	-0.140	0.431	-0.331	0.083
Industrial Land Use	-0.263	0.171	-0.355	0.060	-0.196	0.343	-0.240	0.254
Parks and Recreation Land Use	0.290	0.082	0.153	0.359	0.039	0.829	-0.066	0.722
Public Land Use	-0.027	0.848	-0.041	0.771	-0.314	0.043	-0.402	0.011
Top Attractions	-0.755	0.004	-0.516	0.076	-0.357	0.202	-0.152	0.638
Intersection Density	0.017	0.092	N/A	N/A	0.034	0.002	N/A	N/A
Change in Elevation	-0.009	0.000	-0.006	0.007	-0.009	0.000	-0.008	0.003
Factor 1: High Income - Educated, White	0.444	0.000	0.530	0.000	0.354	0.000	0.453	0.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	0.050	0.524	N/A	N/A	-0.057	0.495	N/A	N/A
Factor 3: Low Population Density Areas with Families	-0.397	0.000	-0.496	0.000	-0.288	0.008	-0.438	0.000
Males	N/A	N/A	0.005	0.359	N/A	N/A	0.008	0.213
Students	N/A	N/A	-0.037	0.383	N/A	N/A	-0.053	0.263
Minorities	N/A	N/A	-0.019	0.175	N/A	N/A	-0.028	0.076
Car-Free Households	N/A	N/A	0.002	0.746	N/A	N/A	-0.004	0.604

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Table 4.17 Under 10 Minutes PM Peak Trip Statistics Linear Regression Coefficients

	Start Weekday PM Under 10 Minute				End Weekday PM Under 10 Minute			
	Mall		No Mall		Mall		No Mall	
R	0.840		0.864		0.825		0.840	
R Square	0.706		0.746		0.680		0.705	
Durbin-Watson	1.569		1.644		1.538		1.683	
ANOVA	0.000		0.000		0.000		0.000	
Outliers	31613, 31623		31623		31101, 31600, 31623		31600, 31623	
Variable	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**	**Coefficient**	**Sig.**
Frequent Transit	-.009	.429	.000	.994	-.030	.019	-.010	.460
Metrorail Station	.481	.003	.573	.001	.080	.646	.086	.633
Not Frequent Transit	.003	.820	.006	.672	-.001	.939	.014	.346
Separated Bike Lanes Under 1000m	-.140	.441	-.236	.143	-.203	.300	-.430	.017
Separated Bike Lanes Over 1000m	.618	.030	.420	.133	.661	.031	.220	.478
Non-Separated Bike lanes	.000	.000	.000	.000	.000	.000	.000	.000
Small Scale Commercial Land Use (<7% Area)	-.498	.005	-.518	.005	-.659	.001	-.749	.000
Low Density Residential Land Use	-.271	.158	-.324	.082	-.276	.182	-.361	.082
Medium Density Residential Land Use	-.005	.718	-.020	.155	.013	.392	-.003	.835
High Density Residential Land Use	0.08	0.002	0.07	0.009	0.093	0.001	0.079	0.008
Institutional Land Use	.002	.989	-.219	.201	-.140	.431	-.331	.083
Industrial Land Use	-.263	.171	-.355	.060	-.196	.343	-.240	.254
Parks and Recreation Land Use	.290	.082	.153	.359	.039	.829	-.066	.722
Public Land Use	-.027	.848	-.041	.771	-.314	.043	-.402	.011
Top Attractions	-.755	.004	-.516	.076	-.357	.202	-.152	.638
Intersection Density	.017	.092	N/A	N/A	.034	.002	N/A	N/A
Change in Elevation	-.009	.000	-.006	.007	-.009	.000	-.008	.003
Factor 1: High Income - Educated, White	.444	.000	.530	.000	.354	.000	.453	.000
Factor 2: High Population Density Areas with Male Students and Car-Free Households	.050	.524	N/A	N/A	-.057	.495	N/A	N/A
Factor 3: Low Population Density Areas with Families	-.397	.000	-.496	.000	-.288	.008	-.438	.000
Males	N/A	N/A	.005	.359	N/A	N/A	.008	.213
Students	N/A	N/A	-.037	.383	N/A	N/A	-.053	.263
Minorities	N/A	N/A	-.019	.175	N/A	N/A	-.028	.076
Car-Free Households	N/A	N/A	.002	.746	N/A	N/A	-.004	.604

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive significance at the 0.05 level. Red highlighting indicates negative significance at the 0.05 level, No color indicates no significance.

Chapter 4.3 presented and evaluated the results from a multivariable linear regression analysis. The following Chapter 4.4 will discuss and evaluate the findings from Chapter 4, and tie them to the literature review in Chapter 2.

4.4. Discussion

Chapter 4 above used three analysis steps and ArcGIS visualization to evaluate the relationship between Capital Bikeshare trips, separated bike lanes and high frequency transit services. This chapter ties together the findings from these three analytical steps and places them within the context of the literature review.

Chapter 4 above found strong relationships generally with trips over 10 minutes originating and ending at bikeshare stations within 400m of separated bike lanes. Statistical relationships with frequent transit services were only found consistently with bikeshare stations within 400m proximity to Metrorail stations and only in specific situations, generally with subscribers after the morning peak departure for trips under 10 minutes.

Capital Bikeshare conducted a Customer User and Satisfaction Survey in November 2012 of its subscriber members. The results of the Customer User and Satisfaction survey were compared with the findings from this study. The results of the survey had two separate components the first of which was an online 4-week survey with a 34% survey response rate or 3,731 responses, and a George Washington University partnership survey to study the Capital Bikeshare’s health related impacts with a 28% response rate or 3,111 responses.

The survey found that 17% had used the bikeshare 6+ times while 54% of respondents had made at least one bikeshare trip that ended or started at a Metrorail station. Otherwise 23% of respondents used the Capital Bikeshare to access a bus in the past month (Capital Bikeshare, 2013, p. ii). The survey also found that respondents had shifted modes from other sustainable transportation modes with 61% riding Metrorail, and 52% riding the bus less often (Capital Bikeshare, 2013, p. ii).

Over half of respondents stated they were using the bikeshare system for at least one trip in the last month to a Metrorail station. The survey also found that forty-four percent of respondents would have ridden a bus or train if a bikeshare had not been available (Capital Bikeshare, 2013a, p. v). These survey results are consistent with the findings from this study, where Metrobus based frequent transit services were sometimes negatively statistically significant with high trip rates. Frequent transit services and the bikeshare system may be competing with each other. Members are opting to use the Capital Bikeshare system to complete the “final mile”, instead of Metrobus routes. This is further confirmed with 78% of the respondents stating that they chose the bikeshare for the recent trip because it was a faster or easier way to reach their destination. (Capital Bikeshare, 2013a, p. iv).

Metrobus fares are not transferrable to the Metrorail services. This could also be discouraging multi-modal trips between Capital Bikeshare stations and Metrobuses. and contributing to the negative statistical significance with high frequency services.

An alternative explanation for the negative statistical significance with high frequency transit services may be that specific bikeshare stations with high unavailability of both bikes and docks to return bikes could be preventing people from using the bikeshare at those stations and thus they opt for the frequent transit services. Either way people may be using the bikeshare as an additional mobility option and will choose the mode that is the most convenient for the purpose and time at hand.

The survey found that 9 in 10 of respondents were employed and that those using the system were more likely to be male, white, highly educated, however slightly less affluent than the adult population in the Washington metropolitan region (Capital Bikeshare, 2013a, p. iii). These survey results coincide closely with the results of this study with the exception that this study found that trips tend to originate or end in areas with household incomes above $100,000.

Similar to Buehler et al. (2011a) the results from this study found for all trip statistics that non-separated bike lanes were significantly related to higher bikeshare trips. The relationship found in this study however is weak, in the sense that it would require a large increase in the length of bike lanes within 400m to encourage a small increase of trips. There is a stronger relationship for trips with bikeshare stations within 400m of 1000m lengths of separated bike lanes. With only 24 bikeshare stations within 400m of 1000m lengths of separated cycling lanes, this could introduce errors into the results. Evaluating the data does not find that noise in the data are significantly influencing the results.

The results for frequent transit show the relationship is situational. There was often a negatively or non-statistically significant relationship with the Metrobus based, traffic mixed Frequent Transit Network. A stronger relationship was found with subscriber members, trips under ten minutes and with peak travelling trips to and from bikeshare stations within 400m proximity of Metrorail stations. The findings show a strong relationship with the commuting trip pattern after the morning peak, indicating that users are likely using the bikeshare to commute from traditional mixed use residential neighbourhoods surrounding downtown to bikeshare stations within 400m of Metrorail stations in the core areas. This suggests that not only are rail transit services related to higher trips but rather frequent transit services that mimic the Metrorail with high capacity, direct-limited stop, and grade separated dedicated right of way.

The findings also show that 75% of the study trips were made by subscribers with a strong commuting behavior. However the findings also show that the Capital Bikeshare system is also being used for non-work related trips. This study found a high volume of trips originating within the National Mall which are closely related to the casual members. In addition strong relationships were found amongst trips over 10 minutes made by casual members within 400m of separated cycling facilities.

The Customer User and Satisfaction Survey found that its subscriber members were using the Capital Bikeshare system for both commuting to work and non-commuting leisurely purposes. The survey found that 66% of respondents used the system to go out for a meal, 55% for shopping trips, meanwhile 58% used the system to go to or from work (Capital Bikeshare, 2013a, p. ii). Buehler (2011b) similarly found that casual user trips were predominantly geographically constrained within the National Mall area mainly for tourism/sight-seeing and social/personal purposes. Since casual users offer the highest potential for revenue generation under the current bikeshare operation model, this suggests a strong case for expanding the traffic separated cycling lane network.

It is acknowledged that the results from this study measure the relationship to the surrounding areas which is different from the 2012 Capital Bikeshare Customer User and Satisfaction Survey (2013a) or Buehler et al. (2011a) and other studies in the literature review in Chapter 2 which may have measured the relationship to respondent's responses. We are not asserting that these are the same; to do so would result in an ecological fallacy.

As an aside the results also found that commercial land use was positively statistically significant from the bivariate analysis. The multivariable linear regression analysis, however due to collinearity issues was only able to examine commercial land use as a dummy variable of less than 7% of the land use within a 400m radius circle (approximately 380,000 square feet). The multivariable analysis in Chapter 4.3 found a negatively statistically significant relationship with 7% or less commercial land use within 400m of a bikeshare station. Since this was a dummy variable this also allows the inference that bikeshare stations with more than 7% commercial land use (380,000 square feet) of commercial floor space within a 400m radius is positively statistically significant with higher Capital Bikeshare trips. This suggests the importance of making bikeshare stations available in commercial areas. This was also confirmed by Buehler et al. (2013, p. 13-16) who found that the Capital Bikeshare system was inducing trips, where a high percentage of respondents making trips would spend money within four blocks of spending destinations.

From this research it also becomes apparent that the Capital Bikeshare stations located in the Anacostia area experience some of the system's lowest usage. The Anacostia area is also dominated by census tracts with higher proportions of household incomes below $25,000 per year, unemployment and African Americans. The area also coincides with lower cycling supportive built form such as a lack of adequate bikeshare station density, and on-street separated bike lanes, hilly topography, and suburban "cul-de-sac" urban form with lower residential density land uses, and streets that do not connect to form the optimal lattice network.

It is possibly the high financial cost to access the Capital Bikeshare system combined with the markedly increased relative disparity of this area are contributing to the lower usage. To support potential increased usage by the lower income and minority communities in this area, a three step “low hanging fruit” solution should be considered as below. A study conducted for the USDOT Federal Highway Administration in 2012 similarly found that systems across the USA saw limited use by similar communities and recommends considering minority and low income populations early on.

The Capital Bikeshare does have a partnership with a local banking institution to provide access to a free checking account for low income residents and therefore system access. Due to the infancy of this program, time will be needed to gauge its success. Alternatively subsidized memberships for low residents should be considered, similar to the one offered by Boston’s Hubway bikeshare system (Hubway, 2014). Through this subsidized membership program low income residents gain access to the entire bikeshare system with a $5 annual membership fee. This would also need to be accompanied with extensive marketing and outreach to ensure that low income residents are aware of the discount.

Analyzing Figure 4.19 shows that most of the trips in the area generally travel north-south to and from the north side of the Anacostia River. Therefore the low station density in this region should be improved by strategically placing stations to improve the station density and open up the system access in this general direction of travel. Improved system density could also improve local travel between locally placed stations. Finally separated bike lanes should be installed on key roads.

These solutions are considered “low hanging” because of the relatively shorter implementation time opposed to changing the areas built form. Regardless if this is the correct solution, it is clear that a broader and more in-depth conversation is needed on making bikeshare systems more inclusionary. Bikeshare systems have the potential to act as an equalizer for city mobility. If bikeshare system access can be made more equitable with both bikeshare system network and pricing design, low income residents can gain city wide access to jobs, services and opportunities through another mobility option.

Alternatively this research has shown that there is a clear relationship between Capital Bikeshare trips and areas with separated bike lanes. It is possible that decision makers will use this evidence to justify the expansion of the separated cycling lane network to maximize system revenue by encouraging longer trips by casual users. This has the added benefit of adding designated and safe routes through the city that anyone can use including those that are “interested but concerned” about starting cycling (Portland, 2013; TransLink, 2011).

Chapter 5.

Conclusion

Bikeshare systems using a fleet of bicycles for public usage have seen gradual evolution from the 1st generation “White bikes” in Amsterdam to the 2nd generation coin deposit operated City Bikes in Copenhagen to the pioneering 3rd generation Rennes SmartBike program in 1998. The first modern version of the 3rd generation bikeshare did not surface until 2005 in Lyon. Since then bikeshares have seen a proliferation with systems in over 500 cities worldwide (2013), with a complex diversity of organizational structures, system generations, business models, system sizes, cultures, climatic environments and infrastructure. Third generation bikeshare systems are still relatively new and it is an evolving process to understand how they best work, how people are using them and how to optimize their operation. This research investigates a small but important development towards better understanding bikeshare systems.

Separated bike lanes were found to be statistically significantly related with higher Capital Bikeshare usage regardless of the time of day or membership type. On the other hand only Metrorail frequent transit services were found to be statistically significant, but only with subscriber trips during peak travel times.

It is acknowledged that this study measures the relationship between the surrounding area and Bikeshare use, which is different from the individual-level measures taken in the 2012 Capital Bikeshare Customer User and Satisfaction Survey (2013a), Buehler et al. (2011a) and other studies noted in the literature review in Chapter 2. We are not asserting that these are the same; to do so would result in an ecological fallacy. Despite this the results from this study closely matched the literature review, generally demonstrating the viability of this analysis method. This also provides strong support to the power of open data. The free and readily accessible availability of rich high quality data can help support governmental and research bodies achieve their objectives by allowing third-parties to conduct independent rigorous research.

Based on the results of this study the following conclusions and recommendations can be made:

1. Only 36% of the region’s Capital Bikeshare stations are located within 400m of a Metrorail station. Locating Capital Bikeshare stations as close as possible within 400m of a Metrorail station may increase ridership.

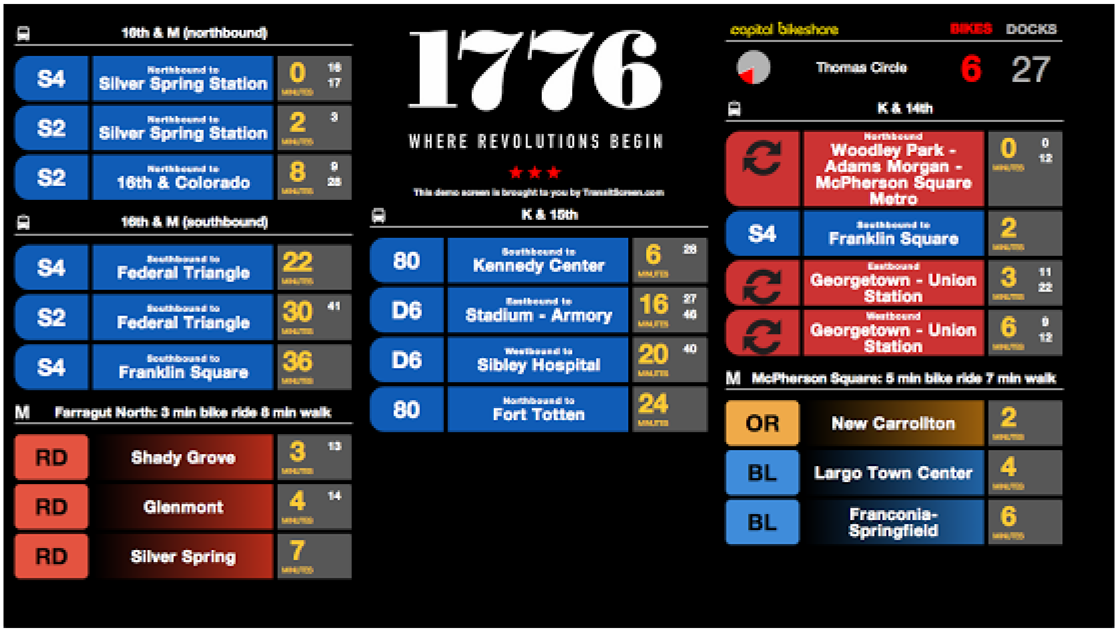
2. It was revealed through the Capital Bikeshare staff interviews (Capital Bikeshare Staff, Personal Communication, March, 2014) that the WMATA bureaucratic procedures were preventing bikeshare station placements on WMATA land surrounding Metrorail stations. This indicates the importance of establishing strong relationships and policies with the necessary transit, regulatory, municipal, and upper level government agencies right from the system conceptualization. This will help guide decision making to optimize bikeshare station placement and maximize system use.

3. It was found that there was often a weak or negative relationship with Metrobus based frequent transit services. This may be a result of the lack of an integrated transit fare system where Metrobus fares are not transferrable to Metrorail services. This lends strong support for establishing an integrated modal fare system so that transit and bikeshare modes complement rather than compete with each other.

4. The results from Buehler et al. demonstrated a low satisfaction with the existing DC Metro bicycle lanes in 2011 (Buehler, 2011b). The results from this study also demonstrate the importance of users making trips to bikeshare stations within 400m proximity of a separated bicycle facility. More importantly strong relationships between separated cycling facilities were found with higher rates of casual user trips. Casual users provide the highest potential for revenue generation under the current bikeshare operation model. Traffic separated bicycle lanes should be expanded to form a network that connects

Metrorail stations, top attractions, employment destinations, commercial and low-medium to high density residential land uses.

5. While the study found bikeshare stations with low usage, planning bikeshare systems, similar to transit planning requires making trade-offs between coverage and higher quality services. However targeted marketing or incentives for specific neighbourhoods or demographics should be considered to increase usage at low ridership bikeshare stations and encourage self-correcting system balancing.



10th & M (northbound)

S4	Northbound to Silver Spring Station	0 MINUTES	16 17
S2	Northbound to Silver Spring Station	2 MINUTES	3
S2	Northbound to 16th & Colorado	8 MINUTES	9 28

16th & M (southbound)

S4	Southbound to Federal Triangle	22 MINUTES	
S2	Southbound to Federal Triangle	30 MINUTES	41
S4	Southbound to Franklin Square	36 MINUTES	

M Farragut North: 3 min bike ride 8 min walk

RD	Shady Grove	3 MINUTES	13
RD	Glenmont	4 MINUTES	14
RD	Silver Spring	7 MINUTES	

1776

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★★★

This demo screen is brought to you by TransitScreen.com

K & 15th

80	Southbound to Kennedy Center	6 MINUTES	28
D6	Eastbound to Stadium - Armory	16 MINUTES	27 46
D6	Westbound to Sibley Hospital	20 MINUTES	40
80	Northbound to Fort Totten	24 MINUTES	

capital bikeshare

	BIKES	DOCKS
Thomas Circle	6	27

K & 14th

	Northbound Woodley Park - Adams Morgan - McPherson Square Metro	0 MINUTES	0 12
S4	Southbound to Franklin Square	2 MINUTES	
	Eastbound Georgetown - Union Station	3 MINUTES	11 22
	Westbound Georgetown - Union Station	6 MINUTES	0 12

M McPherson Square: 5 min bike ride 7 min walk

OR	New Carrollton	2 MINUTES
BL	Largo Town Center	4 MINUTES
BL	Franconia-Springfield	6 MINUTES

Figure 5.1 Screenshot of TransitScreen feature showing real time bus arrival and departure times, and Capital Bikeshare availability
Note: Source (TransitScreen. 2014)

6. Based on the results from this study, Capital Bikeshare should expect bikeshare stations within 400m proximity of Metrorail Stations to experience the highest trip volumes during the peak commuting times. Therefore rebalancing, rebalancing, incentive, and marketing efforts can be focused here. To mitigate the rebalancing requirements and aim for a more even distribution of system trips, the system bike availability can be made more legible. For example, by strategically installing screens (similar to the TransitScreen above) showing real time bicycle availability and next bus

arrival times at Metrorail stations, key offices, shopping centers and institutions, Capital Bikeshare members can readily inform themselves of any ongoing imbalances near their desired destination or origins. With real time members could purposely proceed to another Metrorail station where available bicycles are a certainty or opt to use the local or frequent bus service connections.

5.1. Recommendations for Further Research

This study found a negative correlation with frequent transit services. Further research should be pursued to discover if this is the result of the two modes competing, systems imbalances or if this is the result of non-transferable multi-modal fares.

It was discovered that a streetcar is set to be opened along H-street in the year 2014, it would prove useful to complete a before and after comparison to see if this format of neighbourhood oriented frequent transit improved or reoriented the surrounding Capital Bikeshare usage.

This study also found a negative correlation with students. Future research could explore this further to determine if a possible discount or specific marketing could make an impact.

This analysis could be further improved by differentiating the commercial land uses into offices, goods and services retail or a mixture of both.

This analysis could also be further improved by using the Network Analyst tool in ArcGIS to account for the true path dependent 400m distance from the Capital Bikeshare stations.

Transit services and separated bike lanes could also be weighted based on their usage data provided from DOT and WMATA counts.

Finally the results from this study could be further improved by evaluating the entire system across the Washington D.C. region to include Arlington and Alexandria, VA and Montgomery County, MD.

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Appendix A.

List of Study Capital Bikeshare Stations

Terminal Number	Address
31100	19th St & Pennsylvania Ave NW
31101	14th & V St NW
31102	11th & Kenyon St NW
31103	16th & Harvard St NW
31104	Adams Mill & Columbia Rd NW
31105	14th & Harvard St NW
31107	Lamont & Mt Pleasant NW
31108	4th & M St SW
31109	7th & T St NW
31110	20th St & Florida Ave NW
31111	10th & U St NW
31112	Harvard St & Adams Mill Rd NW
31113	Columbia Rd & Belmont St NW
31114	18th St & Wyoming Ave NW
31115	Columbia Rd & Georgia Ave NW
31116	California St & Florida Ave NW
31117	15th & Euclid St NW
31118	3rd & Elm St NW
31121	Calvert St & Woodley Pl NW
31200	Massachusetts Ave & Dupont Circle NW
31201	15th & P St NW
31202	14th & RSt NW
31203	14th & Rhode Island Ave NW
31204	20th & E St NW
31205	21 st & I St NW
31206	19th & E Street NW
31207	Georgia Ave and Fairmont St NW
31208	M St & New Jersey Ave SE
31209	1st & N St SE
31211	Kennedy Center
31212	21st & M St NW
31213	17th & KSt NW [formerly 17th & LSt NW]
31214	17th & Corcoran St NW

Terminal Number	Address
31215	Georgetown Harbor / 30th St NW
31216	McPherson Square / 14th & H St NW
31217	USDA / 12th & Independence Ave SW
31218	L'Enfant Plaza / 7th & CSt SW
31219	10th St & Constitution Ave NW
31220	US Dept of State / Virginia Ave & 21st St NW
31221	18th & M St NW
31222	New York Ave & 15th St NW
31223	Convention Center / 7th & M St NW
31224	19th & LSt NW
31225	C&O Canal & Wisconsin Ave NW
31226	34th St & Wisconsin Ave NW
31227	13th St & New York Ave NW
31228	8th & H St NW
31229	New Hampshire Ave & T St NW [formerly 16th & U St NW]
31230	Metro Center /12th & G St NW
31231	14th & D St NW / Ronald Reagan Building
31232	7th & F St NW / National Portrait Gallery
31233	17th & K St NW / Farragut Square
31234	20th & O St NW / Dupont South
31235	19th St & Constitution Ave NW
31236	37th & O St NW / Georgetown University
31237	25th St & Pennsylvania Ave NW
31238	14th & G St NW
31239	17th & Rhode Island Ave NW
31240	Ohio Dr & West Basin Dr SW / MLK & FDR Memorials
31241	Thomas Circle
31242	18th St & Pennsylvania Ave NW
31243	Maryland & Independence Ave SW
31244	4th & E St SW
31245	7th & R St NW / Shaw Library
31246	MSt & Pennsylvania Ave NW
31247	Jefferson Dr & 14th St SW
31248	Smithsonian / Jefferson Dr & 12th St SW
31249	Jefferson Memorial
31250	20th & L St NW
31251	12 th & L St NW
31252	21st St & Pennsylvania Ave NW

Terminal Number	Address
31253	19th & K St NW
31254	15th & K St NW
31255	24th & N St NW
31256	10th & E St NW
31257	22nd & I St NW / FoggyBottom
31258	Lincoln Memorial
31259	20th St & Virginia Ave NW
31260	23rd & E St NW
31261	21st St & Constitution Ave NW
31262	11th & F St NW
31263	11th & K St NW
31264	6th St & Indiana Ave NW
31265	5th St & Massachusetts Ave NW
31266	11th & M St NW
31267	17th St & Massachusetts Ave NW
31268	13th & U St NW
31269	3rd St & Pennsylvania Ave SE
31270	8th & D St NW
31271	Constitution Ave & 2nd St NW / DOL
31272	Washington & Independence Ave SW / HHS
31300	Van Ness Metro / UDC
31301	Ward Circle / American University
31302	Idaho Ave & Newark St NW [on 2nd District patio]
31303	Tenleytown / Wisconsin Ave & Albemarle St NW
31304	36th & Calvert St NW / Glover Park
31305	Connecticut Ave & Newark St NW / Cleveland Park
31306	39th & Calvert St NW / Stoddert
31307	3000 Connecticut Ave NW / National Zoo
31308	39th & Veazey St NW
31309	Fessenden St & Wisconsin Ave NW
31310	Connecticut & Nebraska Ave NW
31312	Wisconsin Ave & O St NW
31400	Georgia & New Hampshire Ave NW
31401	14th St & Spring Rd NW
31402	14th St Heights / 14th & Crittenden St NW
31403	5th & Kennedy St NW
31404	9th & Upshur St NW
31405	Georgia Ave & Emerson St NW

Terminal Number	Address
31406	14th & Upshur St NW
31407	14th St & Colorado Ave NW
31500	4th St & Rhode Island Ave NE
31501	12th & Newton St NE
31502	John McCormack Dr & Michigan Ave NE
31503	Florida Ave & R St NW
31504	10th & Monroe St NE
31505	Eckington Pl & Q St NE
31506	1st & Rhode Island Ave NW
31507	1st & Washington Hospital Center NW
31508	Gallaudet / 8th St & Florida Ave NE
31509	New Jersey Ave & R St NW
31510	18th St & Rhode Island Ave NE
31511	12th & Irving St NE
31512	Neal St & Trinidad Ave NE
31513	Rhode Island Ave & V St NE
31600	5th St & K St NW
31601	19th & East Capitol St SE
31602	Park Rd & Holmead Pl NW
31603	1st & M St NE
31604	4th St & Massachusetts Ave NW
31605	3rd & D St SE
31606	Potomac & Pennsylvania Ave SE
31607	14th & D St SE
31608	8th & Eye St SE / Barracks Row
31609	7th & Water St SW / SW Waterfront
31610	Eastern Market / 7th & North Carolina Ave SE
31611	13th & H St NE
31612	D St & Maryland Ave NE
31613	Eastern Market Metro / Pennsylvania Ave & 7th St SE
31614	11th & H St NE
31615	6th & H St NE
31616	3rd & H St NE
31617	Bladensburg Rd & Benning Rd NE
31618	4th & East Capitol St NE
31619	Lincoln Park / 13th & East Capitol St NE
31620	5th & F St NW
31621	4th & D St NW / Judiciary Square

Terminal Number	Address
31622	13th & D St NE
31623	Columbus Circle / Union Station
31624	North Capitol St & F St NW
31625	3rd & G St SE
31626	15th St & Massachusetts Ave SE
31627	M St & Delaware Ave NE
31628	1st & K St SE
31629	8th & East Capitol St NE
31630	15th & East Capitol St NE
31631	8th & F St NE
31632	15th & F St NE
31633	Independence Ave & L'Enfant Plaza SW / DOE
31700	Good Hope & Naylor Rd SE
31701	Branch & Pennsylvania Ave SE
31702	Randle Circle & Minnesota Ave NE
31703	Minnesota Ave Metro / DOES
31705	Benning Branch Library
31706	Fairfax Village
31707	Benning Rd & East Capitol St NE / Benning Rd Metro
31708	Anacostia Ave & Benning Rd NE / River Terrace
31709	34th St & Minnesota Ave SE
31800	Alabama & MLK Ave SE
31801	Anacostia Metro
31802	Good Hope Rd & MLK Ave SE
31803	Good Hope Rd & 14th St SE
31804	Anacostia Library
31805	Pennsylvania & Minnesota Ave SE
31806	Congress Heights Metro
31807	Pleasant St & MLK Ave SE

Appendix B.

List of All Day Frequent Transit Services

Route	Monday to Friday		Saturday		Sunday	
	Frequent Service Start Time	Frequent Service End Time	Frequent Service Start Time	Frequent Service End Time	Frequent Service Start Time	Frequent Service End Time
Blue/Orange Metrorail	5:00	26:55	7:22	26:50	7:22	23:47
Red Metrorail	5:00	26:42	7:00	26:30	7:00	23:30
Yellow/Green Metrorail	5:00	26:44	7:19	26:44	7:19	23:44
70	4:25	24:01	5:40	21:59	9:00	20:05
S2/S4	4:42	23:02	5:05	20:50	5:17	19:16
32/36	4:56	19:00	6:30	19:50	9:42	19:10
B2	5:05	18:03				
X2	5:14	24:32	5:19	22:48		
A2/A6/A8	5:17	23:53	8:16	24:10	8:07	23:50
E2/E4	5:25	19:54				
90/92	5:25	25:05	4:28	23:55	7:21	25:21
80	5:42	18:01				
52/53/54	5:59	23:31	6:29	23:00	9:21	20:57
82/83/86	6:00	20:45				
U8	6:09	20:06				
H2/H4	6:30	22:40	6:27	22:50		
42	6:44	23:17	6:20	18:47	7:05	18:09
31	7:27	18:14				
Note: Using 24 hour clock, hours over 24 indicate additional hours						

Appendix C.

List of On-Road Separated Cycling Lanes

Bike Lane	Completion Date	Start Street	End Street	Direction	Length (km)
15th St NW	2009	U St NW	Massachusetts Ave NW	NS	1.29
15th st NW	2010	Massachusetts Ave NW	K St NW	NS	0.71
15th st NW	2010	Pensylvannia Ave NW	New York Ave NW	NS	0.37
Pennsylvania Ave	2010	3 st NW	15 st NW	EW	1.68
R st NE	2012	3rd st NE	2nd St NE	EW	0.12
L Street NW	2012	New Hampshire Ave NW	Massachusetts Ave NW	EW	1.80

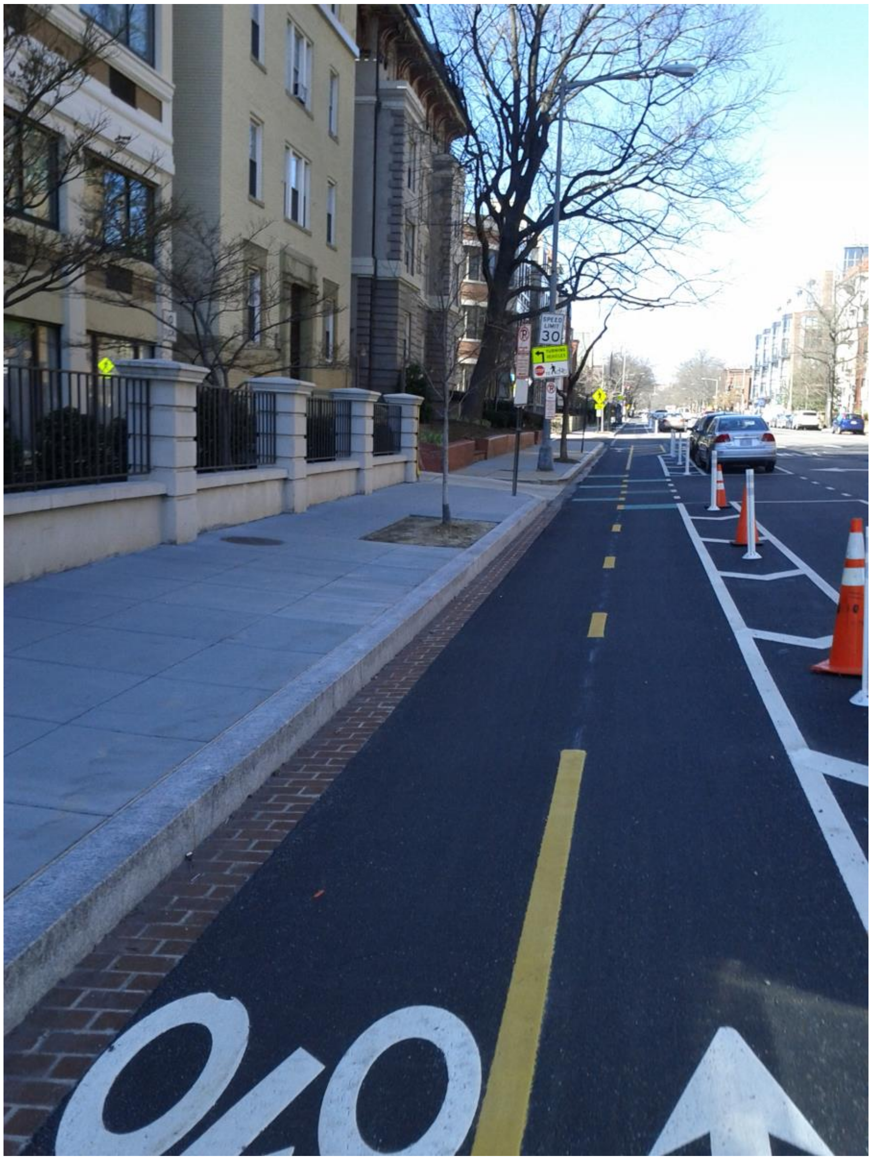

Figure C.1. 15th St. Bike Lane

Figure C.2. **Pennsylvania Ave. Bike Lane**

Figure C.3. L St. Bike Lane

Appendix D.

List of Washington D.C. Top Attractions

Attraction	**2013 Visitation Numbers**
National Museum of Natural History	8,000,000
National Air and Space Museum	7,000,000
Lincoln Memorial	5,400,000
National Museum of American History	4,900,000
World War II Memorial	4,000,000
Vietnam Veterans Memorial	3,800,000
Martin Luther King Jr. Memorial	3,738,336
Korean Memorial	2,900,000
FDR Memorial	2,300,000
National Zoo	2,000,000
Rock Creek Park	2,000,000
Thomas Jefferson Memorial	1,900,000
National Museum of the American Indian (Washington D.C.)	1,400,000
Smithsonian Institution Building	1,300,000
Donald W. Reynolds Center for American Art and Portrature	1,100,000
Hirshorn Museum and Sculpture Garden	645,000
US Capitol	-
White House	-
Washington Monument	-
Verizon Center	-

Note: Source (Smithsonian, 2013)

Variable	Start	End	Start Weekday	End Weekday	Start Weekend	End Weekend	Start Weekday AM	End Weekday AM	Start Weekday PM	End Weekday PM	Start Casual	End Casual	Start Sub-scriber	End Sub-scriber	Start Duration up to 10 min	End Duration up to 10 min	Start Duration 10 to 30 min	End Duration 10 to 30 min	Start Duration over 30 min	End Duration over 30 min
Age Under 5 years	-.323**	-.330**	-.376**	-.368**	-.200**	-.229**	-0.008	-.570**	-.511**	-.160*	-.506**	-.476**	-.174*	-.195**	-.199**	-.198**	-.335**	-.342**	-.500**	-.455**
Age 5 to 9 years	-.383**	-.395**	-.429**	-.431**	-.270**	-.302**	-0.039	-.595**	-.537**	-.240**	-.538**	-.520**	-.274**	-.305**	-.285**	-.299**	-.399**	-.401**	-.540**	-.511**
Age 10 to 14 years	-.484**	-.525**	-.506**	-.544**	-.420**	-.466**	-.174*	-.655**	-.601**	-.393**	-.648**	-.646**	-.338**	-.404**	-.330**	-.367**	-.492**	-.530**	-.634**	-.634**
Age 15 to 19 years	-.571**	-.574**	-.549**	-.558**	-.578**	-.582**	-.325**	-.452**	-.539**	-.532**	-.593**	-.589**	-.428**	-.465**	-.406**	-.424**	-.540**	-.554**	-.556**	-.562**
Age 20 to 24 years	0.059	0.072	0.121	0.124	-0.066	-0.025	0.04	.341**	.191*	-0.005	0.094	0.096	.184*	.168*	.182*	.185*	0.061	0.064	0.101	0.084
Age 25 to 29 years	.459**	.440**	.489**	.467**	.391**	.393**	.507**	.392**	.427**	.466**	.296**	.303**	.628**	.591**	.624**	.601**	.370**	.373**	.249**	.262**
Age 30 to 34 years	.443**	.421**	.452**	.434**	.433**	.416**	.558**	.282**	.348**	.500**	.255**	.266**	.636**	.594**	.639**	.609**	.348**	.352**	.214**	.227**
Age 35 to 39 years	.320**	.294**	.320**	.301**	.340**	.313**	.490**	0.132	.208**	.391**	.181*	.190*	.470**	.421**	.458**	.426**	.273**	.261**	0.138	.169*
Age 40 to 44 years	-.154*	-.148*	-.165*	-.154*	-0.113	-0.121	0.097	-.280**	-.242**	-0.046	-.301**	-.283**	-0.01	-0.03	0.001	-0.001	-.205**	-.203**	-.325**	-.298**
Age 45 to 49 years	-.155*	-.170*	-.163*	-.179*	-0.107	-0.134	0.104	-.327**	-.269**	-0.06	-.282**	-.272**	-0.033	-0.072	-0.053	-0.073	-.230**	-.237**	-.310**	-.295**
Age 50 to 54 years	-.379**	-.367**	-.343**	-.340**	-.426**	-.408**	-.225**	-.288**	-.338**	-.344**	-.416**	-.410**	-.246**	-.264**	-.237**	-.233**	-.397**	-.395**	-.409**	-.413**
Age 55 to 59 years	-.422**	-.405**	-.447**	-.427**	-.338**	-.347**	-.153*	-.515**	-.520**	-.293**	-.506**	-.487**	-.307**	-.314**	-.312**	-.306**	-.448**	-.437**	-.526**	-.494**
Age 60 to 64 years	-.313**	-.304**	-.321**	-.312**	-.259**	-.257**	-0.119	-.312**	-.354**	-.242**	-.316**	-.305**	-.221**	-.239**	-.222**	-.214**	-.307**	-.313**	-.311**	-.288**
Age 65 to 69 years	-.192*	-.195**	-.217**	-.218**	-0.129	-0.133	-0.133	-.223**	-.231**	-.152*	-.190*	-.181*	-0.123	-0.141	-.168*	-.155*	-.180*	-.198**	-.185*	-.166*
Age 70 to 74 years	-.418**	-.409**	-.424**	-.414**	-.388**	-.376**	-.292**	-.355**	-.408**	-.395**	-.372**	-.366**	-.361**	-.369**	-.376**	-.353**	-.404**	-.418**	-.346**	-.339**
Age 75 to 79 years	-.370**	-.361**	-.381**	-.366**	-.333**	-.340**	-.162*	-.371**	-.426**	-.295**	-.416**	-.409**	-.263**	-.272**	-.283**	-.274**	-.384**	-.375**	-.411**	-.408**
Age 80 to 84 years	-.393**	-.384**	-.397**	-.384**	-.356**	-.357**	-.267**	-.367**	-.406**	-.339**	-.360**	-.353**	-.334**	-.342**	-.365**	-.351**	-.323**	-.343**	-.328**	-.312**
Age 85 years and over	-.253**	-.240**	-.253**	-.239**	-.208**	-.205**	-0.133	-.218**	-.258**	-.205**	-.202**	-.196**	-.197**	-.207**	-.211**	-.199**	-.207**	-.220**	-.178*	-.164*
Household Income Less than $10000	-.300**	-.305**	-.241**	-.247**	-.410**	-.398**	-.176*	-0.117	-.223**	-.328**	-.337**	-.347**	-.164*	-.189*	-.155*	-.171*	-.296**	-.296**	-.331**	-.354**
Household Income $10000 to 14999	-.327**	-.319**	-.306**	-.294**	-.357**	-.355**	-0.139	-.290**	-.339**	-.266**	-.430**	-.412**	-.188*	-.198**	-.185*	-.192*	-.345**	-.330**	-.433**	-.422**
Household Income $15000 to 24999	-.421**	-.437**	-.406**	-.418**	-.427**	-.446**	-0.089	-.477**	-.487**	-.339**	-.559**	-.547**	-.269**	-.310**	-.253**	-.273**	-.451**	-.462**	-.558**	-.555**
Household Income $25000 to 34999	-.200**	-.208**	-.179*	-.194**	-.214**	-.211**	0.001	-.254**	-.242**	-.157*	-.296**	-.276**	-0.075	-0.111	-0.089	-0.105	-.203**	-.210**	-.325**	-.301**
Household Income $35000 to 49999	-.228**	-.253**	-.183*	-.212**	-.293**	-.312**	-0.029	-.205**	-.232**	-.223**	-.330**	-.336**	-0.065	-0.121	-0.056	-0.094	-.270**	-.279**	-.336**	-.358**
Household Income $50000 to 74999	-.226**	-.252**	-.218**	-.241**	-.218**	-.248**	-0.024	-.296**	-.261**	-.194**	-.307**	-.307**	-0.133	-.177*	-0.147	-.176*	-.231**	-.260**	-.298**	-.294**
Household Income $75000 to 99999	0.13	0.113	.156*	0.142	0.088	0.086	.265**	0.104	0.099	.166*	0.019	0.029	.262**	.228**	.268**	.240**	0.066	0.077	0.009	0.027
Household Income $100000 to 149999	.222**	.216**	.206**	.204**	.272**	.261**	.419**	0.043	0.096	.339**	0.065	0.082	.396**	.375**	.375**	.371**	.156*	.159*	0.045	0.072
Household Income $150000 to 199999	.241**	.254**	.246**	.254**	.249**	.262**	.298**	.235**	.212**	.306**	.177*	.189*	.391**	.383**	.375**	.387**	.187*	.197**	.155*	.179*
Household Income $200000 or more	.272**	.270**	.274**	.266**	.271**	.280**	.284**	.251**	.256**	.280**	.238**	.239**	.374**	.349**	.376**	.373**	.202**	.205**	.226**	.225**

Note: Source (Capital Bikeshare. 2013) Green highlighting indicates positive statistical significance. Red highlighting indicates negative statistical significance, No color indicates no significance. ** Indicates correlation is significant at the 0.01 level. * Indicates correlation is significant at the 0.05 level.

Appendix F.

Multivariable Linear Regression Model Variable Definitions

Variable	Description
Average Start trips	Average number of trips per days in operation (square root)
Average End trips	Average number of trips per days in operation (square root)
Average Weekday Start trips	Average number of trips per weekdays in operation (square root)
Average Weekday End trips	Average number of trips per weekdays in operation (square root)
Average Weekend Start trips	Average number of trips per weekends in operation (square root)
Average Weekend End trips	Average number of trips per weekends in operation (square root)
Average Start Subscribers trips	Average number of trips per days in operation (square root)
Average End Subscribers trips	Average number of trips per days in operation (square root)
Average Start Casual Members trips	Average number of trips per days in operation (square root)
Average End Casual Members trips	Average number of trips per days in operation (square root)
Average Weekday AM Peak Start trips	Average number of trips per weekdays in operation (square root)
Average Weekday PM Peak Start trips	Average number of trips per weekdays in operation (square root)
Average Weekday AM Peak End trips	Average number of trips per weekdays in operation (square root)
Average Weekday PM Peak End trips	Average number of trips per weekdays in operation (square root)
Average Start Duration Under 10 minutes trips	Average number of trips per days in operation (square root)
Average End Duration Under 10 minutes trips	Average number of trips per days in operation (square root)
Average Start Duration 10 to 30 minutes trips	Average number of trips per days in operation (square root)
Average End Duration 10 to 30 minutes trips	Average number of trips per days in operation (square root)
Average Start Duration Over 30 minutes trips	Average number of trips per days in operation (square root)
Average End Duration Over 30 minutes trips	Average number of trips per days in operation (square root)
Average Weekday AM Peak Start trips Under 10 minutes trips	Average number of trips per weekdays in operation (square root)
Average Weekday PM Peak Start trips Under 10 minutes trips	Average number of trips per weekdays in operation (square root)
Average Weekday AM Peak End trips Under 10 minutes trips	Average number of trips per weekdays in operation (square root)
Average Weekday PM Peak End trips Under 10 minutes trips	Average number of trips per weekdays in operation (square root)

Variable	Description
Metrobus Frequent Transit	Number of bus stops within 400m
Metrorail Station	Dummy = 1 if Metrorail station within 400m
Metorbus Not Frequent Transit	Number of bus stops within 400m
Separated Bike Lanes Under 1000m	Dummy = 1 if 1-1000m of separated cycling lanes within 400m
Separated Bike Lanes Over 1000m	Dummy = 1 if over 1000m of separated cycling lanes within 400m
Non-Separated Bike lanes	Length of separated bike lanes within 400m radius
Small Scale Commercial Land Use (<7% Area)	Dummy = 1 if less than 7% of 400m radius area
Low Density Residential Land Use	Dummy = 1 if more than 0% of 400m radius area
Medium Density Residential Land Use	Percentage of 400m radius area
High Density Residential Land Use	Percentage of 400m radius area
Institutional Land Use	Dummy = 1 if more than 0.005% of 400m radius area
Industrial Land Use	Dummy = 1 if more than 0% of 400m radius area
Parks and Recreation Land Use	Dummy = 1 if more than 0.05% of 400m radius area
Public Land Use	Dummy = 1 if more than 0.05% of 400m radius area
Top Attractions	Dummy = 1 if attraction within 400m
Intersection Density	Number of intersections within a 400m radius
Change in Elevation	Maximum change in elevation within 400m radius
Factor 1: High Income - Educated, Caucasians	Bachelor degrees (Percentage from associated census tract)
	Caucasians (Percentage from associated census tract)
	Household income over $100,000 (Percentage from associated census tract)
Factor 2: High Population Density Areas with Male Students and Car-Free Households	Population density (log)
	Male (Percentage from associated census tract)
	Students (Percentage from associated census tract)
	Car Free Households (Percentage from associated census tract)
Factor 3: Low Population Density Areas with Families	Population density (log)
	Age under 14 (Percentage from associated census tract)
	Age over 40 (Percentage from associated census tract)
Males	Pecentage from associated census tract
Students	Pecentage from associated census tract
Minorities	Pecentage from associated census tract
Car-Free Households	Pecentage from associated census tract

Appendix G.

Principal Component Analysis Results with National Mall Stations Included

Communalities

	Initial	Extraction
tractpercentage0to14	1.000	.815
tractpercent_age40plus	1.000	.803
log_populationdensity	1.000	.889
householdincomeabove100000	1.000	.896
Total_Percent_Bachelorsdegreeorhigher	1.000	.920
malepercentageoftract	1.000	.529
percentnewstudent	1.000	.676
percentnewcaucasian	1.000	.894
percentnewminority	1.000	.620
percentnewnocarhouseholds	1.000	.671

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.962	39.615	39.615	3.962	39.615	39.615	3.408	34.077	34.077
2	2.073	20.727	60.342	2.073	20.727	60.342	2.346	23.465	57.542
3	1.677	16.770	77.113	1.677	16.770	77.113	1.957	19.570	77.113
4	.707	7.075	84.187						
5	.509	5.090	89.277						
6	.449	4.495	93.772						
7	.324	3.237	97.009						
8	.151	1.510	98.519						
9	.099	.987	99.506						
10	.049	.494	100.000						

Component Matrix[a]

	Component		
	1	2	3
tractpercentage0to14	-.123	.837	.316
tractpercent_age40plus	.279	.615	.588
log_populationdensity	.784	.522	-.044
householdincomeabove100000	.744	-.133	.569
Total_Percent_Bachelorsdegreeorhigher	.900	-.295	.151
malepercentageoftract	.612	.306	-.246
percentnewstudent	.211	.536	-.586
percentnewcaucasian	.847	-.388	.159
percentnewminority	.695	-.244	-.277
percentnewnocarhouseholds	.518	.162	-.613

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Rotated Component Matrix[a]

	Component		
	1	2	3
tractpercentage0to14	-.314	.101	.840
tractpercent_age40plus	.210	.003	.871
log_populationdensity	.457	.672	.478
householdincomeabove100000	.887	-.099	.316
Total_Percent_Bachelorsdegreeorhigher	.935	.207	-.044
malepercentageoftract	.321	.631	.166
percentnewstudent	-.229	.783	.103
percentnewcaucasian	.929	.130	-.120
percentnewminority	.591	.438	-.281
percentnewnocarhouseholds	.167	.782	-.176

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

Appendix H.

Principal Component Analysis Results with National Mall Bikeshare Stations Excluded

Communalities

	Initial	Extraction
tractpercentage0to14	1.000	.568
tractpercent_age40plus	1.000	.822
log_populationdensity	1.000	.462
householdincomeabove100000	1.000	.837
Total_Percent_Bachelorsdegreeorhigher	1.000	.941
percentnewcaucasian	1.000	.909

Extraction Method: Principal Component Analysis.

Total Variance Explained

	Initial Eigenvalues			Loadings			Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.044	50.738	50.738	3.044	50.738	50.738	2.876	47.931	47.931
2	1.496	24.929	75.667	1.496	24.929	75.667	1.664	27.736	75.667
3	.871	14.511	90.178						
4	.368	6.130	96.308						
5	.149	2.484	98.792						
6	.072	1.208	100.000						

Component Matrix[a]

	Component	
	1	2
tractpercentage0to14	-.721	.222
tractpercent_age40plus	-.444	.791
log_populationdensity	.219	-.644
householdincomeabove100000	.681	.611
Total_Percent_Bachelorsdegreeorhigher	.956	.164
percentnewcaucasian	.950	.084

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Rotated Component Matrix[a]

	Component	
	1	2
tractpercentage0to14	-.607	.447
tractpercent_age40plus	-.159	.893
log_populationdensity	-.005	-.680
householdincomeabove100000	.845	.352
Total_Percent_Bachelorsdegreeorhigher	.957	-.161
percentnewcaucasian	.924	-.234

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Appendix I.

Site Visit Observation Check List

Station ID:	
Date:	
Time:	
General observations on street life (volume, demographics):	
Bike Lane (painted, separated, on-road, off-road):	
Transit (bus stop, metrorail station):	
Change in Elevation:	
Attractions nearby:	
Retail (Scale and Type):	
Office (Scale and Type):	
Residential (Scale and Type):	
Parks (Scale and Type):	
Other Land Uses (Scale and Type):	