ANALYSIS OF RIDERSHIP TRENDS AND SUCCESS FACTORS FOR
BIKESHARING SYSTEMS IN THE UNITED STATES

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Department of Civil Engineering
Abstract

of

ANALYSIS OF RIDERSHIP TRENDS AND SUCCESS FACTORS FOR BIKESHARING SYSTEMS IN THE UNITED STATES

by

Ava Yaghoobirad

The purpose of this study was to analyze the bikesharing trends in the U.S. and identify the main ridership determinants that were relevant for their success and performance in large and small cities. The study examined the effect of demographic, socio-economic, transportation network, built environment, and climate factors on ridership by conducting a regression analysis at the station level in the cities of Boston and Chattanooga. Furthermore, the study analyzed the overall system efficiency and popularity index of nine bikesharing systems at the city level. The system characteristic data were collected through an electronic survey and email communication with 21 current programs in the U.S. and the most current data from the International Bikeshare Database and also the programs annual or quarterly reports. Variables related to population demographics, socioeconomic, and transportation network were collected from 2010-2014 American Community Survey 5-year estimates at the census block level. The data were aggregated around a 500-meter buffer encircling each bikeshare station using GIS software.

The result showed the number of alternative commuters, number of colleges or universities, length of existing bikeways, number of residents with graduate degree or higher and the household income could positively affect the ridership, and adversely the non-white population had a slightly negative impact on ridership. Moreover, the study found the integration of public
transit with bikeshare is an essential factor for success in larger cities with a more developed transit network. In small cities with less dense downtowns and fewer public transit options, visitor and tourist bicyclists could contribute to improve the system overall ridership. Furthermore, the bicycle infrastructure seems to be a key determinant of ridership in all sizes and types of jurisdictions.

_______________________, Committee Chair
Professor Ghazan Khan, Ph.D.
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Date
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CHAPTER I

BACKGROUND AND INTRODUCTION

There is a strong interest around the globe to promote sustainable transportation modes because of worldwide concerns over climate change, air pollution, energy conservation, and traffic congestion issues. In the past decade, policy makers and government officials have made tremendous attempts to promote innovative modes of transportation to shift vehicle-dependent culture towards more sustainable, non-motorized oriented lifestyle. Bikesharing can serve an essential role to help address these concerns.

1.1 What is Bikesharing?

Bikesharing is a program that allows people to share public bicycles that are provided in a network of stations throughout a city for commute or recreational purposes (I). Citizens or visitors can access the bicycles by either becoming a subscribed member or pay at the kiosk by credit card for a daily or hourly use. For most programs the first 30 minutes is free of charge to promote bikesharing for shorter trips. The U.S. Bureau of Transportation Statistics, Intermodal Passenger Connectivity Database reports as of April 2016, more than 60 cities in the U.S. operated bikesharing systems with a total of 2,655 stations. The recent wave of attention to this innovative transportation mode is in part due to the variety of environmental concerns and other issues that mentioned before, however these concerns are not new. The technology that reduces the risk of theft and vandalism which can help improve communication and the tracking of the bicycles made bikesharing a reliable solution for those concerns. Although the original concept is five decades old, bikesharing has rapidly developed recently in many cities around the world in Europe, Asia, Australia and the United States.
1.2 Benefits and Goals

Public bikesharing can be expanded and integrated into a sustainable transportation system for commuting, recreation, daily short trips and improved health. It can increase personal mobility, reduce congestion, and can improving the air quality, increasing livability and the economic conditions. For short trips or as connections to longer transit trips, bikesharing provides citizens and tourists with a flexible mode of transportation without responsibility of bicycle ownership and maintenance (2). Also for those commuters who live in less-advantaged communities with lower income, financial saving is a motivator factor to use public bicycles. A survey conducted in 2013 of 11,100 members of the Capital Bikeshare system in Washington D.C. showed that for more than 70% of the respondents saving on transportation cost was an important reason to bikeshare (3). The Pennsylvania Economic Council provided the list of bikesharing goals in their business plan recommended for the city of Philadelphia (4). The objectives are summarized below which seem to be applicable to almost any municipality or city in the United States:

**Personal Mobility**: Bikesharing can provide better access to destinations and enhance connectivity. By integrating bikesharing as an extension of public transit, the issue of first and last gap between public transit and origin /final destination may be resolved.

**Cost Effectiveness**: Compared to other modes of transportation, bikesharing can be considered an economical commuting option, especially in larger cities. Bikesharing could improve accessibility for low income and undeserved communities to job and recreation destinations.

**Livability & Economic Competitiveness**: Bikesharing has the potential to raise the city’s attractiveness for business investment and tourism.
**Health and Environment:** Bikesharing can promote an active and healthy lifestyle by diverting a greater share of trips to safe cycling, and it also helps the city to reach its environmental goals, such as reducing carbon footprint as an attempt to be a “green” city.

**Finances and Transparency:** The ideal is to create a financially sustainable system to cover the installation, infrastructure, and operating expenses instead of relying on the federal, state or private funding sources. Bikesharing systems should ensure sustainable capital funding for system growth and maintenance.

**1.3 Bikesharing in the United States**

The United States is not considered to be a bicycle-friendly country. According to the 2015 American Community Survey published by the U.S. Census Bureau, the total estimation of bicycle commuters in the country is 0.6% (5). The result is consistent with another survey conducted by Breakaway Research Group for People for Bicycles (online survey of 16,000 American adults) in which 29% of respondents reported riding their bicycle at least once in the last year but only 14% reported riding at least twice a week (6). In the past decade, there has been a renewed global interest in promoting cycling as a sustainable mode of transportation. In the U.S., partially because of the concerns for saving energy and reducing greenhouse gases, bikesharing has emerged as a cost-effective and sustainable transportation option for many policy makers and municipalities. According to the U.S. Bureau of Transportation Statistics, there are currently 65 cities operating public bikesharing programs in the country (Figure 1).
Most of the 65 cities shown in Figure 1 have bikesharing programs that are relatively new, therefore not enough information has been analyzed to understand which systems are deemed to be successful and why. Success can be recognized from different perspectives; for example in some jurisdictions program’s revenue might be an essential determinant. In other municipalities the durability of the system and maintaining the service over the long term can be considered to be a success. To understand the bikesharing trends in the U.S. and components pertaining to success is important to explore the ridership patterns in variety of cities with different characteristics and capacities. Reviewing the previous methodologies that have been developed to model bikesharing ridership helps to identify a knowledge gap that requires further investigation.
CHAPTER II

LITERATURE REVIEW

Bikesharing has come a long way since its inception in 1960s. Shaheen categorized the bikesharing systems into four main generations (2): The first generation was the initial community bicycle program started in Amsterdam, Netherland in the summer of 1965, by a social innovator, Laurens Schimmelpennink. The system operated as non-profit with 50 bicycles with an environmental emphasis. The white painted bicycles were used by public free of charge to get to their destination throughout the city and were left unlocked for the next user. The program was quickly discontinued due to theft and vandalism (2). The second generation was the idea of coin-deposit system that developed after the collapse of the early free programs. The second generation of bikesharing started in Copenhagen, Denmark in 1995 and launched with 1000 bicycles and 110 specific stands where the bicycles could be unlocked with a small amount of coin deposit. Despite significant improvements, because the users were anonymous vandalism and theft remained an issue (2). The third generation, or IT-based system, was the first information technology (IT) based bikesharing system launched in Rennes, France, in 1998. The system was operated with 200 bicycles at over 25 stations and was the first system deployed for the public in a metropolitan area using a RFID (radio frequency identification) card to access the bicycles. The program was equipped by electronic locking racks, communication systems and smart cards. The new generation was not as cheap as the second generation but it could mostly eliminate the theft and vandalism issues as the system was able to keep track of the bicycles and had access to user’s identification (2). The fourth generation, or the demand responsive system, may be the future generation of bikesharing and was proposed by the Institute of Transportation Studies at UC Davis in March 2010 (7). There are high technical features such as demand-
responsive redistribution system, mobile bicycle stations or “dockless” bicycles and real time transit integration in the new generation to ameliorate some of the weaknesses of the IT generation (2).

Bikesharing systems have started to become an effective transportation mode to serve short trips in urban areas. In recent years, a number of papers have studied the concept and developed a theoretical foundation for evaluating the feasibility of bikesharing systems, identifying an appropriate service area, and predicting the station level and system wide ridership. A summary of studies pertaining to the effect of bikesharing on public and city transportation portfolio is presented here. Many studies have focused on forecasting ridership in hypothetical service areas. There are a few studies based on spatial analyses using a Geographic Information System (GIS) for identifying stations location and exploring each individually.

Shaheen also performed interviews with 19 bikesharing programs in U.S. and Canada and conducted a user survey of four programs in Washington D.C., Minnesota, Montreal, and Toronto (2). The survey found that trip purpose for most bikesharing users was commuting to work or school, and the trip durations were usually less than 30 minutes long. According to the survey, it was more desirable to use the system for shorter commutes which could be an important factor in motivating bikesharing. Fishman also conducted online surveys with bikeshare members and non-members and found that for most bikeshare users, convenience was an essential factor in choosing this innovative mode of transportation (8). This finding was also consistent with the result of a survey conducted by LDA Consulting showing that 69% of Capital Bikeshare members stated that getting around easier, faster, and shorter was an important motivator for their bikeshare use (3).
In order to identify the most suitable areas for bikesharing systems, several studies focused on forecasting ridership in hypothetical service areas using a weighted sum raster analysis. They examined the demographic and geographical factors and combined the input variables into suitability score. Because of lack of ridership data, these variables have been selected based on theory and intuition rather than an experiential analysis of their association with ridership. The suitability score determined the location of future stations in the hypothetical service area.

Krykewycz used a raster-based GIS analysis method to indicate a best potential area for a bikesharing system in Philadelphia and estimated number of system daily trips by utilizing trip diversion rates previously perceived in European cities (9). Olson took a similar approach in the city of Providence, Rhode Island (10). Olson however examined additional variables such as population density of 20-49 years old, proximity to colleges, historic places and libraries. In addition Olson discussed the effect of other possible factors on the success or failure of the system but did not analyze these relationships empirically. These factors included linkages to transit, months of operation, type of the operator and relationship to advertisers and sponsors, infrastructure and equipment required, and the maintenance plan.

As trip data became available for some large cities in the United States, researchers started to conduct regression analysis using the existing bikesharing ridership data. These studies have examined the relationship between ridership and the socio-demographic, transportation infrastructure and built environmental factors at spatial scale by exploring each bikesharing station individually. Buck and Buehler conducted a regression analysis of Capital Bikeshare in Washington D.C. using real time data collected during the months of September to March of the first season of operation (11). The study found that variables such as total population, number of existing bikeways and the number of retail stores with a liquor license had positive effect on Capital Bikeshare ridership. The study also indicated that the proportion of households with low
vehicle availability had a negative impact on ridership, a result that was somewhat counterintuitive. Buck and Buehler also found that the frequency of ridership among the members was not as high as expected (12). The study found that in Washington, D.C., 21% of female Capital Bikeshare members had not used bikeshare in past few months, compared to 13% for men. This study was the only example in the literature comparing demographic profiles of bikeshare users and regular cyclists in Washington D.C., and found bikeshare members were more likely be female, had lower median income, were younger, and had fewer vehicles and bicycles than the regular bicycle riders. The result showed that only 3% of bikeshare members were non-white, while about 50% of the population in the D.C. area is non-white.

Daddio also examined the effect of demographic and transportation network variables on ridership using station-level data from Washington D.C. during the month of October 2012 (13). In addition to the variables identified by Buck and Buehler, this study found that the distance of each station to the central bikesharing network was also significant factor affecting ridership. The study suggested that the following demographic variables were important in forecasting station demand: total population, race, number of retail locations, and geographic features such as distance to metro/rail station.

Maurer used August 2010 rental data from the Nice Ride Bikeshare in Minneapolis to conduct a pair-wise suitability analysis (14). The study categorized 16 independent variables into three groups: trip generation factors, trip attraction factors, and transportation network factors. The study found the following variables were highly influence the ridership: job density, non-auto commuter levels, density of high income jobs, median income, minority population and proximity to rail stations and parks. The findings from Nice Ride program were applied to create a suitable area for bikesharing in the city of Sacramento, CA and predicted the ridership level for the hypothetical stations. Because of different dynamic infrastructure and commute patterns between
the two cities, there were variables that did not positively affect the ridership in Sacramento as expected from the result in Minneapolis. Despite the high ridership in downtown Minneapolis, the study predicted relatively low estimate of ridership in downtown Sacramento and also found the total jobs factor had significantly negative relationship with ridership which might have been offset by the high income jobs and retail jobs factors in the model. Furthermore, the number of existing bikeways and the total population had negative but not significant impact on ridership. The result seemed to be in conflict with theory and common sense which might cause by the multicollinary issue because of the high correlation between the independent variables also a low number of observations (n=65) compared to the number of independent variables.

Rixey also investigated the effects of socio-demographic and built environment factors on ridership at station level in three large U.S. systems: Capital bikeshare in Washington D.C., Nice Ride in Minneapolis and Denver B-cycle in Denver (15). Rixey expanded the previous variables by exploring bikesharing network characteristics and found that the effects of bikesharing station network were significantly important on ridership level. The study suggested relocating of abandoned and isolated stations to the closer distance to central stations would extremely increase the efficiency of the system and increase the ridership.

The Sacramento Metropolitan Air Quality Management District performed the case study in four programs within the U.S. including Capital bikeshare (Washington DC), Denver B-cycle, Nice Ride (Minnesota) and Boulder B-cycle by exploring the systems operation structure, management and funding sources (16). The study conducted a regression analysis in station level to explore the variables affect the ridership and similar to study by Maurer, the significant variables with positive effects on ridership have were combined into a suitability score to apply for hypothetical service area in Sacramento (14). The study found the total population, retail jobs, alternative commuters, median income, and the number of stations within 3,200 meters had a positive
relationship with ridership while the percentage of non-white population had a negative impact on ridership. The study also emphasized on considering the equity issue before planning a bikeshare system in Sacramento, and noted serving the communities with lower household income or large percentage of non-white population should be considered to support social and environmental equity.
CHAPTER II

RESEARCH OBJECTIVES AND METHODOLOGY

The purpose of this study was to review the bikesharing trends in the U.S. and identify the main determinants of bikesharing systems that were relevant for their success and performance. The study examined the effect of demographic, socio-economic, transportation network, built environment and climate factors on ridership. The study was built upon the methodology developed by Buck and Buehler, Maurer and Rixey (11, 14, 15) and then applied it to other areas and conditions. The novelties include:

• Examining the determinants of ridership in small as well as large cities.

• Exploring the data from a time series perspective to include the examination of variables with temporal components, such as time of a year, temperature and precipitation.

• Defining two major factors of success and applying them to measure the success in nine U.S. programs.

The study accomplished these objectives through various tasks described in Figure 2.

![Figure 2- Flowchart of Describing Project Methodology](image-url)
As mentioned earlier, success in bikesharing can be observed from different perspectives. High ridership, longer life time of a program, expansion, revenue, or health and environmental impacts can be important key performance indicators. Among all these factors, ridership seems to be one of the most reliable and measurable indicators of success. This study examined the determinants of bikeshare ridership trends in the United States, particularly related to demographic, socio-economic, built environment, weather, and transportation network factors.

At the station level, regression analysis was conducted of two bikesharing systems in Boston (MA) and Chattanooga (TN). These two programs provided a unique comparison between ridership trends and potential success factors for bikeshare system in a large city versus a small town. To explore the differences and similarities, three regression models were conducted. First, each city was analyzed individually; Hubway in Boston and Chattanooga Bikeshare were examined separately using each system’s total ridership in three months of 2015 (July, August and September) as a dependent variable. The reason for choosing this time period was because all the stations were fully operational at this time of a year in both cities with no closure due to the cold weather or maintenance. Since the frequency distribution of the data was not normal, the dependent variable was converted to the natural log of the number of trips during the analysis period by station.

Another regression analysis was conducted for combined dataset of two programs with additional dummy variables to flag Boston and Chattanooga. The dependent variable employed in the combined model was the same as previous regressions with more observations (n=168). The selection of theoretically important variables that were examined in previous studies was collected from the Census Bureau and various local jurisdiction data portals in geodatabase format (shapefile).
Bikeshare systems in Boston and Chattanooga were also examined from a time series perspective to observe the ridership pattern seasonally with consideration of temporal variables such as temperature and precipitation as well as different type of riders (subscribed members vs. casual riders). Temperature and precipitation were assumed to be constant for all the locations of bikeshare stations throughout the city.

According to the recent guidelines published by the Institute of Transportation and Development Policy, a combination of two metrics of ridership and system efficiency were recommended to measure the success for bikesharing programs (17). In this study, a consistent dataset of ridership from two recent consecutive years (Jan 2014 through December 2015) was collected from nine operating bikeshare systems in the U.S. Two major success factors were examined, including the average monthly trip per resident as an index for measuring the ridership (market penetration) and the average monthly checkouts per bicycle as an indicator of the system apparatus efficiency. Furthermore the effects of variables such as station density and public transit integration were explored thoroughly for all the nine systems. It should be noted that economic sustainability is a major factor of success of any transportation project as well as of bikesharing. In the U.S. bikesharing systems generally utilize federal or public grants to cover the initial expenses (such as equipment, infrastructure and installation). The usage costs are often covered by membership fees as well as the private sponsorships. However due to the restriction of data, cost as one the essential elements for reaching financial sustainability in the system was not analyzed in this study.
CHAPTER IV

THE DATA

The first IT generation of bikesharing systems in the U.S. launched in Denver, CO followed by Minneapolis and Capital Bikeshare in Washington D.C. in 2010. Bikesharing is still considered to be a new concept in the U.S., and there is insufficient data available in a uniform and consistent format. Table 1 summarizes the profile of some of current bikesharing programs in the U.S. with their basic characteristics, such as number of bicycles and stations, launch date, and the systems service area (1). Citi Bicycle in New York (6,000 bicycles), Divvy in Chicago (4,760 bicycles) and Capital Bikeshare in Washington D.C. (3,200 bicycles) are three of the largest bikesharing systems in the country.

Table 1- Basic Components of Various Bikesharing Programs in the U.S.

<table>
<thead>
<tr>
<th>City, State</th>
<th>Program Name</th>
<th>Launch date</th>
<th>Bikes/Stations</th>
<th>Service area (sq. mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston, MA</td>
<td>Hubway</td>
<td>Jul-11</td>
<td>1168/83</td>
<td>11.79</td>
</tr>
<tr>
<td>Boulder, CO</td>
<td>Boulder B-cycle</td>
<td>May-11</td>
<td>300/38</td>
<td>8</td>
</tr>
<tr>
<td>Broward County, FL</td>
<td>Broward county</td>
<td>Dec-11</td>
<td>250/25</td>
<td>25</td>
</tr>
<tr>
<td>Charlotte, NC</td>
<td>Charlotte B-cycle</td>
<td>Jul-12</td>
<td>200/25</td>
<td>28.26</td>
</tr>
<tr>
<td>Chattanooga, TN</td>
<td>Chattanooga Bicycle</td>
<td>Jul-12</td>
<td>300/34</td>
<td>2.5</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>Chicago</td>
<td>Jun-13</td>
<td>4760/476</td>
<td>87</td>
</tr>
<tr>
<td>Denver, CO</td>
<td>Denver B-cycle</td>
<td>Apr-10</td>
<td>700/87</td>
<td>12.57</td>
</tr>
<tr>
<td>Houston, TX</td>
<td>Houston B-cycle</td>
<td>May-12</td>
<td>234/31</td>
<td>2.7</td>
</tr>
<tr>
<td>Kansas city, MO</td>
<td>Kansas City</td>
<td>Jul-12</td>
<td>92/27</td>
<td>15</td>
</tr>
<tr>
<td>Madison city, WI</td>
<td>Madison</td>
<td>May-11</td>
<td>350/39</td>
<td>4</td>
</tr>
<tr>
<td>Miami beach, FL</td>
<td>Miami CitiBike</td>
<td>Mar-11</td>
<td>1640/170</td>
<td>6.3</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>Nice Ride</td>
<td>Jun-10</td>
<td>1700/190</td>
<td>45</td>
</tr>
<tr>
<td>New York, NY</td>
<td>Citi Bicycles</td>
<td>Jul-13</td>
<td>6000/493</td>
<td>81</td>
</tr>
<tr>
<td>Oklahoma city, OK</td>
<td>Oklahoma Spokies</td>
<td>May-12</td>
<td>50/8</td>
<td>1</td>
</tr>
<tr>
<td>San Antonio, TX</td>
<td>San Antonio B-cycle</td>
<td>Mar-11</td>
<td>516/55</td>
<td>4.77</td>
</tr>
<tr>
<td>San Francisco, CA</td>
<td>Bay Area Bikeshare</td>
<td>Aug-13</td>
<td>350/35</td>
<td>6.36</td>
</tr>
<tr>
<td>Spartanburg, SC</td>
<td>Spartanburg B-cycle</td>
<td>Jul-11</td>
<td>39/3</td>
<td>3.5</td>
</tr>
<tr>
<td>Washington DC, DC</td>
<td>Capital Bikeshare</td>
<td>Sep-10</td>
<td>3200/350</td>
<td>35.95</td>
</tr>
</tbody>
</table>
Figure 3 illustrates the scale of various bikesharing programs in the United States according to their city population. Figure 3 shows that the city of Chicago with a total population of 2,720,546 (close to the population of Houston, TX) has the second largest bikeshare system in the country; however, it has almost twenty times more bicycles than Houston B-Cycle. Furthermore, Nice Ride in Minneapolis or Miami CitiBike in Miami Beach show relatively high investment in bikeshare system compared to their populations.

Based on the characteristics and availability of detailed data, regression analysis was used to study the Hubway system in Boston (MA) and Bike Chattanooga in the city of Chattanooga (TN). In addition, nine programs were evaluated at the city level to observe the ridership trends and
examine the success factors. These programs were: Nice Ride in Minneapolis-St. Paul, Divvy in Chicago, Madison B-Cycle in Madison city, Hubway in Boston, Citi Bicycle in New York, Boulder B-Cycle in Boulder, Bike Chattanooga in Chattanooga, Capital Bikeshare in Washington D.C., and Bay Area Bikeshare in San Francisco.

The following section provides a brief description of all the variables that were considered in the regression analysis. The set of explanatory variables were based on the previous empirical studies. The variables that potentially can affect the bikesharing program were grouped into three categories as follows.

1. Bikesharing system characteristics
2. Demographic and socioeconomic characteristics of the city
3. Transportation and built environment

4.1 Bikesharing system characteristics

Basic information such as the number of bicycles, the number of stations, and the size of the service area provides a primary understanding of the program. In this study, the data on bikesharing system characteristics were collected through a survey and email communication with 21 current urban programs (IT generation systems). The survey was sent electronically in October 2013 and follow up questions to insure accuracy of the received data were sent in early November 2013. The survey results were updated using the most recent data from the International Bikeshare Database and also the annual or quarterly reports downloaded from open data portals of the bikesharing programs.

**Service area**: The size of the service area depends on the size of the jurisdiction. Existing bikeshare programs in the U.S. that were part of this analysis ranged from service area coverage
of 2.5 square miles in Chattanooga (TN) to 36 square miles in Washington D.C. area. Several studies argued that to create a successful system with the optimum ridership, it is important to consider the coverage in regions with higher population and employment density (11, 13, 15). The coverage area clearly must have the appropriate size and it needs to be large enough to contain a considerable number of origins and destinations.

**Number of bicycles**: In this study, the total active bicycles in the system were considered as the number of system’s bicycles, excluding the number of bicycles in maintenance or storage. Number of bicycles gives an instant snapshot of the size of the program.

**Number of stations**: Stations contain a designated kiosk for people to choose the bicycle and obtain their pass and also a docking system for picking up or locking the bicycle with a key or a card.

**Station density**: Daddio and Rixey have highlighted the importance of station density in ridership patterns (14, 16). Denser network of stations in the coverage area makes the program more visible and also makes it more accessible to users. When the stations are closer to each other, it is easier to transfer bicycles from one station to another and potentially reduce rebalancing issues and costs.

**Duration of service**: Age of the program is an indication that the system has survived and is working fine. The probability of finding success elements in older programs seems to be higher. In this study, programs that were launched after August 2013 were not considered in this analysis.
4.2 Demographic and socioeconomic characteristics

Variables related to population demographics and socioeconomic factors were collected from 2010-2014 American Community Survey 5-year estimates at the census block level. The aggregated data were stored in the attribute table and transformed into several geographic layers. Furthermore, a 500 meter radius buffer around each bikeshare station was created to analyze the data. It should be noted that one buffer could include several census blocks that might intercept with other buffers. In other words the data from one particular census block might represent the data for different stations. Therefore to estimate the correct data for each station, the sum weighted of the proportion of the area of the intersection of the buffer and each census block to the total area of each intersected census block was calculated. (Figure 4 and Figure 5)
Figure 4- Hubway, Station Buffers-Census Blocks
Figure 5- Bike Chattanooga, Station Buffers-Census Blocks
The socio-demographic characteristics affect individual transportation choices and travel behavior. Variables such as the number of transit commuters, employment status, and vehicle availability are some of the key factors needed to examine the travel patterns and model public transportation ridership. Exploring some fundamental demographic elements such as population density, median income, education level, and non-white population provide insight in understanding the dynamics of the community and their effect on bikeshare use.

**Population density**: This factor was used as a significant index to determine the service area in multiple feasibility studies (11, 14, 15). Locations with higher population density can provide more regular daily users and tend to support higher bikeshare demand.

**Total employment**: Higher employment density often results in greater access to public transportation. This variable can also determine how the pattern of morning commute affects the distribution of bikeshare rides throughout the service area. Due to the lack of data for employment density, this study instead used the total employed residents (number of workers in household 16 years and over). In capital cities like Sacramento or Washington D.C., state officials and government agencies are often concentrated in a downtown area, therefore a density of government employees in particular may be a factor that needs to be considered in future studies.

**Median household income**: Few studies have identified this variable as a significant factor in determining the suitability area for bikeshare use (14, 16). A recent survey by Census Transportation Planning Projects in the Portland metro area reported that about 34 percent of the Portland metro area’s bicycle commuters are from the 25 percent least privileged communities in Portland (18).
**Education** (defined as the number of residents with a bachelor degree or higher): Previous studies have examined the education level of residents near each bikeshare station (14, 15, 16). In general it is presumed that areas with a greater number of highly educated residents tend to be more bicycle friendly communities. Education promotes healthy and “greener” lifestyle and encourages neighborhoods to be more suitable for bicycle riding.

**Low-vehicle households** (defined as a household with zero or one vehicle ownership): Maurer found that number of households with zero or one vehicle had a negative impact on bikeshare ridership. The result showed 10% increase in households with one or zero vehicles is associated with 19% decrease in monthly rentals (14) which seems to be at odds with intuition and theory. This finding could be related to the effect of income on ridership in the model. People with higher incomes usually own more vehicles per household.

**High income households** (defined as households with annual income more than $75,000): Maurer found for every additional 100 workers earning more than $3,333 per month, monthly rentals in Nice Ride, Minneapolis increased by 6.8% (14).

**Non-white population**: The success of bikesharing systems partially depends on resolving the environmental justice issues. There are new and experimental approaches to absorb all the residents by removing barriers such as having a bank account or credit card, but the challenges still remain. Despite a number of innovative approaches bikesharing programs still are not successful in reaching these populations. Aside from ethical issues consideration of diversity is good for the success of the program in the long run.

**Alternative commuters**: Number of people who commute to work by public transportation or by walking gives an instant impression of a city’s commute behavior. Alternative commuters are
more likely to use bikeshare for their daily commute than people who are more dependent on vehicles.

**Bicycle commuters:** Along with public transport users and pedestrians, people who ride their own bicycle to work, are more likely to be bikeshare users. They may prefer to rent a bicycle instead of dealing with hassles of bicycle ownership, such as parking and maintenance. Although this variable has not been a significant factor in previous studies, being a bicycle commuter was examined in this study.

### 4.3 Transportation and Built Environment

**Number of train/light rail/Amtrak stations:** Bikeshare systems are aimed to gradually link to the public transportation network and resolve the “first and last mile” gap issue; therefore it was essential to examine the effects of number of train stations within walking distance of a bikeshare station on the ridership.

**Bus stations:** Similar to train stations, this study identified the locations of all bus stations from local agency databases within 500 meter of bikeshare stations to examine the effects on bikeshare ridership.

**Number of commuting colleges and universities:** Dill and Carr found that university campuses as a major trip attraction factor having a significant effect on cycling (19). Boston is the home to many distinguished schools having a large community of students and university employees. Students are less likely to own vehicle and therefore more likely to use a bikeshare system as part of their daily commute.
**Total length of bikeways:** Bikeway data were collected individually from local government agencies for each municipality. This variable was constituted based on the total miles of bikeways within 500 meter buffer around each station.

**Precipitation and Temperature:** The total monthly participation amount and the average monthly temperature were collected for the cities of Boston and Chattanooga to observe the effect of weather change in seasonal and monthly ridership (20). The variables were collected based on the average monthly data and assumed to be consistent for all the areas of the city.

Table 2 describes the definitions of each variable used in the regression analysis. The consistent set of explanatory variables were collected within the 500 meter buffer of each bikeshare station and compiled in GIS software.
Table 2- Variable Definitions and Sources

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly Ridership</td>
<td>Natural log of the total ridership in 3rd season of 2015 (Jul, Aug, Sep)</td>
<td>System Ridership Data</td>
</tr>
<tr>
<td><strong>Independent</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>Total population in 100 persons</td>
<td>2010-2014 American Community Survey 5-Year Estimates at Census Block Level</td>
</tr>
<tr>
<td>Non-white population</td>
<td>Total population that is of a race other than &quot;white only&quot; in 100</td>
<td></td>
</tr>
<tr>
<td>Median income</td>
<td>Median household income in $1000</td>
<td></td>
</tr>
<tr>
<td>High income households</td>
<td>Number of households with greater than $75,000 annual gross income</td>
<td></td>
</tr>
<tr>
<td>Total employment</td>
<td>Total number of workers in household 16 years and over in 100 persons</td>
<td></td>
</tr>
<tr>
<td>Alternative commuters</td>
<td>Total number of workers who commute by walk or public transportation in 100 persons</td>
<td></td>
</tr>
<tr>
<td>Bicycle commuters</td>
<td>Total number of workers who commute only by bicycle</td>
<td></td>
</tr>
<tr>
<td>Low-vehicle households</td>
<td>Total number of households with access to 1 or zero vehicle</td>
<td></td>
</tr>
<tr>
<td>Bachelor's degree</td>
<td>Total number of people with bachelor degree in 100 persons</td>
<td></td>
</tr>
<tr>
<td>Graduate degree and higher</td>
<td>Total number of people with graduate degree or higher in 100 persons</td>
<td></td>
</tr>
<tr>
<td><strong>Transportation Network</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bikeway</td>
<td>Total miles of bikeway</td>
<td>Massachusetts Office of Geographic Information (MassGIS) and State of Tennessee STS GIS Data</td>
</tr>
<tr>
<td>Bus stops</td>
<td>Number of bus stops</td>
<td></td>
</tr>
<tr>
<td>Train/Amtrak stations</td>
<td>1 if a train station is located within 500 meters, 0 otherwise</td>
<td></td>
</tr>
<tr>
<td><strong>Built Environment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University/ College</td>
<td>1 if a college or university is located within 500 meters, 0 otherwise</td>
<td>MassGIS and State of Tennessee STS GIS Data</td>
</tr>
<tr>
<td><strong>System Specific</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boston flag</td>
<td>1 if the station is in Boston Hubway system, 0 otherwise</td>
<td></td>
</tr>
<tr>
<td>Chattanooga flag</td>
<td>1 if the station is in Chattanooga bikeshare system, 0 otherwise</td>
<td></td>
</tr>
</tbody>
</table>
4.4 Hubway System- Boston

Boston is a notorious “walking city” but it also has a large network of public transportation that connects different regions of the metropolitan area together. According to the city of Boston official, the Hubway bikesharing system can serve as one of the major public transportation modes to reach the city’s goal to be a world-class cycling city (21). The Hubway system launched in July 2011 with 600 bicycles and 61 stations and the program continued to expand to neighboring cities of Brooklyn, Cambridge, and Somerville. It currently has 1,168 bicycles with 83 docking stations. Figure 6 shows the bikeshare station in a city of Cambridge near the Harvard campus area.

Figure 6-Boston Hubway station in Cambridge
4.5 Bike Chattanooga- Chattanooga

Bike Chattanooga was launched in July 2012 with 33 docking stations and 300 bicycles in Chattanooga, Tennessee. The commuting culture in this city appears to be highly dependent on personal vehicle. According to 2010-2014 American Community Survey (5-Year Estimates) almost 80.4% of residents drive to work alone by personal automobile on a daily basis (22). Although it's important to consider that Chattanooga has numerous visitors and tourists for its famous Tennessee aquarium, other attractive festivals and events happen annually along the Tennessee River. Therefore Bike Chattanooga has a great potential to be a favorable mode of transportation for tourists and casual riders. Figure 7 shows bikeshare riders on Walnut Street Bridge over the Tennessee River.

Figure 7- Chattanooga bikeshare riders along Tennessee River
(http://www.Chattanoogafun.com/blog/bicycle-share)
Table 3 presents the data for key variables in both cities.

Table 3: Magnitude of Significant Independent Variables

<table>
<thead>
<tr>
<th></th>
<th>Boston</th>
<th>Chattanooga</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Population</td>
<td>890,791</td>
<td>171,279</td>
</tr>
<tr>
<td>Bikeway (miles)</td>
<td>456.07</td>
<td>21.06</td>
</tr>
<tr>
<td>Number of college and universities</td>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>Alternative commuters</td>
<td>12.2%</td>
<td>0.73%</td>
</tr>
<tr>
<td>Number of residents with graduate</td>
<td>42,650</td>
<td>6,041</td>
</tr>
<tr>
<td>degree and above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total employed residents</td>
<td>334,231</td>
<td>76,446</td>
</tr>
<tr>
<td>Median household income</td>
<td>$62,362</td>
<td>$51,125</td>
</tr>
<tr>
<td>Proportion of non-white population</td>
<td>61.7%</td>
<td>39.8%</td>
</tr>
<tr>
<td>Proportion of households with 0 or 1</td>
<td>65.1%</td>
<td>31.9%</td>
</tr>
<tr>
<td>vehicle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER V

RESULTS AND DISCUSSION

6.1 Station Level Regression Analysis

6.1.1 Hubway Model

The dependent variable was the natural log of the total number of bicycle checkouts during the third quarter of 2015 from 134 Hubway bikeshare stations. Table 4 presents the summary of explanatory variables found to be statistically significant in Hubway model. In order to eliminate the multicollinearity issue the bivariate correlation analysis was performed and the variables with more than 80% correlation with each other were removed from the model. The eliminated variables were total population, the number of residents with bachelor degree, and the number of high income households.

Table 4 - Multivariate Regression Results for Hubway

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficients</th>
<th>Standard Error</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bikeway</td>
<td>0.152</td>
<td>0.027</td>
<td>0.000***</td>
</tr>
<tr>
<td>College or University</td>
<td>0.437</td>
<td>0.120</td>
<td>0.000***</td>
</tr>
<tr>
<td>Alternative Commuters</td>
<td>0.165</td>
<td>0.047</td>
<td>0.000***</td>
</tr>
<tr>
<td>Bicycle Commuters</td>
<td>1.225</td>
<td>0.342</td>
<td>0.000***</td>
</tr>
<tr>
<td>Median Income</td>
<td>0.006</td>
<td>0.002</td>
<td>0.007**</td>
</tr>
</tbody>
</table>

R Squared 0.483

*, **, and *** indicate statistical significance at the 10, 5 and 1 percent levels, respectively.

All the variables showed the expected signs and were statistically significant at the 99% level of confidence, except Median Income which was significant at the 95% level. The results showed number of alternative commuters strongly affecting the bikeshare ridership. The results indicated
that increasing the alternative commuters by 100 persons within 500 meter of station was associated with 16 percent more bikeshare ridership. Total length of bikeway (as an important indicator of the city’s cycling infrastructure) was another strong factor to affect the ridership. The Hubway model showed an additional mile of bikeway length within 500 meters of the bicycle station increased ridership by 15 percent. Another variable that estimated to have a robust relationship with Hubway ridership was number of colleges and universities near the station. As the home of outstanding universities such as Harvard and Massachusetts Institute of Technology (MIT), the small town of Cambridge solely contains more than 30 bicycle stations active through the entire year without closure in the winter months. As a result, there are a significant number of students who live around the campus and use bikeshare as a daily commute. The regression model estimated 44% increase in ridership could be associated with having a station located within 500 meters from the university campus. Household median income was another variable that had a significant and slightly positive affect on ridership consistent with previous studies (14, 15, 16). The regression analysis of Hubway showed a 0.6 percent increase in ridership could be gained from a $1000 rise in median household income. The percentage of people who commute with their bicycle can be an essential measure for observing a current bicycle culture of the community, and this factor appeared to be heavily influential on Hubway ridership. People who habitually commute by bicycle could have a great potential to choose bikeshare as a hassle and maintenance free substitute for their daily commute.

6.1.2 Chattanooga Model

Similar to the Hubway model, the natural log of the total number of bicycle checkouts during the third quarter of 2015 were gathered from 31 active stations. Table 5 identifies the significant variables affecting Bike Chattanooga ridership. As it was performed for the Hubway model, the
result of bivariate correlation analysis showed the bachelor degree and the graduate variables were highly correlated, therefore the bachelor degree variable was eliminated from the model.

Table 5 - Multivariate Regression Results for Chattanooga Bikeshare

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficients</th>
<th>Standard Error</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative Commuters</td>
<td>1.091</td>
<td>0.475</td>
<td>0.032**</td>
</tr>
<tr>
<td>High Income Households</td>
<td>0.030</td>
<td>0.009</td>
<td>0.004***</td>
</tr>
</tbody>
</table>

R Squared 0.612

*, **, and *** indicate statistical significance at the 10, 5 and 1 percent levels, respectively.

The result from this model were less reliable because of a small number of observations (n=31). However since the previous studies were based on only the large jurisdiction systems such as Capital Bikeshare in Washington D.C. (11, 13) or combination of large systems such as Denver B-Cycle, Nice Ride in Minneapolis, and Capital Bikeshare (15), this study took advantage of the recently released data from small-scale city of Chattanooga to observe its distinctive characteristics. There was one variable statistically significant in the model that did not pertain to ridership in the Hubway model. The regression result showed that one additional household with annual income more than $75,000 within 500 meter of bikeshare station was associated with 3% increase in ridership. Furthermore the model estimated 109% percent raise in ridership could be related to 100 additional alternative commuters within 500 meter of the bicycle station. Both of these observations were consistent with previous literature (14, 15, 16).
6.1.3 The Combined Model

In order to gain further insight into ridership patterns, a combined dataset of both systems with common variables was used to conduct the regression analysis with the same dependent variables as previous models with a larger sample size (n=164). Table 6 shows the summary of explanatory factors that were found to be statistically significant in this model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficients</th>
<th>Standard Error</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bikeway</td>
<td>0.118</td>
<td>0.030</td>
<td>0.000***</td>
</tr>
<tr>
<td>College or University</td>
<td>0.256</td>
<td>0.127</td>
<td>0.045**</td>
</tr>
<tr>
<td>Graduate Degree and higher</td>
<td>0.150</td>
<td>0.072</td>
<td>0.038**</td>
</tr>
<tr>
<td>Non-White Population</td>
<td>-0.064</td>
<td>0.019</td>
<td>0.001***</td>
</tr>
</tbody>
</table>

R Squared                  0.646

*, **, and *** indicate statistical significance at the 10, 5 and 1 percent levels, respectively.

In the combined model, the R-squared increased to almost 65% and the results were similar to those from the Hubway analysis except with additional factors of Graduate Degree and Non-White Population. The results showed with every 100 more residents with a graduate degree or higher near the bikeshare station, the ridership could increase by 15%. Furthermore, the population with race other than white-only showed as significant and slightly negative factor.

6.2 Examine the Effect of Temporal Variables on Hubway and Bike Chattanooga

Previous studies (13, 14, 15) had focused on forecasting ridership by using panel data. This study analyzed the effectiveness of temporal elements from a longitudinal or time perspective. As noted before, the demographic and socio-economic data are limited to the Census Bureau surveys every couple years and there is limited spatial data available on a monthly or seasonal basis. Hence, this part of analysis was conducted at the city level rather than the station level. The monthly ridership
of Hubway system and Bike Chattanooga was collected from two consecutive years in 2014 and 2015 to observe the influence of temperature, precipitation, and type of system users on a monthly basis.

Quarterly ridership in the Hubway system from January 2014 to December 2015 (Figure 8) showed an enormous decline in the first season for both years. It appears that number of trips decreased dramatically in winter months. During months of January, February, and March in 2014 and 2015, all the stations were closed except 33 stations located in the town of Cambridge.

As displayed in Figure 9, the total monthly bicycle checkouts were at maximum in third quarter of the year with an average temperature of 71.5° F. This peak in ridership could be related to good weather, which shows people enjoy riding and using the bikeshare program during warm season.
The other weather component examined in this section was the total monthly precipitation which was assumed to be constant for entire service area. Figure 10 showed the total ridership in May 2014 was approximately 13% less than the ridership in July 2014; however there was 1.7 inches more precipitation in July than May. The reason for the decrease in ridership was most likely due to temperature. Average temperature in May 2014 was 59 °F, which is 15° colder than July 2014 (74°F). Observing the weather variables in Boston showed the ridership had a stronger relationship with the temperature rather than with precipitation.
Exploring the type of riders in terms of their membership status provided a great overall scheme of the program. The Hubway system offered 24-hour passes for casual riders and a monthly or annual membership for regular users. Figure 11 shows the number of subscribed members was in average 66 percent more than casual riders consistently for both years.
The regression analysis showed that University and College element significantly affect ridership in Boston area. Students and university employees were more likely to become subscribed members of the bikesharing system, because it is convenient to commute by bicycle. The college town of Cambridge alone generated nearly half of the total trips for the entire system in 2014 and 2015 consecutively (Figure 12).

Hubway also offers subsidized memberships to low-income population and residents with health or weight problems, although there was an 18% decline in number of subscribed members in 2015 compared to the previous year (Figure 11). According to the city of Boston government official, the program expanded with 10 additional stations in East Boston area in April 2016 (21). According to Boston Department of Transportation, the city plans to grow even more as the demand continues to thrive (21).
In Chattanooga, ridership was at the peak in the second and third quarters consecutively (Figure 13), whereas in Boston the highest ridership was observed only in the third quarter with a nearly 75 percent decline in the second quarter for both years of 2014 and 2015.

Figure 13- Bike Chattanooga Quarterly Ridership 2014-2015

Chattanooga has generally a mild climate, with warm summers and moderate winters, all of which is suitable for cycling. In Boston, the average temperature in third quarter was 13 degrees warmer than a second quarter of the year. In Chattanooga this difference was only 7 degrees. As shown in Figure 16, during the peak month of May ridership has increased by 12% in 2015 compared to the previous year. The increase could be partially caused by a major cycling competition which turned out to be a big draw for many athletes to visit Chattanooga in May 2015. Even in winter months with lowest observed ridership, there was 11% increase in 2015 compared to the previous year. Exploring the average monthly temperature and the precipitation effect on ridership in Chattanooga showed similar results as the Hubway system in Boston. Figure 14 shows that in the month of October 2014, the total rainfall was 6.3 inches which was
twice amount as March; however the ridership was 14% higher in October, again similar to the observation from Boston, and probably this observation was due to the temperature. The average temperature in March 2014 was 13 degrees cooler than in October (Figure 15). Precipitation appeared to be less significant when the weather was not cold.

Figure 14- Bike Chattanooga Monthly Ridership vs. Precipitation

Figure 15- Bike Chattanooga Monthly Ridership vs. Temperature
To gain further insight about ridership patterns in Chattanooga, the study examined the type of riders in the program. Figure 16 illustrated the type of users of the system according to their membership status.

As expected, in Chattanooga the number of casual riders in average was 56% higher than the number of subscribed members; this result was completely opposite in Boston. As mentioned earlier, there are many students and university employees who reside in the Boston area that are more likely to use the system frequently in a daily bases. On the other hand, Chattanooga as a vehicle-oriented community seems to have a high potential to absorb visitors and tourists for recreational use. As shown in Figure 16, the gap between number of casual users and subscribed members was lower in 2015 compared to the previous year which might be due to the change in the fee structure. The program included various types of subscriptions and short-term passes for residents who ride the bikeshare occasionally for leisure or recreational purposes as well as special fares for conference and festival membership in April 2015.
Table 7 presents the summary of the results described in this section.

### Table 7 – Effects of Temporal Variables

<table>
<thead>
<tr>
<th></th>
<th>Hubway</th>
<th>Bike Chattanooga</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ridership Peak Months</strong></td>
<td>June through August</td>
<td>April through August</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>significant decrease in ridership in winter months</td>
<td>significant decrease in ridership in winter months</td>
</tr>
<tr>
<td><strong>Precipitation</strong></td>
<td>The effect depends on the temperature</td>
<td>The effect depends on the temperature</td>
</tr>
<tr>
<td><strong>Type of Riders</strong></td>
<td>66% more subscribed members than casual riders</td>
<td>56% more casual riders than subscribed members</td>
</tr>
</tbody>
</table>

### 6.3 Macro-Analysis at the City Level

At this part of the study, two major success factors were defined. Market penetration and the overall efficiency of nine systems were examined to determine the relative success of bikesharing programs in the U.S. Exploring the result of both metrics could provide insight about the efficiency and popularity of bikesharing systems, and the combined observation of both indexes could represent a relatively valid evaluation of bikesharing’s overall success. Table 8 presents the summary of basic components of the systems that were analyzed in this part of the study.

### Table 8- Bikeshare Systems in the United States (included in the study)

<table>
<thead>
<tr>
<th>City, State</th>
<th>Program Name</th>
<th>Launch date</th>
<th>Bike-Station</th>
<th>Service area (sq. mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston, MA</td>
<td>Hubway</td>
<td>Jul-11</td>
<td>1168-83</td>
<td>11.79</td>
</tr>
<tr>
<td>Boulder, CO</td>
<td>Boulder B-cycle</td>
<td>May-11</td>
<td>300-38</td>
<td>8</td>
</tr>
<tr>
<td>Chattanooga, TN</td>
<td>Chattanooga Bike</td>
<td>Jul-12</td>
<td>300-34</td>
<td>2.5</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>Divvy</td>
<td>Jun-13</td>
<td>4760-476</td>
<td>87</td>
</tr>
<tr>
<td>Madison city, WI</td>
<td>Madison B-cycle</td>
<td>May-11</td>
<td>350-39</td>
<td>4</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>Nice Ride</td>
<td>Jun-10</td>
<td>1700-190</td>
<td>45</td>
</tr>
<tr>
<td>New York, NY</td>
<td>Citi Bicycles</td>
<td>Jul-13</td>
<td>6000-493</td>
<td>81</td>
</tr>
<tr>
<td>San Francisco, CA</td>
<td>Bay area Bikeshare</td>
<td>Aug-13</td>
<td>350-35</td>
<td>6.36</td>
</tr>
<tr>
<td>Washington DC, DC</td>
<td>Capital Bikeshare</td>
<td>Sep-10</td>
<td>3200-350</td>
<td>35.95</td>
</tr>
</tbody>
</table>
6.3.1 Overall Efficiency of the Systems

To gain further insight into the system efficiency in terms of bicycle usage and the related infrastructure, the number of average monthly checkouts per bicycle was measured (Figure 17). Higher average daily uses per bicycle resulted in the higher benefits per bicycle and a lower cost-benefit ratio all of which ultimately leads to the higher revenue per bicycle and thus a more economically sustainable program. A successful, efficient, and reliable bikesharing program is the one that is both popular and economically sustainable. As indicated before, the term “efficient” here only applied to the equipment, infrastructure, and specifically a bicycle usage. This study has not considered any type of cost factor to analyze the economic efficiency of the systems.

![Average Monthly Rides Per Bike](image)

**Figure 17- Systems Monthly Average Ride per Bicycle, 2014-2015**

CitiBike in New York with almost 116 monthly rides per bicycle on average, and Nice Ride in Minneapolis with 112 monthly rides had the highest bicycle usage among the other programs. CitiBike with 6,000 bicycles is the largest system in the U.S., and Nice Ride with 1,700 bicycles is the second oldest IT bikesharing program in the country launched in June 2010. As observed
from the graph in Boston, Chicago, and Washington D.C. the average bicycle checkouts have declined slightly in 2015. Chattanooga showed the fewest number of rides per bicycle, which was meant the program’s infrastructure, was not sufficiently utilized by the residents and indicated a lack of support from the residential community in Chattanooga.

6.3.2 Market Penetration

The higher average daily trips per resident leads to more benefits associated with the program, such as less congestion or air pollution and a healthier population of users. Bicycle usage solely cannot be a sufficient measurement of the program’s success; therefore it was essential to explore the popularity of the program by observing the average number of trips taken by residents each month (Figure 18).

![Figure 18- Systems Monthly Average Trip per Resident, 2014-2015](image)

Nice Ride in Minneapolis was the only program that had a comparatively large number of monthly trips per resident (3.3) and a high number of average monthly checkouts per bicycle
From Bay Area Bikeshare system, only the city of San Francisco has been explored in this study (Bay Area Bikeshare includes half around the city of San Francisco, alongside the Caltrain corridor in Redwood City, Mountain View, Palo Alto and San Jose), and the graph showed the market penetration was not as high as it might be expected from city of San Francisco (0.2 average monthly trips per resident) with strong public transit culture, mild winters, and a large percentage of tourists and visitors. However there are some challenges to consider: according to National Oceanic and Atmospheric Administration (NOAA) data center, San Francisco is ranked as the seventh windiest city in the U.S. with average annual wind speed of 10.6 mile per hour (22). San Francisco is also a hilly city with steep streets which makes it challenging for bicycle riding. San Francisco is a major tourist attractor in the U.S. and it may have a significant number of trips generated by visitors and tourists (as noted earlier, this study only considered the city’s populated residents for calculating the average monthly trip per resident).

The results also showed the CitiBike in New York had a relatively low number of trips per resident (0.98) despite the system’s high bicycle usage efficiency. This observation could suggest the program has not been popular partially because of a limited geographical area of the system which has restrained the use for people outside of the core and busy neighborhoods. Twin Cities (Minneapolis and St. Paul) with almost 8% of the population of New York had 70% more monthly trips per resident. Similar to San Francisco, New York City is one of the largest tourist absorbers in the world, so it is possible that excluding the number of visitors and tourists in a population factor has played a role in the unexpected result. Chattanooga also indicated poor usage by the residents.

Overall result from exploring both indexes is summarized in Table 9 below. The data reflect two years of ridership in 2014 and 2015.
Table 9- Summary of Monthly Rides per Bicycle and Monthly Trips per Resident

<table>
<thead>
<tr>
<th>Bikeshare System</th>
<th>City</th>
<th>Monthly Rides per Bike</th>
<th>Monthly Trips per Resident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nice Ride</td>
<td>Minneapolis</td>
<td>112.39</td>
<td>3.3</td>
</tr>
<tr>
<td>Hubway</td>
<td>Boston</td>
<td>82.3</td>
<td>1.29</td>
</tr>
<tr>
<td>Capital Bikeshare</td>
<td>Washington D.C.</td>
<td>80.47</td>
<td>1.5</td>
</tr>
<tr>
<td>Divvy</td>
<td>Chicago</td>
<td>69.45</td>
<td>1.46</td>
</tr>
<tr>
<td>Citi Bike</td>
<td>New York</td>
<td>115.94</td>
<td>0.98</td>
</tr>
<tr>
<td>Bay Area Bikeshare</td>
<td>San Francisco</td>
<td>42.15</td>
<td>0.2</td>
</tr>
<tr>
<td>Boulder B-Cycle</td>
<td>Boulder</td>
<td>17.31</td>
<td>0.61</td>
</tr>
<tr>
<td>Chattanooga Bikeshare</td>
<td>Chattanooga</td>
<td>14.88</td>
<td>0.31</td>
</tr>
<tr>
<td>Madison B-Cycle</td>
<td>Madison City</td>
<td>27.75</td>
<td>0.47</td>
</tr>
</tbody>
</table>

As a result of both index analyses, Nice Ride in Minneapolis was the only program among others with comparatively largest market penetration and popularity within the community (3.3 monthly rides per resident), also relatively high bicycle usage efficiency (112 monthly rides per bicycle). Minneapolis has invested largely in bicycle infrastructure in past decade. According to the study by Pucher and Buehler about cycling trend in large North American cities, Minneapolis has the most bicycle parking per capita of any city nationwide (23). Capital Bikeshare in Washington DC area, Hubway in Boston, and Divvy in Chicago, which are all close to each other, ranked after the Nice Ride system. These cities have excellent bicycle-transit integration and substantial mixed-use trail network that expands into the entire region.

6.3.3 Effect of Station Density

The result of the study by National Association of City Transportation Officials (NACTO) has recommended that bikesharing systems should maintain the high station density of approximately 28 stations per square mile across all the neighborhoods including low-income areas (21). As shown in Figure 19, the Nice Ride system with only 4.22 stations per square mile had almost 7.5 times more monthly rides per bicycle than Chattanooga Bikeshare with 13.6 stations per square
mile. Even in San Francisco with the second largest station density among other programs (11),
the number of monthly rides per bicycle was dramatically low compared to other large systems.
The result showed station density could be one of the many components to affect the total
ridership of the system, but it was not clearly the most important one among others.

![Graph showing average monthly rides per bike and station density for different cities.]  

Figure 19- Systems Average Monthly Ride per Bicycle vs. Station Density, 2014-2015

6.3.4 Effect of Public Transit Integration

Since the regression analysis for both Hubway and Bike Chattanooga showed the proportion of
workers who commute by either public transportation or walk (excluding taxi cab) was a
significant variable in ridership trend. The assessment of the connectivity of bikeshare and public
transit was essential in a larger scale for all the programs (Figure 20).
Figure 23 indicates relatively consistent relationship between percentage of trips by public transit and the monthly bikeshare rides, although Minneapolis-St. Paul, New York, and San Francisco did not follow the same trend. Minneapolis and St. Paul are not considered to be public transportation-oriented cities. According to the Census Bureau (5-years survey estimation) approximately 33% of residents drive to work with personal automobiles (26). However the result of the analysis showed among those residents who do not drive to work, a large percentage chose Nice Ride bikeshare instead of other public transportation modes. Conversely in New York and San Francisco which have relatively large population commuting by public transportation in a daily basis, small percentage used CitiBike as a ride. According to study by Pucher and Buehler among large cities in Northern America, New York City has failed in the essential areas of bicycle-transit integration and cyclist rights (24). The result could describe that people who live in the public transportation oriented cities still feel more comfortable using transit rather than
bikeshare and could be due to inadequate connections between transit stations and bikeshare stations. According to recent report from the Bureau of Transportation Statistics (BTS), of the 3,378 bicycle-share stations nationwide only 13% connect with transit rail (commuter rail, heavy rail, and/or light rail) and 74.9% connect with transit bus (27).

Table 10- Bikeshare-Transit Mode Connectivity

<table>
<thead>
<tr>
<th>Connecting Transit Mode</th>
<th>Connections</th>
<th>Near Connections</th>
<th>No Connection</th>
<th>No Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>2,531</td>
<td>477</td>
<td>368</td>
<td>2</td>
</tr>
<tr>
<td>Transit Rail</td>
<td>440</td>
<td>512</td>
<td>1,707</td>
<td>719</td>
</tr>
<tr>
<td>Heavy Rail</td>
<td>292</td>
<td>358</td>
<td>1,336</td>
<td>1392</td>
</tr>
<tr>
<td>Light Rail</td>
<td>131</td>
<td>149</td>
<td>1,809</td>
<td>1289</td>
</tr>
<tr>
<td>Commuter Rail</td>
<td>59</td>
<td>78</td>
<td>2,191</td>
<td>1050</td>
</tr>
<tr>
<td>Ferry</td>
<td>21</td>
<td>34</td>
<td>1,632</td>
<td>1,691</td>
</tr>
</tbody>
</table>

One of the main goals of bikesharing is to serve as first or last mile coverage between public transit and the final destination. Therefore the connectivity between bikeshare stations and the public transportation network seem to play an important role on increasing the number of bikeshare trips taken by residents.
CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Each city has particular underlying characteristics and different dynamic which affect the bikesharing trend and could be related to human factors or cultural differences. This study examined the effect of demographic, socio-economic, transportation network, built environment and climate factors on ridership in small and large cities in the U.S. The determinants of ridership pattern were established through several regression models based on the ridership data from Hubway in Boston and Bike Chattanooga. This study suggests that characteristics such as length of bike lanes, number of college or university near the bikeshare station, number of people who commute by public transit or walk are the key determinants of ridership. The result from a large scale city such as Boston with sturdy public transportation network and extensive number of students showed the different components could delineate the ridership pattern in larger cities. In small cities with relatively high vehicle dependent culture and few student populations, it seems more challenging to absorb the residents to use bikeshare for a regular commute; however the visitors and tourists could boost the ridership especially in small vibrant towns with variety of activities to attract casual riders. The connectivity between public transit system and bikesharing was another important key determinant for ridership especially in larger jurisdictions with more intense transit network. Perhaps introducing the “transit fare card” into American public transit system similar to some European and Chinese cities which can be used for all transit systems including bus, light rail, subway, and bikeshare could be a great step towards the integration of bikesharing to the public transportation network. Furthermore the study examined the effect of temperature, precipitation and type of users. The result was relatively consistent across both cities and showed there is a dramatic decrease in ridership in winter months; however the effect of
precipitation was not as clear as the temperature. Graphs showed riders used the systems in high precipitation month similar to the other months with less rainfall as long as the temperature was not low.

Among nine programs examined in macro analysis part of the study, Nice Ride program in Minneapolis- St. Paul, Divvy in Chicago, and Capital Bikeshare in Washington D.C. had the largest magnitude of number of monthly trips taken by residents and number of monthly checkouts per bicycle consecutively. These cities have excellent bicycle-transit integration and substantial mixed-use trail network that expands into the entire region and clearly have invested significantly in bicycle infrastructures. However planners should consider that the two success metrics used in this analysis could have a reverse relationship. For example a system could have a high average daily use per bicycle, because it has too few bicycles in circulation. The situation implies that the market penetration is low, and only the few existing bicycle stations are economically sustainable. The system could also have high average daily trips per resident and low average use per public bicycle which this circumstance implies high market penetration but low efficiency and perhaps an indicator of low rate of return on investment. Such system may need public support for its survival. Public support might be justified if the benefits outweigh the costs, but dependency on public support makes the system vulnerable to swings in economic cycles and public opinions.

The infrastructure and bicycle culture should be examined as closely related components. A robust infrastructure removes the obstacles such as unsafe and poor quality routes however policy makers and municipalities needs to show a strong ridership to justify the bicycle friendly expenditures. Developments in cycling culture, substructure and policy should be considered simultaneously to develop a greater enthusiasm for bicycling in the U.S.
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