

# Evaluating Spatial Equity in Bike Share Systems

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## About

This report was developed by the New Jersey Bicycle and Pedestrian Resource Center within the Alan M. Voorhees Transportation Center (VTC) at Rutgers, The State University of New Jersey. The research team included Charles T. Brown, MPA, Principal Investigator, Devajyoti Deka, PhD, Aashna Jain, Anish Grover, and Qingyang Xie.

The Alan M. Voorhees Transportation Center (VTC) is a national leader in the research and development of innovative transportation policy. Located within the Edward J. Bloustein School of Planning and Public Policy at Rutgers University, VTC has the full array of resources from a major research university on transportation issues of regional and national significance.

The New Jersey Bicycle and Pedestrian Resource Center (BPRC) assists public officials, transportation and health professionals, and the public in creating a safer and more accessible walking and bicycling environment through primary research, education and dissemination of information about best practices in policy and design. The Center is supported by the New Jersey Department of Transportation through funds provided by the Federal Highway Administration.

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# 1. INTRODUCTION

## 1.1 BACKGROUND

Public Bike Share Systems (BSSs) provide bikes as an alternative mode of transportation in cities and regions. They are extremely popular for increasing mobility and access, along with their health, economic, and environmental benefits (DeMaio, 2004; Toole Design Group, Pedestrian and Bicycle Information Center, 2012). They are also used for improving last-mile connectivity near transit stations (DeMaio, 2004; Toole Design Group, Pedestrian and Bicycle Information Center, 2012). BSSs provide bikes for short distance trips at reasonable and affordable prices, without any ownership costs.

These aforementioned systems emerged in the United States with the development of the third generation Bike Share System (also known as Smart Bikes) that allow providers to better track and manage their bikes in case of a theft. In these systems, bikes are securely docked in automated kiosks that require magnetic stripe cards or ride codes to check out a bike (DeMaio, 2004; Toole Design Group, Pedestrian and Bicycle Information Center, 2012). Users can unlock a bike from any station and return it at any station in the system. They are also required to pay a hefty recovery fee (or replacement cost) if a bike is lost/stolen while in the hands of the user. Compared to previous bike share systems that were either free or coin-operated, these systems allow the providers to identify and penalize users who do not return the bikes thus reducing theft or displacement of bicycles.

Washington DC implemented the first third generation BSS in the country in 2008, followed by Denver (2010), Minneapolis-St. Paul (2010), Metro DC (2010) and Des Moines (2010) (NACTO, 2017). Since then, bike share has become a rapidly growing micromobility option in the United States. The



number of BSSs in the country increased from 4 to 55 between 2010 to 2016, while their ridership grew from 0.32 to 28 million trips in a year (NACTO, 2017). In recent years, bike share has also gained popularity in the State of New Jersey. About 7 bike share systems have been launched in the state since 2015, while approximately 3 more systems are underway (Sinclair, 2018; Kujan, 2018).

Given the proliferation of BSSs in this country, this research explores the equity dimension of docked bike share systems across the U.S. and in the State of New Jersey. As an affordable, healthy and growing mobility alternative, the importance of equity in the planning and implementation of bike share systems cannot be highlighted enough, particularly because of their potential to benefit disadvantaged populations that rely on affordable/alternative modes of travel more than affluent populations (Clark, 2017; Ogilvie & Goodman, 2012). However, past research has consistently found BSSs to provide unequal access to disadvantaged populations. This study builds upon the existing research in the field, identifying best practices used to measure equity, and developing a method to evaluate equity in bike share systems throughout the U.S.

This research analyzes 10 of the largest third generation docked bike share systems in the United States along with 3 docked bike share systems in New Jersey. These bike share systems were carefully selected to reflect diversity in their size and age, and their host region's size and geography as well as data availability. The selected bike share systems are as follows:

1. Relay Bike Share – Atlanta, GA
2. Blue Bikes (Hubway) – Metro Boston, MA
3. Divvy – Chicago, IL
4. Capital Bikeshare – Metro DC, DC-MD-VA
5. Houston BCycle – Houston, TX
6. CITI Bike – Miami Region, FL
7. CITI Bike – New York City, NY
8. Bay Wheels (Ford GoBike) – Oakland (East Bay), CA
9. BIKETOWN – Portland, OR
10. Bay Wheels (Ford GoBike) – San Francisco, CA

Bike Share Systems in the State of New Jersey:

11. Zagster Bike Share – Asbury Park, NJ
12. Hudson Bike Share – Hudson County (Bayonne, Hoboken, North Bergen, Guttenberg, West New York and Weehawken, NJ)
13. CITI Bike – Jersey City, NJ



## 1.2 RESEARCH OBJECTIVES

This research explores inequalities in 10 of the largest docked BSSs across the country and 3 bike share systems in the State of New Jersey. While there are non-spatial aspects to equity in bike share (such as fare structure), this study focuses on spatial equity in bike share systems. It analyzes disparities in spatial densities across different socio-economic categories, which is one of the key factors that influences access to bike share and its practicality as a “real” transportation option for all types of users (NACTO Bike Share Equity Practitioners, 2015). The purpose of this study is to:

- Explore inequalities in spatial distribution of bike share stations across different socio-economic groups.
- Rank the BSS of the 10 cities by their spatial densities in the most-disadvantaged socio-economic category.
- Serve as a reference model for assessing existing and developing bike share systems in the State of New Jersey.

The following paper is divided into 7 sections. Section 2 explores the existing body of literature analyzing spatial equity in bike share systems. Section 3 describes the methodology used in this paper to analyze the spatial distribution of stations across socio-economic categories. Section 4 and 5 contain a detailed analysis of each of the 10 bike share systems (BSSs) and the 3 bike share programs in New Jersey respectively. The sections compare spatial densities across socio-economic categories to identify populations that have the greatest and the least access to bike share in a system. It further explores how access in the most-disadvantaged socio-economic category compares to the average level of access in a BSS.

Section 6 discusses the findings from the analysis and gives the Bike Share System Equity Rankings based on the access provided to the most-disadvantaged populations. The section further reflects on the impact of the analysis findings on the existing and emerging bike share systems along with its limitations. Finally, Section 7 concludes the research with the findings and the Bike Share System Equity Rankings produced by the study.



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## 2. LITERATURE REVIEW

This section reviews the existing body of literature analyzing spatial equity in bike share systems in the United States and across the globe. The researchers used it to extract the best practices used to measure equity in BSSs and used it to inform the analysis methodology developed in this study.

Despite their potential to benefit lower income and disadvantaged populations, past research has consistently found BSSs to disproportionately underserve disadvantaged populations. Smith et al. (2015) created an economic hardship index (low to high) for 42 BSS planning areas at block group level and found that 75.4 percent of the bike share stations were located in areas with very low and low levels of economic hardship. NACTO (2015) found low income areas in the US to have the lowest densities of bike share stations, making it an inconvenient/unrealistic option in these areas (NACTO Bike Share Equity Practitioners, 2015). Another study compared the socio-economic characteristics of populations living inside and outside of bike share service areas in 7 US cities (Ursaki & Aultman-Hall, 2016). It found that populations living inside the service areas were wealthier than the outside populations, and in 5 of the 7 cities, the inside population was predominantly White and less African American.

Additional research in the field shows that disadvantaged populations are more likely to use bike share compared to less-disadvantaged population (Ogilvie & Goodman, 2012). On considering the respective station densities and proximities, Ogilvie & Goodman (2012) found that users from disadvantaged locations on an average make higher number of trips on bike share than those from less-disadvantaged areas. With reduced access to bike share in disadvantaged areas, BSSs fail to tap into this need to increase system ridership and benefit these populations.

Bike share systems are often planned through a market-driven approach that focuses on locating stops in areas that are favorable for BSSs by the virtue of their built environment (such as downtowns) or capitalizing on existing demand (such as tourism) (DeMaio, 2004; Ricci, 2015). This is one of the key factors that is commonly used to explain spatial inequity in BSSs. This approach, however, by not taking equity into consideration, contributes to unequal access further marginalizing already-underserved populations.

Given the existing research, it is clear that bike share systems have not been equitable in serving a region's disadvantaged population. This research provides a methodology to quantify spatial access to different populations in a region and rank bike share systems by their extent of access to their most-disadvantaged populations. The research uses the block group approach similar to the methodology followed by Smith et al. (2015) to evaluate spatial equity in bike share systems, identify existing disparities, and determine system success as a resource for all. The framework can be employed by the existing as well as emerging BSSs to assess their system designs and rank them by the extent of service accessible to the most-disadvantaged populations in a region.





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### 3. RESEARCH METHODOLOGY

This paper uses the block group approach – determining the spatial density and socio-economic category for each block group – to analyze spatial densities across socio-economic categories. The methodology builds upon the best practices and resources identified from existing research mentioned in the previous section, and can be segmented into the following four parts:

- Defining the BSS Study Areas
- Preparing Predictor Variables for the BSS Study Areas
- Computing Socio-economic Hardship Scores at block group level and classifying them into Socio-Economic Hardship Quintiles
- Computing Station Densities for each block group and Socio-Economic Quintiles

#### *Defining the BSS Study Areas*

In the first part of the analysis, a study area was defined for each BSS based on the location of its bike stations. As some systems extended to multiple jurisdictions, the study area was defined to include all the places (i.e., incorporated and census-designated places) that were served by a BSS. However, if a system comprised of two independent networks – for example, Citi Bike in NYC and Jersey City – only the main network within the principle city was included in the BSS study area.

The analysis began with building a repository of system-specific station locations for over 75 third generation bike share systems in the US. As the bike station locations data for some systems is not readily available in a GIS shapefile or lat-long format, data was collected from various sources and

formats. For these systems, the General Bikeshare Feed Specification (GBFS) database files were downloaded from the city/operator's website or through NABSA's github page. The GBFS data is available in a Java script object notation or JSON format which was then mined to extract system-specific locations API, which were converted into the CSV (comma separated values) format and then mapped in GIS. The 10 of the largest third generation BSSs and the 3 BSSs in New Jersey evaluated in this study were selected from this repository based on a multitude of geographic, regional, and systemic factors as mentioned in the first section.<sup>1</sup>

The next step involved gathering the Census Place boundaries GIS shapefiles for the selected bike share systems. For each BSSs, 2017 Census Place Boundary shapefiles were downloaded from the US Census website. The bike stations data was then overlaid with the census place boundary shapefiles and all the places that intersected a BSS's bike stations were selected to determine the BSS study area. For systems with multiple independent networks, places were selected using the network in the main city only. The selected places were then combined to create the study areas for each BSS. The BSS study areas for each system are discussed in detail in the Analysis section of the report.

### ***Preparing Predictor Variables for the BSS Study Areas***

The second step in the analysis involved identifying demographic variables that were used as predictor variables to generate a socio-economic hardship score for each block group. The research identified 8 inter-related variables that jointly explain different dimensions of socio-economic condition. Four of the 8 variables were taken from the Smith et al. (2015) study. The 8 predictor variables used in the study are as stated:

1. Carless households (CL\_HH), defined as the percentage of total households without a car.
2. More than 30 percent of gross income as rent (MT30INC), defined as the percentage of total households for which gross rent or ownership cost is more than 30% of the total household income.
3. Health insurance (NO\_HI), the percentage of population 19 years or older with no health insurance coverage of any form.
4. Median household income (HINC100000)
5. Education (LT\_HS\_EDU), calculated as the percentage of population 25 years or over with less than high school education.
6. Household size by median number of rooms (HHS\_MNR), defined as the average occupancy per room computed by taking a ratio of average household size by the median number of rooms.
7. Minority population (MIN\_POP), percent non-white population in a block group.
8. Unemployment (UNEMP), percent unemployed population equal to or older than 16 years.

2016 5-Year American Community Survey (ACS) data for the stated variables was downloaded for the defined BSS study areas at block group level. Additionally, data for total population and total adult population for each study area was also downloaded at block group level. The downloaded

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<sup>1</sup> The bike share station locations data was downloaded in 2017. Hence, the study does not reflect any subsequent changes/additions in the systems since 2017.

data was then processed and imported into GIS. 2017 Tigerline Census Block Group shapefiles for the BSS study areas were also downloaded and joined with the 8 predictor variables. Block group shapefiles with the predictor variables were then intersected with the combined study area boundary for each BSS with the following considerations:

- a. Block groups that extended beyond the study area boundary were clipped to the region in such a way that its population fields were prorated.
- b. If a block group extended over water boundaries only rather than land, its population fields were not prorated.
- c. If a BSS had bike stations outside CDPs/Incorporated Places, their corresponding block groups were included in the analysis. Capital Bikeshare had 7 such stations that did not fall into any Census Place boundaries.

Block groups data with predictor variables was then exported into Excel, SPSS, and Statistical Analysis System (SAS) format for further analysis.

### ***Computing Socio-economic Hardship Scores at block group level and classifying them into Socio-Economic Hardship Quintiles***

In the third part of the analysis, socio-economic hardship scores (factor scores or F-scores) were generated for each block group using the Confirmatory Factor Analysis (CFA) method. The analysis was done in SAS for each BSS study area independently to highlight the local/regional variances in socio-economic conditions of populations. The analysis assumed that one latent factor – socio-economic conditions – explains the interrelationships between the 8 predictor variables.

For each of the 10 BSS study areas, the model generated F-scores for each block group and found that each of the 8 variables had a statistically significant relationship with the factor. As CFA method requires a complete dataset, block groups with missing data were excluded from the analysis. For each study area, the mean F-score was applied to these block groups if they had any residents, while block groups without any population were kept excluded.

Block groups in a study area were then classified into 5 quintiles based on the F-scores to identify block groups with the following 5 socio-economic categories in a region: Most Advantaged, Advantaged, Neither Advantaged Nor Disadvantaged, Disadvantaged, and Most Disadvantaged. Appendix A details the quintile intervals for each socio-economic category in a region.

### ***Computing Station Densities for each block group and Socio-Economic Quintiles***

Finally, the bike location data was spatially joined with the block group data, computing the number of bike stations in each block group. Station densities in each block group were then computed based on two measures – adult population and area – as indicators for spatial access in each block group. Station density by population computed the number of stations in a block group per 1,000 adult residents, while station density by area computed the number of bike stations in a block group per square mile. The two measures were used to account for variation in a block group's population size and area. For station density by population, adult population was used as most bike share systems can only “legally” be used by people who are at least 18 years old.

The station densities for block groups in a socio-economic category were then used to compute the average station densities for each socio-economic category. The average was computed at block group level to account for the variation in spatial distribution within a socio-economic category instead of assuming uniform distribution. The average station density at block group level for each BSS study area was also computed. The formulas used for the calculations are as follows:

*Average Station Density by Population in a block group in a socio-economic category (or the BSS study area)*

$$= \frac{\sum \left( \frac{NUM\_BS \times 1000}{ADULT\_POP} \right)}{N}$$

*Average Station Density by Area in a block group in a socio-economic category (or the BSS study area)*

$$= \frac{\sum \left( \frac{NUM\_BS}{AR} \right)}{N}$$

Where NUM\_BS = Total number of bike stations in the block group

ADULT\_POP = Total adult population in the block group

AR = Area of the block group in square miles

N = Total number of block groups in the socio-economic category (or the BSS study area)

Block groups with outlier station densities were excluded from the above calculations. For instance, the Central Park block group in New York City had a station density by population of 3500 stations per 1,000 people as it is primarily non-residential and had only 5 residents, while the station densities of all other block groups in the city ranged from 0 – 68.18 stations per 1,000 people. Hence, the block group was identified as a significant outlier and its station density was excluded from the analysis.

The computed average station densities in socio-economic categories and across study areas were then analyzed to identify inequalities in spatial distribution of stations across socio-economic categories in each BSS in the study.



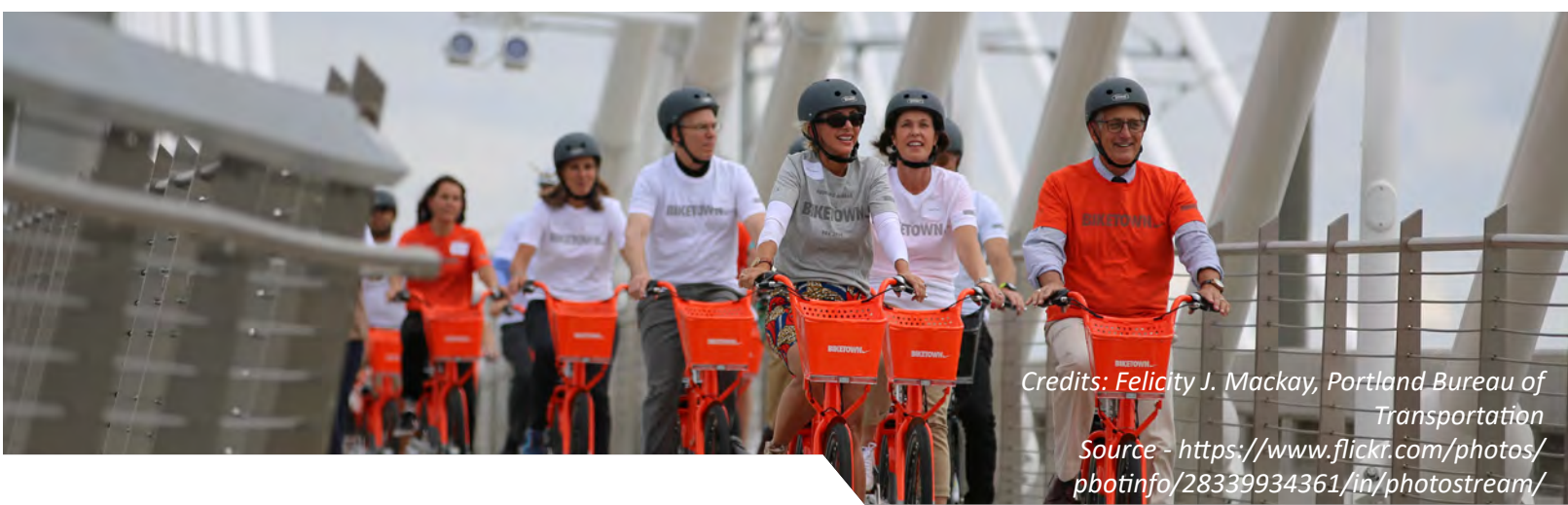


## 4. ANALYSIS

This section includes a detailed analysis of each of the 10 selected bike share systems and the 3 bike share systems in New Jersey. For each BSS, the analysis compares spatial densities across socio-economic quintiles to identify populations that have the greatest and the least access to bike share in a city/region. It further explores how access in the most-disadvantaged socio-economic category compares to the average level of access in a BSS.

The indicator used to measure spatial density is average station density in a block group in a socio-economic hardship quintile, computed by population as well as area. The two measures are used to account for variation in population and area size of the block groups.

The systems are chronologically organized according to their average station density by population (highest to lowest) in the most-disadvantaged socio-economic category.

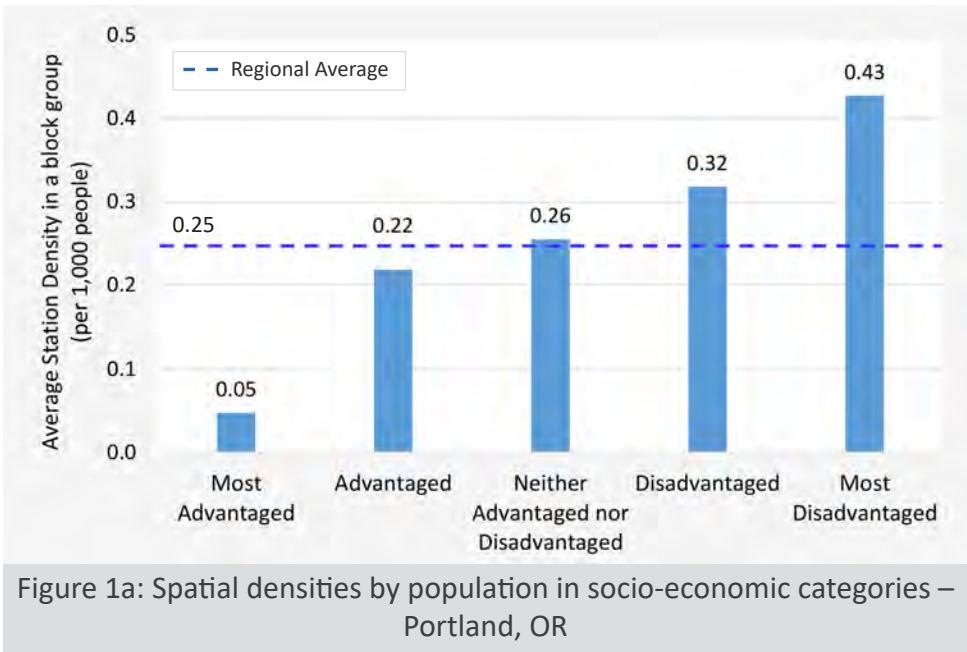


## 4.1 BIKETOWN - Portland, OR

BIKETOWN, the bike share system in Portland, OR is a relatively new system that was launched in 2016. With 123 stations, the system serves the central areas of the city – the downtown and its adjacent areas east of the Willamette River (see Map 1). It covers 68 of the 468 block groups in the city that correspond to 8.2% of its area and 16.2% of its population.

Map 1 shows the bike station locations and the socio-economic categories in Portland, OR. Its disadvantaged and most-disadvantaged block groups are concentrated in the downtown and area east of the Willamette River, where most of the bike stations are also located, while its advantaged and most-advantaged block groups are concentrated west of the river and in the central part of the area east of the river.

With respect to population, the most-disadvantaged category in Portland has the highest average station density of 0.43 stations per 1,000 people at block group level, while its most-advantaged

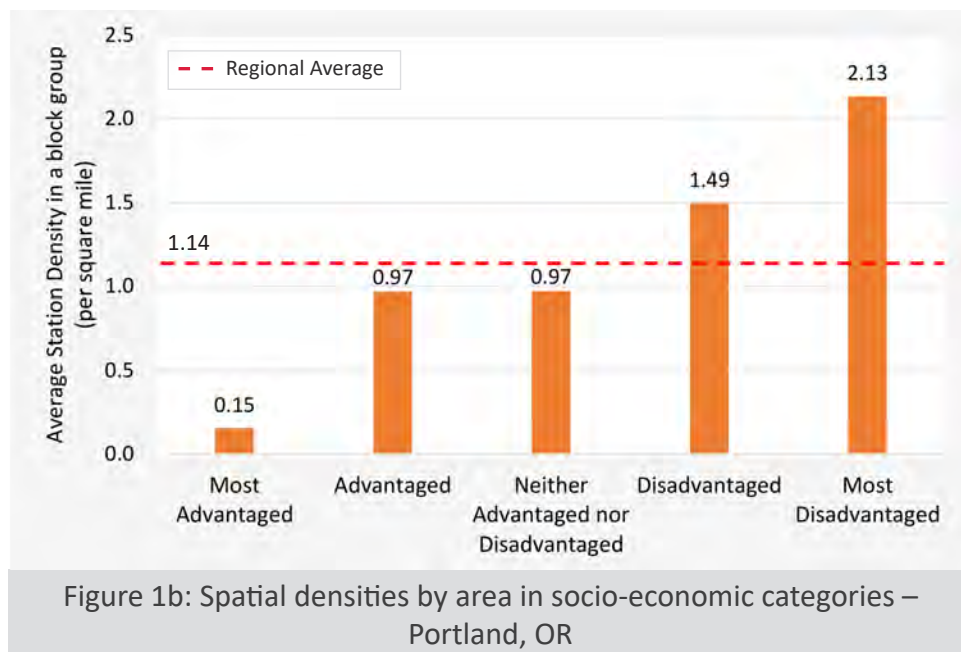


category has the lowest average station density of 0.05 stations per 1,000 people (see Figure 1a). As the level of socio-economic hardship in socio-economic categories goes from lowest to highest (most-advantaged to most-disadvantaged), the average spatial density increases in Portland. The system, thus, provides higher spatial densities for populations with higher level of socio-economic hardship.

Additionally, among the 10

**BSSs, BIKETOWN is the only system that has higher than regional average station densities in both of its disadvantaged socio-economic categories, while it has lower than regional average station densities in both of its advantaged block group categories.**

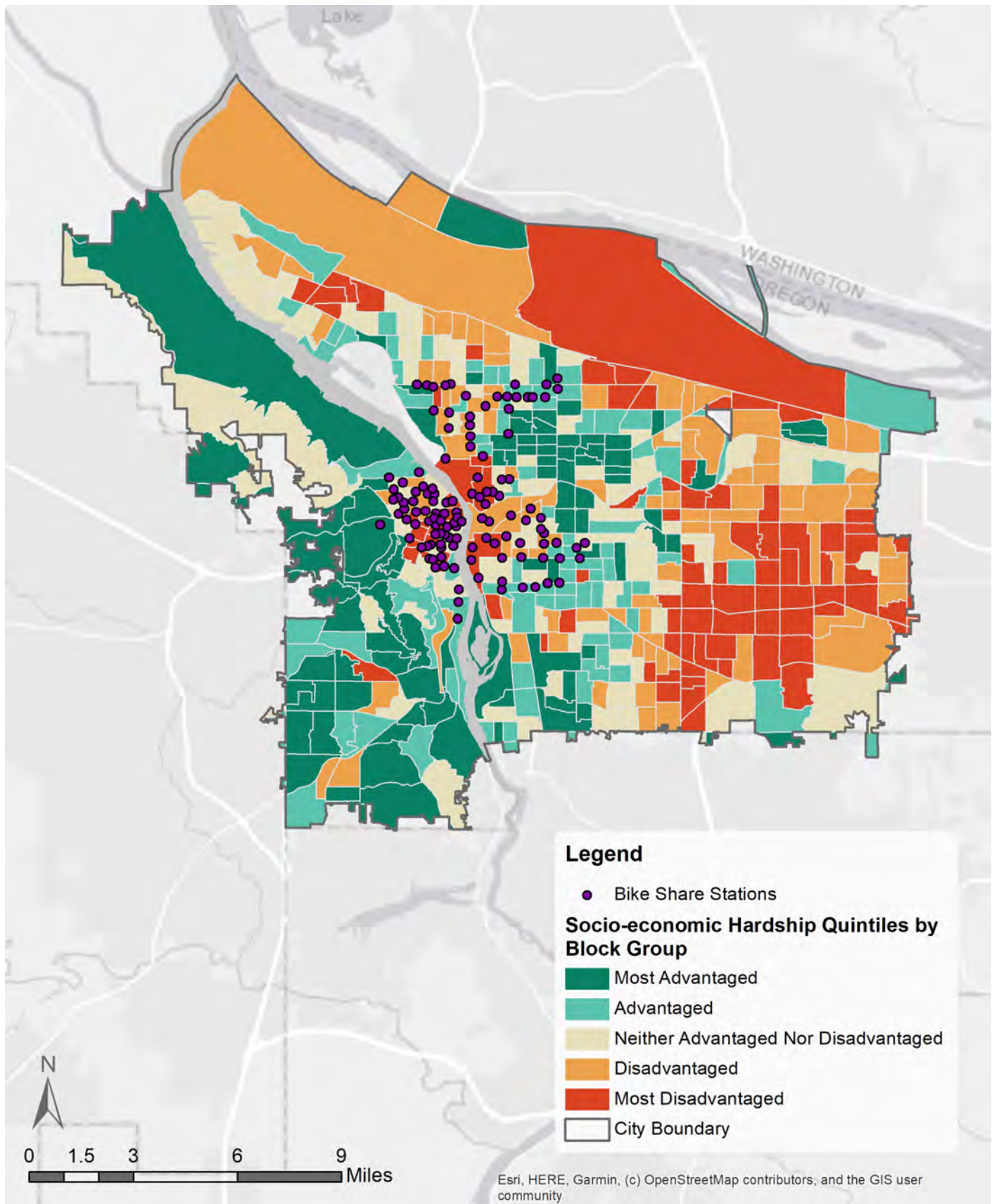




With respect to area, the most-disadvantaged category in the city has the highest average station density of 2.13 stations per square mile, while the most-advantaged category has the lowest average station density of 0.15 stations per square mile (see Figure 1b). Similar to station density by population, it provides higher spatial densities by area for populations with higher levels of socio-economic hardship.

Compared to the regional average, it has higher station densities in both of its disadvantaged socio-economic categories, while it has lower station densities in both of its advantaged socio-economic categories.

With a 123 station system concentrated near the downtown, Portland successfully provides higher station densities in its disadvantaged areas, by population as well as area. Among the 10 BSSs, Portland has the highest average station density by population in the most-disadvantaged category. It also has the third highest average station density by area in the most-disadvantaged category. Considering both metrics, it is the only bike share system that provides not only equitable, but better service in its disadvantaged areas compared to its advantaged areas. Additionally, the system also offers discounted memberships for its low-income residents (Rousculp, 2016).



Map 1: Bike share stations and socio-economic categories in Portland, OR





## 4.2 Capital Bikeshare and Jump Bikes – Metro DC, DC-MD-VA

Launched in 2010, Capital Bikeshare, Metro DC is the third oldest bike share system in the US. It has 500 bike stations in the Metro DC region. The study area for the system includes Washington, DC, the City of Alexandria, Arlington County, down county places and few outer places in Montgomery County, and two outer places in Fairfax County.

The system has bike stations in the central part of DC – the downtown and its adjacent areas – both north and south of the Potomac River (see Map 2). Away from the central city, it has stations around transit stops and its surrounding suburban towns. It covers 315 of the 1,066 block groups in the BSS study area corresponding to 34.5% of its population and 30.8% of its area, the highest in terms of area as well as population among the 10 BSSs. The disadvantaged and most-disadvantaged socio-economic block groups in the region are concentrated in the east side of DC and Montgomery County, while the advantaged and most-advantaged block groups are concentrated in the west half

of the region (see Map 2).

Visually, the bike stations in the system appear to be distributed among the socio-economic categories.

With respect to population-based station densities, Metro DC has higher spatial densities in its middle three socio-economic categories – advantaged, neither advantaged nor disadvantaged, and disadvantaged (see Figure 2a). The advantaged socio-economic category has the highest average station density of 0.54 stations per 1,000 people in a block

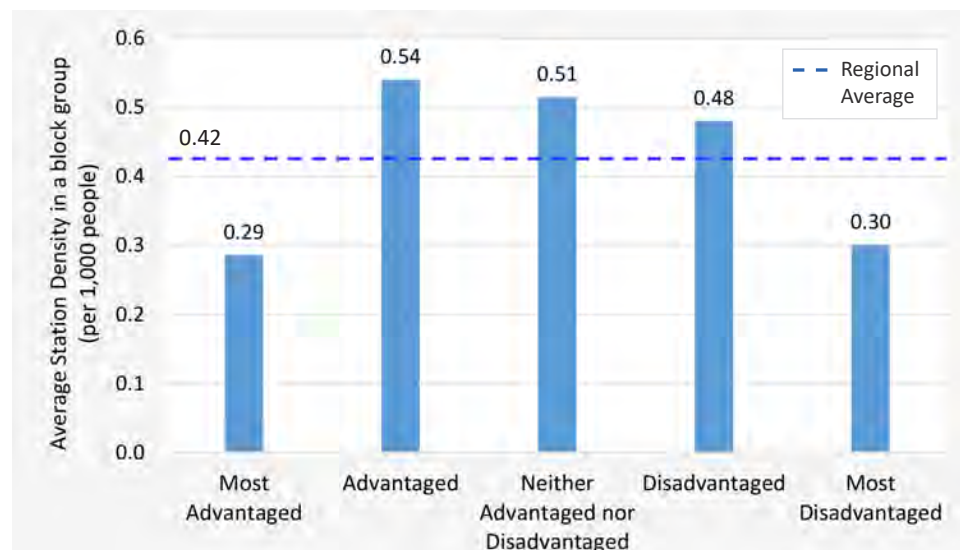
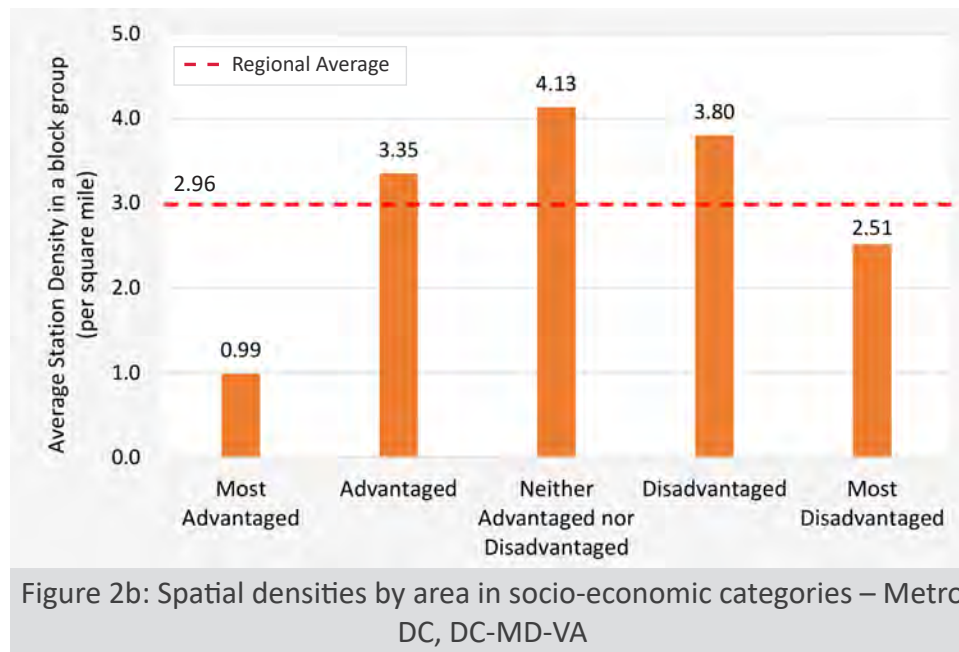


Figure 2a: Spatial densities by population in socio-economic categories – Metro DC, DC-MD-VA

Note: Two mainly non-residential block groups – the National Mall block group (65 residents) and the Arlington National Cemetery block group (15 residents) – were excluded from the analysis as outliers. The block groups had a station density of 276.92 and 66.67 stations per 1,000 people, while the station densities of all other block groups in the region ranged from 0 – 11.64.

group in the region, while the most-advantaged category has the lowest average station density of 0.29 stations per 1,000 people. The most-disadvantaged socio-economic category has the second lowest average station density of 0.30 stations per 1,000 people in a block group in the region.



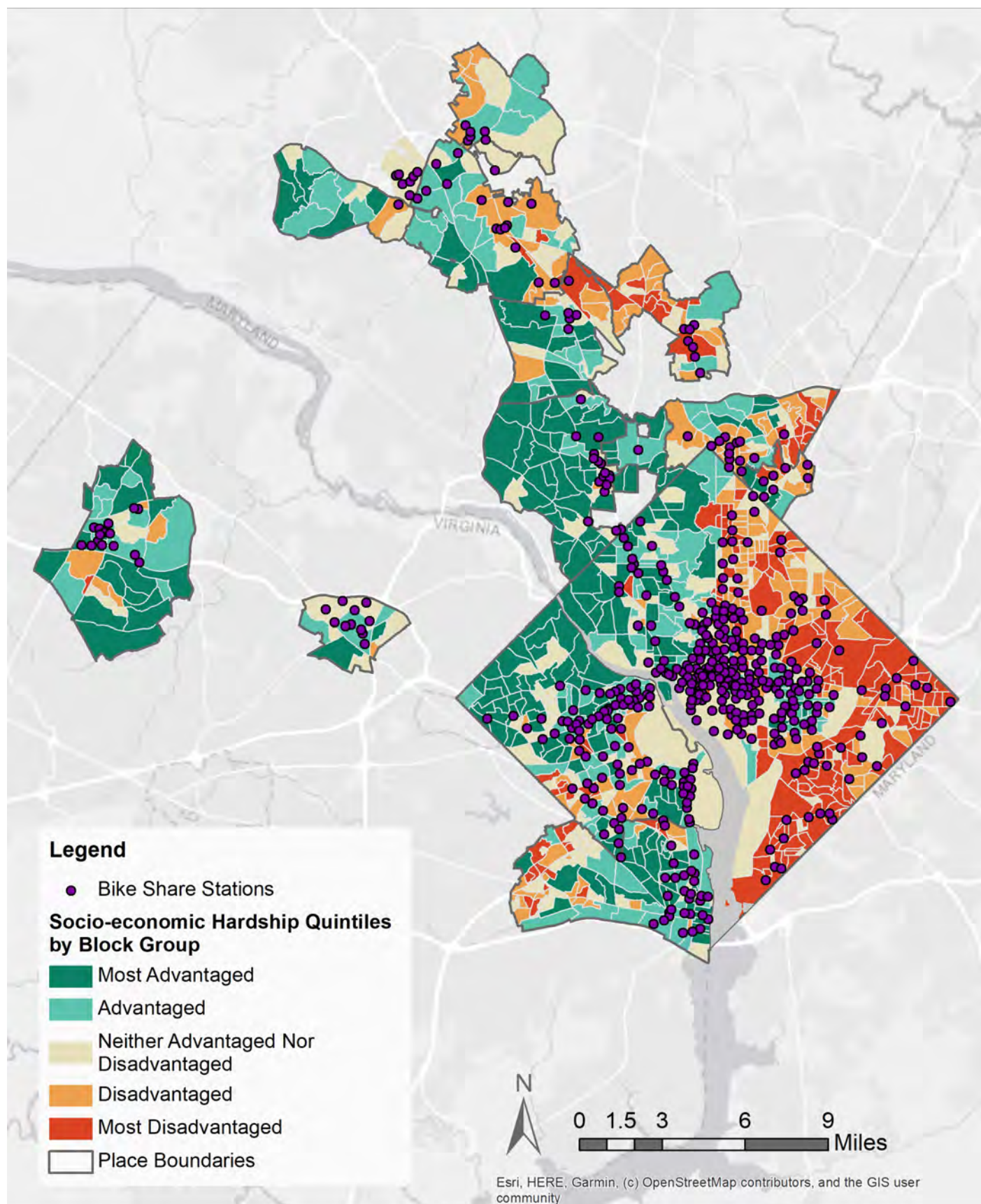
With respect to area, the neither advantaged nor disadvantaged socio-economic category in the region has the highest average station density of 4.13 stations per square mile, while the most-advantaged category has the lowest average station density of 0.99 stations per square mile (see Figure 2b). Similar to station density by population, the system has higher station densities by area in the middle three

socio-economic categories, while it has lower station densities in the most-advantaged and most-disadvantaged socio-economic categories.

Capital Bikeshare, Metro DC does not favor its advantaged populations over its disadvantaged populations. Based on both metrics, the system provides greater service to its middle socio-economic categories – advantaged, neither advantaged nor disadvantaged and disadvantaged, whereas it has lower service in its most-advantaged and most-disadvantaged categories. Compared to the 10 BSSs, Metro DC has the second highest average station density in the most-disadvantaged category, by population as well as area.

Recently, the system added stations in Montgomery County, and expanded to Prince George's County and the City of Falls Church (Carvell, And Then There Were Five, 2018; Carvell, Bringing More CaBi to Montgomery County, 2018; Wiener, 2019). The stations are located near transit stops for last-mile connectivity. The system also offers discounted memberships for residents that are enrolled in need-based services in Washington, DC, the City of Alexandria, and Arlington County. Montgomery County also has discounted memberships for low-income residents/workers in the County, while Fairfax County does not offer discounted memberships (Motivate International, 2019).





Map 2: Bike share stations and socio-economic categories in Metro DC Region



### 4.3 Divvy – Chicago, IL

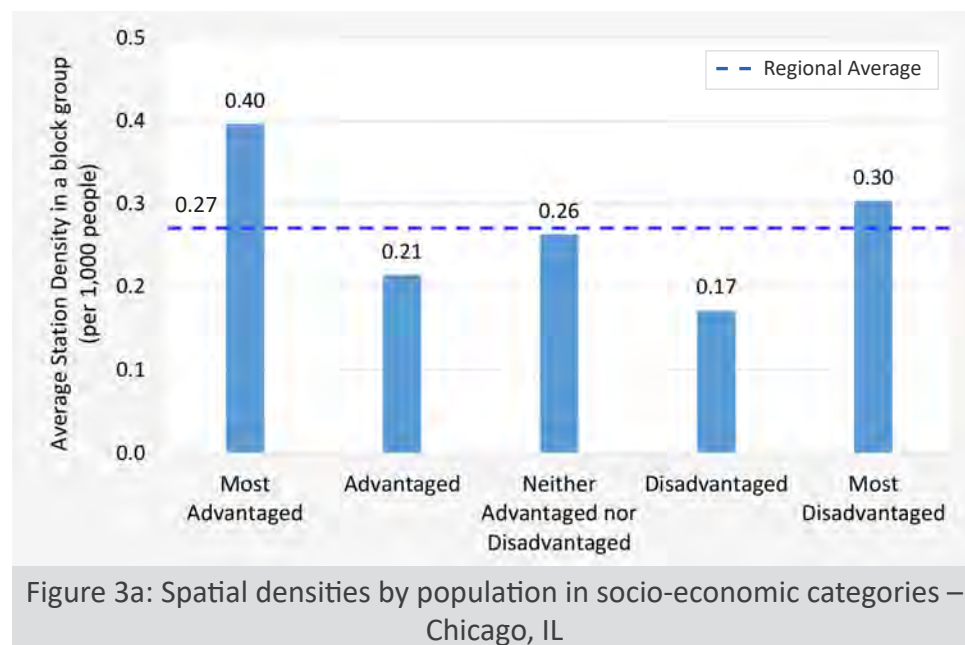
Divvy in Chicago, IL is the second largest bike share system in the US. It has 572 stations in total in the City of Chicago and Evanston. Its stations are located in the downtown, along the banks of Lake Michigan and the central parts of the Chicago-Evanston region. The system serves 427 of the 2,246 block groups in the region, covering 23.5% of its population and 21.0% of its area.

Map 3 shows the bike locations over the socio-economic categories in the Chicago-Evanston region. Its disadvantaged and most-disadvantaged block groups are concentrated in the region south of I-90 and the downtown, while the two advantaged categories' block groups are primarily concentrated in the downtown, the region north of I-90 and the City of Evanston. The system has bike stations all across the region, excluding the disadvantaged southern and south-western areas, and the advantaged north-western areas of the region.

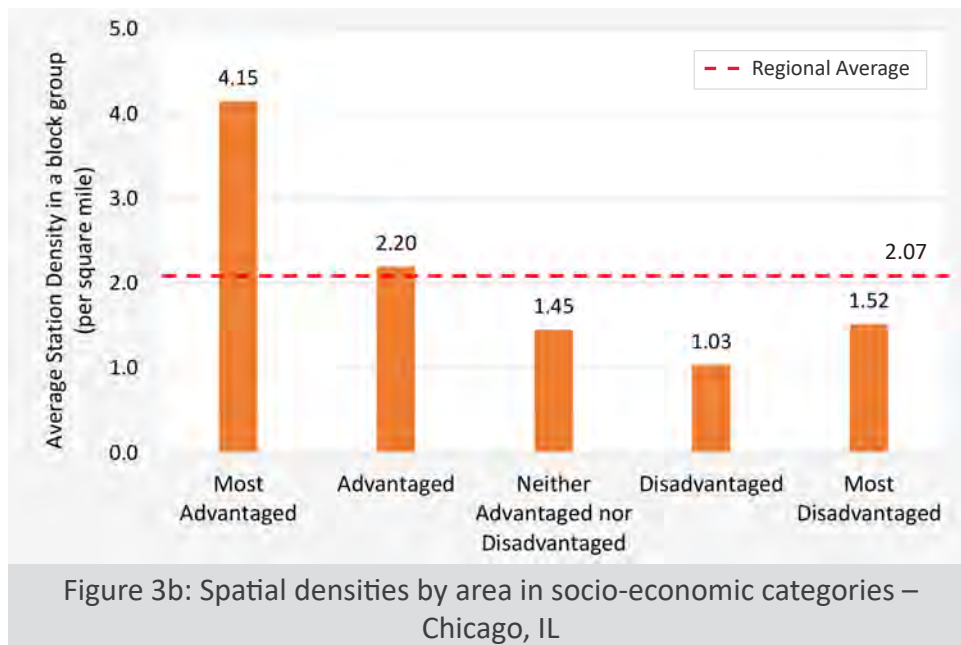
With respect to population, the most-advantaged category in the region has the highest average station density of 0.40 stations per 1,000 people in a block group, while the disadvantaged category has the lowest average station density of 0.17 stations per 1,000 people in the region (see Figure 3a). The most-disadvantaged category has the second highest average station density of 0.30 stations per 1,000 people in a block group in the region. In terms of distribution of spatial

densities, Divvy has higher than regional average station densities in its most-advantaged and most-disadvantaged categories, while it has lower than regional average station densities in the remaining socio-economic categories.

Among the 10 BSSs, *Divvy is one of the two systems that has higher than regional average station density in the most-disadvantaged category.*





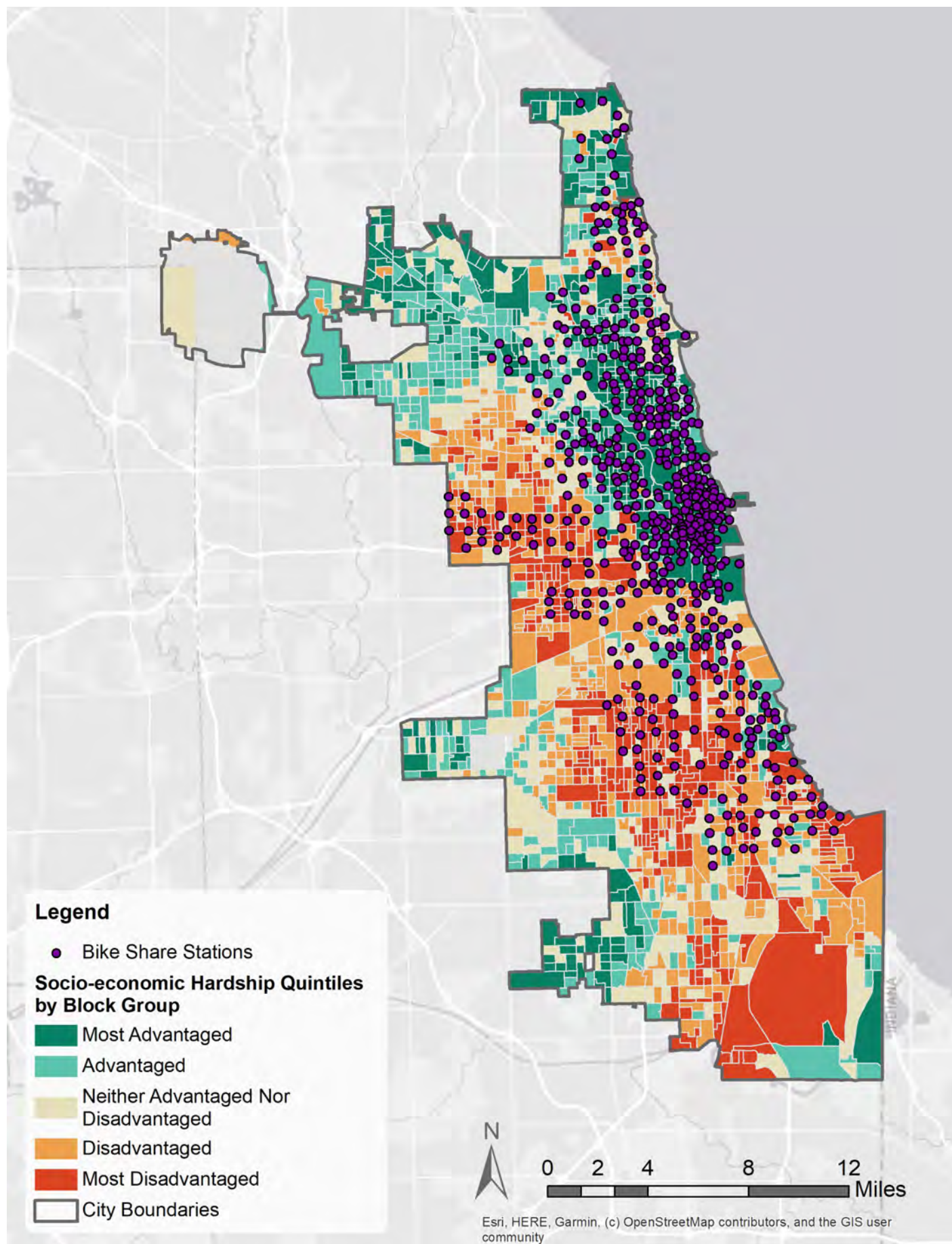


With respect to area, the most-advantaged socio-economic category in the region has the highest average station density of 4.15 stations per square mile in a block group, while the disadvantaged category has the lowest average station density of 1.03 stations per square mile (see Figure 3b). Unlike station density by population metric, the system has higher than regional average station densities by area in both of

its advantaged socio-economic categories, while it has lower than regional station densities in the remaining categories. The system, thus, provides lower spatial densities to its disadvantaged and most-disadvantaged populations.

Divvy, Chicago is slightly inclined towards serving its advantaged populations more than its disadvantaged populations. Based on both metrics, the system has its highest service in the most-advantaged socio-economic category, while it has its lowest service in the disadvantaged socio-economic category. With respect to station density by population, Divvy also has its second highest station density in the most-disadvantaged category. However, it provides better service to its advantaged populations across both metrics.

The system also offers discounted memberships for its low-income families (Motivate International, Divvy Bikes, 2019). Last year, it released a plan to install 30 new stations in four neighborhoods of the city, which was criticized for targeting relatively affluent communities rather than its underserved areas (Greenfield, 2018).



Map 3: Bike share stations and socio-economic categories in Chicago and Evanston, IL





Credits: Barry Dale Gilfry  
Source: <https://www.flickr.com/photos/websterwebfoot/31226829258>

## 4.4 BlueBikes (Hubway) – Metro Boston, MA

Launched in 2011, Blue Bikes (previously known as Hubway) is the third oldest bike share system among the 10 BSSs. The study area for the system includes Boston, Somerville and Cambridge City, and Brookline Census-Designated Place in the Metro Boston region. It comprises of 194 stations that are mostly located in the north half of the study area. The system serves 152 of the 755 block groups in the area covering 23.3% of its population and 25.1% of its area.

Map 4 shows the bike stations and the socio-economic categories in the BSS area in the Metro Boston region. The disadvantaged and the most-disadvantaged block groups in the region are concentrated in Boston in the northern, southern and western parts of the city. The two advantaged category block groups are concentrated in the central city and south-western areas of Boston, and in Somerville, Cambridge and Brookline. Spatially, the system appears to cater to all the socio-economic categories in the north half of the region, while the disadvantaged and the advantaged block groups in the southern and south-western areas of the region lack service.

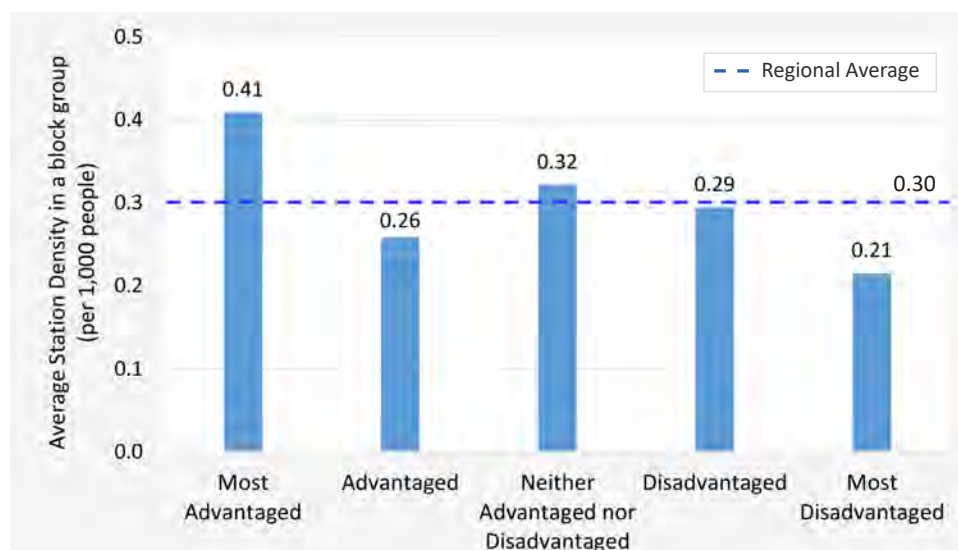
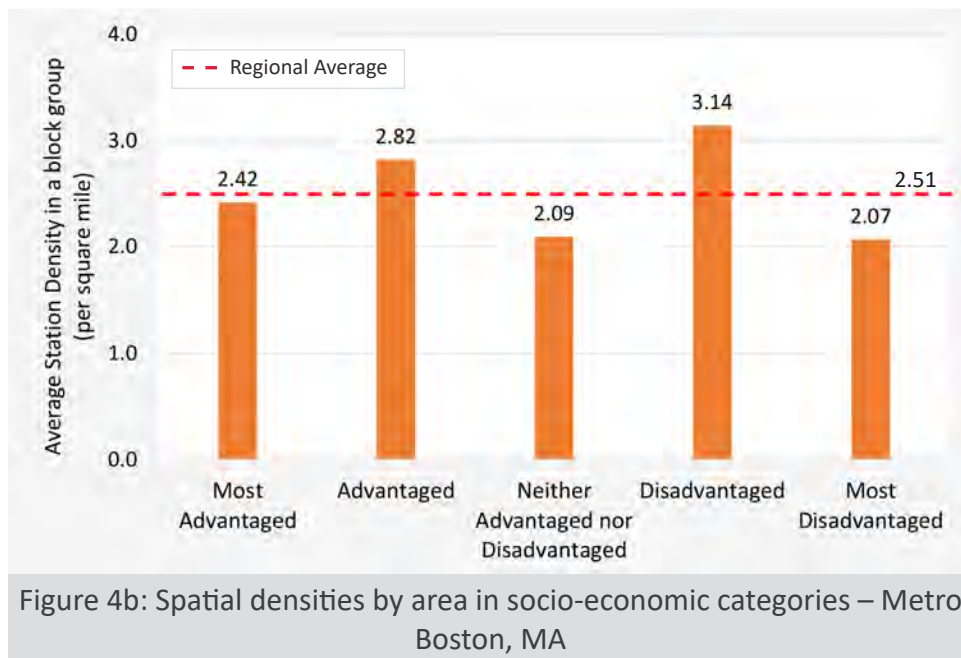


Figure 4a: Spatial densities by population in socio-economic categories – Metro Boston, MA

Note: One mainly non-residential block group with 20 residents was excluded from the analysis as an outlier. The block group had a station density of 50 stations per 1,000 people, while the station densities of all other block groups in the region ranged from 0 – 10.34.

With respect to population, the most-advantaged socio-economic category in the region has the highest average station density of 0.41 stations per 1,000 people in a block group, while the most-disadvantaged category has the lowest average station density of 0.21 stations per 1,000 people (see Figure 4a). In terms of distribution of densities, the system has lower than regional average spatial densities in both of its disadvantaged socio-economic categories, while it has higher than regional average spatial densities in



the most-advantaged and neither advantaged nor disadvantaged categories.

With respect to area, the disadvantaged socio-economic quintile in the region has the highest average station density of 3.14 stations per square mile, while the most-disadvantaged socio-economic category has the lowest average station density of 2.07 stations per square mile (see Figure 4b). The system has higher than

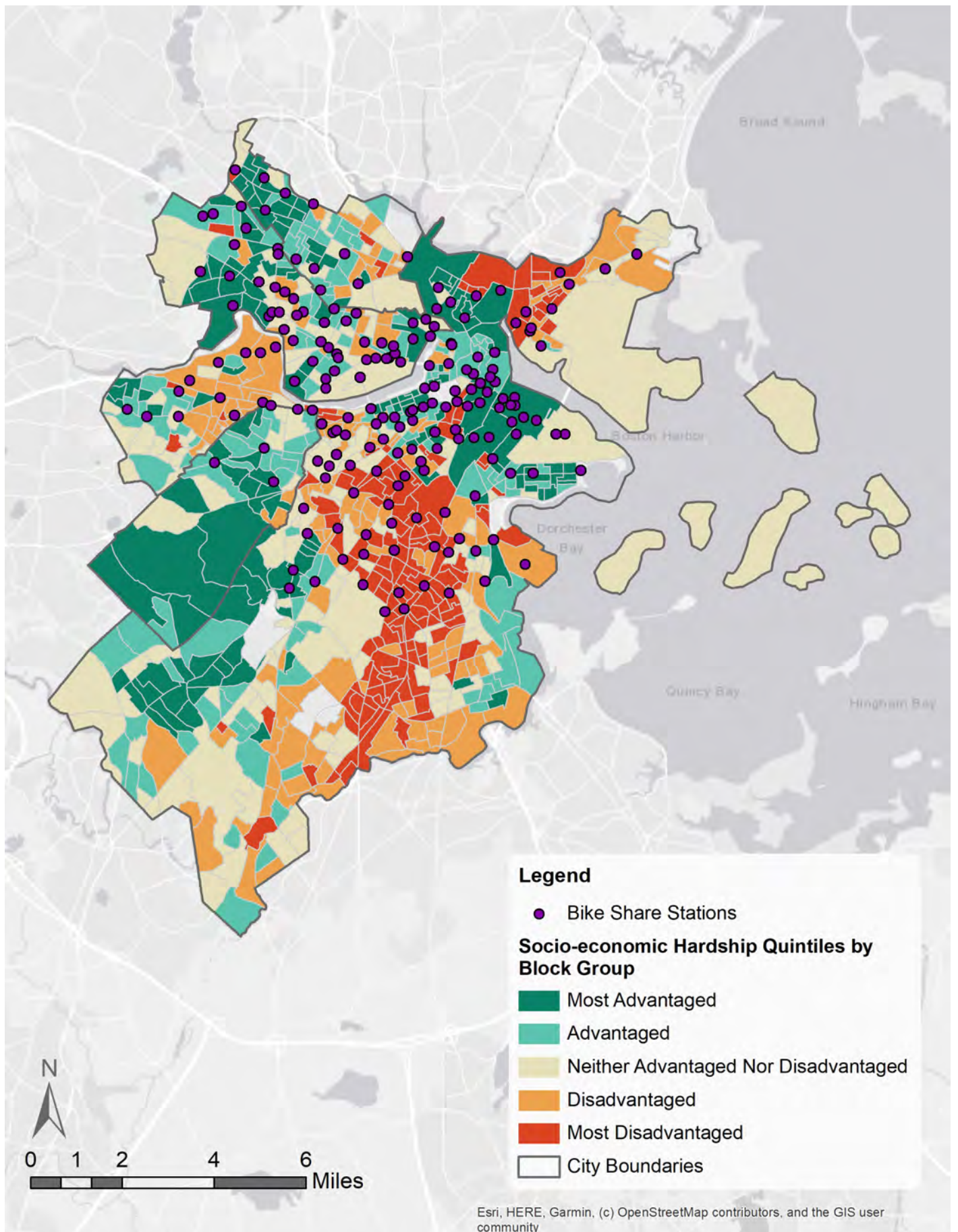
regional average station densities in the advantaged and disadvantaged socio-economic categories, while it has lower than regional average station densities in the most-advantaged and most-disadvantaged categories.

With respect to population-based densities, BlueBikes, Metro Boston is somewhat inclined towards serving its advantaged populations. The system has its highest spatial density in the most-advantaged category, whereas its lowest station density is in the most-disadvantaged category.

Based on station density by area, on the other hand, Bluebikes does not favor its advantaged or disadvantaged populations. The system has higher station densities by area for its advantaged and disadvantaged categories, whereas it has lower station densities for its most-advantaged and most-disadvantaged categories.

Recently, the system expanded to the City of Everett, whose median household income and median property values are lower than any other city in the BSS study area (Hayes, 2019). It also offers discounted plans for its low-income residents (Motivate International, 2019).





Map 4: Bike share stations and socio-economic categories in Metro Boston, MA



Credits: Elizabeth K Joseph  
Source - <https://www.flickr.com/photos/pleia2/39188479335/>

## 4.5 Bay Wheels (Ford GoBike) – San Francisco, CA

Launched in 2013, Bay Wheels in San Francisco, CA is a part of the Bay Wheels' bike share services in San Francisco, Oakland (East Bay), and San Jose. With 128 stations, the system serves 82 of the 581 block groups in the city corresponding to 6.2% of its area and 15.2% of its population. Its stations are located in the downtown and its adjacent areas in the city.

Map 5 shows the socio-economic categories overlaid with the bike stations in San Francisco, CA. The downtown and its adjacent areas where the system is primarily located, have block groups from each of the five socio-economic categories in the city. Additionally, the disadvantaged and most-disadvantaged block groups are concentrated in the southern and western parts of the city, while the advantaged and most-advantaged block groups are concentrated in the central and northern parts of the city.

With respect to population, the most-advantaged and disadvantaged categories have the highest average station density of 0.20 stations per 1,000 people in a block group in the city,

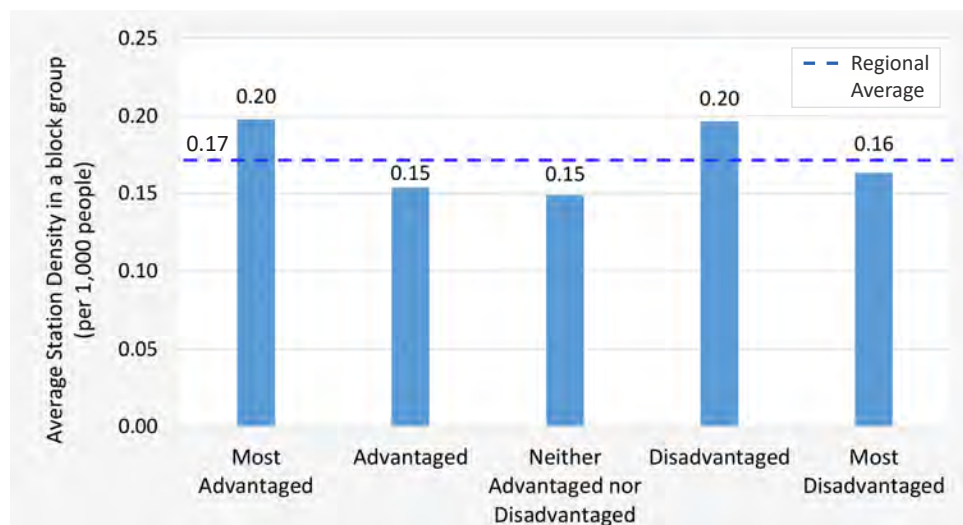


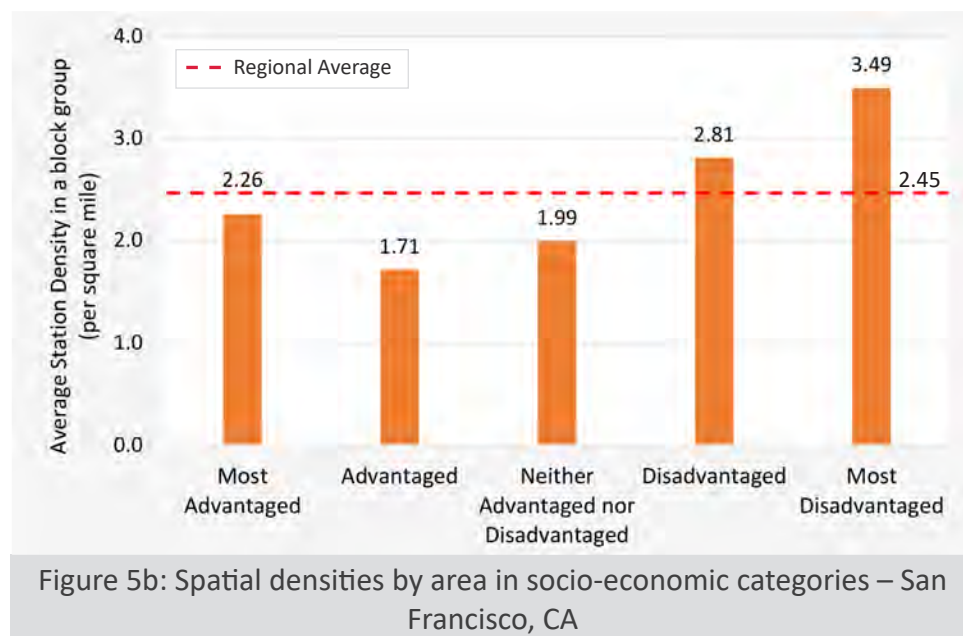
Figure 5a: Spatial densities by population in socio-economic categories – San Francisco, CA

Note: Two mainly non-residential block groups with 168 and 120 residents were excluded from the analysis as outliers. The block groups had a station density of 33.11 and 16.67 stations per 1,000 people respectively, while the station densities of all other block groups in the region ranged from 0 – 4.30.

while the advantaged and neither advantaged nor disadvantaged categories have the lowest average station density of 0.15 stations per 1,000 people in a block group (see Figure 5a). The average spatial densities across categories in San Francisco are somewhat uniformly distributed, with no single socio-economic category having the highest or the lowest service, while the relative difference between them is also low compared to the same in other bike share systems.



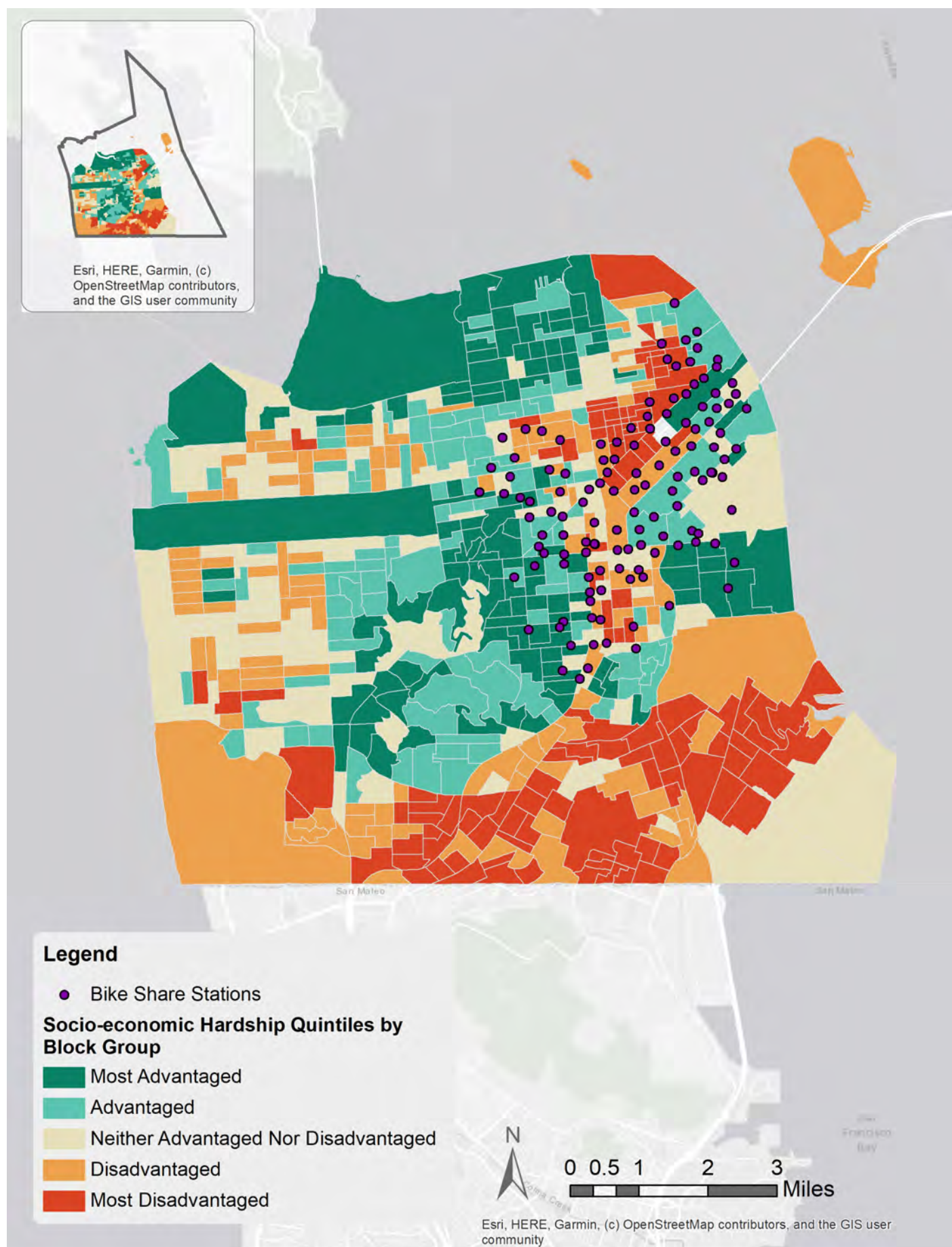
With respect to area, on the other hand, the most-disadvantaged category in the city has the highest station density of 3.49 stations per square mile in a block group, while the advantaged category has the lowest station density of 1.71 stations per square mile in a block group (see Figure 5b). The system has higher than regional average station densities in both of its disadvantaged categories, while it has lower than regional average station densities in the remaining socio-economic categories. The system, thus, provides higher spatial densities to its disadvantaged and most-disadvantaged populations.



Among the 10 BSSs, San Francisco is one of the two cities that has higher than regional average spatial densities in both of its disadvantaged socio-economic categories. It also has the highest average station density in a block group in the most-disadvantaged socio-economic category.

Based on station density by area, Bay Wheels in San Francisco is inclined towards serving its disadvantaged populations more than its advantaged populations. The system has higher service in both of its disadvantaged socio-economic categories, while it has lower service in both of its advantaged categories. ***It also has the highest spatial density by area in its most-disadvantaged category in all the 10 bike share systems.***

With respect to population, on the other hand, Bay Wheels does not favor its advantaged or disadvantaged populations. The system has higher service for its most-advantaged and disadvantaged populations, whereas it has lower service for its advantaged and most-disadvantaged populations. Additionally, the relative difference between the highest and lowest service in San Francisco is low compared to the same for other bike share systems in the study. The system is thus closer to achieving the same level of service across all socio-economic categories. It also offers discounted memberships for its low-income residents (Lyft, 2019).



Map 5: Bike share stations and socio-economic categories in San Francisco, CA





## 4.6 CITI Bike – Miami Region, FL

CITI Bike in Miami-Miami Beach region is the fifth oldest bike share system in the US. Established in 2011, the system has 146 stations in the Miami region. Its study area includes the Miami and Miami Beach City, Surfside town, Bay Harbor Islands town and Bal Harbour Village. The system has stations throughout Miami Beach and the adjacent towns, in downtown Miami and its nearby areas along the shore. It covers 89 of the 422 block groups in the region corresponding to 18.2% of its area and 17.0% of its population.

Map 6 shows the socio-economic categories overlaid with the bike stations in the Miami region. The disadvantaged and most-disadvantaged block groups are concentrated in the west side of the region away from the beaches and coastal areas where most of the system is located. The advantaged and most-advantaged block groups, on the other hand, are concentrated along the beaches/coast where the system is located. As the system only has a minor overlap with the two disadvantaged socio-economic categories, its service in these areas is expected to be low.

With respect to population, the advantaged category has the highest average station density of 0.92 stations per 1,000 people in a block group in the region, while the most-disadvantaged

category has the lowest average spatial density of 0.14 stations per 1,000 people in a block group (see Figure 6a). As the level of socio-economic hardship in categories increases, the average spatial density in socio-economic categories decreases in the region. The system, thus, provides lower spatial densities for populations with higher level of socio-economic hardship.

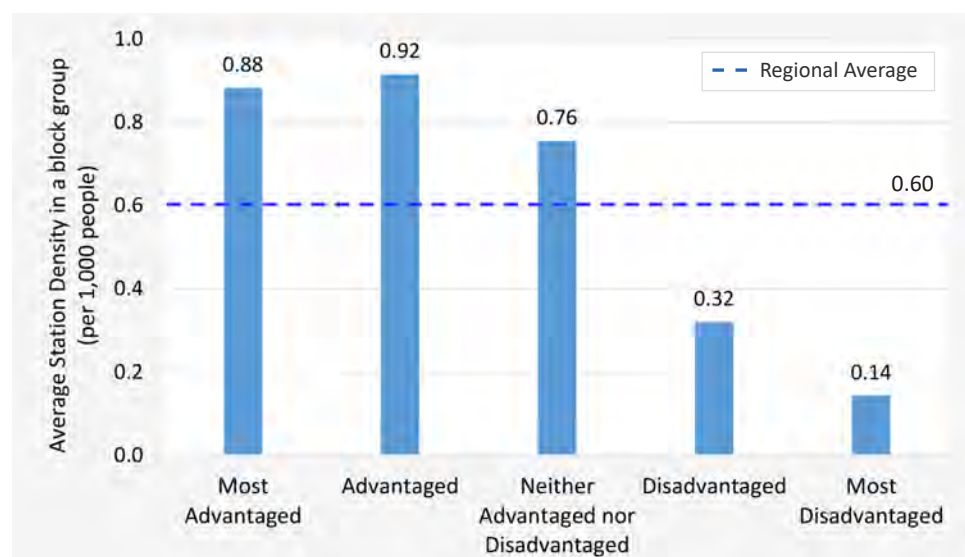


Figure 6a: Spatial densities by population in socio-economic categories – Miami Region, FL

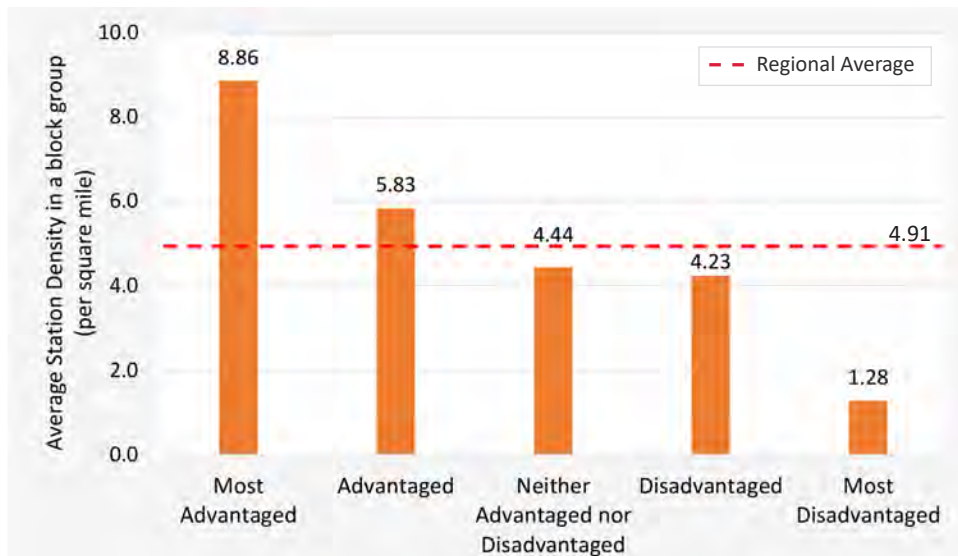
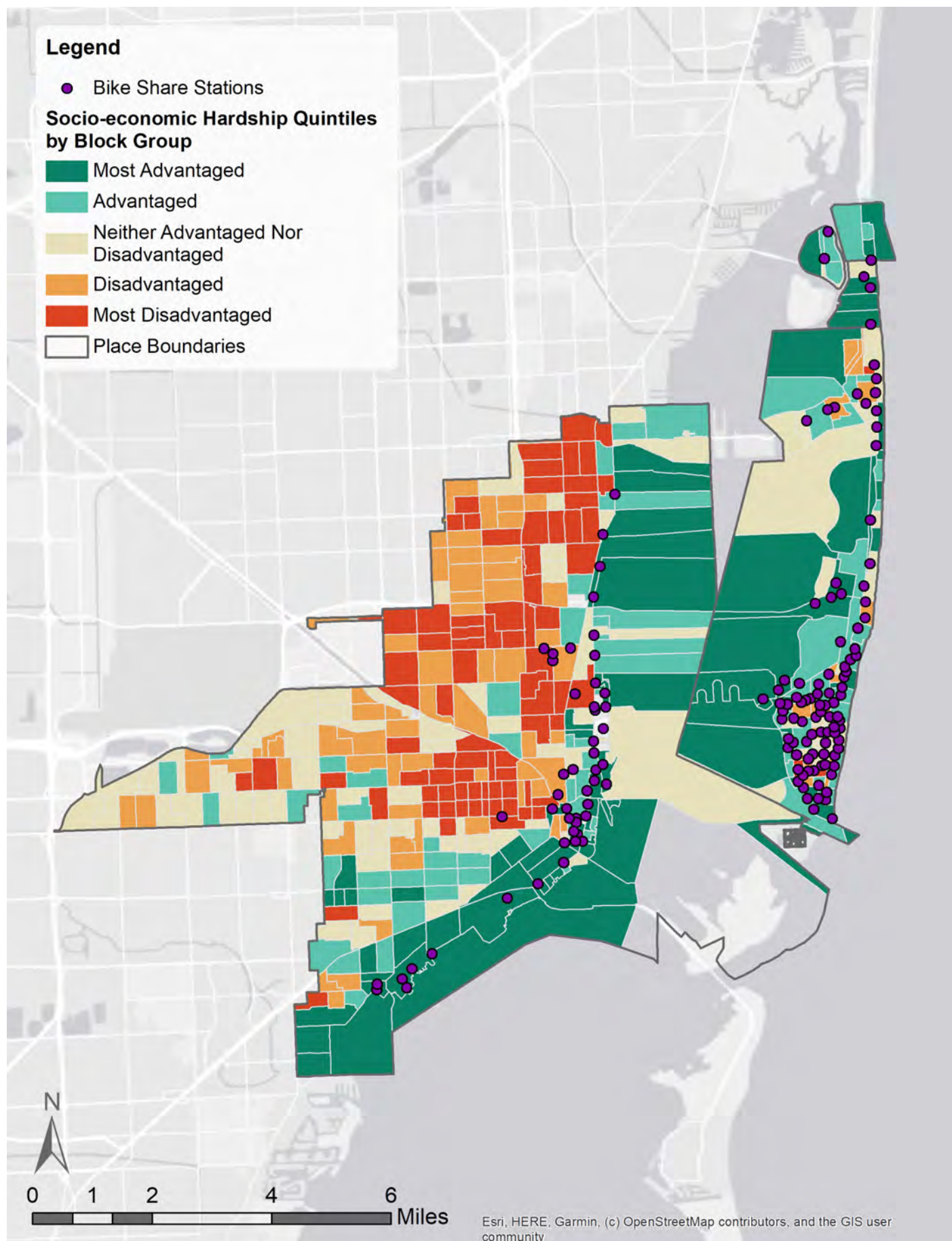


Figure 6b: Spatial densities by area in socio-economic categories – Miami Region, FL

With respect to area, the most-advantaged category in the region has the highest average station density of 8.86 stations per square mile, while the most-disadvantaged category in the region has the lowest average station density of 1.28 stations per square mile (see Figure 6b). Similar to station density by population, it provides lower spatial densities by area for populations with higher level of socio-economic hardship.

CITI Bike, Miami is heavily inclined towards serving its advantaged populations more than its disadvantaged populations. Considering both metrics, the system is heavily skewed towards service for its advantaged categories. It has its lowest spatial densities in the disadvantaged and most-disadvantaged socio-economic categories. As one of the oldest bike share systems in the country, the system has continually prioritized tourist destinations and downtown locations in the region, neglecting equity in the system. It also does not offer membership discounts for low-income populations.





Map 6: Bike share stations and socio-economic categories in Miami Region, FL





## 4.7 Relay Bike Share – Atlanta, GA

Relay Bike Share in Atlanta, GA is a relatively new bike share system that was established in 2016. The system has 112 stations located in the central parts of the city – the downtown and its adjacent areas. It serves 61 of the 325 block groups in the city, corresponding to 12.9% of its area and 27.5% of its population.

Map 7 shows the socio-economic categories overlaid with the bike stations in Atlanta, GA. The disadvantaged and most-disadvantaged categories are concentrated in the southern half of the city, while the two advantaged categories are in the northern half of the city where most of the bike stations are located.

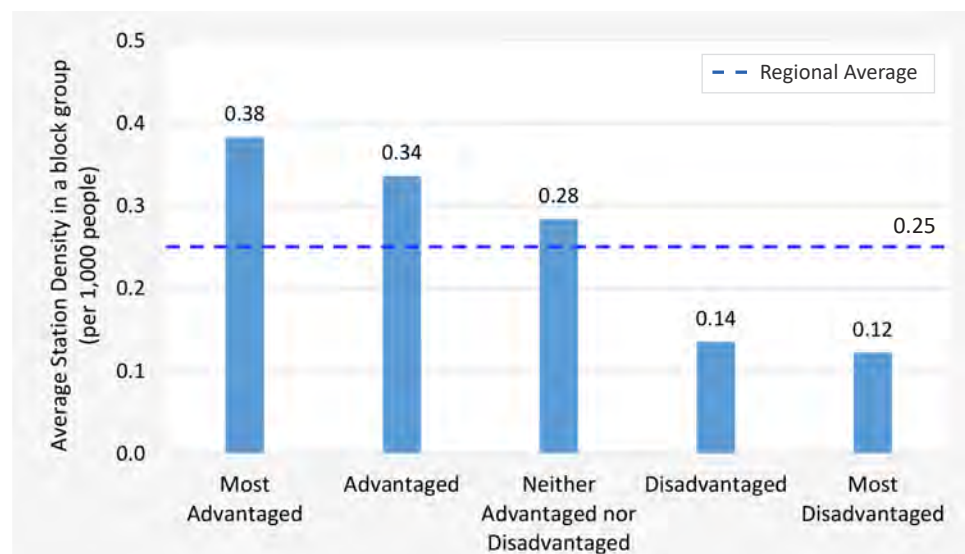


Figure 7a: Spatial densities by population in socio-economic categories – Atlanta, GA

With respect to population, the most-advantaged socio-economic category in Atlanta has the highest average station density of 0.38 stations per 1,000 people in a block group, while the most-disadvantaged category has the lowest average station density of 0.12 stations per 1,000 people in a block group (see Figure 7a). As the level of socio-economic hardship in categories increases, the average station density in the

categories in Atlanta decreases. The system, thus, provides lower spatial densities to populations with higher socio-economic hardship.

With respect to area, the two advantaged socio-economic categories in the city have the highest average station density of 1.69 stations per square mile in a block group, while the disadvantaged socio-economic category has the lowest average station density of 0.39 stations per square mile

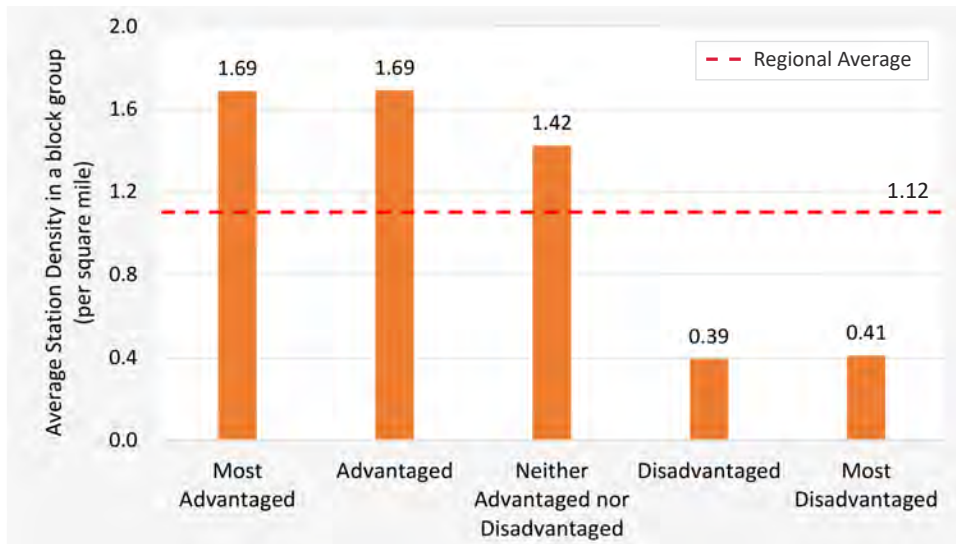
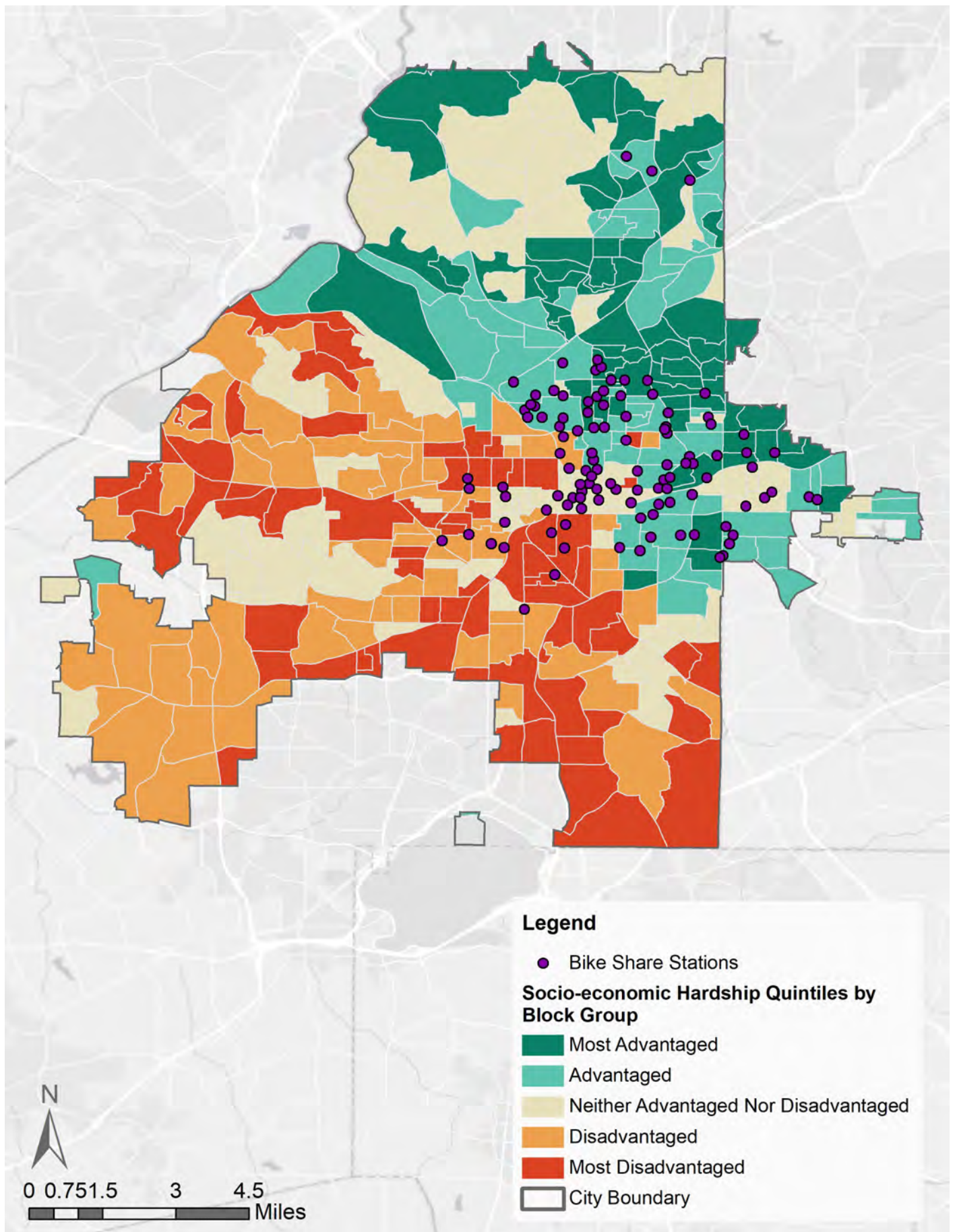


Figure 7b: Spatial densities by area in socio-economic categories – Atlanta, GA

in a block group. Similar to population-based station densities, the system provides lower spatial densities by area to populations with higher socio-economic hardship.

Relay Bike Share, Atlanta provides discounted plans for its low-income populations accounting for their needs through non-spatial methods. However, spatially, the system is heavily inclined towards

serving its advantaged populations rather than its disadvantaged populations. The system provides higher average spatial densities to its advantaged populations, while its disadvantaged populations have the lowest average spatial densities in the city.



Map 7: Bike share stations and socio-economic categories in San Francisco, CA





## 4.8 Bay Wheels (Ford GoBike) – Oakland (East Bay), CA

Bay Wheels, Oakland is a part of Bay Wheels' bike share services in San Francisco, Oakland (East Bay), and San Jose. Launched in 2013 in the city of San Francisco, Bay Wheels (then Ford GoBike) expanded to the East Bay – the City of Oakland, Berkeley and Emeryville – in 2017 (Fowler, 2017). The system has 126 stations in the region, located in downtown Oakland, Berkeley and Emeryville and their adjacent areas. It covers 93 of the 440 block groups in the region corresponding to 20.0% of its area and 24.7% of its population.

Map 8 shows the socio-economic block group categories overlaid with the bike stations in the region. The disadvantaged and most-disadvantaged socio-economic block groups in the region are concentrated along the southern edge of the City of Oakland, while the two advantaged socio-economic categories are concentrated in the northern and eastern areas of the region. The system has stations in the central parts of the city, away from the most-disadvantaged and most-advantaged block groups in the south and the east respectively.

With respect to population, the advantaged socio-economic category in the region has the highest average spatial density of 0.46 stations per 1,000 people in a block group, while the most-

disadvantaged category has the lowest average station density of 0.12 stations per 1,000 people in a block group (see Figure 8a). In line with the spatial distribution of stations observed in the map, the most-advantaged and the most-disadvantaged socio-economic categories have the lowest service in the region. With the exception of the most-advantaged socio-economic category, as the level of socio-economic hardship

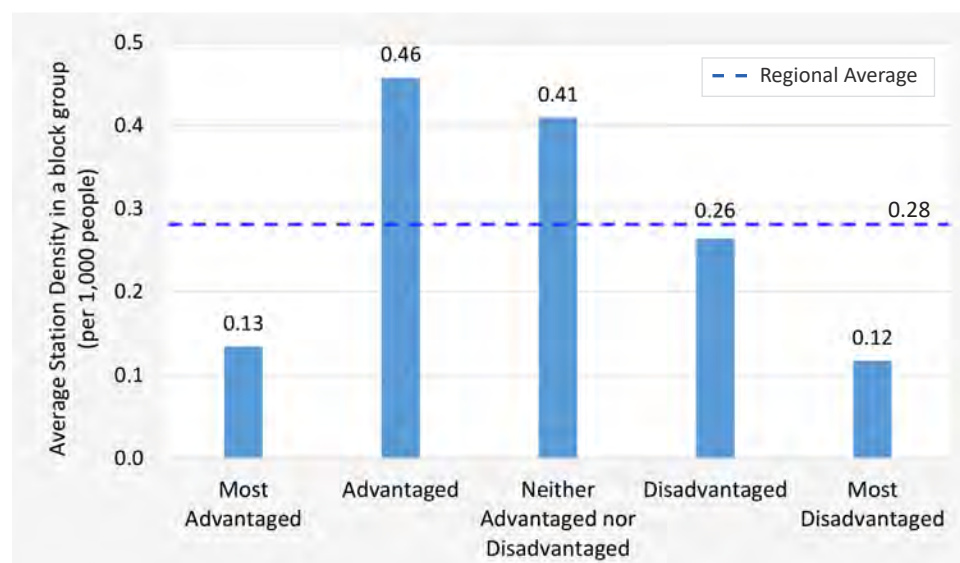


Figure 8a: Spatial densities by population in socio-economic categories – Oakland (East Bay), CA

in categories increases, the average spatial density in the categories decreases in the region. The system, thus, provides lower spatial densities for populations with higher levels of socio-economic hardship.

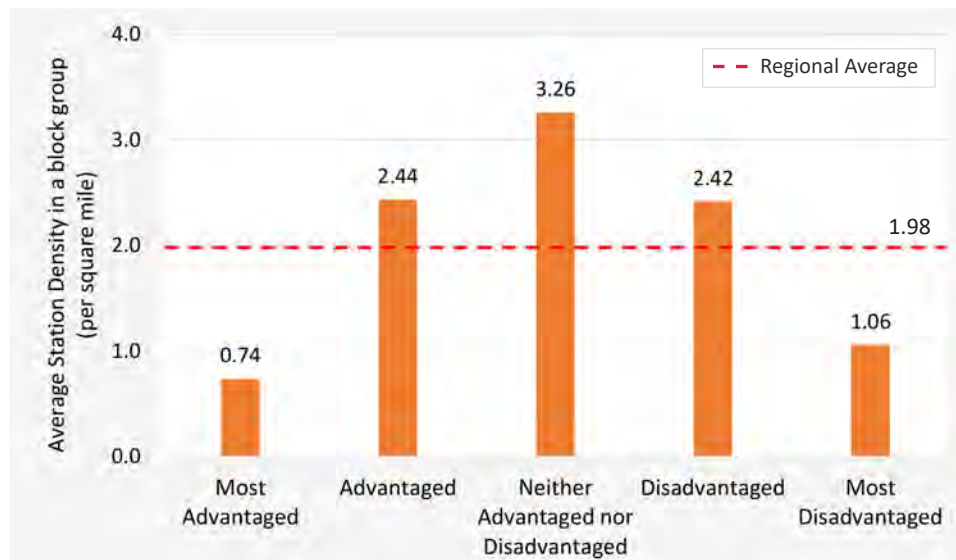


Figure 8b: Spatial densities by area in socio-economic categories – Oakland (East Bay), CA

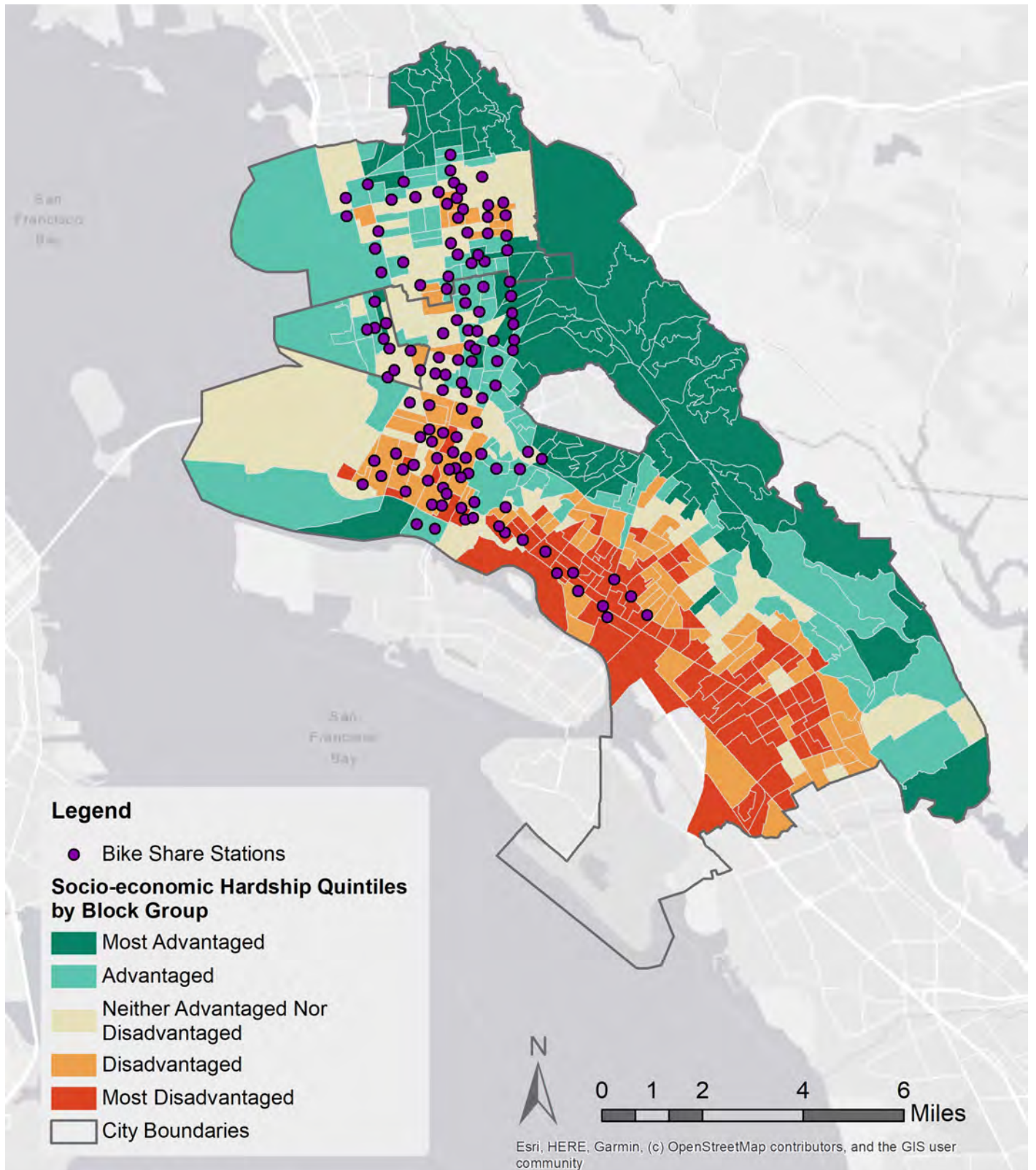
With respect to area, Bay Wheels in the region has higher spatial densities in its middle three socio-economic categories – advantaged, neither advantaged nor disadvantaged, and disadvantaged. The neither advantaged nor disadvantaged category has the highest average spatial density of 3.26 stations per square mile in a block group, while the most-advantaged category has the lowest average station density of

0.74 stations per square mile in a block group. The system also provides low service to its most-disadvantaged populations that have the second lowest average station density of 1.06 stations per square mile in a block group. However, it is not inclined towards its most-advantaged populations as well that have the lowest average spatial density in the region.

With respect to population, Bay Wheels in Oakland (East Bay) is inclined towards serving its advantaged populations more than its disadvantaged populations. The system provides lower service to both of its disadvantaged socio-economic categories, while it has its greatest service in the advantaged socio-economic category.

With respect to area, on the other hand, Bay Wheels is not inclined towards serving its advantaged or disadvantaged populations. The system provides greater service to its middle socio-economic categories – advantaged, neither advantaged nor disadvantaged and the disadvantaged. It provides lower service to its most-advantaged and most-disadvantaged socio-economic categories. It also offers discounted memberships for its low-income residents (Lyft, 2019).





Map 8: Bike share stations and socio-economic categories in Oakland (East Bay), CA





## 4.9 CITI Bike – New York City, NY

Launched in 2013, CITI Bike in New York City is the biggest bike share system in the US. The system has 763 stations in the city, located in Manhattan and its surrounding areas in the Kings and Queens County. It covers 596 of the 6,493 block groups in the city that correspond to 10.7% of its population and 7.2% of its area.

Map 9 shows the socio-economic categories overlaid with the bike stations in New York City, NY. The disadvantaged and most-disadvantaged socio-economic categories in the region are concentrated in Bronx, and parts of Kings and Queens County in the city. The advantaged and most-advantaged populations, on the other hand, are concentrated in Manhattan and its adjacent areas in Kings and Queens County, and Richmond County in the city.

With respect to population, New York City has higher spatial densities in its advantaged socio-economic categories, while it has lower spatial densities in both of its disadvantaged categories

(see Figure 9a). The most-advantaged socio-economic category in the city has the highest average station density of 0.32 stations per 1,000 people, while the most-disadvantaged category has the lowest average station density of 0.04 stations per 1,000 people in a block group.

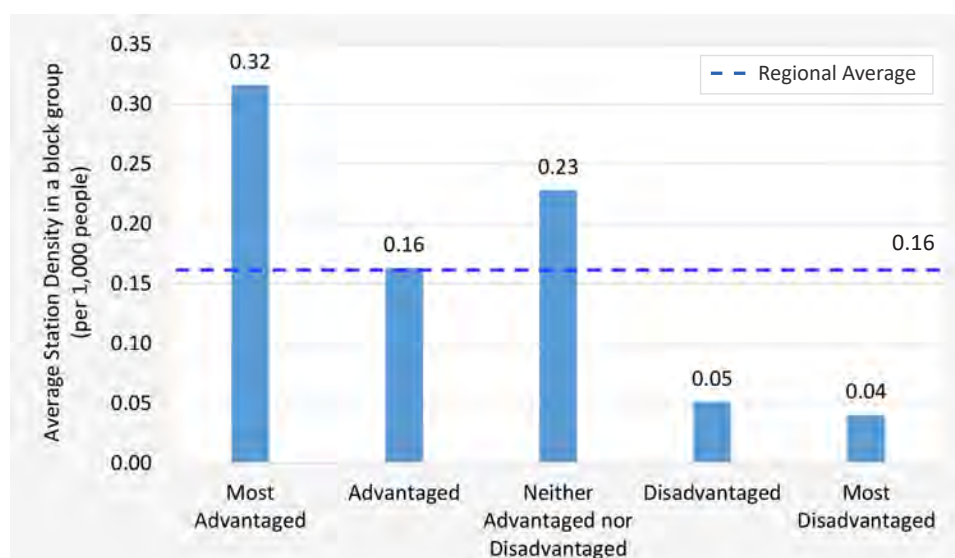
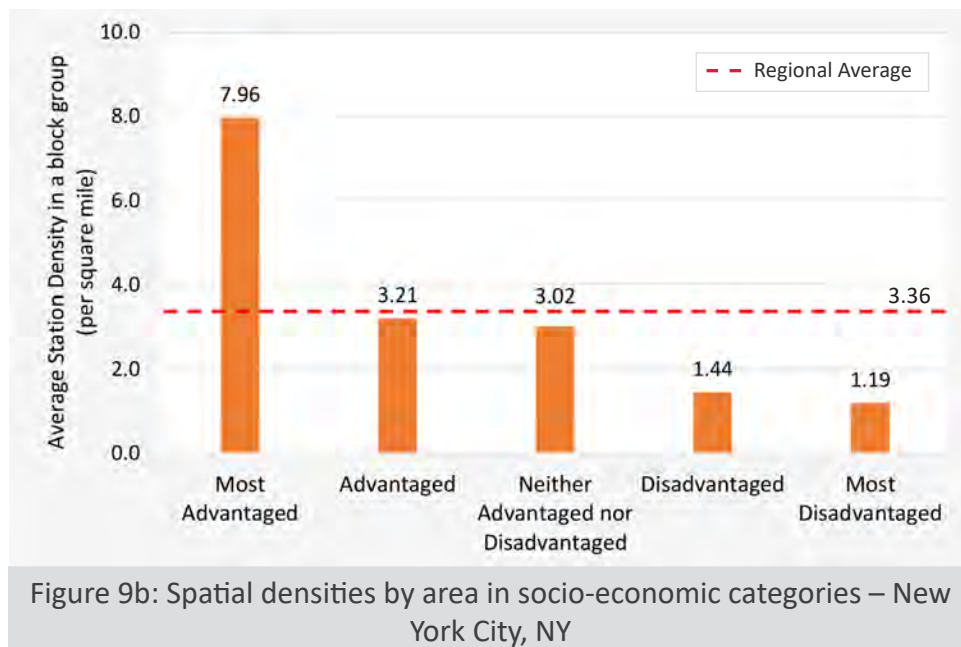


Figure 9a: Spatial densities by population in socio-economic categories – New York City, NY

Note: The block group containing the Central Park (5 residents) in the city was excluded from the analysis as an outlier. It had a station density of 3500 stations per 1,000 people, while the station densities of all other block groups in the region ranged from 0 – 68.18.

***Even though New York City has the largest bike share system in the US, it has the second lowest average station density by population in its most-disadvantaged category, second to Houston – the smallest system among the 10 BSSs.***



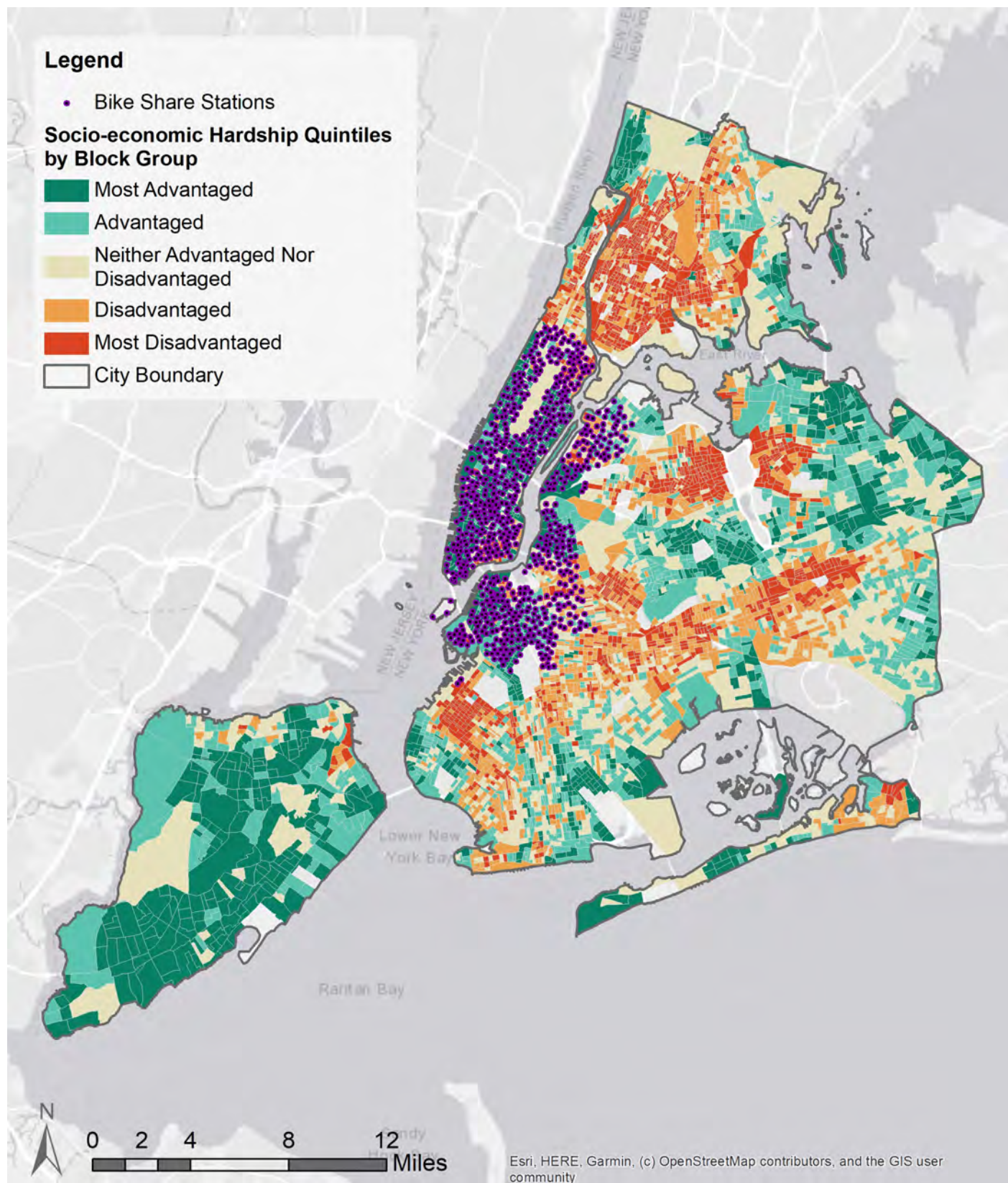
Similar to station density by population metric, with respect to area as well, New York City has its lowest spatial densities in its disadvantaged and most-disadvantaged socio-economic categories, while it has higher spatial densities in both of its advantaged categories (see Figure 9b). The advantaged socio-economic category in the city has the highest average station density of 7.96 stations per square mile in

a block group, while the most-disadvantaged category has the lowest average station density of 1.19 stations per square mile. As the level of socio-economic hardship in categories increases, the average spatial density in the categories in the city decreases. The system, thus, provides lower spatial densities to more disadvantaged populations.

CITI Bike in New York City, the nation's biggest bike share system is heavily inclined towards serving its advantaged populations compared to its disadvantaged populations. Across both metrics, the system provides higher spatial densities to its advantaged populations, while the disadvantaged populations have the lowest service in the city.

For the future, the City has released a major expansion plan that extends into the disadvantaged neighborhoods in Bronx, Queens and Brooklyn doubling the system's service area in the city (DiBarba, 2019). The system also started offering discounted memberships for low-income residents in 2018.





Map 9: Bike share stations and socio-economic categories in New York City, NY





## 4.10 Houston BCycle – Houston, TX

Launched in 2012, Houston BCycle is the smallest bike share system among the 10 BSSs. It has 60 stations located in the downtown and its surrounding areas in the city. The system covers 32 of the 1,861 block groups in the city that correspond to 1.9% of its area and 2.9% of its population, the smallest among the 10 BSSs in terms of area as well as population.

Map 10 shows the socio-economic categories overlaid with bike stations in the city. The disadvantaged and most-disadvantaged block groups in the city are mostly concentrated in the south-western areas and the western half of the city, while its advantaged and most-advantaged block groups are concentrated in the central and eastern parts of the city, including the downtown where most of the stations are located.

With respect to population, the most-advantaged category in Houston has the highest average station density of 0.05 stations per 1,000 people, while the disadvantaged category has the lowest average station density of 0.004 stations per 1,000 people in a block group (see Figure 10a). In terms of how the spatial densities are distributed, Houston has lower average spatial densities

in categories with greater socio-economic hardship, with the exception of the most-disadvantaged category that has marginally higher spatial densities compared to the disadvantaged socio-economic category.

With respect to area, the most-advantaged socio-economic category in Houston has the highest average spatial density of 0.18 stations per square mile in a block group, while

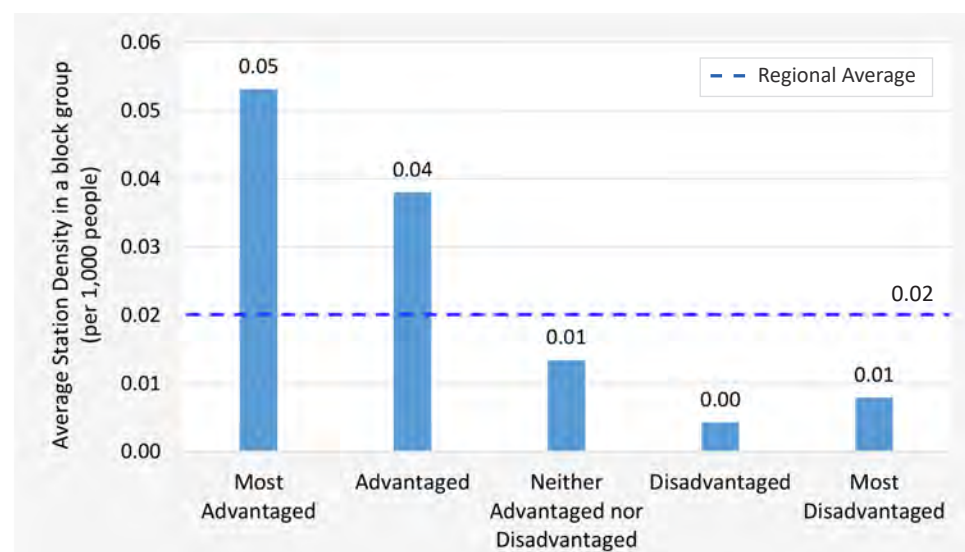


Figure 10a: Spatial densities by population in socio-economic categories – Houston, TX

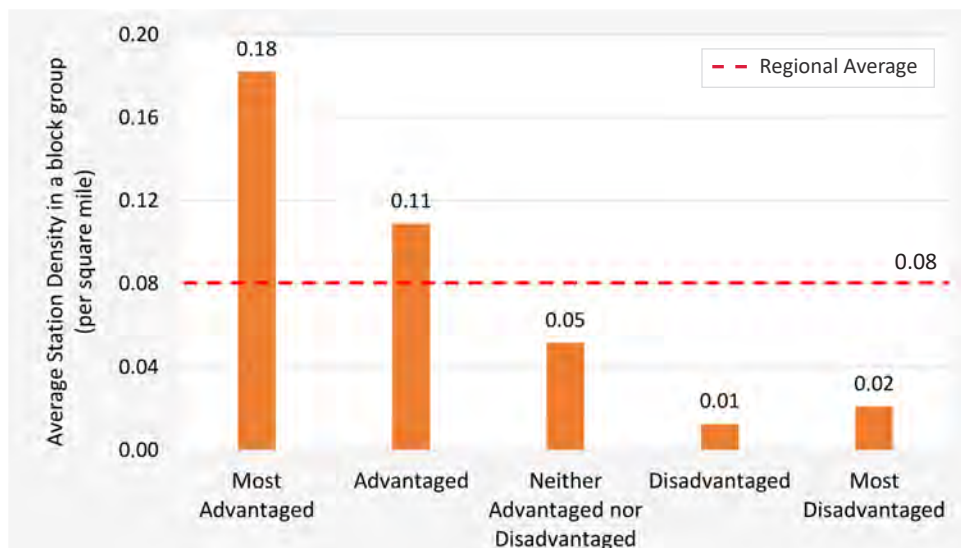
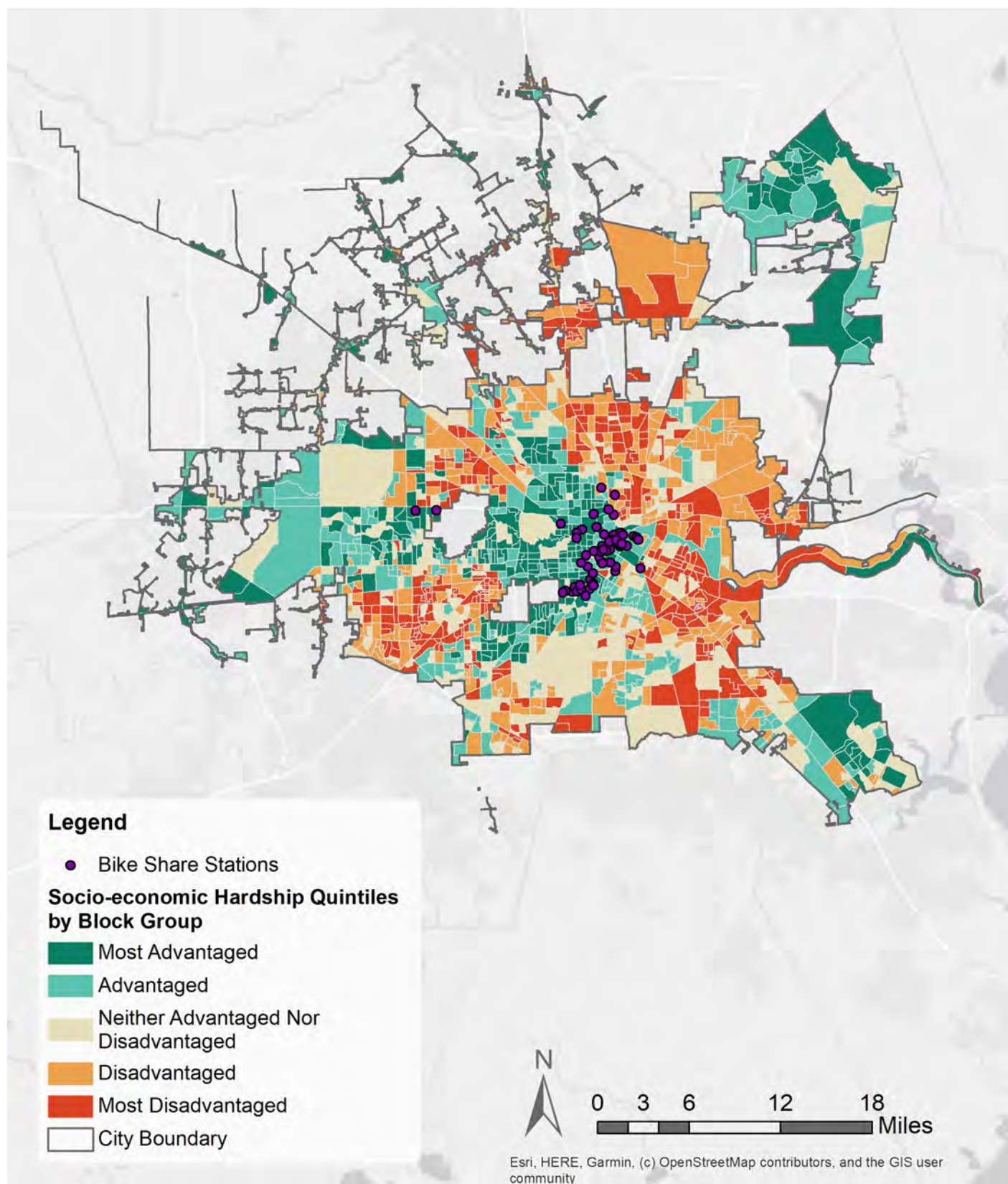


Figure 10b: Spatial densities by area in socio-economic categories – Houston, TX

the disadvantaged socio-economic category has the lowest average spatial density of 0.01 stations per square mile (see Figure 10b). Similar to population-based spatial densities, the city has lower average spatial densities by area in categories with greater socio-economic hardship, with the exception of the most-disadvantaged category that has marginally higher average spatial density than the disadvantaged category.

Overall, Houston BCycle, the smallest bike share system among the 10 BSSs, is heavily inclined towards serving its advantaged populations rather than its disadvantaged populations. Based on both metrics, the system provides greater service to its advantaged and most-advantaged populations, while it has lower service for the disadvantaged and most-disadvantaged populations. Additionally, among the 10 BSSs, ***Houston has the lowest average spatial density in the most-disadvantaged category, by population as well as area.***

In 2018, Houston added 39 new stations to the central city and few gentrified neighborhoods in the city, neglecting underserved areas (Plautz, 2018). The system recently also started a discounted membership plan for its low-income residents (West, 2019).



Map 10: Bike share stations and socio-economic categories in Houston, TX





Credits: Kate Fillin-Yeh, National Association of City Transportation Officials (NACTO)  
Source - <https://www.flickr.com/photos/nacto/26075928943>

## 5. EQUITY IN BIKE SHARE PROGRAMS IN NJ

Given the growth of BSSs in the state, this section analyzes spatial equity in the 3 bike share systems in the State of New Jersey (mentioned on page 3). For each BSS, the analysis uses the spatial indicators described in the methodology section to compare the spatial distribution of stations across socio-economic categories. Similar to the analysis for the 10 of the largest BSSs in the US, its findings include:

- Identifying populations that have the greatest and the least service in the cities.
- Determining how the level of service in the most-disadvantaged populations compares to the average service at the city level.

The three bike share systems are chronologically ordered by their spatial density by population in the most-disadvantaged category.



## 5.1 Zagster Bike Share – Asbury Park, NJ

Zagster Bike Share was launched by the City of Asbury Park in 2017. The system has 8 stations in 5 of the 17 block groups in the city, corresponding to 35.1% of its population and 37.3% of its area.

Map 11 shows the socio-economic categories and the bike stations in Asbury Park, NJ. Three-fourths of the stations in the system are located in the downtown and along the beach, which primarily hosts the most-advantaged and neither advantaged nor disadvantaged populations of the city. The remaining stations are located in the most-disadvantaged category in the south-western parts of the city.

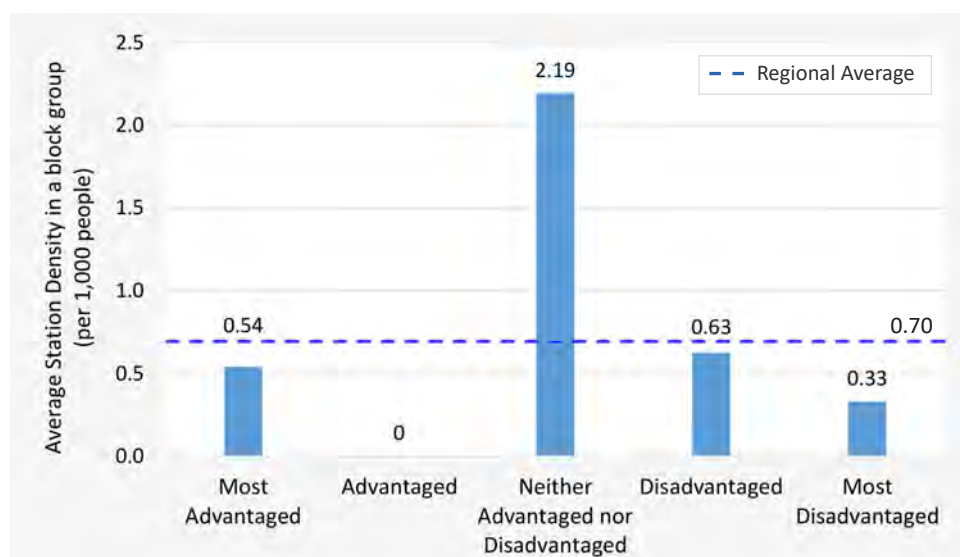


Figure 11a: Spatial densities by population in socio-economic categories – Asbury Park, NJ

With respect to population, the neither advantaged nor disadvantaged socio-economic category has the highest station density of 2.19 stations per 1,000 people in a block group (see Figure 11a). The advantaged category does not have any stations in the city and therefore, has the lowest average station density in a block group. The system has higher than regional average station densities in its neither advantaged

nor disadvantaged socio-economic category, while all other categories have lower than regional average station densities.

Similar to station density by population, with respect to area, the neither advantaged nor disadvantaged socio-economic category in the city has the highest average station density of 7.86 stations per square mile in a block group, while the advantaged category has the lowest



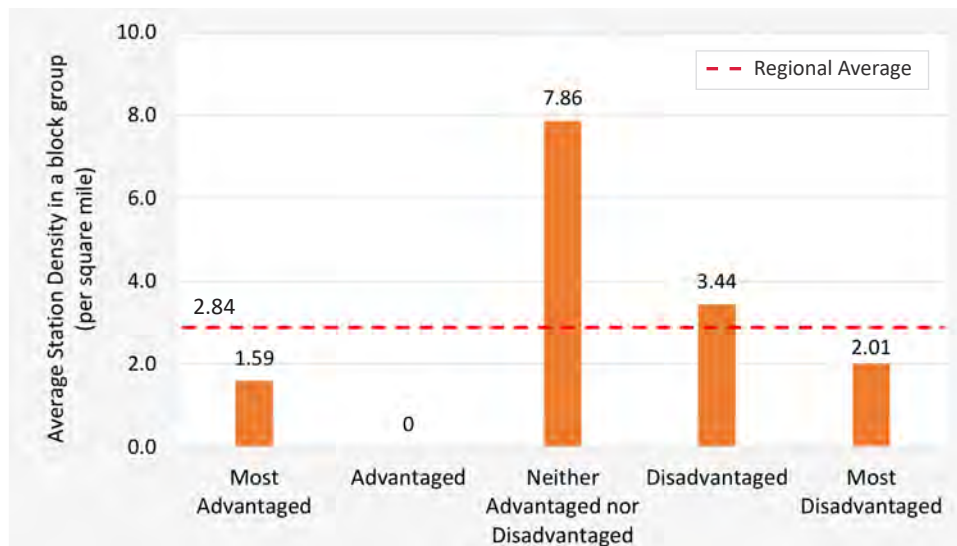


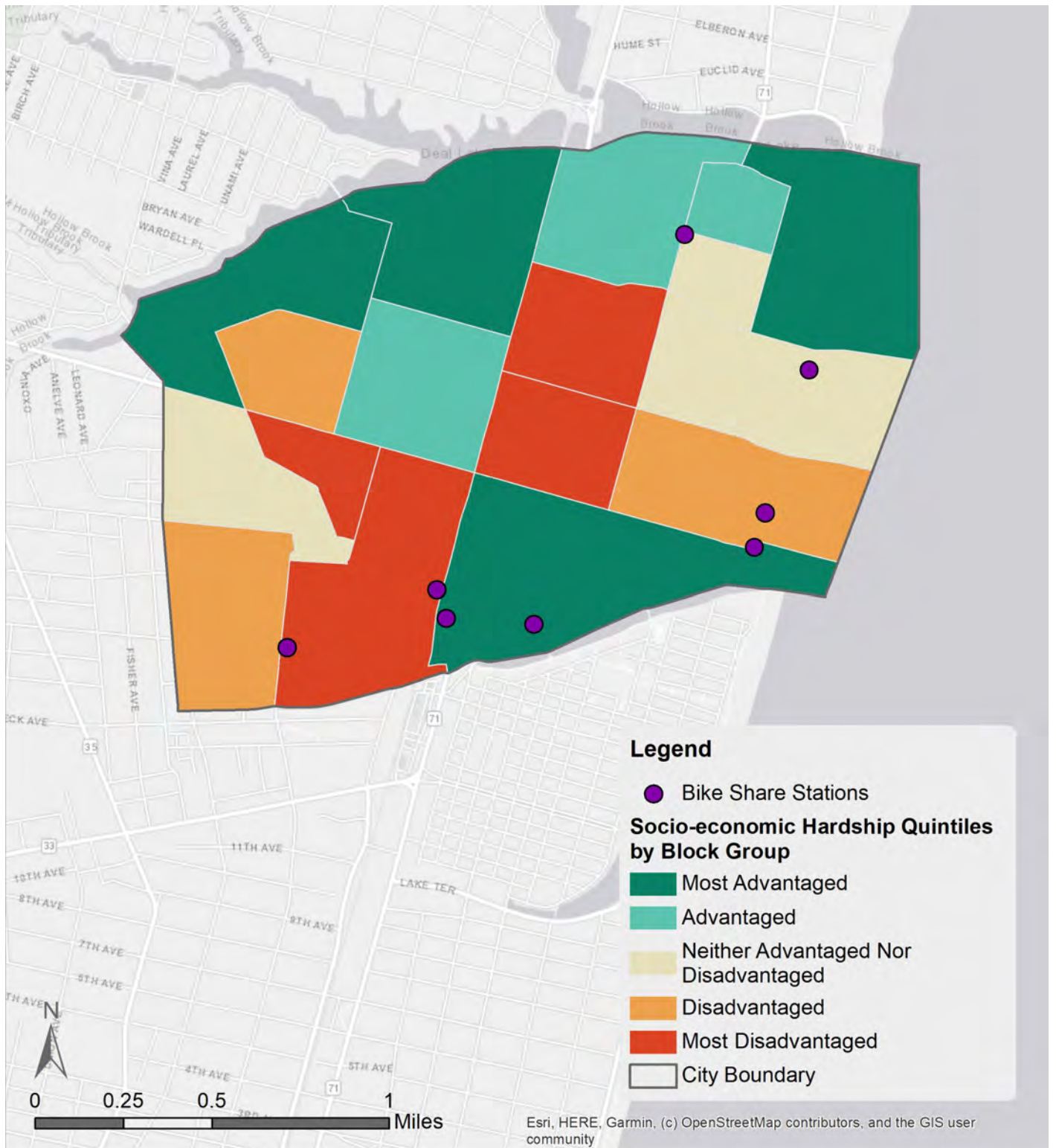
Figure 11b: Spatial densities by area in socio-economic categories – Asbury Park, NJ

average station density with no stations per square mile in a block group (see Figure 11b). The system has higher than regional average station densities in its neither advantaged nor disadvantaged and disadvantaged socio-economic categories, while the remaining categories have lower than regional average station densities.

Zagster Bike Share in the City of Asbury Park provides

higher service to its neither advantaged nor disadvantaged populations compared to other populations. With respect to station density by population, the system has higher service in its neither advantaged nor disadvantaged socio-economic category in the city, while it has lower service in all other categories. With respect to station density by area, the system provides higher service to its neither advantaged nor disadvantaged and disadvantaged categories, while it has lower service in all other categories. However, it is important to note that this analysis might be inaccurate as the block groups identified in the middle socio-economic originally did not have complete data and were adjusted accordingly. The effect of this adjustment in the analysis may have been substantial because the city has 17 block groups only.





Map 11: Bike share stations and socio-economic categories in Asbury Park, NJ



## 5.2 Hudson Bike Share – Hudson County, NJ

Hudson Bike Share is the bike share system in Hudson County, New Jersey. The system serves the City of Bayonne and Hoboken, Town of Guttenberg and West New York, Township of North Bergen and Weehawken, and the Liberty State Park area in Jersey City. It has over 65 stations in 43 of the 182 block groups in the region that correspond to 43.3% of its area and 25.8% of its population.

Map 12 shows the socio-economic categories and the bike stations in the County. The advantaged and most-advantaged block groups in the region are located along the banks of Hudson river where a majority of the stations are also located. The disadvantaged and most-disadvantaged block groups in the region, on the other hand, are located away from the river.

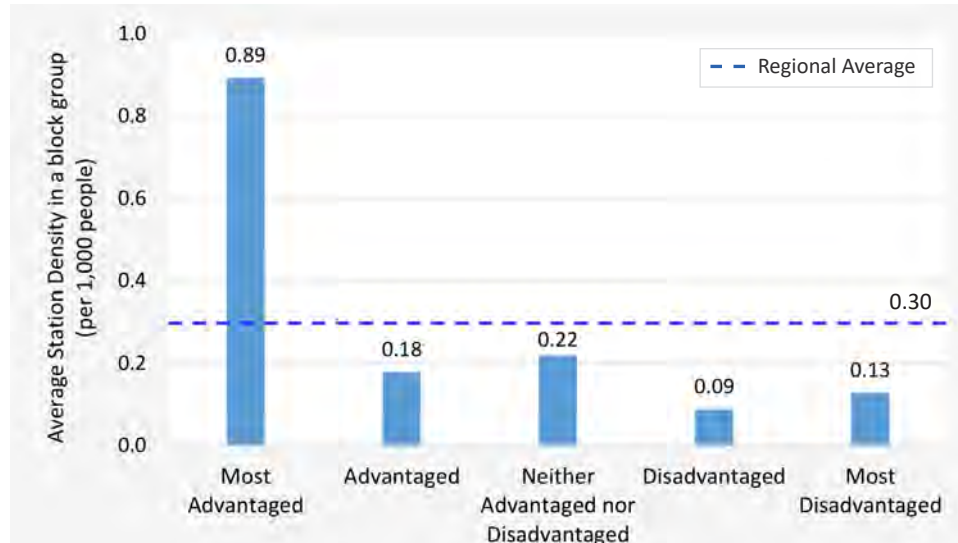


Figure 12a: Spatial densities by population in socio-economic categories – Hudson County, NJ

With respect to population, the most-advantaged category in the region has the highest average station density of 0.89 stations per 1,000 people in a block group, approximately 4-10 times the average station density in any other category (see Figure 12a). The disadvantaged and most-disadvantaged categories in the region have the lowest and the second lowest average station density in a block group respectively.

With respect to area, the most-advantaged socio-economic category in the region has the highest average station density of 13.15 stations per square mile in a block group, approximately 4-13 times the average station density in any other category (see Figure 12b). The disadvantaged category in the region has the lowest average station density of 1.03 stations per square mile in a block group, while the most-disadvantaged category has the second highest average station density of 3.04 stations per square mile.

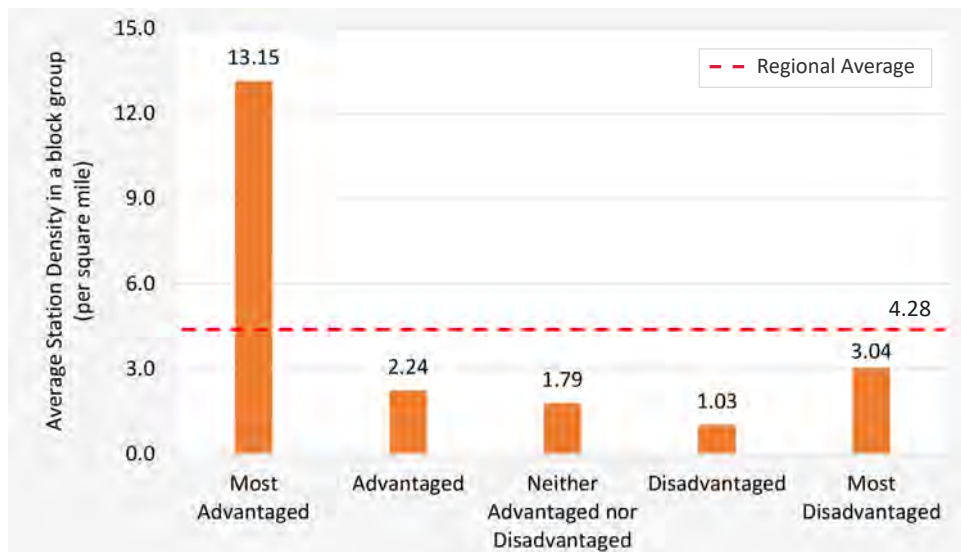
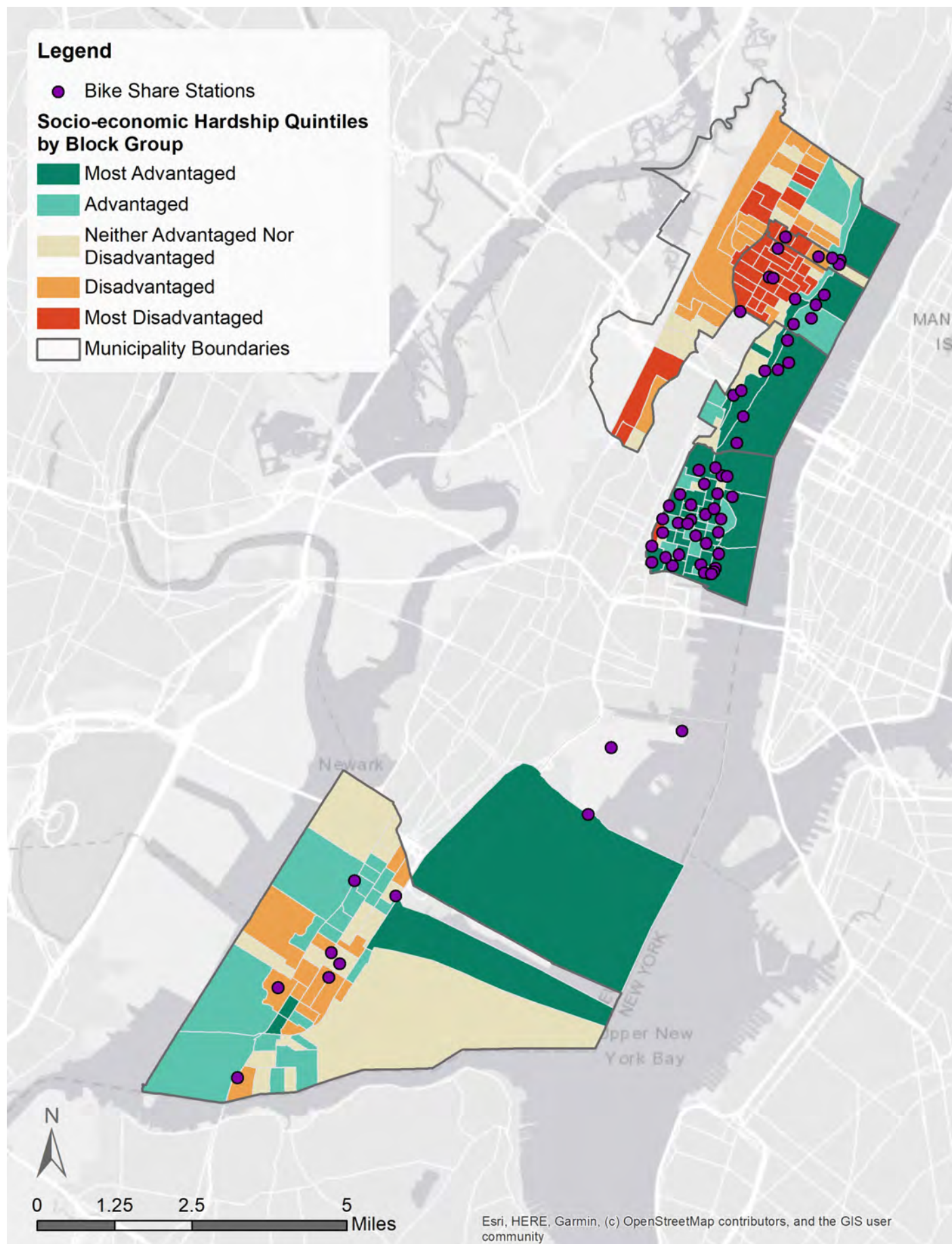


Figure 12b: Spatial densities by area in socio-economic categories – Hudson County, NJ

Hudson Bike Share is heavily inclined towards serving its most-advantaged populations compared to other populations. Based on both metrics, the system has its greatest service in the most-advantaged category, which is substantially higher than its service in all other categories. The system also provides its lowest service to the disadvantaged populations, by population as well as area.

In 2018, the system announced its expansion to the Point Pleasant Beach and Woodbridge in New Jersey, but further progress on the plan has not been released.





Map 12: Bike share stations and socio-economic categories in Hudson County, NJ



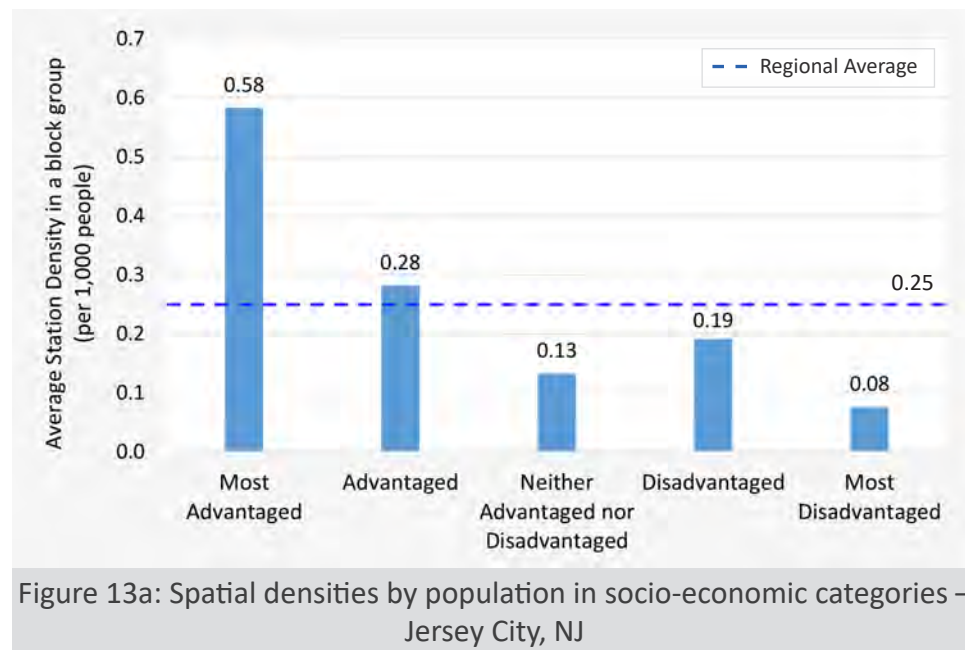
### 5.3 CITI Bike – The City of Jersey City, NJ

CITI Bike, Jersey City was launched in 2015 as an independent bike share system that is interoperable with CITI Bike in New York City (CITI Bike Jersey City, 2015). The system has 49 stations located in the downtown and its adjacent areas in the northern half of the city. It serves 36 of the 166 block groups in the city, corresponding to 17.0% of its area and 24.2% of its population.

Map 13 shows the socio-economic categories overlaid with the bike stations in the city. A majority of the most-advantaged block groups in the city are located in the east, on the banks of the Hudson river, while the disadvantaged, most-disadvantaged and advantaged block groups are located away from the river. The most-disadvantaged block groups are mostly concentrated in the southern half of the city, where there are no stations.

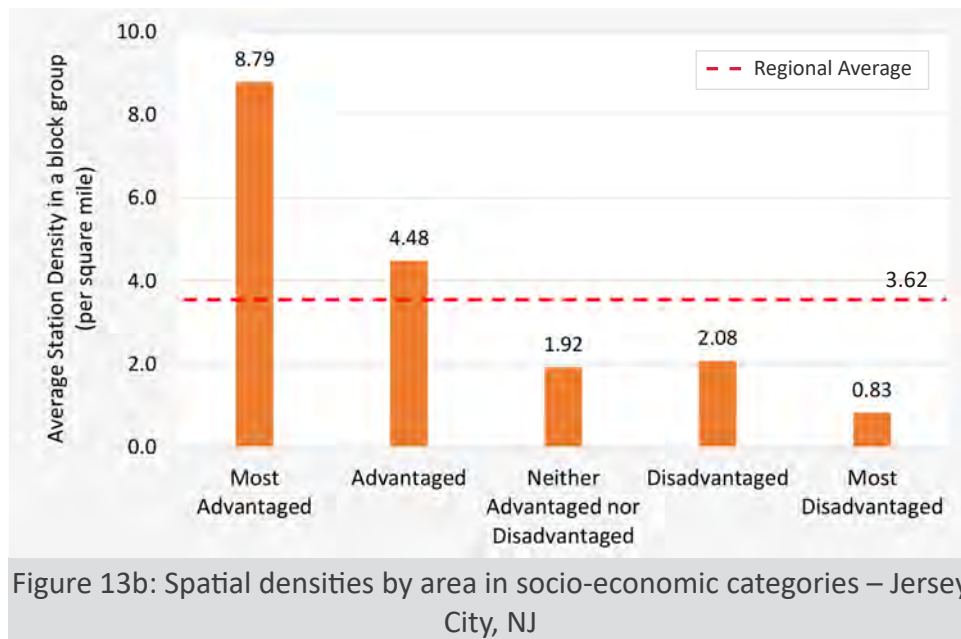
With respect to population, the most-advantaged socio-economic category in the city has the

highest average station density of 0.58 stations per 1,000 people in a block group, while the most-disadvantaged category has the lowest average station density of 0.08 stations per 1,000 people in a block group (see Figure 13a). The system has higher than regional average station densities in the two advantaged categories, while it has lower than regional average station densities in the remaining categories.



Similar to station density by population, the most-advantaged socio-economic category has the highest average station density of 8.79 stations per square mile in a block group in the city, while the most-disadvantaged category has the lowest average station density of 0.83 stations per square



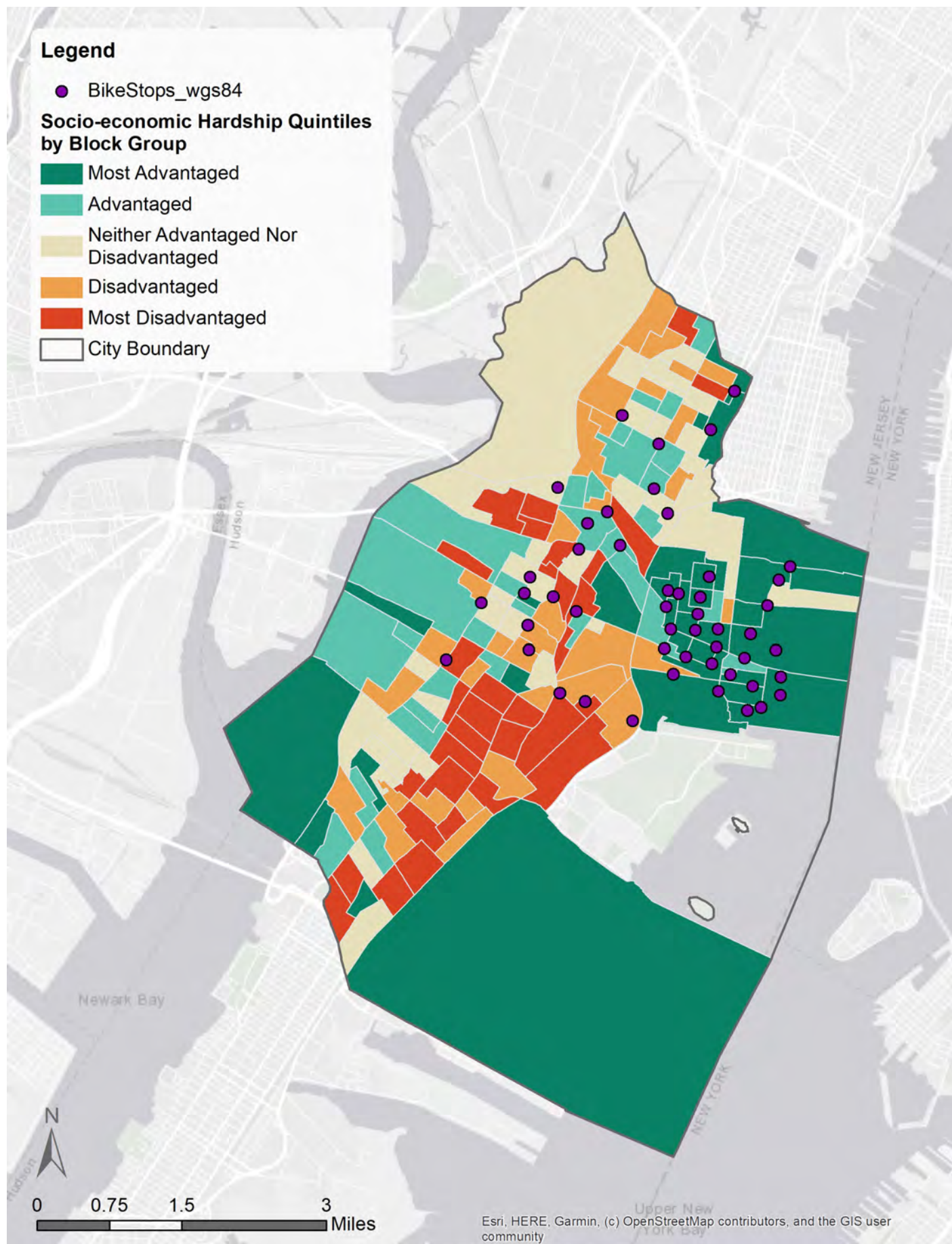


mile in a block group (see Figure 13b). The system has higher than regional average station densities by area in its most-advantaged and advantaged socio-economic categories, while it has lower than regional average station densities for the remaining categories.

CITI Bike in Jersey City is a typical example of a system that favors its advantaged populations over its disadvantaged populations.

Based on both metrics, the system has its highest service in the most-advantaged category, while it has its lowest service in the most-disadvantaged category. Compared to the city level average, the system provides higher service to its advantaged populations, while it has lower service for its disadvantaged populations. The system offers discounted memberships to increase accessibility for its low-income residents.





Map 13: Bike share stations and socio-economic categories in Jersey City, NJ





## 6. DISCUSSION

The analysis findings indicate that most of the selected bike share systems provide reduced access to their disadvantaged populations. While exceptions exist, generally, higher spatial densities are more commonly found in advantaged categories while lower spatial densities are found in disadvantaged categories.

BIKETOWN in Portland presents an exemplary exception to this trend. Based on both metrics, BIKETOWN has its lowest spatial densities in its advantaged categories while its disadvantaged populations have the highest average spatial densities in the city. Capital Bikeshare in Metro DC presents another exception as based on both the metrics, it has its lowest average spatial densities in the most advantaged category. Bay Wheels in San Francisco is also an exception as based on both metrics, the system has its highest densities in the disadvantaged categories.

Table 1a and 1b give the average station densities in socio-economic categories in each of the 10 bike share systems. Analyzing the distribution of station densities across socio-economic categories in the 10 BSSs shows that:

- Out of the 10 systems, 9 systems have their highest average station density by population in one of the two advantaged socio-economic categories, while only 2 cities – Portland and San Francisco – have their highest average station density by population in one of the two disadvantaged socio-economic categories.
- 3 of the 10 systems – Portland, San Francisco and Metro DC – have their lowest spatial densities by population in either of the advantaged categories, while 7 systems have their lowest average spatial densities in either of the disadvantaged categories.

	Socio-economic Category					Study Area Average
	Most Advantaged	Advantaged	Neither Advantaged nor Disadvantaged	Disadvantaged	Most Disadvantaged	
Atlanta	0.38	0.34	0.28	0.14	0.12	0.25
Metro Boston	0.41	0.26	0.32	0.29	0.21	0.30
Chicago	0.40	0.21	0.26	0.17	0.30	0.27
Houston	0.05	0.04	0.01	0.00	0.01	0.02
Miami Region	0.88	0.92	0.76	0.32	0.14	0.60
New York City	0.32	0.16	0.23	0.05	0.04	0.16
Oakland	0.13	0.46	0.41	0.26	0.12	0.28
Portland	0.05	0.22	0.26	0.32	0.43	0.25
San Francisco	0.20	0.15	0.15	0.20	0.16	0.17
Metro DC	0.29	0.54	0.51	0.48	0.30	0.42

Table 1a: Average spatial densities by population in a block group, by Socio-economic Category

	Socio-economic Category					Study Area Average
	Most Advantaged	Advantaged	Neither Advantaged nor Disadvantaged	Disadvantaged	Most Disadvantaged	
Atlanta	1.69	1.69	1.42	0.39	0.41	1.12
Metro Boston	2.42	2.82	2.09	3.14	2.07	2.51
Chicago	4.15	2.20	1.45	1.03	1.52	2.07
Houston	0.18	0.11	0.05	0.01	0.02	0.08
Miami Region	8.86	5.83	4.44	4.23	1.28	4.91
New York City	7.96	3.21	3.02	1.44	1.19	3.36
Oakland	0.74	2.44	3.26	2.42	1.06	1.98
Portland	0.15	0.97	0.97	1.49	2.13	1.14
San Francisco	2.26	1.71	1.99	2.81	3.49	2.45
Metro DC	0.99	3.35	4.12	3.80	2.51	2.96

Table 1b: Average spatial densities by area in a block group, by Socio-economic Category

- With respect to area, 5 of the 10 systems have their highest average station density in one of the two advantaged socio-economic categories, while 3 systems – Portland, San Francisco and Boston – have their highest average station density by population in one of the two disadvantaged socio-economic categories.
- 4 of the 10 systems – Portland, San Francisco, DC and Oakland – have their lowest spatial densities by area in either of the advantaged categories, while 6 cities/regions have their lowest average spatial densities in either of the disadvantaged categories.



Even though there are exceptions, bike share systems in the United States are generally found to provide unequal access to their disadvantaged populations over their advantaged populations. An analysis of the 3 bike share systems in the State of New Jersey is found to resonate with these findings as 2 of the 3 BSSs – Hudson Bike Share and CITI Bike in Jersey City – are found to favor their advantaged populations over their disadvantaged populations, while Asbury Park’s analysis was seemingly inaccurate because of missing data and small number of block groups in the city.

## Bike Share System Equity Rankings

The research further ranks the 10 bike share systems by their service to the most-disadvantaged populations highlighting systems with the greatest and lowest service to the most-disadvantaged populations.<sup>2</sup> The rankings are based on average station densities in the most-disadvantaged category and do not account for other factors such as bike availability, fare structure and bike/walk infrastructure in a region.

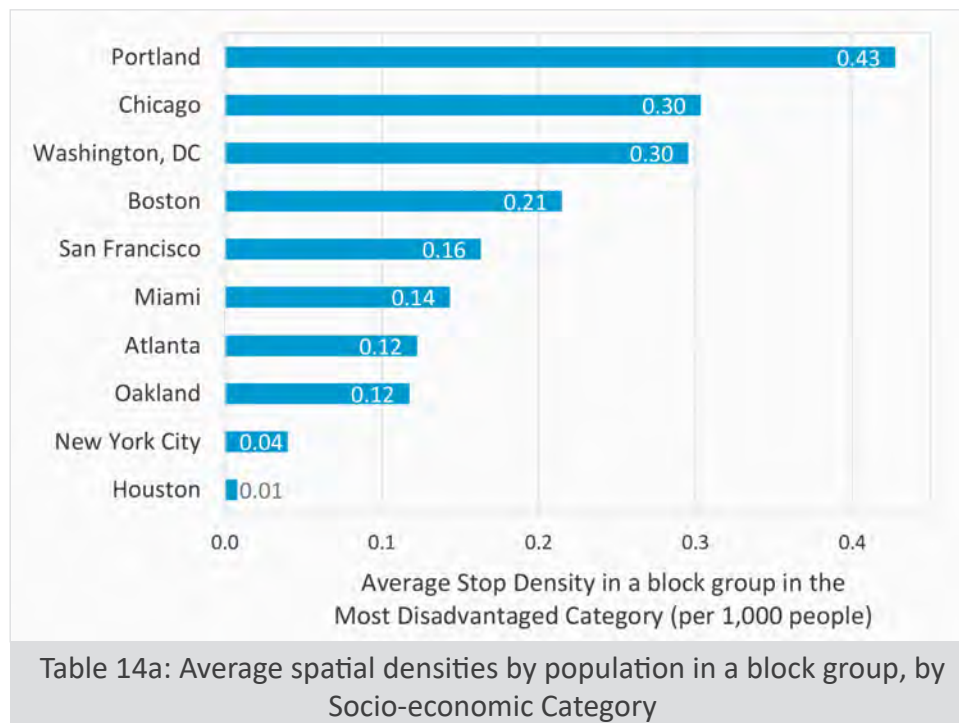
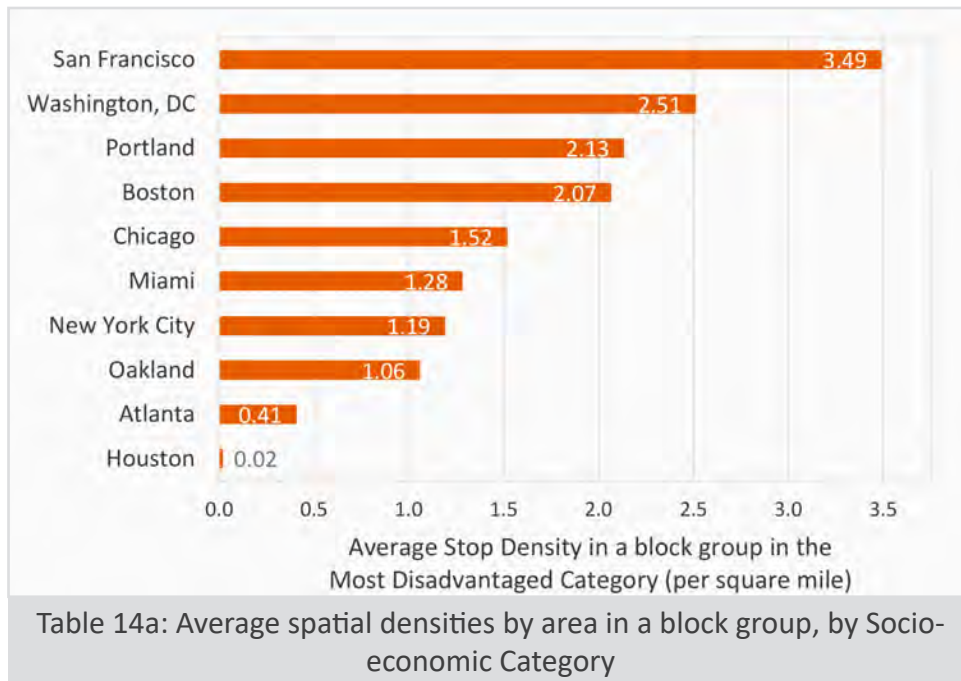


Figure 14a gives the Bike Share System Equity Rankings among the 10 bike share systems by population. Based on station density by population, BIKETOWN in Portland has the highest average spatial density of 0.43 stations per 1,000 people, while Houston BCycle has the lowest with 0.01 stations per 1,000 people. Capital Bikeshare, Metro DC has the second highest average spatial density of 0.31 stations per 1,000 people in a block group.

Figure 14b gives the Bike Share System Equity Rankings among the 10 bike share systems by area. With respect to station density by area, Bay Wheels, San Francisco has the highest average spatial density of 3.49 stations per square mile in a block group, while Metro DC and Portland are second and third in the ranking respectively. Similar to station density by population rankings, Houston has the lowest average spatial density by area in a block group.

Overall, across both the metrics, 5 bike share systems – Metro Boston, Chicago, Metro DC, Portland and San Francisco – have the top 5 Bike Share System Equity Rankings, while the other 5 systems – Atlanta, Houston, Miami Region, New York City and Oakland (East Bay) – are placed in the bottom 5 ranks.

<sup>2</sup> Note that in some cases, relative comparison of average station densities in the most-disadvantaged category across systems may not reflect equity across socio-economic categories within a system. For instance, in the bike share system equity rankings by area, the BSS in Miami (Rank – 6) is heavily inclined towards serving its advantaged populations, while the system in Oakland (Rank – 8) does not favor its advantaged populations over its disadvantage populations.



The researchers recognize that several limitations underline this analysis and its findings. Evaluating equity in bike share systems is a challenging task that depends on multiple factors such as street network density, presence of bicycle infrastructure, availability of bikes, proximity to other transit/para transit services, and so on. Studying these factors and incorporating them in the analysis would give a more practical evaluation of equity in bike

share systems. This study provides a working methodology to analyze spatial equity by comparing service across socio-economic categories which can effectively act as a base for further analysis.





## 7. CONCLUSION

This research presented a framework to analyze the equity dimension of bike share systems in the US and the State of New Jersey, which is consistently identified as a problem in bike share systems across the country. The researchers reviewed the existing literature in the field, identified best practices used to measure equity, and developed an advanced comprehensive methodology to analyze and quantify equity in bike share. The research began with building a repository of station locations in more than 75 bike share systems across the country, which was filtered to select the 10 bike share systems evaluated in this study based on a multitude of geographic, regional and systemic factors. The study defined socio-economic hardship for each block group in the bike share systems using 8 demographic variables as predictors each of which explained different dimensions of socio-economic hardship. It used the Confirmatory Factor Analysis (CFA) method to compute socio-economic hardship scores using the predictor variables. Finally, the researchers employed the population and area normalized approach to study station densities at block group level across socio-economic categories that also accounted for outliers. The methodology allowed for a detailed analysis of the bike share systems by – 1) analyzing service in the most-disadvantaged category, 2) Comparing service across socio-economic categories, and 3) Comparing service to the average service provided.

The analysis results found that based on both the metrics, a majority of the evaluated bike share systems provide higher service to their advantaged populations compared to their disadvantaged populations, with the exception of these 3 bike share systems – Portland, Metro DC and San Francisco. By population as well as area, the 3 systems do not favor their advantaged populations over their disadvantaged populations. While the City of Portland provides higher service to

its disadvantaged populations, Metro DC provides comparable service to both its advantaged and disadvantaged populations. The City of San Francisco provides comparable service to all its populations based on station density by population, while it provides higher service to its disadvantaged populations by station density by area metric.

Station Density by Population Rankings	Station Density by Area Rankings
1. Portland	1. San Francisco
2. Chicago	2. Metro DC
3. Metro DC	3. Portland
4. Metro Boston	4. Metro Boston
5. San Francisco	5. Chicago
6. Miami Region	6. Miami Region
7. Atlanta	7. New York City
8. Oakland (East Bay)	8. Oakland (East Bay)
9. New York City	9. Atlanta
10. Houston	10. Houston

The analysis findings indicate that the bike share systems in New Jersey also follow this trend without any exceptions. The bike share systems in Hudson County and Jersey City provide better service to their advantaged populations rather than their disadvantaged populations, while the findings for Asbury Park were not accurate because of missing data and its small sample size. The analysis of Asbury Park also illustrates a probable limitation of the research methodology in working with small sample sizes.

Lastly, the Bike Share System Equity Rankings ranked the 10 bike share systems by their average station densities in the most-disadvantaged socio-economic category, by population as well as area. The rankings were as follows:

Based on the both the metrics, the top 5 bike share systems in the rankings are Metro Boston, Chicago, Metro DC, Portland and San Francisco, while the bottom 5 bike share systems are Atlanta, Houston, Miami Region, New York City and Oakland (East Bay). With respect to population, Portland has the first rank with the highest average station density of 0.43 stations per 1,000 people. With respect to station density by area, Bay Wheels, San Francisco has the highest average spatial density of 3.49 stations per square mile in a block group. The City of Houston has the lowest average station densities in both of the rankings.

The research has analyzed equity in bike share systems based on the socio-economic characteristics of the residents in a region. A potential extension of the work could be to analyze spatial equity across socio-economic characteristics of jobs (workers). The research methodology could also act as a base for future research to incorporate additional factors such as street network density, availability of bikes and presence of bicycle infrastructure in the analysis.

# APPENDIX A

	F-score Quintile Intervals in Socio-economic Categories				
	Most Advantaged	Advantaged	Neither Advantaged Nor Disadvantaged	Disadvantaged	Most Disadvantaged
<b>Atlanta</b>	-0.27 - -0.10	-0.10 - -0.01	-0.01 - 0.05	0.05 - 0.10	0.10 - 0.20
	(65)	(65)	(65)	(65)	(65)
<b>Metro Boston</b>	-0.21 - -0.07	-0.07 - -0.03	-0.03 - 0.01	0.01 - 0.08	0.08 - 0.21
	(149)	(149)	(149)	(149)	(150)
<b>Chicago</b>	-0.29 - -0.05	-0.05 - 0.00	0.00 - 0.03	0.03 - 0.06	0.06 - 0.13
	(448)	(447)	(447)	(447)	(448)
<b>Metro DC</b>	-0.23 - -0.09	-0.09 - -0.02	-0.02 - 0.02	0.02 - 0.10	0.10 - 0.30
	(213)	(212)	(213)	(214)	(213)
<b>Houston</b>	-0.07 - -0.03	-0.03 - -0.01	-0.01 - 0.01	0.01 - 0.03	0.03 - 0.12
	(372)	(372)	(372)	(372)	(373)
<b>Miami Region</b>	-0.30 - -0.08	-0.08 - 0.00	0.00 - 0.04	0.04 - 0.07	0.07 - 0.19
	(83)	(77)	(87)	(84)	(83)
<b>New York City</b>	-0.22 - -0.06	-0.06 - -0.01	-0.01 - 0.02	0.02 - 0.06	0.06 - 0.26
	(1,246)	(1,244)	(1,245)	(1,244)	(1,248)
<b>Oakland (East Bay)</b>	-0.13 - -0.05	-0.05 - -0.01	-0.01 - 0.01	0.01 - 0.06	0.06 - 0.17
	(88)	(87)	(87)	(87)	(88)
<b>Portland</b>	-0.18 - -0.05	-0.05 - -0.01	-0.01 - 0.01	0.01 - 0.05	0.05 - 0.17
	(94)	(93)	(93)	(93)	(94)
<b>San Francisco</b>	-0.20 - -0.08	-0.08 - -0.03	-0.03 - 0.00	0.00 - 0.07	0.07 - 0.38
	(116)	(115)	(116)	(115)	(116)
<b>New Jersey Bike Share Systems</b>					
<b>Asbury Park, NJ</b>	-0.10 - -0.06	-0.03 - -0.02	0.00 - 0.00	0.01 - 0.03	0.03 - 0.15
	(4)	(3)	(3)	(3)	(4)
<b>Hudson County, NJ</b>	-0.12 - -0.05	-0.05 - -0.02	-0.02 - 0.00	0.01 - 0.04	0.04 - 0.13
	(36)	(35)	(36)	(35)	(0)
<b>Jersey City, NJ</b>	-0.09 - -0.02	-0.02 - 0.00	0.00 - 0.02	0.02 - 0.04	0.04 - 0.11
	(33)	(33)	(33)	(33)	(0)

Table A: F-score Quintile Intervals in Socio-economic Categories

Note: (n) gives the number of block groups in each Socio-economic Category



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