Center for Advanced Multimodal Mobility Solutions and Education

Project ID: 2018 Project 15

INVESTIGATING THE IMPACT OF DIFFERENT ATTRIBUTES ON BICYCLING MODE SHARE AS A MULTIMODAL CONNECTIVITY STRATEGY IN LARGE CITIES: A CASE STUDY IN HOUSTON

Final Report

by

Mehdi Azimi, PhD, PE (ORCID ID: https://orcid.org/0000-0001-5678-032)
Assistant Professor, Department of Transportation Studies, Texas Southern University
Phone: (713) 313-1293; E-mail: mehdi.azimi@tsu.edu

Lan Lan (ORCID ID: https://orcid.org/0000-0002-4833-788X)
Graduate Research Assistant, Dept. of Transportation Studies, Texas Southern University
Phone: (713) 313-5696; E-mail: lan.lan@student.tsu.edu

Mohammed Suyedur Luqman Rahman (ORCID ID: https://orcid.org/0000-0002-4274-8557)
Graduate Research Assistant, Dept. of Transportation Studies, Texas Southern University
Phone: (713) 313-5696; E-mail: m.rahman4014@student.tsu.edu

Yi Qi, PhD (ORCID ID: https://orcid.org/0000-0002-6314-2626)
Professor and Chair, Department of Transportation Studies, Texas Southern University
Phone: (713) 313-6809; E-mail: yi.qi@tsu.edu

for

Center for Advanced Multimodal Mobility Solutions and Education
(CAMMSE @ UNC Charlotte)
The University of North Carolina at Charlotte
9201 University City Blvd.
Charlotte, NC 28223

September 2019

ACKNOWLEDGEMENTS

This project was funded by the Center for Advanced Multimodal Mobility Solutions and Education (CAMMSE @ UNC Charlotte), one of the Tier I University Transportation Centers that were selected in this nationwide competition by the Office of the Assistant Secretary for Research and Technology (OST-R), US Department of Transportation (US DOT), under the FAST Act. The authors would like to thank Houston BCycle for providing the ridership data.

DISCLAIMER

Table of Contents

List of Figures

List of Tables

EXCUTIVE SUMMARY

The role of cycling in city transportation systems has gain increasing attention in the recent years with the initiation of increasing cycle usage, improving the first mile/last mile connection to other modes of transportation, and lessening the environmental impacts of transportation activities. Houston implemented its public bike share system in May 2012, and the system has experienced major increase in ridership and users since the last seven years. Therefore, there was a need to examine the users' activities and investigate the impacts of different attributes on the bike share usage. This study investigated the joint effects of built environment (infrastructure, land use and socio-demographics) and temporal characteristics (weather, and events) on a station-level hourly ridership. The ridership data and also the data for the weather and built environment information were collected from various sources. A Generalized Linear Mixed Model (GLMM) is used to evaluate the effects of temporal, weather, and built environment on the hourly bicycle checkouts and returns at each bike share station. Modeling outcomes are also compared based on three spatial scales (one mile, 0.5 mile, and 0.25 mile) in quantifying the built environment factors of each bike share station.

The results of the study show that people tend to use Houston BCycle more on weekends, non-peak hours and non-winter seasons. Bike lanes, number of docks, and employment density are found to have positive correlations with bicycle checkouts and returns in all three spatial scales. Furthermore, the number of nearby stations and percentage of park land use are negatively correlated with the hourly ridership in the larger spatial scales while the correlations are positive in 0.25-mile buffer radius. The findings of this research will help planners to predict hourly ridership, choose future station locations and improve and rebalance the bicycle efficiency.

1.1 Problem Statement

The role of cycling in city transportation systems has gain increasing attention in the recent years with the initiation of increasing cycle usage, improving the first mile/last mile connection to other modes of transportation, and lessening the environmental impacts of transportation activities. Houston implemented its public bike share system in May 2012, and the system has experienced major increase in ridership and users since the last seven years. Therefore, there was a need to examine the users' activities and investigate the impacts of different attributes on the bike share usage.

1.2 Objectives

The goal of this research is to investigate the joint effects of built environment and temporal variables on hourly bike share usage in Houston. For this purpose, hourly ridership is defined as the sum of hourly trips. For instance, ridership means the number of people using Houston BCycle in every hour. Station-level ridership means the number of people who check out and return the bicycles at each bike share station. Although a significant number of studies have studied various variables that have impact on bike share usage in different cities worldwide, none of the studies have focused on the bike share usage in Houston. To fill this gap, a large and comprehensive ridership data were obtained from Houston BCycle. Built environment characteristics were also collected from different sources to estimate the effect of these variables on bike share usage. Specific research objectives include:

- Review the literatures related to bike share systems, and the effects of built environment and temporal attributes on bike share demand.
- Analyze the bike share station activities.
- Employ a model to analyze and investigate the bike share station activities and the effect of built environment and temporal attributes on bike share demand.
- Identify important attributes that affect bike share demand and provide insights to enhance bike share station location decisions and improve the efficiency of the bike system by rebalancing.
- Recommend the equity considerations.

1.3 Expected Contributions

To accomplish the objectives of the study, several tasks have been undertaken to investigate the impact of different attributes on bicycling mode share as a multimodal connectivity strategy in Houston. The findings of this research will help planners to predict hourly ridership, choose future station locations and improve and rebalance the bicycle efficiency in large cities.

1.4 Report Overview

This report consists of four main chapters:

- Introduction and Literature Review – Introduces the history of bike share program and the background of Houston's bike share program, as well as the purpose of studying bike share in Houston. It also identifies the relationship between temporal factors, built environment, and bike share ridership, and then summarizes the limitations of existing literatures.

- Solution Methodology – Describes and analyzes the dataset and introduces the regression model used for this study, and presents the analysis of the results.
- Recommend the Equity Considerations – Explores the equity barriers for targeted equity users and also for organizations and identifies the considerations that may make the bicycle share more equitable.
- Summary and Conclusion – Discusses the results, recommendations and limitations.

Chapter 2. Literature Review

2.1 Introduction

In recent years, an increasing attention has been paid on how various factors, such as weather, built environment, and transportation infrastructure have impact on bike share ridership. Based on the analysis results in different cities and in different scales, it is possible to provide decision makers with planning suggestions and policies to encourage cycling and improve the performance of bike share programs in urban areas. This chapter consists of four parts. First, it introduces bike share system and its history. Second, it reviews the existing studies on investigating the relationship between temporal and weather variables and bike usage and/or station-level bike share ridership. Third, it states the existing research on how built environment, land use and socio-demographic variables associate with bike share usage. The last part summarizes the limitations of existing research.

2.2 Bike Share

The role of cycling in the city transportation systems has attached increasing attention in recent years due, at least in part, to climate change, unstable fuel prices and concerns about global motorization. The increasing environmental problems have caused many decision makers and planners to closely examine the need for more sustainable transportation options. Bike share, a shared use of a bicycle fleet, stands out among different types of sustainable transportation modes. In the past decade, this evolving concept has gained increasing interests across the world. There are an estimated 500 cities in 49 counties that operate bike share systems. The global bike share fleet is estimated approximately at 550,000 bicycles by 2012 (Larsen, 2013). As a public bicycle system, it is initiated with the idea of increasing cycle usage, improve the first mile/last mile connection to other modes of transportation, and lessen the environmental impacts of transportation activities.

Various advantages of bike share can explain the reason why this type of transportation mode becomes very popular. First, bike share fills the gap between trips that are too far to walk and not long enough to use public transit. (Shaheen, Guzman, and Zhang, 2010). Bike share helps commuters to save effective travel time from congested traffic and avoid long walking distance. Second, bike share creates additional mobility in a community by adding transportation options. Many bike share users combine membership in a bike share program with transit, car-share, walking, and other transportation options to reduce their dependency on automobile travel and save driving or transport cost. Third, bike share plays an important role in increasing health benefits. Studies show that bicycling can be a healthful exercise in daily life (Pucher and Dijkstra, 2003). According to British Medical Association's research, cycling for 30 minutes a day, e.g. using bike share to go to and from work each day, can reduce the risk of heart disease by 82 percent. Lastly, bike share can have a positive impact on reducing greenhouse gas emissions by replacing trips taken previously by automobile. These impacts can be multiplied when combine bike share with other modes of transportation. According to the survey of Capital bike share members in Washington D.C. in 2011, bike share trips had replaced approximately 4.4 million vehicle miles (LDA Consulting, 2012), decreased four percent of the city's annual driving mileage.

These advantages provide reasons for government planners and decision makers to advocate the idea of implementing bike share system. Many cities have begun to implement bike share systems, as shown in Figure 2.1, the first generation of bike share program started in Amsterdam, Netherlands in 1965 with the implementation of the "White Bike" program. The program offered free unlocked bikes and simply placed them on streets for public use. However, without any payment requirement or dedicated locks, the program was terminated after experienced repeatedly stolen and vandalized. While the program seemed to be failed, it was a significant first step for future bike share system.

Figure 2.1: "White Bike" in Amsterdam
(*Source*: www. parool.nl, 2017)

Having learned from this experience, other European cities started to propose their own bike share systems with different rules and technologies (DeMaio, 2009). Figure 2.2 shows a similar system that first took place and established in the U.S. in Portland, Oregon in 1994 by the United Community Action Network. While Portland's "Yellow Bike" Project was successful in terms of publicity, it was also unsustainable due to theft and vandalism of the bicycles. It eventually stopped operating in 2001. In other cities, such as Boulder, Colorado in 1995, Minneapolis and St. Paul in 1996, and Washington, D.C. in 1996, followed Portland to implement their own bike share systems (Shaheen, Guzman, and Zhang, 2010). However, bike share systems in the 2010s are different from those in the 1990s. Bicycles are locked in the dock station and users need to pay a fee before use. After the improvement of the second generation, third generation, and till now the fourth generation of bike share system, more and more cities in the world have implemented bike share system. As a relative latecomer to bike share, the U.S. has 54 cities offering bike share systems and many major metropolitan are experimenting, the fourth generation, dockless bike share system which does not need a docking station. Dockless bicycles can be located and unlocked using smartphone apps. Although the system adds more convenience for users who no longer need to worry about empty bike share stations before use or full stations upon arrival, it can also be a problem for system operators who must rebalance bikes to meet demand.

Figure 2.2: "Yellow Bike" in Portland
(*Source*: www.oregonlive.com, 2016)

Houston BCycle is the first bike share program in Houston and initially began as a pilot project in May 2012 with three bike stations and 18 bicycles in Downtown area and has since grown to a network of 65 stations and more than 400 bikes. Many of the stations are located in the area of Downtown, Midtown, East Downtown, Museum District, West University District and Texas Medical Center. People can purchase a single trip by paying $3 for the first 30-minute use, a monthly membership for $9, or an annual membership for $99 per year, and will be able to borrow and return bikes at any open station in the system. Membership users can take unlimited numbers of trips. However, each trip duration must be less than 60 minutes in order to avoid extra charges. Figure 2.3 shows one of the bike share stations in Houston.

Figure 2.3: A Houston BCycle Station
(*Source:* Houston BCycle, 2017)

After five years of operation, the system has experienced major increase in both ridership and users. As described in the 2017 Houston BCycle annual report, there were a total of 52,332 BCycle riders in 2017, a 40.8% increase from 2016. Furthermore, 142,257 Houston BCycle trips were made in 2017, which was a 25.6% increase compared to the previous year. Table 2.1 lists the number of riders and trips in each year since the program started.

Table 2.1: Houston BCycle Riders and Trips from 2012-2017

Year	**Checkouts**	**% Change**
2012 (April – December)	2,135	
2013	46,005	2054.8%
2014	80,956	76.0%
2015	98,411	21.6%
2016	113,283	15.1%
2017	142,257	25.6%
Year	**Riders**	**% Change**
2012 (April – December)	762	
2013	12,819	1582.3%
2014	23,777	85.5%
2015	31,164	31.1%
2016	37,170	19.3%
2017	52,332	40.8%

Source: Houston BCycle 2017 Annual Report

Studying the travel behaviors of system users can not only help to optimize the system operation and rebalance, but also help to design a better plan for future network through selecting station locations and determining the number of docks at each station.

2.3 Temporal Variables Affecting Bike Share

Bike share use can vary based on the time of a day, day of a week, or season of a year. Study on time-of-day variations of Montreal bike share (Faghih-Imani et al., 2014) showed that the bike use was greater during the afternoon/evening hours and there was a higher concentration of arrival rates in the central business district in the morning peak hours, which represented the daily commute. An analysis of Seattle's bike share system reached the similar conclusions (Sun and Chen, 2016). Faghih-Imani et al. also found that bike flows are more spatially widespread in the evening peak hours compared to the morning peak.

In terms of weekdays and weekends, a study in Toronto found that bike share usage in weekdays increased during morning, mid-day, and afternoon peak hours whereas the system usage in weekends increased only during mid-day and afternoon peak hours. Similarly, the analysis of CitiBike data from New York indicates that the weekday system usage peaks during the morning and evening commutes, while the weekend demand is highest during the middle of the day between noon and 4 p.m. (Schneider, 2016). Faghih-Imani et al. (2014) studied in Montreal, people were more likely to bike on the weekdays than the weekends, and the program is more predominantly used during the PM period relative to other times of the day. These results are also supported through analyses of bike share systems outside the United States, in Vienna, Barcelona, Lyon, and Paris: morning and evening commuters heavily influence system demand during the working days of the week, while mid-days on the weekend experience significant recreational ridership (Borgnat, 2011; Etienne et al, 2014; Kaltenbrunner et al, 2010; Vogel et al, 2011.).

The impact of seasonal factors on bike share usage has been investigated in different cities. Differences were seen from different climates among the cities. Capital Bikeshare in Washington, DC, experiences a noticeable ridership drop in the winter and a peak in the summer. CityCycle system in Brisbane shows spring and fall peaks, and summer and winter troughs. A study from Toronto also illustrated the variation of bike share usage across the four seasons (El-Assi et al. 2017). Moreover, Gebhart and Noland (2014) studied seasonal variations after accounting for weather and darkness effects.

2.4 Weather Affecting Bike Share

A growing body of research has examined the impacts of weather conditions on bike share in different cities, usually in combination with other factors that may influence bike share. Results vary as to how important weather is affecting bike share usage.

Faghih-Imani et al. (2014) analyzed hourly station-level arrival and departure rates in Montreal and found a positive correlation between temperature and bike share use. The results show that humidity had a negative impact on use, and rainy weather had a negative impact on departure rates. In Washington, DC, Gebhart and Noland (2014) studied the impact of weather conditions on bike share trips by analyzing Capital Bikeshare's hourly trip data and relating it to hourly weather data. The study suggested that adverse weather conditions such as cold temperatures, rain, high humidity, and increased wind speed decreased bike share activity. Similar results were also observed in a study conducted by El-Assi et al. (2015) for a bike share system in Toronto. Gebhart and Noland (2014) also examined that the number of trips decreased as temperatures decreased, but the number also decreased when temperatures were above 90 degrees. They found that there is less bike share use when it is dark outside, independent of any temperature effects. Their results also suggest that the availability of transit influences how potential users respond to adverse weather conditions. More people will choose to bike in the rain or cold if transit is less of an option.

While adverse weather and low temperatures decrease bicycling and bike share activity, there is significant number of year-round bicyclists who are comfortable riding their bicycles in freezing temperatures (as cold as -20°C) (Amiri and Sadeghpour 2015). Many Canadian and European cities have facilitated bicycling activity through winters and found that, although winter bicycling is not an option for many users, 10 to 20 percent of the users bicycle in winter in freezing conditions when proper winter maintenance and snow clearing is performed (Miranda-Moreno et al. 2013, Amiri and Sadeghpour 2015, Spencer et al. 2013, Bergstrom and Magnusson 2003). Also, studies have shown that better winter maintenance of bicycle facilities and infrastructure has improved the willingness of people to bicycle (Miranda-Moreno et al. 2013, Amiri and Sadeghpour 2015, Bergstrom and Magnusson 2003).

2.5 Built Environment Affecting Bike Share

Many studies have stated that built environment and land use variables can have significant impacts on bike share usage. Research in Seattle, New York, Toronto, Zhongshan, Minneapolis/St. Paul, Washington, DC, Denver, and Australia, have found the presence of bicycle infrastructure to be crucial. Bicycle infrastructures, such as bike lanes and bike paths, have a positive impact on bike share usage (Faghih-Imani 2014, El-Assi et al. 2015, Fishman et al. 2014, Wang et al. 2016). Few studies also focused on bike infrastructure within a particular buffer size of stations and found out that the bike lanes that are within 250 meters of stations have been linked to higher bike share station usage (Faghih-Imani et al. 2014; Mateo-Babiano et al. 2016). However, the effect of bike infrastructure/built environment is not consistent across different studies. For instance, Rixey (2013) indicated that the positive effect of bike lanes only become significant when including the days with precipitation. More studies also indicated that the joint impact of street lights and trees with bike lanes has a higher influence on bike share usage (Sun et al. 2016). In terms of land use, the number of different land use types or greater mixed land use of each station was associated with a positive impact on bike share demand (Zhang et al. 2017, Heinen et al. 2010, Moudon et al. 2005, Saelens et al. 2003). For example, the study in Zhongshan noted that the larger the number of different land use types within the 300-meter buffer, the larger bike share demand generated at the stations. Similar results were also seen in Seattle; employment density and office land use both had a positive effect on trip generation, however bike share stations located in the areas with higher household density were less likely to have newly generated trips (Sun et al. 2016).

The distance to the central business district has been shown to have a negative effect on the station use (Faghih-Imani et al. 2014, Wang et al. 2016), and El-Assi et al. (2015) both found that the stations located near university campuses had increased demand, as did stations located near a transit station. Similar studies also stated that population density, job density, and access to restaurants and other commercial activities have been shown to have positive impacts on bike share use (Faghih-Imani et al. 2014, Rixey 2013, and Wang et al. 2016). Wang et al. (2016) concluded that, in general, bike share programs are best suited for the locations with higher population densities which have the scope to access a higher number of destinations. Neighborhood sociodemographic characteristics have also been found to have significant impacts on bike share use (Wang et al. 2016, Rixey 2013).

2.6 Summary

The following section identifies some limitations of existing literature from the perspectives of methodology and case study.

- Different scales to measure built environment. Prior research has measured built environment in various ways, but lacks investigation on the relationship between built environment and bike share ridership across different spatial scales. This paper measures built environment and transportation elements in different scales and compares the different results.
- Special features of Houston. According to the previous literatures, the relationship between weather and bike share ridership is clear. However, no studies have looked at the

impact of weather on Houston's ridership. Considering the special weather conditions in Houston, the relationship between the weather and the travel behavior may be different from other locations.

- Model employed. Most researchers use separate models to the effects of temporal variables and spatial variables on the bike share usage, which ignores the joint effects of these two types of variables on bike share ridership.

Chapter 3. Solution Methodology

3.1 Introduction

To investigate the factors affecting bike share ridership, weather information, built environment data, land use data, and bike ridership are collected to create a complete dataset. This section first describes the study area and data collection, then summarizes hourly, weekly, and membership ridership, as well as weather information and built environment attributes. Model development and discussion on the model choice are also introduced in this section.

3.2 Study Area and Data Collection

In this study, the ridership data of 59 stations, which had been implemented before August 2018 with more than 400 bikes, were collected from Houston BCycle. Most of the stations were located in the Downtown area, University Place, Midtown, Washington Avenue/Memorial Park, and Neartown – Montrose area. Figure 3.1 illustrates the bike station locations in these neighborhoods. The neighborhood boundaries data were collected from the Houston-Galveston Area Council ("H-GAC GIS Datasets", 2010).

Bike share stations are mostly scattered within five neighborhoods. Sixteen stations, which are 27% of all the stations, are located in Downtown area; eight stations are located in University Place including five stations at Rice University. Eight stations are within Midtown neighborhood. Five stations are located in each Washington Avenue/Memorial Park and Montrose areas. Eight neighborhoods have less than four stations. Three stations are located at the west of Second Ward boundary which are close to Downtown Houston. Medical Center area also has three stations implemented in 2018. The north of Downtown Houston has three stations located in Greater Heights and two stations located in Near Northside. Greater Third Ward area and Museum Park, each, have two bike share stations. Greater Eastwood and Memorial, each, have one bike share station.

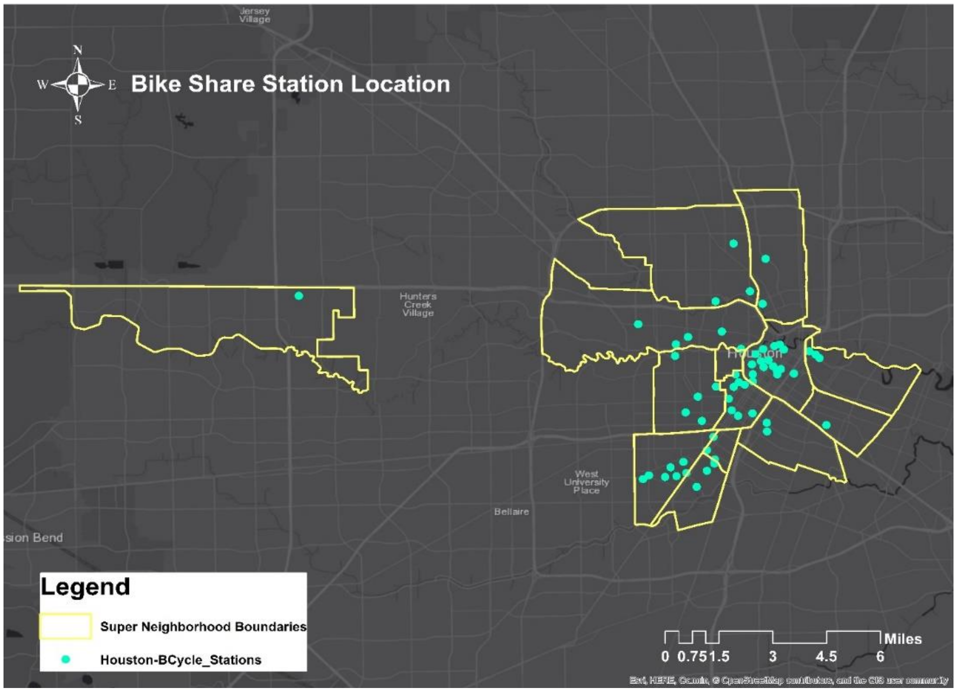

Figure 3.1: Houston Bike Share Station Location

The data used in this research were collected from various sources, including Houston BCycle, the City of Houston, the Houston-Galveston Area Council, and the National Centers for Environmental Information (NCEI) of the National Oceanic and Atmospheric Administration (NOAA). The data descriptions are as follows.

- Houston BCycle operation data from January 1st, 2016 to August 31th, 2018. The entire dataset consists of two elements including trip data and station data: 1) Trip data is one of the most important data elements in this research and contain a unique trip ID column, user membership type, trip starting date/time, ending date/time, bike ID, trip duration, trip route type, travel distance, estimated carbon offset, estimated burned calories, and the station names where user checked out and returned the bike. If a user is a registered system member with annual, monthly, or student membership, the trip data include the program name, city, state, zip code, and country where he/she signed up for local bike share program as well. If a user is a short-term pass holder, the information had been left as blank. 2) Station data contain longitude, latitude, the number of docks, station name, and the opening date.
- Houston-Galveston Area Council Regional Growth Forecast and Land Use GIS data: 1) 2015 H-GAC's Regional Growth Forecast of population, employment, and land use data for the eight-county H-GAC Transportation Management Area (Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller counties) were extracted from GIS shapefile (the data corresponding to Harris County was used for the analysis). Population and employment densities are summarized at the Transportation Analysis Zones (TAZ) geographic scale. 2) Land use data had been categorized into ten land use types (residential, commercial, governmental/medical/educational, industrial, parks/open

spaces, multiple, vacant developable, undevelopable, unknown, and other). Four land use types (residential, commercial, governmental/medical/educational, and parks/open spaces) were selected and their sizes around each bike share station were calculated using Arc GIS.

- The City of Houston provides the bike lane, school, and street tree shapefiles. Bus stop and light rail station shapefiles were downloaded from H-GAC GIS Datasets. ArcGIS was used to measure the length of bike lanes, and the number of school, street tree, bus stop, and light rail stations near the bike share stations.
- Weather data were obtained from the National Centers for Environmental Information (NCEI). The data included the daily maximum, average, and minimum temperature, average wind speed, and precipitation. The data also contained the summary of daily weather conditions such as fog, thunder, ice pellet, snow, and smoke or haze.

3.3 Descriptive Statistics

3.3.1 Bike Trip Summary

The total number of trips among the 59 stations from January 1st, 2016 to August 31th, 2018 is 366,076. Figure 3.2 shows the trip volume by different membership types during that time. More than 74% of all trips (272,936 trips) was made by short-term pass holder (24 Hour Kiosk and Single Use Pass), whereas annual and monthly membership holders contributed 44,849 trips and 42,326 trips, respectively.

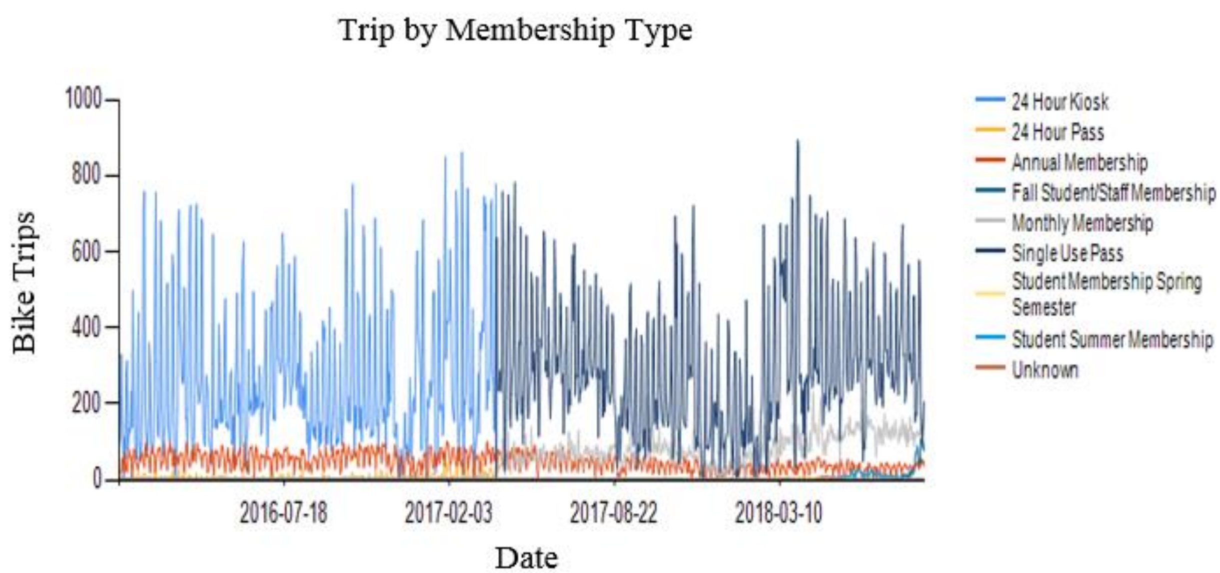

Figure 3.2: Trip by Membership Type
(*Source*: Houston BCycle, 2018)

Figure 3.3 illustrates the station-level ridership (trip origins and trip destinations) by using the circle size to present the magnitude of ridership. Downtown, Memorial Park, and Hermann Park areas have high counts of both trip origins and destinations. Compared with the station-level ridership in other areas, the overall ridership in University Place and Midtown are relatively low for both origins and destinations.

Figure 3.3: Station Level Ridership by Origin and Destination

Table 3.1 presents the top 10 stations with greatest counts of bicycle checkouts and returns. As seen in the table, the stations with high bicycle checkouts also experience high bicycle returns. There are four such stations in the downtown area, three stations in Memorial Park, one in Hermann Park, and one in Stude Park. Although University Place has a large proportion of stations among the others (eight stations), none of its stations are in the list of the top 10 stations.

Table 3.1: Top 10 Popular Stations by Bicycle Checkouts and Returns

CHECKOUT			RETURN		
Station Name	**Ridership**	**Location**	**Station Name**	**Ridership**	**Location**
Sabine Bridge	55,731	Memorial Park	Sabine Bridge	56,728	Memorial Park
Hermann Park Lake Plaza	33,142	Museum District	Hermann Park Lake Plaza	33,853	Museum District
La Branch & Lamar	22,159	Downtown	La Branch & Lamar	22,490	Downtown
Spotts Park	19,815	Memorial Park	Spotts Park	19,887	Memorial Park
Crawford Island	16,845	Downtown	Crawford Island	16,589	Downtown
Lamar & Crawford	15,403	Downtown	Stude Park	15,275	Greater Heights
Stude Park	15,148	Greater Heights	Lamar & Crawford	15,003	Downtown
Market Square	13,768	Downtown	Market Square	14,372	Downtown
Jackson Hill & Memorial Dr.	12,630	Memorial Park	Jackson Hill & Memorial Dr.	12,855	Memorial Park

3.3.2 Trip by Month

Figure 3.4 shows monthly bike counts for the period of January 1st, 2016 to August 31th, 2018. Ridership peaks in July and hits a low point in December 2016, and similar trend is also seen in 2017. It should be noted that even though the data doesn't include the whole year of 2018, the monthly ridership from March to August have all exceeded the peak volumes in 2016 and 2017.

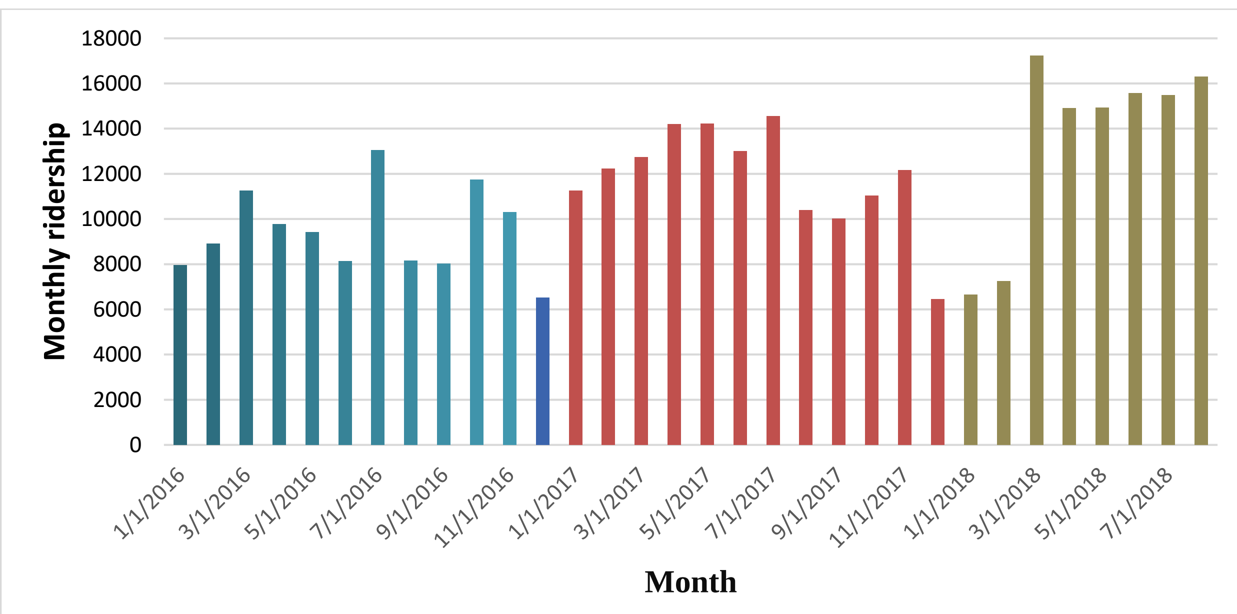

Figure 3.4: Monthly Ridership

3.3.3 Trip by Day of Week

As shown in Figure 3.5, the total number of trips made by short-term pass holders (i.e. 24 Hour Kiosk and Single-Use Pass) on weekdays and weekends is larger than the total number of trips by annual and monthly members. Also, short-term pass holders generate more trips on weekends than weekdays, whereas the situation is just the opposite for annual members. The average daily trip on weekdays for short-term pass holders is about 206 while annual members generate an average of about 53 daily bike counts. On the weekends, the short-term pass holders generate about 495 daily trips versus 128 trips made by the annual members.

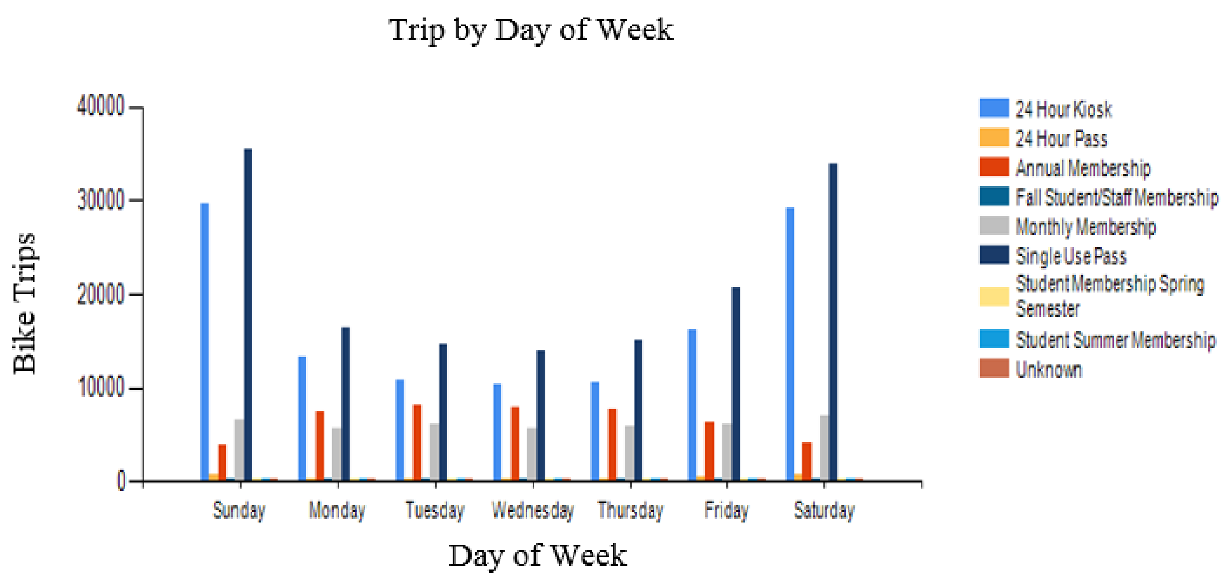

Figure 3.5: Trip by Day of Week and User Type
(*Source*: Houston BCycle, 2018)

3.3.4 Trip by Hour of Day

In this study, peak periods are defined as the hours between 6 a.m. and 8 a.m. and the hours between 5 p.m. and 7 p.m. Figure 3.6 shows the total hourly ridership by different membership types. Approximately 32% of the total trips are generated during peak hours while about 68% is made during off-peak hours. The ridership of the short-term pass holders increases gradually from 7:00 in the morning and experience a dramatic increase from 4:00 in the afternoon, and hits a peaking point at 7 p.m. Then, a noticeable decrease begins right after 7 p.m. For annual members, there are three peaking points of hourly ridership which are 8:00 and 11:00 in the morning and 5:00 in the afternoon.

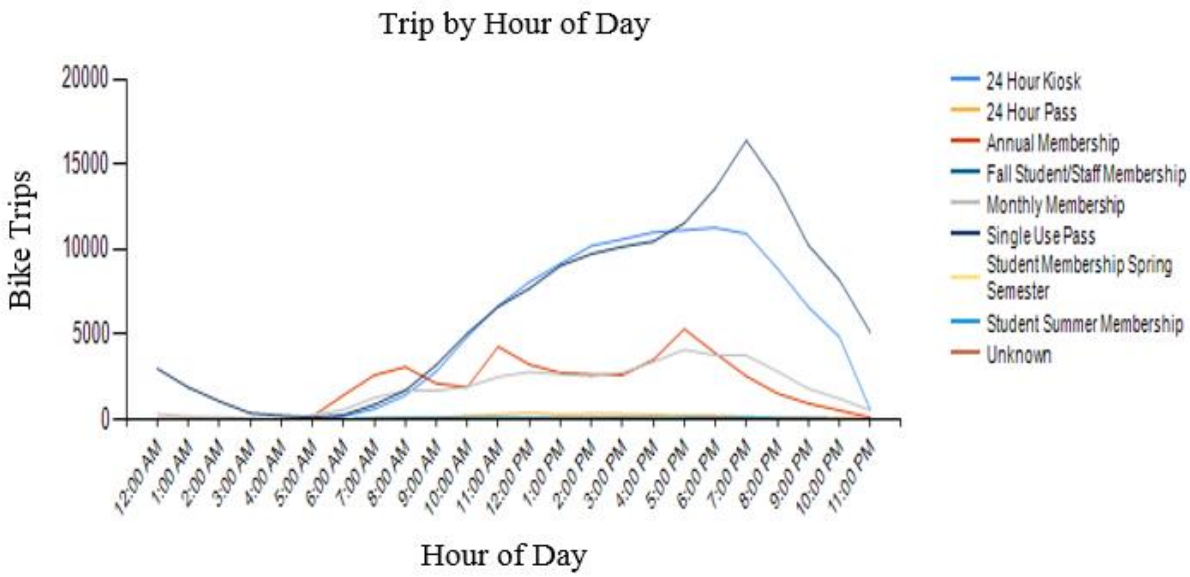

Figure 3.6: Trip by Hour of Day and User Type
(*Source*: Houston BCycle, 2018)

3.3.5 Trip by Duration

Houston BCycle allows the annual members to use the bikes for 60 minutes without additional fees. However, short-term pass holders must pay $3 for every 30-minute ride. Figure 3.7 shows the trip duration distribution by different user types. Most bikes are returned within 60 minutes after the trips start. More than 83% of the trips generated by the annual members are under 30 minutes while about 68% trips made by short-term pass holders are within 60 minutes. For annual members, the average trip duration is about 18 minutes with a 5-minute peak. However, the trip duration pattern of short-term pass holders is totally different from the annual members, with an average of 70 minutes and a 28-minute peak.

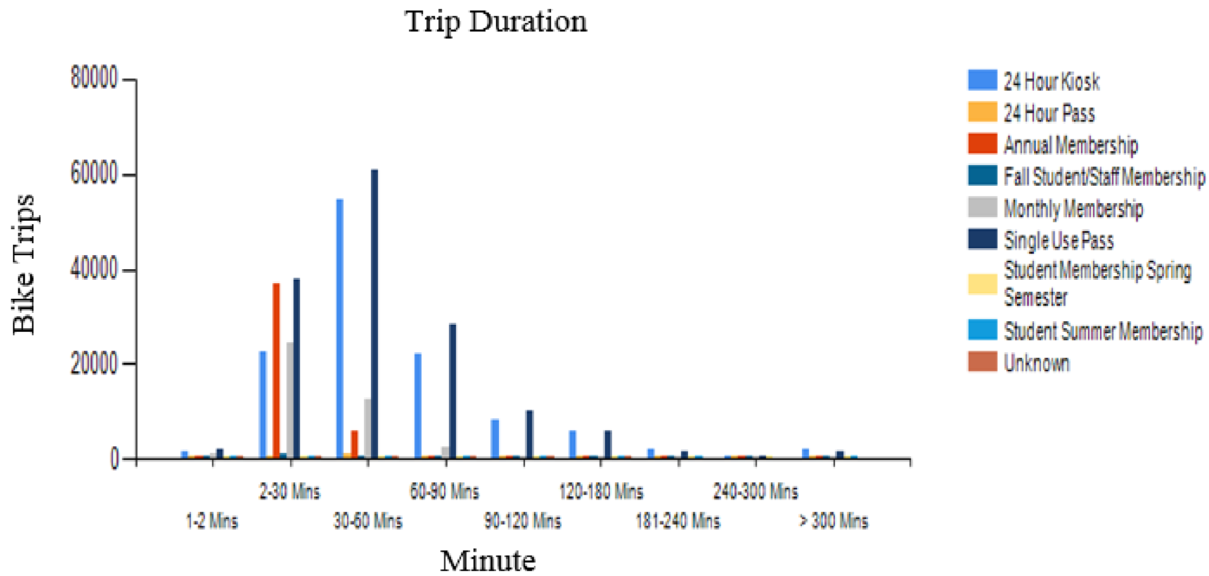

Figure 3.7: Trip by Duration and User Type
(*Source*: Houston BCycle, 2018)

3.4 Preliminary Analysis

This section of report describes a preliminary analysis to better identify the relationship between the temporal variables (i.e. weather and event) and the ridership. For this purpose, the descriptive data and the data source for the weather information and the event variables are presented. Furthermore, this section contains the description of the built environment variables.

3.4.1 Temporal Variables

As mentioned in the data description section, the large difference between the ridership on the weekdays and weekends points to the importance of considering temporal factors on the ridership. Many studies have identified the temporal factors to be significantly associated with the bike ridership. However, those findings are not consistent; some studies identified weekend is negatively related to the ridership compared to the weekdays while others found that it has a positive relationship. Therefore, it would be interesting to examine how temporal factors affect Houston BCycle's ridership. In order to incorporate such differences, a dummy variable is created with 0 denoting weekdays and 1 denoting weekend. Furthermore, to better capture the daily temporal pattern and seasonal trend, another two additional dummy variables are created, representing for peak hour with 1 indicating 6 a.m. to 8 a.m. and 5 p.m. to 7 p.m. and 0 otherwise, and 0 denoting winter months (November, December, and January) and 1 otherwise. Table 3.2 summarizes the description of the temporal and weather variables and the source of the data.

Table 3.2: Temporal Event Variables Description

Category	Variable	Description	Unit	Source
Temporal Event	Peak hour	Bike trip counted in 6 - 8 am or 5 - 7 pm	Dummy (1 or 0)	Houston Bcycle
	Weekend	Bike trip counted on Saturday or Sunday	Dummy (1 or 0)	Houston Bcycle
	Winter	Bike trip counted in November, December, or January	Dummy (1 or 0)	Houston Bcycle

3.4.2 Weather Variables

Many literatures have concluded that the weather plays a significant role in determining bike share usage. Temperature, wind speed, and precipitation has been identified by previous research as variables that can affect bike share ridership (Miranda-Moreno and Nosal, 2011; Gebhart and Noland, 2014). In most studies, the temperature has been showed to be positively related to the bike share ridership, while the wind speed and precipitation are negatively associated with the bike ridership. For our study, the average daily temperature, average daily precipitation, and average daily wind speed are chosen as the indicators of daily weather conditions. These three indicators are expected to have the most effect on the safety and amenity of cycling, thus must have the most significant impact on ridership. It is worth notice that weather information is joined to trip count by day and is invariant across all the stations on the same date. Table 3.3 shows the summary of the weather variables. The following part of this report will discuss more details about the relationship between the daily ridership and weather variables.

Table 3.3: Weather Variables Description

Category	Variable	Description	Unit	Source
Weather	Mean temperature	The average daily temperature	°F	NOAA
	Mean precipitation	The average daily precipitation	mm	NOAA
	Mean wind speed	The average wind speed	mph	NOAA

Temperature. Figure 3.8 shows the relationship between daily number of trips and daily average temperature. It is visible that daily ridership increases when temperature is high. More trips are generated when temperature is higher than 68°F, and the increasing ratio of ridership decrease dramatically when the temperature is over 87°F. A few outlier days can be explained by the adverse weather that impacts that day. August 28th, 2017, for example, saw only 93 trips, due to 9 inches of precipitation that day. Extremely low number of 68 trips was also seen on August 25th, due to the high wind speed of 17 mph and the average precipitation of 1.4 inches.

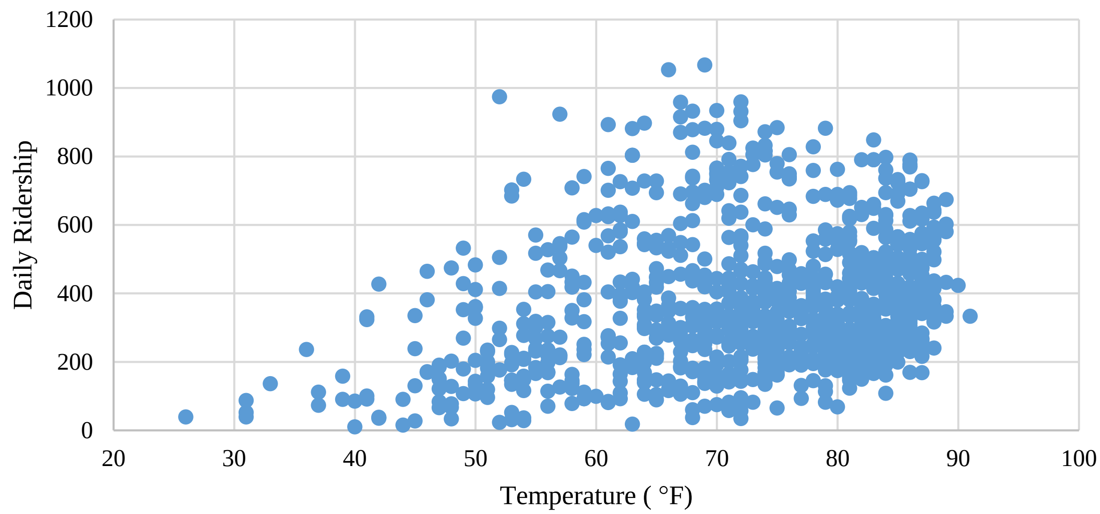

Figure 3.8: Daily Ridership and Average Daily Temperature

Precipitation. According to the standards created by the American Meteorological Society and National Meteorological Library, contiguous precipitation data has been transformed into five categories for this study. As shown in Table 3.4 (Precipitation Level Standards), from January 1st, 2016 to August 31st, 2018, 681 days had no precipitation; 112 days had light precipitation; 64 days had moderate precipitation; 102 days had heavy precipitation while 15 day had violent precipitation. That means about 69% of the days had no precipitation while 31% had less or more precipitation.

Table 3.4: Precipitation Level Standards

Precipitation Category	None	Light	Moderate	Heavy	Violent
Standard (inch)	0	0 - 0.1	0.1 - 0.3	0.3 - 2.0	Over 2.0
Days	681	112	64	102	15

Figure 3.9 shows the total ridership in each precipitation level. More than 77% trips are generated in days without precipitation. When precipitation level gets higher – from none precipitation to violent – the ridership tends to decrease significantly.

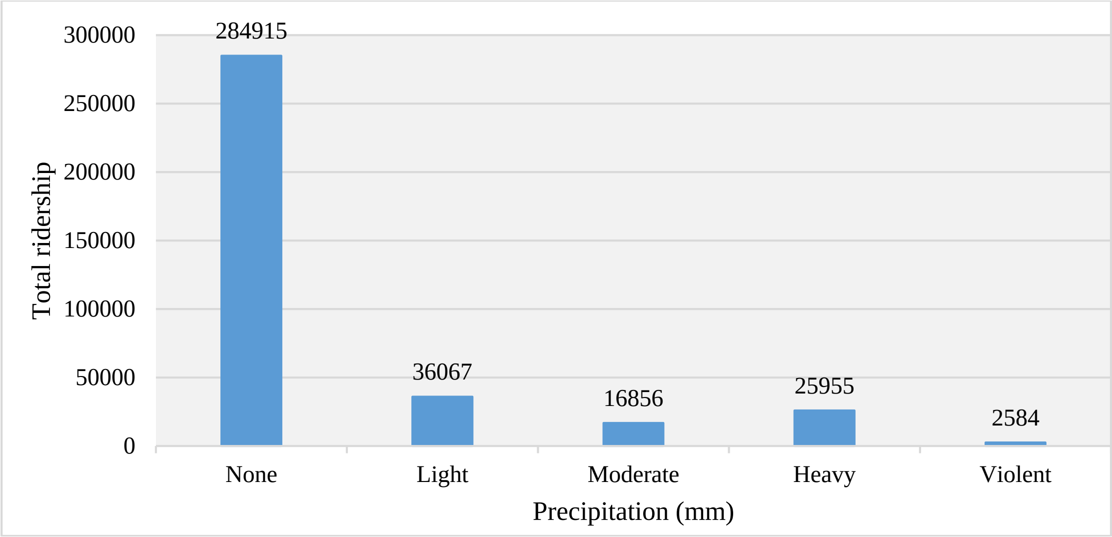

Figure 3.9: Total Ridership and Precipitation

Wind speed. Figure 3.10 shows the relationship between daily ridership and the average wind speed; when the wind speed is lower than 10 mph, more trips tend to be generated; when the wind speed is higher than 10 mph, ridership starts to decrease substantially.

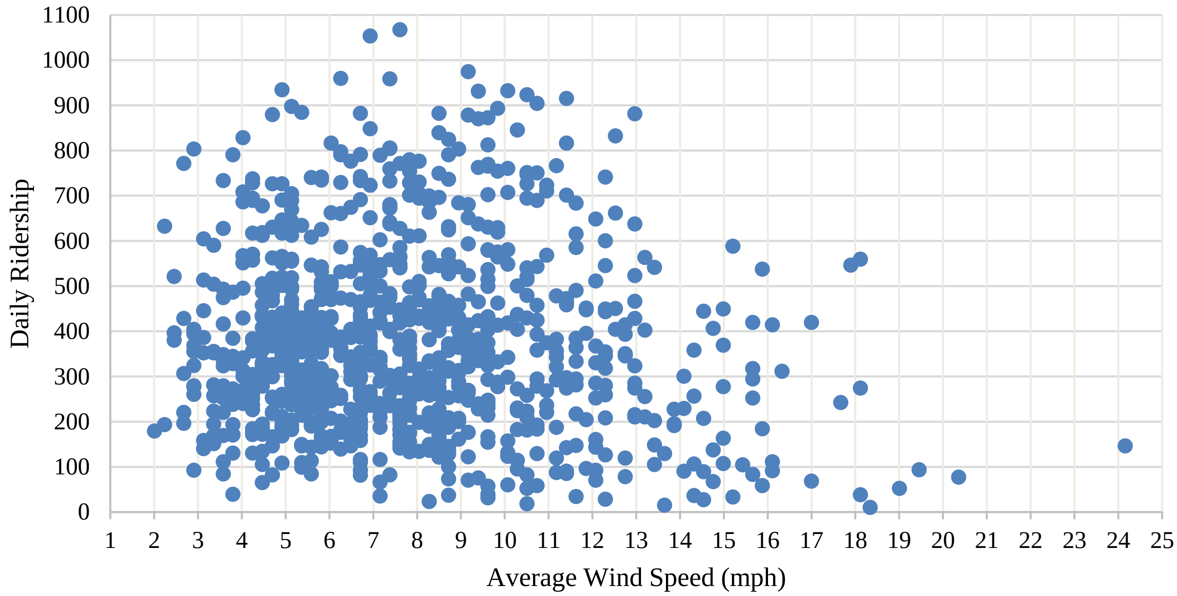

Figure 3.10: Daily Ridership and Average Daily Wind Speed

3.4.3 Built Environment Variables

As mentioned in the previous chapter, one of the limitations of the existing literatures is lacking a consistent spatial scale to measure spatial variables including built environment, land use, and socio-demographic variables. It is reasonable to assume that different measurements can lead to different results. To investigate the effects of scale and verify the consistency of the relationship between ridership and the built environment, land use, and socio-demographic variables, this study considers three buffer radiuses (0.25-mile, 0.5-mile, and one-mile) – estimated 5-min,10-min, and 20-min walking distances, in quantifying spatial factors of each bike share station. Figure 3.11 displays these three radius buffers around the bike share stations.

Figure 3.11: 0.25-mile, 0.5-mile, and One-mile Station-level Buffer

In order to ensure the consistency of the dataset and to include more stations in the analysis, ridership data from September 1st, 2017 to August 31st, 2018 are selected from the historical ridership data, and 42 out of the total 59 stations are chosen since 17 stations were launched or relaunched after September 1st, 2017.

To measure the effects of built environment, land use and socio-demographics around each station, variables are measured with different buffer radiuses and used the “spatial join” and “intersect” functions in the ArcGIS to compile the spatial data to different buffer areas linked to each bike share station. Table 3.5 shows the description of built environment, land use and socio-demographics variables used in this study.

Table 3.5: Built Environment Variables Description

Category	Variable	Description	Unit	Source
Socio-Demographics	Household density	The number of households per square mile	1000pers/Mi^2	H-GAC
	Employment density	The number of employments per square mile	1000pers/Mi^2	H-GAC
Built Environment	Bike lane	The sum of bike lane length	mile	City of Houston
	Bus stop	The number of metro bus stops	NA	H-GAC
	Light rail station	The number of metro rail stations	NA	H-GAC
	Nearby station	The number of bike share stations in buffers	NA	Houston Bcycle
	Docks	The number of docks at bike share stations	NA	Houston Bcycle
	School	The number of schools in buffers	NA	City of Houston
	Street tree	The number of street trees in buffers	NA	City of Houston
Land use	Percent of commercial	The percent of commercial land use	%	H-GAC
	Percent of governmental/medical /educational	The percent of governmental/medical /educational land use	%	H-GAC
	Percent of residential	The percent of residential land use	%	H-GAC
	Percent of park	The percent of park	%	H-GAC

Moreover, the data summary for selected variables corresponding to each buffer radius is listed in Tables 3.6, 3.7, and 3.8. The household density and employment density increase as the buffer radius decreases, while the length of bike lanes, the number of bus stops, light rail stations, schools, trees, and nearby stations decrease as the radius decreases. The weather and temporal variables are constant across the three spatial scales regardless of the buffer radius. However, the percentage of different land use types varies in each buffer radius

Table 3.6: Built Environment Variables Summary in one-mile Buffer

	One-mile buffer			
Variable	Mean	S.D.	Min.	Max.
Household Density	6745.10	2177.62	3009.37	11785.19
Employment Density	21769.55	16775.57	1578.61	43657.24
Bike Lane	16.80	5.48	5.37	26.74
Bus Stop	197.86	69.28	89.00	300.00
Light Rail Station	7.17	5.01	0.00	14.00
School	6.93	4.15	1.00	17.00
Street Tree	8912.64	3301.57	3476.00	18837.00
Nearby station	11.26	7.12	0.00	23.00
Pct.of Residential	0.28	0.12	0.08	0.60
Pct.of Commericial	0.28	0.12	0.04	0.53
Pct.of Gov/Med/Edu	0.13	0.12	0.01	0.55
Pct.of Park	0.08	0.09	0.01	0.39

Table 3.7: Built Environment Variables Summary in 0.5-mile Buffer

	0.5-mile buffer			
Variable	Mean	S.D.	Min.	Max.
Household Density	7131.09	3093.16	2521.25	12904.64
Employment Density	36520.60	45679.98	1599.79	160534.44
Bike Lane	3.86	1.68	1.17	6.70
Bus Stop	61.36	41.31	13.00	149
Light Rail Station	2.79	3.10	0.00	10
School	1.33	1.52	0.00	5
Street Tree	2385.86	1126.66	545.00	6118
Nearby station	3.88	3.18	0.00	12
Pct.of Residential	0.29	0.20	0.02	0.69
Pct.of Commericial	0.32	0.16	0.00	0.58
Pct.of Gov/Med/Edu	0.09	0.13	0.01	0.65
Pct.of Park	0.07	0.13	0.00	0.69

Table 3.8: Built Environment Variables Summary in 0.25-mile Buffer

	0.25-milebuffer			
Variable	Mean	S.D.	Min.	Max.
Household Density	7045.37	4390.44	0.00	17337.52
Employment Density	51507.37	91665.72	488.91	384215.81
Bike Lane	1.05	0.67	0.00	2.20
Bus Stop	18.69	16.65	0.00	56
Light Rail Station	0.81	1.09	0.00	4
School	0.48	0.92	0.00	4
Street Tree	611.62	324.53	0.00	1604
Nearby station	1.12	1.31	0.00	5
Pct.of Residential	0.28	0.20	0.00	0.73
Pct.of Commericial	0.32	0.22	0.00	0.71
Pct.of Gov/Med/Edu	0.07	0.12	0.00	0.50
Pct.of Park	0.12	0.22	0.00	0.99

3.5 Choice of Model

In this study, the Generalized Linear Mixed Model (GLMM) is used to analyze the hourly bicycle counts of checkout and return at a station-level. As describe in the previous section, the bicycle counts, as longitudinal data, generated from and attracted to bike share stations exhibit both temporal differencing and spatial clustering, GLMM helps estimate the joint effect of temporal variables (e.g. event and weather) and spatial variables (e.g. built environment, land use, socio – demographics) on the bicycle counts. GLMM combines the characteristics of generalized linear models and mixed models. It is an extension of generalized linear models (GLM) for data that are collected and summarized in groups. Alternatively, it also works as a generalization of linear mixed models (LME) for the data where the response variable is not normally distributed and the independent variables have both time-variant (fixed effect) and time-invariant (random effect) variables.

The GLMM used in this study follows the traditional linear model specification by assuming the logarithmic link function $\ln(\mu_{it})$ and is expressed in Eq.1 below:

$$\ln(\mu_{it}) = \beta_0 + \beta X_{it} + \gamma Z_i + \varepsilon_{it} \quad (1)$$

where μ_{it} is the mean of bicycle count at the 42 bike share stations over the moment t; β_0 is the overall intercept; X_{it} refers to the fixed effects which are time-variant variables with coefficientβ; Z_i refers to the random effects which are time-invariant variables with coefficient γ; and ε_{it} is the error term.

3.6 Analysis and Results

In this section, the results of the GLMM are presented to understand the different effects of the built environment and temporal variables on the bike share usage in Houston. The estimated results for each buffer radius (i.e. 1 mile, 0.5-mile, and 0.25-mile) based on the hourly checkouts and returns are provided in Tables 3.9, 3.10, and 3.11, respectively, and their impacts are discussed below.

One-mile Buffer. Table 3.9 shows the results of the GLMM for station-level hourly analysis for the one-mile buffer. It is noticeable that three temporal-varying variables – weekends, peak hours, and non-winter seasons – have significant impact on the bike share usage. The bike share in Houston is more popular in weekends. Forth more, the bike share ridership is higher in the non-peak hours and non-winter seasons. All results correspond with the trip pattern observed in the descriptive statistics.

In terms of the weather effects, the temperature is negatively correlated with bicycle checkouts and positively correlated with bicycle returns. The precipitation has a significant impact on bike share usage. More precipitation will discourage both bicycle checkouts and returns. Besides, unlike the previous studies, wind speed increase plays a positive role in encouraging bicycle checkouts in Houston and discouraging bicycle returns. This is reasonable because with a relatively high average temperature in most months, high wind speed reduces the impact of the heat.

For socio-demographics factors, the employment density is statistically significant and positively correlated with both bicycle checkouts and returns while the household density is negatively associated with bike share usage. This result reveals that commute to work is a major purpose in a one-mile buffer in addition to the recreational use of the bike share.

In terms of infrastructure in a one-mile buffer of each station, the length of the bike lanes, trees, and number of docks are positively correlated with hourly ridership while bus stops, light rail stations, schools, and nearby stations are negatively associated with the hourly trips. In addition, the number of docks in one-mile buffer is found to be statistically significant for both bicycle checkouts and returns. The results provide an indication that substitution effect exists between the transit infrastructures and Houston bike share.

As for land use factors, it is expected that commercial and the government, medical and educational land use are positively correlated with the bicycle checkouts and returns while the residential lands and parks are negatively associated with the bike share usage. This result is also supported by the result of socio-demographics discussed above.

Table 3.9: Generalized Linear Mixed Model Results of One-mile Buffer

One-mile buffer					
		Checkout		**Return**	
		Estimate	P-value	Estimate	P-value
	(Intercept)	0.7311	0.2402	0.8378	0.2053
Temporal Event	Weekend	0.2917***	0.0000	0.2883***	0.0000
	Peak hour	-0.0366**	5.17e-10	-0.1074**	3.73e-66
	Non-winter	0.1266**	9.00e-25	0.0392**	1.50e-07
Weather	Mean Temperature	-9.88e-05	0.7682	0.0001	0.3951
	Mean Precipitation	-0.0604**	8.49e-11	-0.0713**	1.59e-13
	Mean Wind speed	0.0012	0.2658	-0.0040**	0.0004
Socio-Demographics	Household density	-1.12e-05	0.7927	-3.83e-05	0.3900
	Employment density	3.09e-05**	0.0008	3.40e-05**	0.0005
Infrastructures	Bike lane	0.0020	0.9170	0.0035	0.8604
	Bus stop	-0.0038	0.2335	-0.0042	0.2127
	Light rail station	-0.0205	0.4763	-0.0366	0.2263
	School	-0.0069	0.6460	-0.0047	0.7651
	Tree	2.60e-05	0.3122	3.51e-05	0.1953
	Nearby station	-0.0268	0.1901	-0.0193	0.3700
	Dock	0.2384**	0.0019	0.2356**	0.0036
Land Use	Pct. Residential	-0.7811	0.4121	-0.6459	0.5187
	Pct. Commercial	0.7367	0.3751	0.9546	0.2744
	Pct. Gov/Med/Edu	0.9464	0.1150	1.1341	0.0720
	Pct. Park	-1.0546	0.2965	-1.2173	0.2520
	Level of significance: "***", 0.001; "**", 0.01; "*", 0.05.				
	Random effects	Station ID			
	Model fit	AIC	BIC	Likelihood	Deviance
	Checkout	1.72e+05	1.72e+05	-85968	1.71e+05
	Return	1.58e+05	1.59e+05	-79243	1.58e+05

0.5-mile Buffer. A GLMM is estimated for the data measured within a 0.5-mile buffer. Similar to the results of the one-mile buffer, people tend to bicycle more on weekends, non-peak hours, and non-winter seasons as highlighted by the positive coefficient of the weekend and non-winter variables and the negative coefficient of the peak hour variable.

To compare the impacts of weather on bicycle checkouts and returns in a 0.5-mile buffer, similar to previous findings of the one-mile buffer, the high temperature will impact less bicycle checkouts and lead to more bicycle returns and shorter trip duration; the impact of the precipitation are negatively correlated with bicycle checkouts and returns, while the wind speed encourages people in Houston to ride more and longer.

For the infrastructure factors, the length of bike lane is statistically significant and positively correlated with both bicycle checkouts and returns. This result indicates that comparing with bike lanes in a one-mile buffer of each station, adding more bike lanes in a 0.5-mile buffer of each station is more likely to attract more bike share usage. In the 0.5-mile buffer, the number of bus stops becomes statistically significant and negatively associated with both bicycle checkouts and returns which increase the substation impact between the public transit and bike share. However, the number of the light rail stations is positively correlated with the bicycle checkouts and returns with no statistically significant relationship in a 0.5-mile buffer. One possible explanation for this situation is because the service area of light rail is relatively small in Houston, however, majority of the light rail stations are located in a distance of 0.5 mile to the bike share stations with the high ridership.

In terms of land use factors in a 0.5-mile buffer, different from the results in one-mile buffer, the commercial land use become negatively correlated with the bicycle checkouts and returns while the park land use is positively correlated with the bike share usage in a 0.5-mile buffer.

Table 3.10: Generalized Linear Mixed Model Results of 0.5-mile Buffer

0.5-mile buffer					
		Checkout		**Return**	
		Estimate	P-value	Estimate	P-value
	(Intercept)	0.2116	0.4153	0.2945	0.2053
Temporal Event	Weekend	0.2917***	0.0000	0.2883***	0.0000
	Peak hour	-0.0366**	5.38e-10	-0.1074**	4.10e-66
	Non-winter	0.1266**	9.70e-25	0.0392**	1.50e-07
Weather	Mean Temperature	--9.46e-05	0.7779	0.0001	0.3869
	Mean Precipitation	-0.0604**	8.36e-11	-0.0713**	1.56e-13
	Mean Wind speed	0.0012	0.2644	-0.0040**	0.0004
Socio-Demographics	Household density	3.87e-05	0.0601	4.44e-05	0.0503
	Employment density	5.90e-06*	0.0211	5.90e-06*	0.0365
Infrastructures	Bike lane	0.0724*	0.0288	0.0749*	0.0390
	Bus stop	-0.0077**	0.0098	-0.0077*	0.0181
	Light rail station	0.0198	0.5369	0.0208	0.5572
	School	-0.0104	0.7627	-0.0130	0.7321
	Tree	-1.96e-05	0.7224	-3.02e-05	0.6199
	Nearby station	-0.0220	0.5215	-0.0210	0.5804
	Dock	0.0758	0.3615	0.0790	0.3880
Land Use	Pct. Residential	-0.2730	0.5302	-0.2563	0.5927
	Pct. Commercial	-9.81e-05	0.9998	-0.0067	0.9912
	Pct. Gov/Med/Edu	0.5550	0.1489	0.6399	0.1312
	Pct. Park	0.4167	0.2902	0.2837	0.5138
	Level of significance: "***", 0.001; "**", 0.01; "*", 0.05				
	Random effects	Station ID			
	Model fit	AIC	BIC	Likelihood	Deviance
	Checkout	1.72e+05	1.72e+05	-85969	1.71e+05
	Return	1.58e+05	1.59e+05	-79246	1.58e+05

0.25-mile Buffer. This section covers the results of GLMM estimation for the 0.25-mile buffer. As shown in Table 3.11, similar results are seen from previously used temporal variables – people tend to use the bike share more on weekdays, in peak hours, and non-winter seasons in all three models. The impact of the weather variables is also consistent through all three different buffers. The length of the bike lanes is statistically significant and positively correlated with the bike ridership which confirms that dense bike lanes in a small area encourage more ridership.
It is worth notice that in 0.25-mile buffer, the percentage of park land use become statistically significant and positive correlated with bicycle checkouts and returns. This result is reasonable because a large number of trips in Houston are generated for the purpose of recreation and fitness.

Table 3.11: Generalized Linear Mixed Model Results of 0.25-mile Buffer

0.25-mile buffer					
		Checkout		**Return**	
		Estimate	P-value	Estimate	P-value
	(Intercept)	0.3691**	0.0314	0.4903**	0.0094
Temporal Event	Weekend	0.2917***	0.0000	0.2883***	0.0000
	Peak hour	-0.0366**	5.34e-10	-0.1074**	4.09e-66
	Non-winter	0.1266**	9.83e-25	0.0392**	1.43e-07
Weather	Mean Temperature	--9.46e-05	0.7779	0.0001	0.3896
	Mean Precipitation	-0.0604**	8.39e-11	-0.0713**	1.56e-13
	Mean Wind speed	0.0012	0.2650	-0.0040**	0.0004
Socio-Demographics	Household density	-1.17e-06	0.9230	7.19e-07	0.9574
	Employment density	4.84e-07	0.5248	5.96e-07	0.4789
Infrastructures	Bike lane	0.1497**	0.0199	0.1529*	0.0317
	Bus stop	-0.0035	0.5264	-0.0036	0.5586
	Light rail station	-0.0420	0.3787	-0.0513	0.3318
	School	-0.0134	0.7649	-0.0096	0.8461
	Tree	0.0002	0.1675	0.0002	0.1920
	Nearby station	-0.0581	0.1990	0.0625	0.2120
	Dock	0.0426	0.5917	0.0408	0.6428
Land Use	Pct. Residential	-0.3829	0.1731	-0.4295	0.1678
	Pct. Commercial	-0.3308	0.3307	-0.3987	0.2900
	Pct. Gov/Med/Edu	-0.3902	0.3134	0.3483	0.4165
	Pct. Park	0.5413**	0.0141	0.4968*	0.0422
	Level of significance: "***", 0.001; "**", 0.01; "*", 0.05				
	Random effects	Station ID			
	Model fit	AIC	BIC	Likelihood	Deviance
	Checkout	1.72e+05	1.72e+05	-85969	1.71e+05
	Return	1.58e+05	1.59e+05	-79246	1.58e+05

The following table (Table 3.12) summarizes the coefficients of temporal and built environment variables and the significance of three models. As mentioned in Chapter 2, one of the limitations in existing literatures is that researchers use different scales to measure built environment and may lead to different results. This research provides a comparison between the results of different spatial scales. As shown in Table 13, the temporal and weather variables, and the employment density are significant in three buffer scales, while other variables are either significant in one or two scales. Comparisons between different scales not only provide an indication that the subjective measurement, especially built environment variables, could lead to biased results, but also highlight the important effects of bike lane and parks in particular spatial environment. Although the results vary in different buffers, it provide the planners and decision makers insights on choosing the scale that fits the most in their situation.

Table 3.12: Coefficients Significance in Different Buffer Scales

	One-mile buffer		**0.5-mile buffer**		**0.25-mile buffer**	
	Checkout	Return	Checkout	Return	Checkout	Return
Weekend	0.2917***	0.2883***	0.2917***	0.2883***	0.2917***	0.2883***
Peak Hour	-0.0366**	-0.1074**	-0.0366**	-0.1074**	-0.0366**	-0.1074**
Non-winter	0.1266**	0.0392**	0.1266**	0.0392**	0.1266**	0.0392**
Mean Temperature	-9.88e-05	0.0001	--9.46e-05	0.0001	--9.46e-05	0.0001
Mean Precipitation	-0.0604**	-0.0713**	-0.0604**	-0.0713**	-0.0604**	-0.0713**
Mean Wind Speed	0.0012	-0.0040**	0.0012	-0.0040**	0.0012	-0.0040**
Household Density	-1.12e-05	-3.83e-05	3.87e-05	4.44e-05	-1.17e-06	7.19e-07
Employment Density	3.09e-05**	3.40e-05**	5.90e-06*	5.90e-06*	4.84e-07*	5.96e-07
Bike Lane	0.0020	0.0035	0.0724*	0.0749*	0.1497**	0.1529*
Bus Stop	-0.0038	-0.0042	-0.0077**	-0.0077*	-0.0035	-0.0036
Light Rail Station	-0.0205	-0.0366	0.0198	0.0208	-0.0420	-0.0513
School	-0.0069	-0.0047	-0.0104	-0.0130	-0.0134	-0.0096
Tree	2.60e-05	3.51e-05	-1.96e-05	-3.02e-05	0.0002	0.0002
Nearby Station	-0.0268	-0.0193	-0.0220	-0.0210	-0.0581	0.0625
Dock	0.2384**	0.2356**	0.0758	0.0790	0.0426	0.0408
Pct. Residential	-0.7811	-0.6459	-0.2730	-0.2563	-0.3829	-0.4295
Pct. Commercial	0.7367	0.9546	-9.81e-05	-0.0067	-0.3308	-0.3987
Pct. Gov/Med/Edu	0.9464	1.1341	0.5550	0.6399	-0.3902	0.3483
Pct. Park	-1.0546	-1.2173	0.4167	0.2837	0.5413**	0.4968*

Level of significance: "***", 0.001; "**", 0.01; "*", 0.05.

3.7 Summary

The ridership data and also the data for the weather and built environment information were collected from various sources. A Generalized Linear Mixed Model (GLMM) was used to evaluate the effects of temporal, weather, and built environment on the hourly bicycle checkouts and returns at each bike share station. Modeling outcomes were also compared based on three spatial scales (one mile, 0.5 mile, and 0.25 mile) in quantifying the built environment factors of each bike share station.

The results of the study show that people tend to use Houston BCycle more on weekends, non-peak hours and non-winter seasons. Bike lanes, number of docks, and employment density are found to have positive correlations with bicycle checkouts and returns in all three spatial scales. Furthermore, the number of nearby stations and percentage of park land use are negatively correlated with the hourly ridership in the larger spatial scales while the correlations are positive in 0.25-mile buffer radius.

Chapter 4. Recommend Equity Considerations

4.1 Introduction

Equity is the quality of being fair and impartial irrespective of race, color and financial status. It is the foundation of any fair society where each section of the society has the opportunity to reach its full potential. Equity prevents any section of society (middle or upper-class communities) from dominating other sections (underserved communities). Some communities may need more support than others in order to achieve their full potential. However, Equity does not allow generalizations about particular groups of people.

Bike Share Equity is providing equitable, fair and impartial access to bicycle station facilities for each section of the society. Equity in bike share should be done from the start of the bike share project, i.e., of choosing the location in particular neighborhoods to facilitating the use of the bicycles. Learning to tolerate differences within the community makes a better society with more involved citizens. Such lessons contribute to a balanced curriculum and may lead to creating a safe environment in which there will be less issues of underserved community; and the resulting social, emotional, and spiritual repercussions will decrease in the society.

4.2 Bike Share Barriers

There have been legitimate concerns that traditionally underserved communities are marginalized or incompetent to share in the full advantages of existing and future bicycle oriented designing efforts. Bike share operates best in high-density and mixed-use neighborhoods. However, recent and growing bike-share systems have targeted mainly middle and upper-class communities despite the facts that underserved communities, generally African American and Latino, tend to undergo: (1) lower rates of mobility/accessibility; (2) higher rates of obesity and related health risks; and (3) higher rates of pedestrian- and bicycle-related fatalities (Fishman 2015).

Low income and minority populations are less likely to have cars and depend more often on non-motorized modes of transportation (Litman, 2014b; McConville, 2013). Even though bike share systems have grown and expanded, the vast majority of users are still from the wealthy and white communities in the cities these programs serve (Ursaki and Aultman-Hall, 2016; Smith, Oh and Lei, 2015). A study showed that there is no lack of desire to ride among residents of underserved neighborhoods. In fact, residents of low-income, majority-minority neighborhoods have an overwhelmingly favorable view of bike share. They are less likely to have close social connections to people who use bike share, information on discount programs, access to safe streets and protective gear, and reassurance about liability and hidden fees (McNeil et al., 2017).

For the standard membership, most bike share system users are required to have credit cards or smartphones which lower-income residents are less likely to have. Moreover, even if they have credit cards, some may not want to use it for the fear that they will be charged more than they expect due to overage fees or probable bike damage (McNeil et al., 2017). Language barriers or the lack of ability to ride a bicycle also prevent some people, while many others think their local streets are not safe enough for bicycling (McNeil et al., 2017). Lower-income communities may be more likely to experience difficulties related to mobility and accessibility overall and tend to be underserved by bicycle share systems (Smith et al., 2015).

Strategic bike-related investments in underserved neighborhoods hold promise for expanding travel options, access to jobs and possibilities, and the equitable distribution of infrastructure. Additionally, bicycling stretches mobility issues; influencing the well-being of communities by giving opportunities to be physically active, the security of the environment, and investments in future generations (Cavill, Kahlmeier and Racioppi, 2006; Dora and Philips, 2000). Every community making bicycling investments should understand who is and is not benefiting from access to infrastructure, the potential inequities that may result from investments, and use that understanding to ensure more equitable processes and outcomes.

Hence, from a transportation equity viewpoint, certain groups are essential to be considered because they may possess a greater requirement of affordable modes of transportation and should be superiority for alternative transportation investment (Zelalem, Glas, Greenlee, Vanik, Bowman and Dieber, 2009). There is a belief that bike share systems could do much more to make lower-income people of color feel comfortable joining and to let them know what their options are.

4.3 Houston Bike Share and Equity

Houston's bike sharing system (Houston BCycle) is a 501(c)(3) non-profit organization that administers bike sharing for the City of Houston was launched in May 2012. Houston is located in Harris County, and Harris County population has grown substantially since 1990. Between 1990 and 2019, the Harris County area added over 1.95 million people. That increase in population has brought significant changes to the region. Analyzing 1990, 2000, and 2010 censuses shows that Houston has become more racially/ethnically diverse over the past 20 years, such that every racial/ethnic group is now a demographic minority. In fact, Houston is one of the most racially/ethnically diverse metropolitan areas in the nation (one of the ten most diverse metropolitan areas in the U.S.). Unlike the other large metropolitan areas, all four major racial/ethnic groups have substantial representation in Houston with Latinos and Anglos occupying roughly equal shares of the population (Michael O. Emerson et al., 2016). Although Houston is ethnically diverse, it seems that the bike share system has not reached the underserved communities.

Houston's bike share system provides different types membership, described in Chapter 2. Houston BCycle is one of the few bike share systems in the nation that has a discounted membership for its low income users and also gives the option for payment through cash. Offering discounts on purchases is a way to bring low-income and underserved community closer to the bike share system and draw them into the system quickly. On the other hand, payment method characteristics may present a challenge to lower-income and minority communities. Houston BCycle undertook the measure of making the payment options more appealing and accessible for low-income users who may not be able to or interested in committing to long-term memberships or using credit or debit cards for payment. For low-income people having an option of payment through cash makes them feel more acceptable in society and also removes the fear of getting charged with hidden fees. GO Pass is a special membership for qualified Houstonians without the financial means to pay for standard $13 per month or $79 per year membership fee. GO Pass members can pick up a bike at any station, ride for up to 90 minutes (30 minutes more than regular membership), and then drop that bike off at any station. To be eligible for GO Pass, the applicant must show a self-reported annual income of $35,000 or less, a verifiable phone number, 18 years of age and must pay at least $3 in cash or credit card payment for the first month at BCycle partner institution, “Change Happens”. If paying in cash, recurring payments will need to be made in person. If paying with credit/debit card, the first payment will need to be made in person.

Houston BCycle recently launched a program named ambassador program. The system chooses one ambassador from each neighborhood within the service area in order to bolster the low-income areas in the future. BCycle ambassadors spread the word about the bike share system by hosting events, rides, and tabling at community get-togethers. These volunteer opportunities are called “engagement activities.” The program was made with the understanding that word-of mouth and grassroots information delivery generally works best in underserved communities, where the reisdents might not think that the bikes are there for them.

Houston BCycle is the official healthcare partner of CHI St. Luke’s Health to increase access to healthier transportation options and to launch 5-Day Health Challenges among the users who sign up at their official website. At CHI St. Luke’s Health website users receive a Houston BCycle membership promo code and three different levels of challenges to choose from. This program aims to utilize bike share services to address health concerns of the people of the community including minorities through increasing access to bicycles and offering alternative ways to increase physical activity.

4.4 Recommended Strategies for Bike Share Equity in Houston

4.4.1 Temporal Variables

There is a risk of further marginalizing traditionally underserved populations if station distribution is not equitable across a region. Station locations and density are among the most important factors in bike share system success. Stations should be located close together so that the users are not taxed with walking far distances in order to access the system while also giving the riders increased options to connect with the stations (Lindsey Conrow et al., 2018). “Convenience” is often stated as a motivator for taking advantage of bicycle share; and living in close proximity to a bicycle share station results in higher utilization (Fishman et al.,2013, 2014; Fuller et al., 2011). However, a study has showed that people of color and lower-income people are less likely to reside within walking distance of a bike share station (e.g., Ursaki and Aultman-Hall, 2016). Despite lower bicycle station density in the areas with lower socioeconomic status, the users in those areas make a higher number of trips. Controlling station densities and expanding systems into lower income areas tend to increased ridership among low-income users (Ogilvie and Goodman, 2012; Goodman and Cheshire, 2014). Therefore, Houston BCycle bike is suggested to expand its bicycle stations in the low income and underserved communities in order to provide convenient access which is crucial in developing both equity and increased ridership within the bicycle share system.

4.4.2 Rebalancing

A key to success for any bike-sharing system is the effectiveness of rebalancing operations (Liu and Xiong, et al. (2016)), that is restoring the number of bicycles in each station to its target value by routing vehicles through pick-up and drop-off operations. If a station gets full with no available docks, the riders cannot return the bicycles to that specific station. On the other hand, a station with all empty docks means that the potential riders cannot pick up the bicycles from there. To keep the system efficient and the users happy, the bike share system needs to maintain the appropriate and sufficient number of bicycles at all the stations. This process of distributing and redistributing the bicycles throughout a bike share system to ensure consistent bike/dock availability is known as "rebalancing". The dynamics of human mobility often lead to inevitable bicycle supply/demand imbalance. Thus, Houston BCycle must redistribute bicycles among stations in a proactive way to ensure the system is functioning effectively in those underserved neighborhoods. An essential component to approaching bike-share accessibility issues in Houston demands not only having stations placed in underserved communities, but also ensuring that there are bicycles located and redistributed back to those areas and stations.

4.4.3 Bicycle Infrastructure

Accessibility is commonly described as a person's ability to reach the desired services and activities. It represents the ease or effort required in reaching services or events from a given place by utilizing a particular transportation system (Morris, Dumble and Wigan, 1979). Checking the accessibility is a critical evaluation and useful for examining the condition of a transportation system (Murray and Davis, 2001). Accessibility of bicycle infrastructure would allow one to assess the ability to reach services and opportunities using bike lanes. Lack of bicycle infrastructure within the bike share service area can be an essential equity challenge (McNeil et al., 2019). Even if the stations are placed in underserved neighborhoods, there will be still a need for safe bicycle facilities and route infrastructures near the stations. The marginalization of certain groups is believed to lead to greater disinvestments in the communities, including poor infrastructure (Williams and Collins, 2001). Houston's BCycle can encourage bike share users to request facility upgrades from the local governments. It also can work with city and county to align the bike share service with the installation of safe bicycle routes although bike share systems are usually managed separately from the transportation departments that are responsible for maintaining the bike routes.

4.4.4 Facilitated Enrollment

The result of not having access to a computer, internet, or smartphone can be a simple barrier for accessing and using bike share system as the user cannot create a rider account to become a member and cannot sign up to use the system. Language barrier and lack of understanding of how bike share works or what is required to participate can also result in such a barrier. Houston BCycle webpage is currently in two languages (English and Spanish), which may not be sufficient for a major city such as Houston with a broad diversity. The ultimate goal of a facilitated enrollment program is to make the sign-up process easy and convenient while also providing additional information and educational opportunities for new members. The programs include, but not limited to, tabling at community events, offering the option to make in-person appointments at locations convenient to individual residents, and provide enrollment help at other specialized cycling workshops or classes (McNeil et al., 2019).

4.4.5 Organized Rides

Many cycling clubs in Houston plan organized ride events, in which bicyclists of all levels can participate. Such events can be organized by ambassadors or bike advocacy organizations, too. The events usually start with a large group of riders, called the mass; and they thin out throughout the ride. Many riders prefer to ride together in groups of the same skill level to take pleasure of drafting. Those organized rides might be a key component to bike share equity programming. Organized rides can help new riders in underserved neighborhoods become familiar with the service provided by Houston BCycle, educate the riders about safe routes to utilize, make stronger connections between Houston BCycle and underserved neighborhoods, and foster a sense of community. Organized rides are geared to provide fun experiences that assist people to learn how the system works and gain comfort using it. Houston BCycle can help the community members to arrange the organized rides themselves and encourage them to use BCycle bikes and facilities. Houston BCycle can also provide snacks on those events as a way to make the experience more pleasant for the participants.

4.4.6 Advertise Bike Share Services

Previous studies have proved that low-income and underserved communities lack information about how to access the bike share systems. One of the best ways to spread information and promote a business is through advertising. Advertising leads to a higher volume of memberships in any system. Regular and focused advertising on particular groups such as underserved neighborhoods and providing them with the names, locations, and the information on how to access the services might lead them to involve more in the bike share system. With Houston's vast ethnic diversity, advertising in different languages will attract more customers as those customers feel more valued when expressed in their own language literally and figuratively. The different ways in which Houston BCycle can make the advertisement are as follows:

- online advertising and social media marketing;
- newspaper, radio and television advertising;
- door hangers and flyers; and
- advertisement in places where underserved communities are the targeted group.

4.4.7 Community Meetings and Surveys

Community meetings and surveys are excellent ways to involve the targeted community in the needs assessment process. These are investigative and evaluative tools that can provide a quick, intensive, and broad visibility picture of community concerns. They provide an opportunity for people of Houston with diverse backgrounds to share ideas and experiences about bike share. The usefulness of a community meeting and surveys depends on how representative participants are of the diverse community and the targeted audience. The success depends on the fact that the participants feel to express themselves openly at such events. Having an influential individual or respected organization sponsor the meeting can help to attract a broader range of participants.

Meeting and surveys can effectively involve local community members in planning, publicizing, moderating, and evaluating the Houston's Bike Share system. Underserved community feels as though they have been heard. The results will help identify the problems, assess the needs, or to suggest the questions requiring further study.

4.4.8 Adaptive Bicycles

Adaptive bicycles can help increase access to Houstons BCycle by offering accessible options for persons with disabilities in accordance with the Americans with Disabilities Act (ADA). This means providing opportunities for people who are not physically able or not comfortable to ride a standard bicycle (e.g., balance concerns), or need assistance in the form of riding with another person (e.g., tandem). Adaptive bicycle options make bike share systems more equitable and accessible by offering alternatives to people who would otherwise be unable to ride a bicycle. The options include handcycles, side-by-side tandem bicycles, heavy-duty cruisers, tricycles, and recumbent bicycles (McNeil et al., 2019). Starting an adaptive program may need purchasing and maintaining a more expensive fleet of bicycles, creating and sustaining community buy-in for these programs, and developing or possibly retrofitting existing docking stations and technology interfaces.

4.4.9 Internal Operations

Reaching equity requires conducting outreach, interfacing, and co-operating with diverse groups from disadvantaged neighborhoods and individuals with a variety of needs. Employee training and internal operations are other vital components of improving equity within an organization (McNeil et al., 2019). Hiring and training the employees in order to effectively and appropriately collaborate with various groups of people is essential to promote and achieve bike share equity. Recruiting staffs from various background and diverse neighborhoods and training the employees are crucial parts of creating positive relations with communities that are sensitive to social inequities. Houston BCycle should hire specific target percentages of employees from lower-income and disadvantaged communities. Its internal practices and programmatic efforts might also provide another route for producing equity through bike share. Houston BCycle can reach out to underserved community organizations for acquiring assistance in recruiting staff and sharing job openings with those organizations. Hiring bilingual staff and not asking about criminal background attempts to reach equity goals through hiring practices (McNeil et al., 2019). Houston BCycle should prepare its ambassadors and customer service team to appropriately and adequately interface, communicate, and interact with different groups in a culturally responsible and decent manner. Houston BCycle should partner with underserved community organizations to better understand how to conduct outreach with targeted groups and also train staff to be responsive to various rider needs.

4.4.10 Lucky Draws and Coupons

Lucky draws and coupons are exclusively used for engaging customers in any business. Similarly, Houston BCycle can set different strategies to promote bike share in underserved neighborhoods:

- organizing lucky draws and distributing coupons in particularly bike share stations to make the locals involved in the system;

- awarding the riders some credit points for each ride;

- setting a threshold for the credit points so once the points meet the threshold value, the coupon opens up and allows the members to get free rides.

Those strategies make the members of the underserved communities involved with the system and they can be expected for frequent visits from then on. Even the word-of-mouth advertisements about these kinds of promotion via social media could quickly boost ridership in those neighborhoods. These kinds of promotion have the potential to increase users and hopefully will encourage them to repeat the experiences in the future which, in turn, may build equity in bike share.

4.4.11 Internal Operations

Integrating Public Transportation

A step towards providing equity is integrating Houston BCycle with the existing public transportation service in Houston, i.e., Houston Metro. This creates more significant connections to available public transportation options, expands access to a variety of modes of transportation, eases bike to-transit trips, and reduces barriers to utilizing each of the systems for the users. Integrating the public transport system proposes using the same Metro Q card or Houston BCycle RFID card across the systems, creating integrated reduced-fare programs, and placing the bike share stations and the bike racks at the public transportation stops. Integrating bike share and public transportation systems would address equity concerns through reducing barriers to system use through pricing structures, payment methods, facilitating bike to transit trips for captive transit populations, and aiding more superior connectivity. Combining access, pricing, and payment methods of Houstons BCycle and Houston Metro can help facilitate easier access from bike to transit and vice versa for the riders.

Chapter 5. Summary and Conclusions

5.1 Introduction

A generalized linear mixed model was used to examine the effects of the built environment and temporal factors on the hourly count of bicycle checkouts and returns at a station level in Houston. Results of the analysis were presented in Section 3.6 with interpretations. The rest of this chapter is organized as follows. Section 4.2 provides a summary of the results, and concludes with the author's views. Section 4.3 describes the limitations and details the directions for further research in order to improve similar studies.

5.2 Summary and Conclusions

In this research, a generalized linear mixed model was used to examine the effects of the built environment and temporal factors on the hourly count of bicycle checkouts and returns at a station level in Houston. Three buffer radiuses were considered in this research to compare the impact of built environment variables in different spatial scales. The modeling framework incorporates built environment characteristics and multiple levels of temporal factors simultaneously. The results would be helpful for planners and decision makers to enhance the bike station location selection, aid in development of expansion plans, and improve bike rebalancing efficiency.

By analyzing the hourly bicycle checkouts and returns, this research is able to identify the variables effects between times of a day, day of a week, and season of a year. Many results are not surprising, people in Houston use bike share more frequently in the weekends and non-peak hours for the purpose of recreation and fitness. Therefore, Houston BCycle can expect a higher demand for bike rebalance at popular stations on weekends and off-peak hours.

The results of weather conditions and temporal factors with bike share ridership show that temperature and seasons have limited impacts on Houston's bike share. But higher precipitation will result in significantly ridership decrease. This is reasonable due to the relatively a short period of winter time and less weather variation in Houston. However, different from the existing studies, higher wind speed may lead to an increase of bike share in Houston. This is most probably because the average wind speed is relatively low, for about 7 mph, in Houston. For a city that is well known as having high heat and even higher humidity, light winds provide a more comfortable condition for cyclists. For future planning, information and guidance could be provided to system users on how to ride in the rain or even provide rain gear.

In terms of built environment factor, the results provide new insights regarding the built environment characteristics in different spatial scales of bike share stations. The results can be used by planners to locate new stations and optimize the existing system. As introduced before, bike share is initiated with the idea of assisting the first mile/last mile problem, therefore bike station locations are normally located in the high population areas and places of interests. The bike share station locations in Houston are also found to have the same characteristic. The coefficient estimates for socio-demographics and land use indicate that future stations should be implemented to serve dense employment areas and relatively singular land use type, especially the parks.

Another notable finding is that the public transit has a substitution impact and serves as a competing travel mode for the bike share stations that are located over 0.5 mile from public transit, for instance, bus stops. However, with the distance between bike stations and bus stops shorten to below 0.25 mile, bike share ridership is most likely to increase. This result provides recommendations for the bike share program to coordinate the new bike share stations and existing public transit in order to increase efficiency and save public funding.

In summary, this research fills a gap in the study of Houston's bike share system. It developed a GLMM that can be utilized to predict hourly bicycle checkouts and returns, and furthermore, it compares the impact of the built environment characteristics on the station-level ridership across different spatial scales. The results of this model provide planners' reference on choosing a particular spatial scale that beat fit their situation. It also provides insights for selecting the station location and assist hourly bicycle redistribution.

5.3 Directions for Future Research

Although this research provides insights into hourly ridership across different scales, one limitation should be noted is that longitudinal count data should be collected in a relatively long period of time for a longitudinal analysis of the built environment impact on bike share usage. Most built environment features could remain unchanged in a one-year period for a developed city like Houston.

Second, weather conditions in Houston may change unpredictably in one day period. To better analysis the pattern of hourly bicycle checkouts and returns, hourly weather information should be collected instead of daily average weather information to examine a more reliable relationship between the weather conditions and the bike share ridership in Houston. It would be meaningful to consider this problem in the future studies when data are available. Moreover, a stepwise regression procedure (e.g. backward elimination) is recommended to reduce the degree of the model.

Third, with the limitation of users' information, this study does not evaluate the possible impact of temporal, weather, built environment, and other variables on the numbers of trips generated by different user types and user characteristics such as gender, age, race, etc. A more comprehensive research on this topic will help to encourage more people in joining bike share and promote a more equitable cycling environment for all groups of the people.

References

Amiri, M., and Sadeghpour, F. (2015). Cycling Characteristics in cities with cold weather. ScienceDiret, Vol.14. pp. 397-403.
Bergstrom, A., and Magnusson, R. (2003). Potential of Transferring Car Trips to Bicycle During Winter. Transportation Research Part A, Vol. 37, No. 8. pp. 649-666.
Borgnat, P., Robardet, C., and Rouquier, J. (2011). Shared bicycles in a city: A signal processing and data analysis perspective. Advances in Complex Systems, Vol.14, No.3. pp. 415-438.
Cavill, N., Kahlmeier, S., and Racioppi, F. (Eds.) (2006). Physical activity and health in Europe: evidence for action. World Health Organization.
Conrow, Lindsey, Alan T. Murray, and Heather A. Fischer (2018). An optimization approach for equitable bicycle share station siting. Journal of Transport Geography 69 163-170.
DeMaio, P. (2009). Bike sharing: history, impacts, models of provision, and future. Journal of Public Transportation, 12 (4), pp. 41–56.
Dora, C., Phillips, M. A., and Phillips, M. (Eds.) (2000). Transport, environment and health. (No. 89). WHO Regional Office Europe.
El-Assi, W., Mahmoud, M., and Habib, K. (2015). Effects of Built Environment and Weather on Bike Sharing Demand: A Station Level Analysis of Commercial Bike Sharing in Toronto. Transportation, pp. 1-25.
Emerson, Michael O., et al. (2012). Houston region grows more racially/ethnically diverse, with Small declines in segregation. A Joint Report Analyzing Census Data from 1990, 2000, and 2010.
Etienne, C. and Latifa, O.(2014). Model-based count series clustering for bike sharing system usage mining: a case study with the Vélib'system of Paris. ACM Transactions on Intelligent Systems and Technology, Vol.5, No.39.
Faghih-Imani, A., Eluru, N., El-Geneidy, A. M., Rabbat, M., and Haq, U. (2014). How Land-Use and Urban Form Impact Bicycle Flows: Evidence from the Bicycle-Sharing System (BIXI) in Montreal. Journal of Transport Geography, Vol.41, pp. 306-314.
Fishman, Elliot, et al. (2013). Bike Share: A Synthesis of the Literature. Transport Reviews 33 (2): 148–65. doi:10.1080/01441647.2013.775612.
Fishman, E., Washington, S., Haworth, N., and Mazzei, A. (2014b). Barriers to Bikesharing: An Analysis from Melbourne and Brisbane. Journal of Transport Geography, Vol. 41, pp. 325-337.
Fishman, Elliot, et al. (2015). Factors influencing bike share membership: an analysis of Melbourne
Gebhart, K., and Noland, R. (2014). The impact of weather conditions on bikeshare trips in Washington, DC. Transportation, Vol.41, No.6. pp.1205-1225.
and Brisbane. Transportation research part A: policy and practice 17-30.
Goodman, Anna, and James Cheshire (2014). Inequalities in the London bicycle sharing system revisited: impacts of extending the scheme to poorer areas but then doubling prices. Journal of Transport Geography 41: 272-279.
Goodman, Brianna, and Susan Handy (2015). Providing Equitable Access to Sacramento's Bike Share System. No. UCD-ITS-RR-15-10.
Heinen, E., Van Wee, B., and Maat, K. (2010). Commuting by bicycle: An overview of the literature. Transport Reviews, 30(1), pp. 59–96.

Kaltenbrunner, A., Meza, R., Grivolla, J., Codina, J., and Banchs, R. (2010). Urban cycles and mobility patterns: Exploring and predicting trends in a bicycle-based public transport system. Pervasive and Mobile Computing, 6(4). pp. 455-466.
Larsen, J., (2013) Bike-Sharing Programs Hit the Streets in Over 500 Cities Worldwide. Earth Policy Institute.
Retrieved from http://www.earth-policy.org/plan_b_updates/2013/update112
LDA Consulting. (2012). Capital Bikeshare 2011 Member Survey Report.
Retrieved from https://d21xlh2maitm24.cloudfront.net/wdc/Capital-Bikeshare-SurveyReport-Final.pdf?mtime=20161206135935
Litman, Todd (2014b). Evaluating Public Transportation Local Funding Options. Journal of Public Transportation 17(1), 43-74.
Mateo-Babiano, I., Bean, R., Corcoran, J., and Pojani, D. (2016). How Does Our Natural and Built Environment Affect the Use of Bicycle Sharing? 1transportation Research Part A: Policy and Practice, Vol. 94, pp. 295-307.
McConville, M. (2013). Creating equitable, healthy, and sustainable communities: Strategies for advancing smart growth, environmental justice, and equitable development, Report No. EPA 231-K-10-005.
McNeil, N., MacArthur, J., Broach, J., Cummings, A., Stark, R. L., Sanders, R., and Witte, A. (2019). National Scan of Bike Share Equity Programs: Approaches and Best Practices for Promoting Equity in Bike Share.
McNeil, Nathan, et al. (2017) Breaking Barriers to Bike Share: Insights from Bike Share Users.
Morris, J. M., Dumble, P. L., and Wigan, M. R. (1979). Accessibility indicators for transport planning. Transportation Research Part A: General, 13(2), 91-109.
Miranda-Moreno, L., Nosal, T., Schneider, R., and Proulx, F. (2014). Classification of Bicycle Traffic Patterns in Five North American Cities. Transportation Research Record: Journal of the Transportation Research Board, Vol.2339.
Moudon, A. V., Lee, C., Cheadle, A. D., Collier, C. W., Johnson, D., Schmid, T. L., and Weather, R. D. (2005). Cycling and the built environment, a US perspective. Transportation Research Part D: Transport and Environment, 10(3), pp. 245–261.
Ogilvie, F., and Goodman, A. (2012). Inequalities in usage of a public bicycle sharing scheme: socio-demographic predictors of uptake and usage of the London (UK) cycle hire scheme. Preventive Medicine, 55(1), 40-45.
Pucher, J. and Dijkstra, L. (2003). Promoting safe walking and cycling to improve public health: lessons from The Netherlands and Germany. American Journal of Public Health, 93(9): 1509-16.
Rixey, R. A. (2013). Station-Level Forecasting of Bikesharing Ridership: Station Network Effects in Three U.S. Systems. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2387, pp. 46-55.
Saelens, B., Sallis, J., and Frank, L. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. Annals of Behavioral Medicine, 25(2), pp. 80–91.
Schneider, T.W. (2016). A Tale of Twenty-Two Million Citi Bike Rides: Analyzing the NYC Bike Share System. Retrieved from http://toddwschneider.com/posts/a-tale-of-twenty-two-million-citi-bikes-analyzing-the-nyc-bike-share-system/
Shaheen, S. A., Guzman, S, and Zhang, H. (2010). Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future. Transportation Research Record, Vol. 2143. No.1, pp. 159-167.

Smith, C. Scott, Jun-Seok Oh, and Cheyenne Lei. (2015). Exploring the Equity Dimensions of US Bicycle Sharing Systems. Transportation Research Center for Livable Communities. Western Michigan University Kalamazoo, MI.
Spencer, P., Watts, R., Vivanco, L., and Flynn, B. (2013). The Effect of Environmental Factors on Bicycle Commuters in Vermont: Influences of Northern Climate. Journal of Transport Geography, Vol. 31, pp. 11-17.
Sun, F. And Chen, P. (2016) Impact of Built Environment and Temporal Factors on Public Bike-Sharing. 95th Transportation Research Board Annual Meeting.
Retrieved from http://docs.trb.org/prp/17-05281.pdf.
Ursaki, J., and Aultman-Hall, L. (2015). Quantifying the equity of bikeshare access in US cities. Report No. TRC Report 15-011, University of Vermont,. Transportation Research Center.
Vogel, P., Greiser, T., and Mattfeld, D.C. (2011). Understanding Bike-sharing Systems using Data Mining: Exploring activity patterns. Procedia-Social and Behavioral Sciences, Vol. 20, pp. 514-523.
Wang, X., Lindsey, G., Schoner, J. E., and Harrison, A. (2016). Modelling Bike Share Station Activity: Effects of Nearby Businesses and Jobs on Trips to and from Stations. Journal of Urban Planing and Development, Vol. 142, No.1. 04015001.
Williams, D. R., and Collins, C. (2001). Racial Residential Segregation: A Fundamental Cause of Racial Disparities in Health. Public Health Reports, 116(5), 404-416.
Zhang, Y., Thomas, T., Brussel, M.J.G., and Maarseveen, M.F.A.M. (2017). The characteristics of bike-sharing usage: case study in Zhongshan, China. International Journal of Transport Development and Integration, Vol.1, No.2. pp. 245-255.