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Biking Equity

The unresolved puzzle piece in San Francisco's biking renaissance

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Biking Equity

The unresolved puzzle piece in San Francisco's biking renaissance

by

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Report

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We are because We *Think* ...

To all those who influenced and honed my *thinking* in UT, Austin and in San Francisco,

This is dedicated to all of you

Thank you

Abstract

Biking equity
The unresolved puzzle piece in San Francisco's biking renaissance

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The surging bicycling rates in U.S. cities and the growing interest to improve avenues of active transportation substantiates the growing presence of the American biking renaissance. San Francisco's sizeable share of bike-related improvements in the planning pipeline along with its third highest bike mode share amongst U.S. cities affirms that the city is in its most bike-conducive planning phase of history. As cities continue to invest their public dollars towards "Let's Make Our Cities Bikeable" vision, growing number of planning studies are beginning to show that bike shares and biking infrastructure are inequitably distributed throughout the cities and in a manner that low-income households or communities of color do not use them as often or as comfortably (Smith, 2015) and San Francisco's case is no different. With numerous Federal and State level grants being used to develop and expand the biking infrastructure in U.S. cities, communities are beginning to realize that biking can be a means to social justice. Additionally, for a high cost of living and housing price area like San Francisco, the low-income communities might benefit the most from the positive externalities accrued from improved access to the biking infrastructure. These benefits include but are not limited to - improved household transportation savings, lower fuel consumption, lowered health risks related to cardiovascular diseases and improved carbon footprint. The intent of this study is to inquire whether San Francisco's existing biking infrastructure (including bike share programs) are absent or less accessible in communities of lower socioeconomic status. And if yes, how is this persisting inequity being influenced by the upcoming bikeway improvement projects and bike share programs. The study finds that bikers in San Francisco tend to be young, white, males with lower-to-middle income background. The study ran Geographically Weighted Regression (GWR) between perceived bike accessibility index and socioeconomic indicators to observe that the low-income neighborhoods in San Francisco have an inequitable access to biking infrastructure. Households in low-income neighborhoods of San Francisco with high dependency rates, low educational levels and with no access to health insurance show low bike accessibility. The study elicits that although the city's long-term bike and ped planning projects are geared towards addressing this persisting inequity, a closer look at bikeway improvement projects implementation since 2012 hasn't mended the equity gap. Improving access to safe and convenient biking infrastructure through physical planning and design is a traditional model of addressing inequitable distribution of civic amenities. The study gathers evidence from other U.S. cities in promoting equitable bike share lessons. It postulates that San Francisco with its bike sharing expansion stands at an opportune moment, where appropriate sequencing of bike infrastructure expansion, bike share station siting in low-income communities, active bike sharing advocacy, discounted membership for low-income households, improved bike share and transit integration, and predicted surge in ridership in the newly expanded residential neighborhoods might bridge the equity gap that traditional modes of bike infrastructure improvements have not been able to accomplish.

Keywords: *Biking equity, bike share, active transportation, social justice* and *Geographically Weighted Regressions* (GWR)

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1. Introduction

1.1 Research Context and Purpose

Biking rates in American cities have surged in the past two decades (Shaheen, 2012). John Pucher, Ralph Buehler and Mark Seinen in their article “Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies” make a strong case for the phenomenon of biking renaissance that is increasingly becoming manifest in U.S. metropolitan cities of New York, Chicago, San Francisco, Washington D.C., Portland and Minneapolis (Pucher, et al, 2011). The article uses quantitative and geospatial data to demonstrate that the American landscape is in its most bike-conducive and bike-progressive planning phase in history and more so for the above-mentioned U.S. metropolitan regions. The context of biking renaissance is well-supported by a time in planning history where cities are investing unprecedentedly in biking infrastructure and bike sharing projects (Shaheen, 2012). Planning literature has shown that there exists a “positive correlation between cycling levels and supply of bike paths, lanes, and other similar infrastructure, even after controlling for other explanatory factors such as city size, climate, topography, automobile ownership, income, and student population” (Dill and Carr, 2003). That being established, the question regarding in which neighborhoods the infrastructure is being introduced and for whom, is worth a critical inquiry to promote the use of biking infrastructure as a public good (Goddard, 2016).

In the past few decades, many regional and local transportation agencies have recognized the need to invest in improving the active transportation choices both for recreational purposes and for ways of getting in and around the city. In part, this need emerges from vehicular congestion, approaching capacity limits for automobile-based transportation networks, depreciating level of service (LOS) on vehicular travel networks and high maintenance costs associated with roads. Planning literature has given a strong indication regarding the negative externalities associated with car-centric land use and transportation planning approach. These quantify how increasing levels of vehicular travel is negatively associated with higher carbon footprints, higher obesity rates, and prevalence of cardiovascular diseases and diabetes, the higher share of household income and time spent on travel-related needs, and poor neighborhood-level social ties (Gardner, 1998). In recent times, planners have recognized that improving active transportation and multi-modal transportation access is a resource-efficient way of remediating the negative externalities caused by car-centric urban development model of yesteryears. Biking research "…shows that accelerated foothold of biking programs in North American cities are reporting back with improved carbon emissions, improved public health risks (like obesity, stress-levels, and diabetes), lower car-related household spending, improved quality of life and a lesser amount of human time commuting" (Shaheen, 2012). This ideological shift has acted as a catalyst to the North American biking renaissance and has strengthened the need and realm of active transportation planning.

This approach of prioritizing active transportation is becoming more prevalent and actively shaping the spatial form of American cities through Federally, State and locally funded programs like Vision Zero, Safe Routes to Schools, Complete Streets, and Bike to Work etc. This activism towards integrating active transportation and encouraging multimodally balanced transportation has resulted in American cities undertake massive infrastructure improvement projects which prioritize pedestrians, bikers and transit users over drivers. The infrastructural investments and the planning strategies adopted during these biking renaissance years will generate long-lasting consequences for non-motorized transportation. There is a growing body of literature that provides evidence that "biking infrastructure and bike shares are inequitably *distributed throughout the cities and in a manner that low-income households or minority communities do not have access to* *them as frequently or as comfortably"* (Smith, 2015). Quantitative and qualitative shreds of evidence from a decade-long planning literature/surveys on this topic suggest that bikers and bike share users across most U.S. cities mostly tend to be young (25-45 years old), male and predominantly white with middle to high-income households (Pucher, et al, 2011) (Buck et al, 2013) (Shaheen, 2012). These demographic indicators as a measure of access to biking infrastructure is a well-documented argument for existing inequity. But more recently, there is an evolving discourse about where or which neighborhoods have access to safe and comfortable biking infrastructure. As planning literature is beginning to demonstrate that living in bikeable (and walkable locations) and not relying on driving as a principal mode of getting around the city can bring down housing and transportation costs effectively (Goddard, 2016), the question relating to which neighborhoods have the access to bike infrastructure is increasingly becoming important from an equity standpoint. For rent-burdened households in larger metropolitan cities like New York, San Francisco, and Washington D.C. etc., biking paired with reliable transit service and walking can relieve a substantial proportion of car-related household spending. With numerous Federal and State level grants being used to develop and expand biking infrastructure in U.S. cities, there is a growing consensus towards biking as a means of social justice and especially in the low-income communities which might benefit most from it (Goddard, 2016).

San Francisco has the third highest bike commuting mode share (around 5%) in the U.S. next to Portland (7%) and Minneapolis (6%)

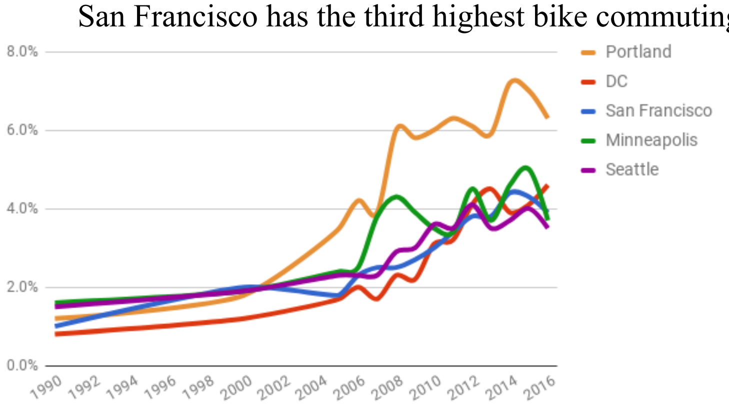


Figure 1 Biking rates in U.S. cities (Source: American League of Bicyclists)

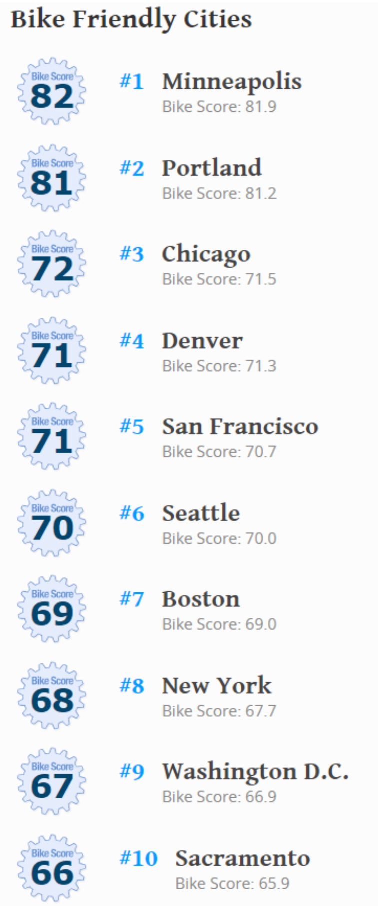


Figure 2 Bike Score of U.S. cities
(Source: Bike Score)

(McLeod, 2017). Bike score 2017 ranks San Francisco as the fifth most bikeable city in the U.S., next to Portland, Oregon (Bike Score, 2016). City's dedication to improving biking experience is resolute with the share of bike-related improvements in the planning pipeline. This proportion of capital spending on bike infrastructure substantiates that San Francisco is undergoing a biking renaissance, as suggested by Pucher, Buehler and Steiner.

Bay Area has one of the most expensive housing prices and a high cost of living. This housing price centrifuge has been pushing low- and middle-income families out of the city thereby burdening their transportation costs. The housing and transportation (H+T) affordability index models elicit that San Franciscans find themselves burdened by the high housing and transportation costs which at an average consumes around 45% and 16% of their income respectively. As compared to

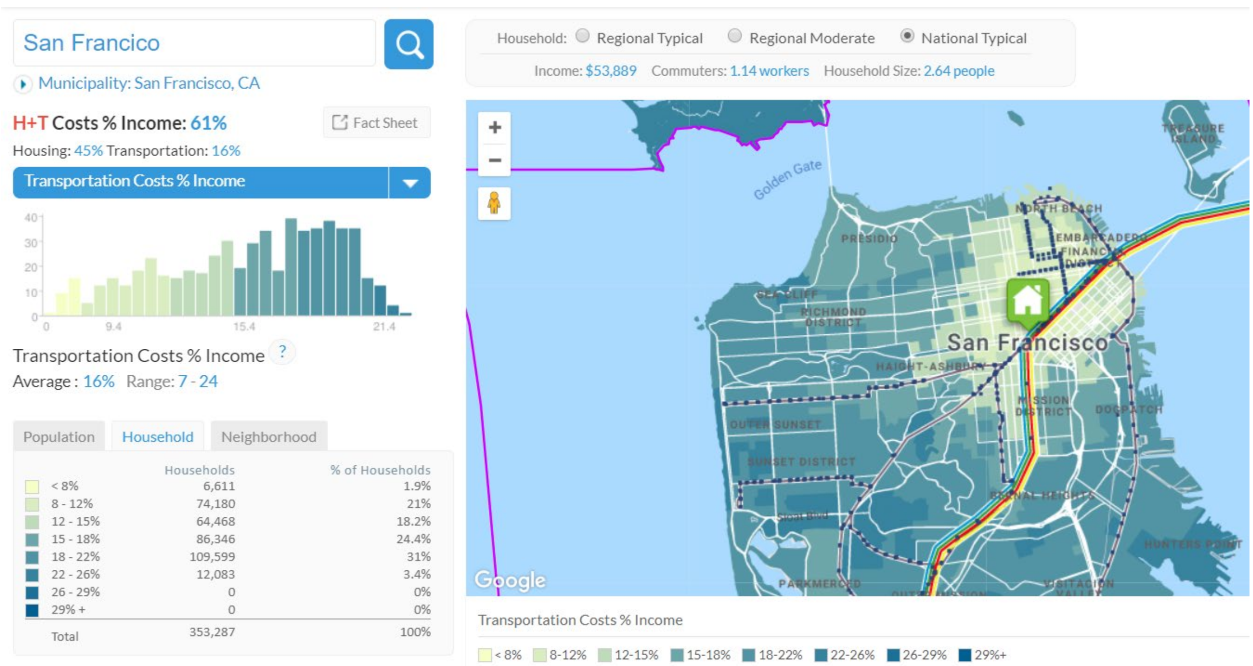


Figure 3 San Francisco's transportation costs as percentage of income (Source: H+T Affordability Index)

the national average, these percentages figure at the last quartiles (see Fig.3 and Fig. 4).

Given these housing pricing statistics, saving on transportation costs for middle- and lower-income households is an incentive to reduce the overall household expenditure. Planning literature has proved that car-free low-income households find a more productive alternative use of ‘not incurred’ automobile related spending if they can access employment and educational opportunities by other means (Litman, 2002).

San Francisco is one of the few American cities (after New York) where living car-free does not hinder access to opportunities (Biggar and Ardoin, 2017). City’s compact spatial layout, good regional and local transit connectivity, reliable transit frequency and walkable neighborhoods complement car-free living (Muuser, 2017). Therefore, investing in San Francisco’s equitable bike infrastructure (bikeways and bike sharing program) is a cost-and-resource efficient way of getting around the city for the residents and commuters alike.

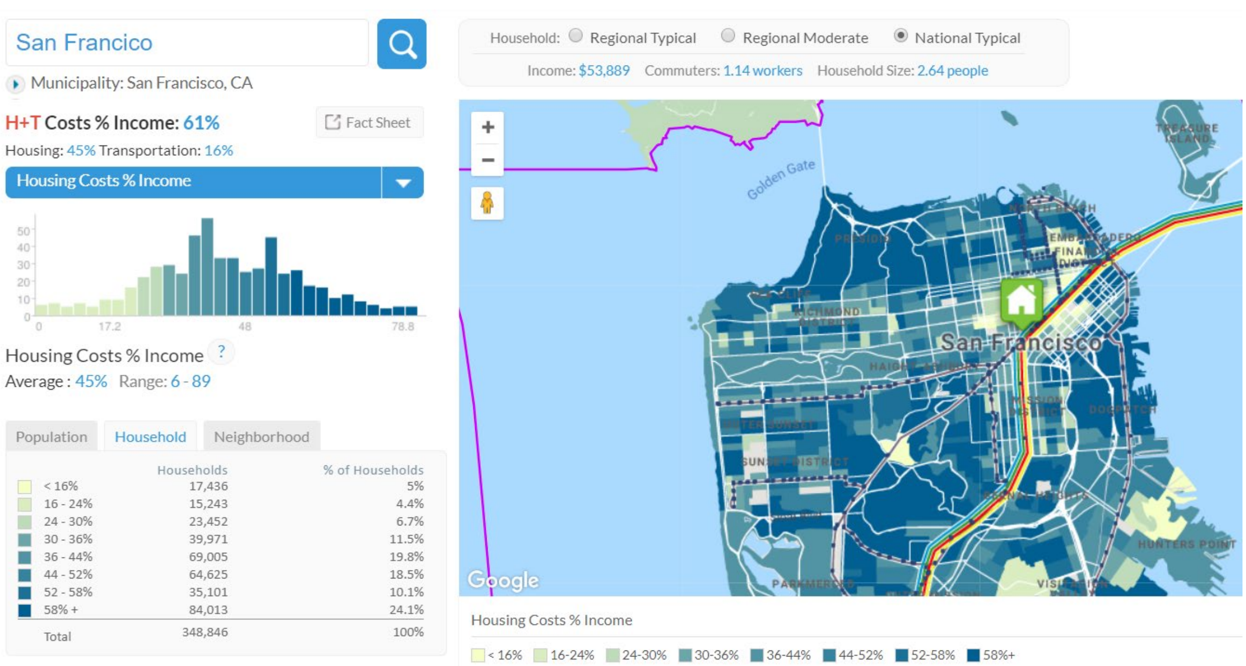


Figure 4 San Francisco's housing costs as percentage of household income (Source: H+T Affordability Index)

1.2 Research questions

The intent of this study is to inquire whether San Francisco's existing biking infrastructure (including bike share programs) are absent or less accessible in communities of lower socioeconomic status. And if yes, how can biking infrastructure expansion be influenced to account for more equitable biking resources for all San Franciscans. This research intent has been broken down in 4 sub-questions:

1- *Who bikes and uses bikesharing systems in San Francisco? Spatially within San Francisco, which neighborhoods (block groups) demonstrate higher biking rates?*

2- *Empirically, how bike-accessible are San Francisco's neighborhoods. And how does the bike accessibility correlate with socioeconomic equity indicators?*

3- *Will the upcoming bikeway improvement projects by SFMTA (San Francisco Metropolitan Transit Agency) impact the biking equity in the city?*

4- *Can the city's bike sharing enhance biking equity?*

2. Gathering literature-based evidence on biking and bike sharing trends in U.S. cities

This chapter summarizes the literature-based evidence on biking and bike sharing trends in major U.S. cities.

2.1 Demographic Indicators

A study on biking and walking trends in the Bay Area infers that demographic factors like age, gender, race, and socio-economic indicators are strong predictors of whether people choose to walk, bike, take transit or drive as compared to the built environment indicators (Cervero and Duncan, 2003). These findings make it clear that demographics play a role in an individual's choice to use active transportation.

Biking and Gender

In North America, there is nationwide literature evidence establishing that men tend to bike more than women. As of 2012 in U.S., male account for approximately 75% of bike trips while women make the rest of 25% of bike trips (Pucher et al, 2011). The principal reason behind the difference in biking gender share is *perceived safety* (Dill and Carr, 2003). As bike-related fatalities have gone down in past years, an increasing number of women are beginning to use the bike to commute.

Biking and Age

Regarding age-related demographic evidence for biking, Pucher article notes that the age group of 25-45years old is the cohort which bikes the most. However, recent trends have shown that there is a growth in cycling rates in the age group of 45 to 65 years old (Pucher et al, 2011). This can be attributed to the larger demographic trend where empty nesters and baby boomer's generation are increasingly relocating in central city locations with functional biking facilities. Planning literature provides evidence that this generation is interested in car-free urban lifestyles and are probable to use transit, biking and walking as the principle mode of getting around their destinations. Biking levels study also indicates that a higher share of college students along with a high share of car-free households is a strong indicator of high cycle rates in metropolitan regions nationwide (Pucher et al, 2011).

Biking and Income levels

There are mixed results from studies on income levels as a determinant of biking rates. There is one school of finding which concurs that mostly middle-income households (with some mix of high-income households) tend to bike (Buck et al, 2013). The other school of finding suggests that income levels do not act as a predictable indicator of biking but what is determinable is, "*that low-income people bike mainly for work trips and other utilitarian purposes, while high-income people bike for recreational purposes*". (Krizek et al, 2009)

Biking and Ethnicity

Most planning studies concur that nationwide whites tend to bike the most of all ethnicities but for past decade this trend has been diversifying with increasing levels of participation amongst African Americans followed by Hispanics and Asians. (Pucher et al, 2011)

Bike sharing and demographic characteristics

There are many recent but limited planning studies which focus on the demographic profiling of bike share users in U.S. cities. A study focusing on Washington D. C. and Virginia's Capital Bike share (CaBi) users used intercept surveys and found that compared to area bicyclists, CaBi users (short-term and annual members) were more likely to be young females with lower household incomes and lower vehicle ownership (Buck et al, 2013). This demographic segment did not prefer to own bicycles and was more likely to use bike share for more utilitarian purposes than recreational purposes. Additionally, the study found that CaBi long-term and short-term users shared similar demographic characteristics, but the short-term users used CaBI for more recreational and tourism purposes and were less likely to wear helmets while the long-term users used bike share for more commuting and utilitarian purposes (Buck et al, 2013). The study findings hint that bike sharing programs across U.S. cities is encouraging new demographic segments to bike and can influence overall bike mode share given robust network coverage and station siting of bike share stations (Buck et al, 2013). There isn't enough availability of planning literature on socioeconomic indicators of bike share users in U.S. cities. However, one such study which tried to bridge this gap was conducted by Shaheen and colleagues across various U.S. cities. The study found that annual members of bike share users in Minneapolis, Montreal, Denver, and Washington D.C. were mostly young, white, highly educated males with middle-to-high household incomes. The trip purpose was not comparable across multiple cities but was predictable on a city-to-city basis (Shaheen, 2012). For instance, in Washington D.C. area and Boston, bike share is used more for utilitarian, commuting and social purposes by the residents but in Denver, the trip purpose was more closely related for recreational and leisure purposes (Shaheen, 2012) (Buck et al, 2013).

Another such demographic study was undertaken on Philadelphia's Indego bike share system. The study summarized that Indego was increasingly being used by youth, students who come from middle-to-high income households. The study looked at depth regarding the trip purpose of the bike share system and summarized that 26% of trips were made for commuting purposes while 57% of the trip attributed from running errands and social activities and rest for leisure or exercise (Hoe, 2015). Long-term Indego users liked the convenience of the bike share system and regarded it as a good alternative for short transit trips. The study's anomaly finding was that low-income Indego users preliminarily use bike sharing for recreational and exercising purpose. This observation goes against the majority of literature findings (till early 2012) which shows that low-income households' bike (and use bike share) for more utilitarian and commuting purposes while middle-to-high income households' bike for recreational purposes (Pucher, et al, 2011) (Shaheen, 2012).

This trend reversal could probably be best explained with the onset of bike renaissance - *increasing supply of bike infrastructure, active bike advocacy and equity discounts for lower-income households to use bike share systems*- people (especially from middle-and-lower-income backgrounds) are recognizing biking as a legitimate form of utilitarian mobility option. This perhaps explains why middle- and high-income households increasingly adopting biking as a commuting and day-to-day mobility needs. The biking renaissance is changing the biking landscape but most prominently in the urban centers and downtowns. Traditionally, low incomes households have jobs situated off the downtown and urban cores with low levels of access to the biking infrastructure for commuting or utilitarian purposes. However, due to discounted membership access to these bike share system, low-income households still tend to use bike shares where and when they can, like on weekend leisure trips or recreation cycling in and around parks etc.

2.2 Mode pairing and trip characteristics

There is a nationwide consistent trend that "*In a car-centric society like US, biking for commuting purposes is mainly concentrated in and around central city areas, with pronounced visibility in university towns, research institutions with housing facilities and gentrified neighborhoods near city's center*" (Pucher et al, 2011). In an automobile-centric society where land use density and diversity are sparse, it isn't resource efficient nor convenient to rely on biking as primary commute mode for day-to-day needs. In such a context, to offer biking as a true alternative mobility choice it must be cross-paired with transit. "*Biking supports public transport* *by extending the catchment area of all rail stations and bus stops far beyond walking range and at a much lower cost than neighborhood feeder buses and park and ride facilities for cars. Access to public transport helps cyclists make longer trips than possible by bike. Public transport services act as a convenient alternative when cyclists encounter bad weather, steep topography and gaps in bikeway network*" (Pucher et al, 2011).

Cycling rates decline sharply with increased car ownership. Data from 2001 and 2009 nationwide bike mode share shows that "*bike mode share was twice as high for households without cars as for households with 2 or more cars*" (Pucher at al, 2013). The study also noted that bike mode share grew most rapidly among households with no or one car. An intercept survey-based study in Washington D.C and Virginia bike share users found that bike share trips are replacing walking and short transit trips (Buck et al, 2013).

2.3 Spatial characteristics of biking conducive urban environments

There is an inverse relationship between biking levels and cycling fatalities (Bhatia and Wier, 2011). Cities with highest bike mode share report least cycling fatalities (Elvik, 2009). This trend can be explained with the principle of safety in numbers. Pucher's study concurs with this finding on major U.S. metropolitan cities and posits a causation relationship between the two. The study states, "*safer cycling environment encourages more cycling, and more cycling encourages greater safety*" (Pucher at al, 2011).

Land use characteristics

A study done by Cervero and Duncan on walking and biking trends in the Bay Area shows that "*built environment exerts higher impacts biking in and around a person's residential neighborhood than at destinations*" (Cervero and Duncan, 2003). This can be traced back to rider's perceived psychological comfort regarding familiarity with bike lanes, signals, and parking in their neighborhood as compared to the ones at the destinations. Literature shows that perceived psychological comfort is one of the most influential factors while choosing the mode of their travel. The study also elucidates that well-connected streets, small city blocks, mixed land uses and proximity to retail activities can induce substantial non-motorized travel. Proximity and connectivity of origins and destinations are the two aspects of the land use that is most closely associated with bikeability of the neighborhood (Scheepers et al, 2014) (Harding, 2014). For biking, "*density, diversity and design- land use variables at origin weigh in equally to determine whether the person will bike or not*" (Cervero and Duncan, 2003).

Biking and topography

A study by McCormack and Rowe finds that topography matters more than climate or land use variables when people are deciding if they want to bike or not. It shows that for cities with steep topography, double weighing the topography slope relative to other measures produces a realistic measure of biking experience (McCormack and Rowe, 2014). The study references another quantitative research which determined that the San Francisco bicyclists would travel up to a mile extra to avoid 100 feet elevation gain (Hood et al, 2011). From personal experience of biking in and around the city of San Francisco, I concur with the observation.

2.4 Effects on household transportation costs

Planning literature suggests that *captive riders* (riders who bike because it is the only mode of transportation available to them) often bike because of restraint household spending on transportation or lack of access to other forms of mobility. For *choice riders* (bike riders who have other transportation modes available to them), saving incurred from biking in lieu of other modes is generally a positive consequence of a more healthful or environmental conscious form of transportation. As mentioned earlier, there is a strong global negative relationship between biking mode share and car ownership. Literature findings suggests that increased car ownership is positively related to high overall household transportation spending. Comparing San Francisco's annual auto ownership costs and annual transportation costs map (Fig. 4 and 5), the neighborhoods which have high automobiles ownerships costs also have high annual transportation costs. There could be a complex causal-nexus relationship between neighborhoods with high bike mode share/high bikeability and lower car dependency as both indicators feed off each other. This trend also explains how mode shifting to active transportation can bring down the annual transportation-related spending by reducing the operational costs incurred from gas refills, parking costs and maintenance costs.

In a nationwide study named Breaking barriers to bike share: lessons on bike share equity authors summarize that "*almost 90% of the participants who availed discounted membership to bike share programs that the monetary discount was crucial for getting enrolled in the program. Once these target users become regular users, they ride as frequently and almost one-fourth of them save $ 21 or more per week on their transportation costs*" (Nathan, Broach, and Dill, 2018).

The survey design also revealed that although lower-income households are interested in bike share programs, subscribing to these services is an additional transportation spending for them. Also, lower-income residents are far less likely than higher income residents to have a driver's license or own a working bike. At large, most of the low-income households agree that can't rely on biking or bike-sharing completely for fulfilling their mobility needs. In large metropolitan cities, where average miles traveled per day are sizable, bike share trips can at best replace short distance walking or transit trips. Following this reasoning, traditionally low-income

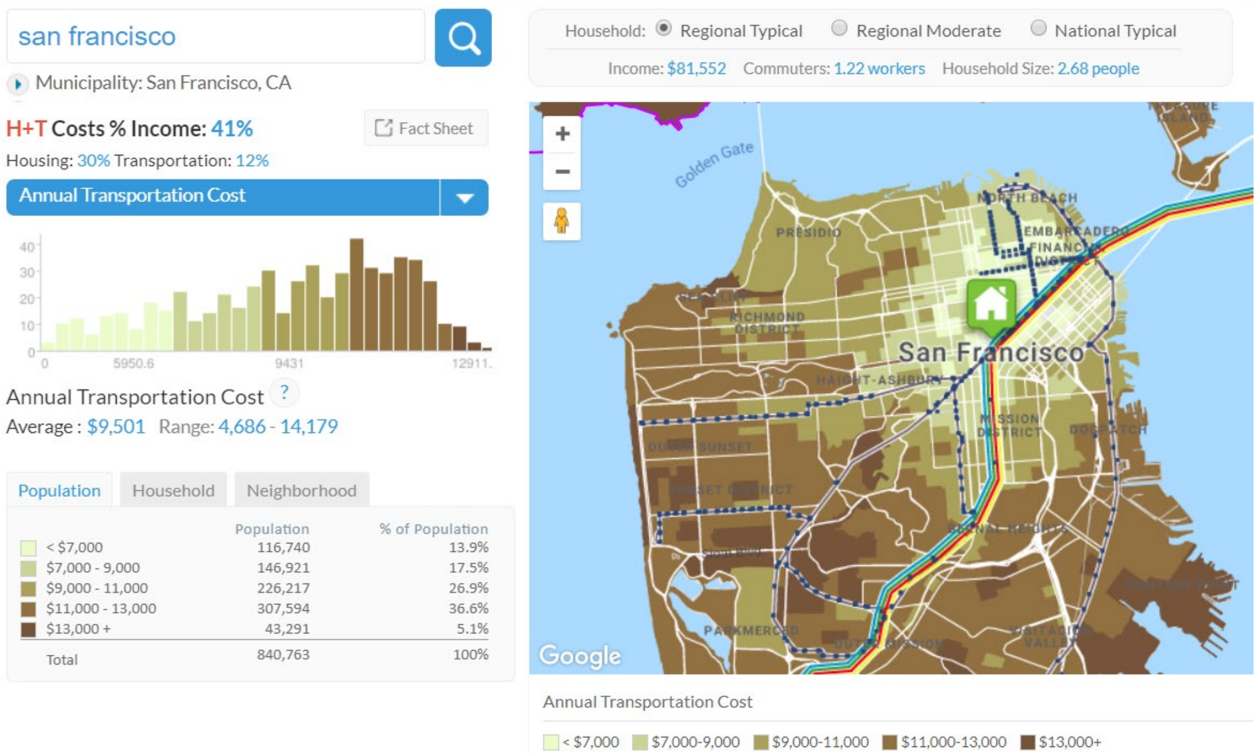


Figure 5 San Francisco's annual transportation cost (Source: H+T Affordability Index)

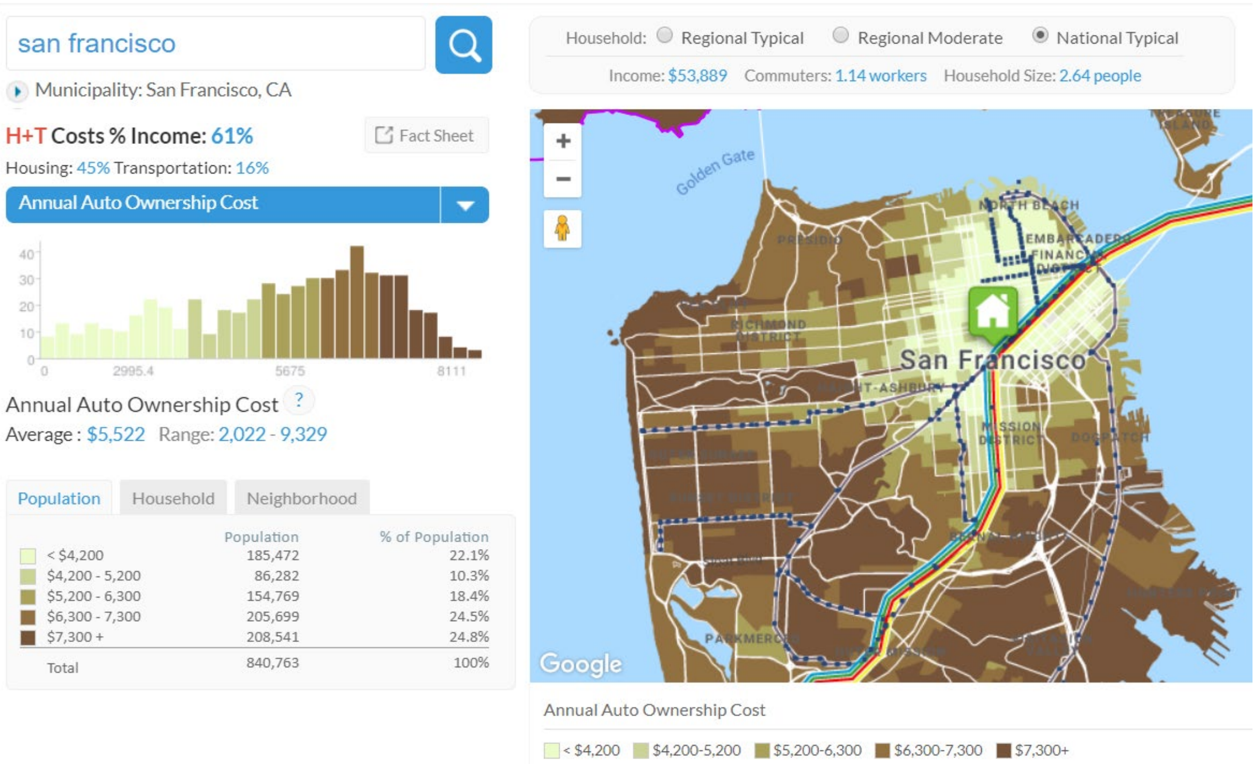


Figure 6 San Francisco's annual auto ownership cost (Source: H+T Affordability Index)

neighborhoods are located on the land of least economic productivity and are not well-integrated into the city's mobility network and central areas. These complex pervasive conditions in U.S cities don't let low income-households escape from owning an automobile and incurring the auto ownership cost. Bike share systems at their best can substantially reduce VMT costs and marginally reduce transit costs for low-income households. The research elucidates that therefore membership discounts based on socioeconomic status is the most fruitful way of making bike share accessible to low-income households.

2.5 Investigating through the lens of public health and environmental benefits

Cross-disciplinary research in realm of biking and benefits in public health and greenhouse gas emissions has demonstrated that biking can positively influence public health by bringing down obesity levels, stress levels and anxiety (Khan et al, 2009) (Pendola and Gen, 2007), and reduce greenhouse gas emissions caused by "*if not bike then*" auto-dependent alternative mode of travelling (Pucher and Buehler, 2012).

A Chicago based study researching on the equity dimensions of the public bike share systems borrows from the environmental justice literature to build an argument that, given the prevailing lack of access to healthful environment in form of access to fresh and healthy food, recreational facilities and other services to low income communities and communities of color in U.S, subsidizing bike share to make it accessible to communities with low socioeconomic index will yield benefits in all the spheres (Smith et al., 2015).

Another study calls out "*although walking/biking to work is rare in the U.S., greater proportions of such workers in neighborhoods relate to lower weight and higher activity levels. Bikeability fares better than walkability as a predictor of obesity control in a community, especially for men*" (Brown et al, 2013)

In a study, to determine whether the quantifiable benefits from reducing automobile usage for short urban and suburban trips, improve physical fitness given the externality of inhaling automobile exhaust air while riding. The results suggest that there are significant health benefits (exhaust fumes do negligible harm in comparison to improvement in physical fitness levels) and economic benefits if the bike replaces short automobile trips. The findings also predict that "*lower levels of dependence on automobiles in city center areas substantially improves the air quality in downwind rural and suburban communities*" (Grabow, Spak and Holloway, 2011).

San Francisco's annual greenhouse gas emissions map (Fig.7) show that neighborhoods with high GHG emissions are the ones with high auto ownership rates. Given the previous knowledge of cycling rates in the neighborhood as a function of auto ownership rates, household transportation spending, it can be extrapolated that neighborhoods with higher cycling rates will exhibit lower GHG emissions and have supportive land use (density, diversity, and design) variables.

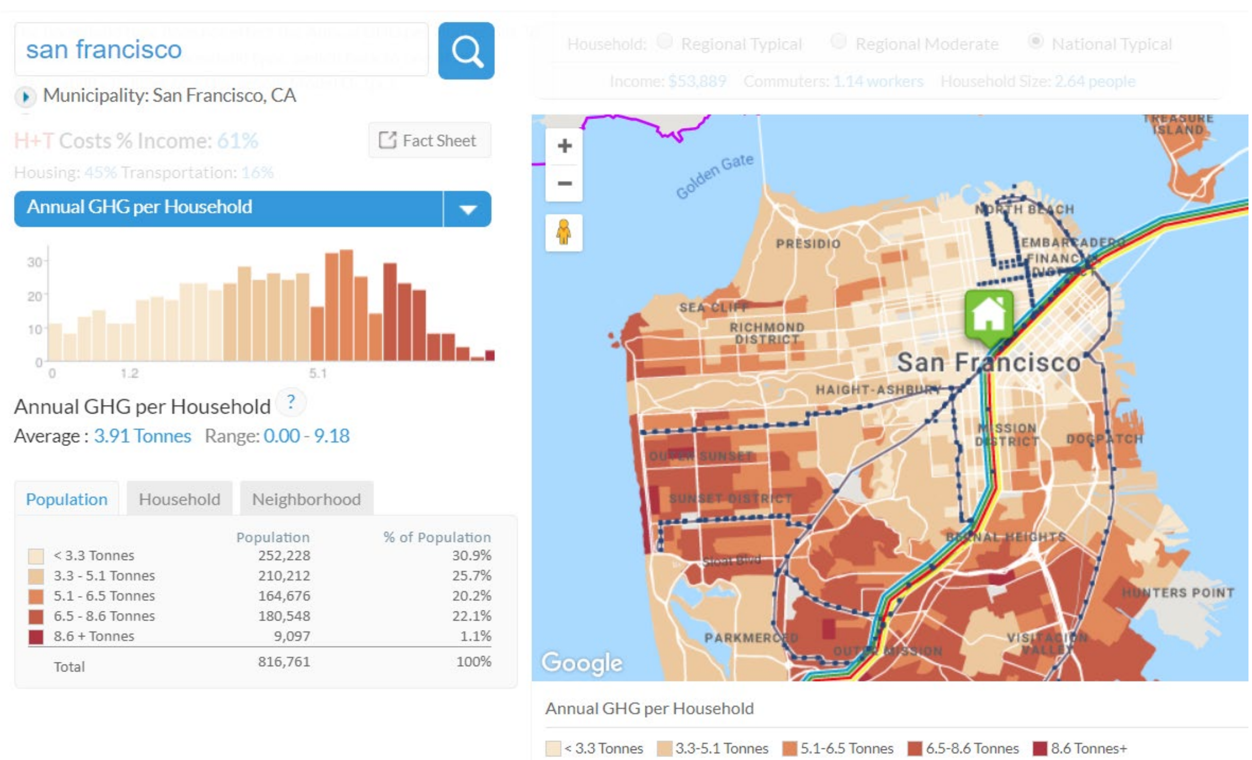


Figure 7 San Francisco's annual greenhouse gas emissions per household (Source: H+T Affordability Index)

3. San Francisco's biking renaissance

After assimilating the findings from literature review in the previous chapter, this chapter inquires San Francisco's biking characteristics like demographic profile of who bikes in the city and who uses the bike share - is there any commonality between these two groups; trip purposes, evidences of trip chaining and neighborhoods/spots which are most frequently biked in San Francisco; and most frequent start and end points/routes for bike sharing trips, public perception of biking and bike sharing program in the city. The chapter then delves into assimilating argument for quantitatively addressing the equity component of the city's biking trends.

3.1 San Francisco- its geography and its neighborhoods

Figure 8 San Francisco and neighboring Counties (source: Wikipedia Commons)

The City and County of San Francisco share the same geographic extent and covers an area of almost 49 sq. miles. Situated on the northern tip of the Bay, it is bounded by Daly city (San Mateo County) on South, San Rafael (Marin County) further North, and East Bay area (Berkeley and Oakland- Alameda County) in East. San Francisco is connected to this 9 County Bay Area region through two main Interstates- 101and 280 (Fig. 8).

San Francisco is well connected to the neighboring Bay areas via regional transit system- BART, CalTrain, and Muni. The area is also richly served by local transit systems like AC Transit, VTA, Golden Gate Transit, SamTrans and others which make frequent to-and-fro trips in

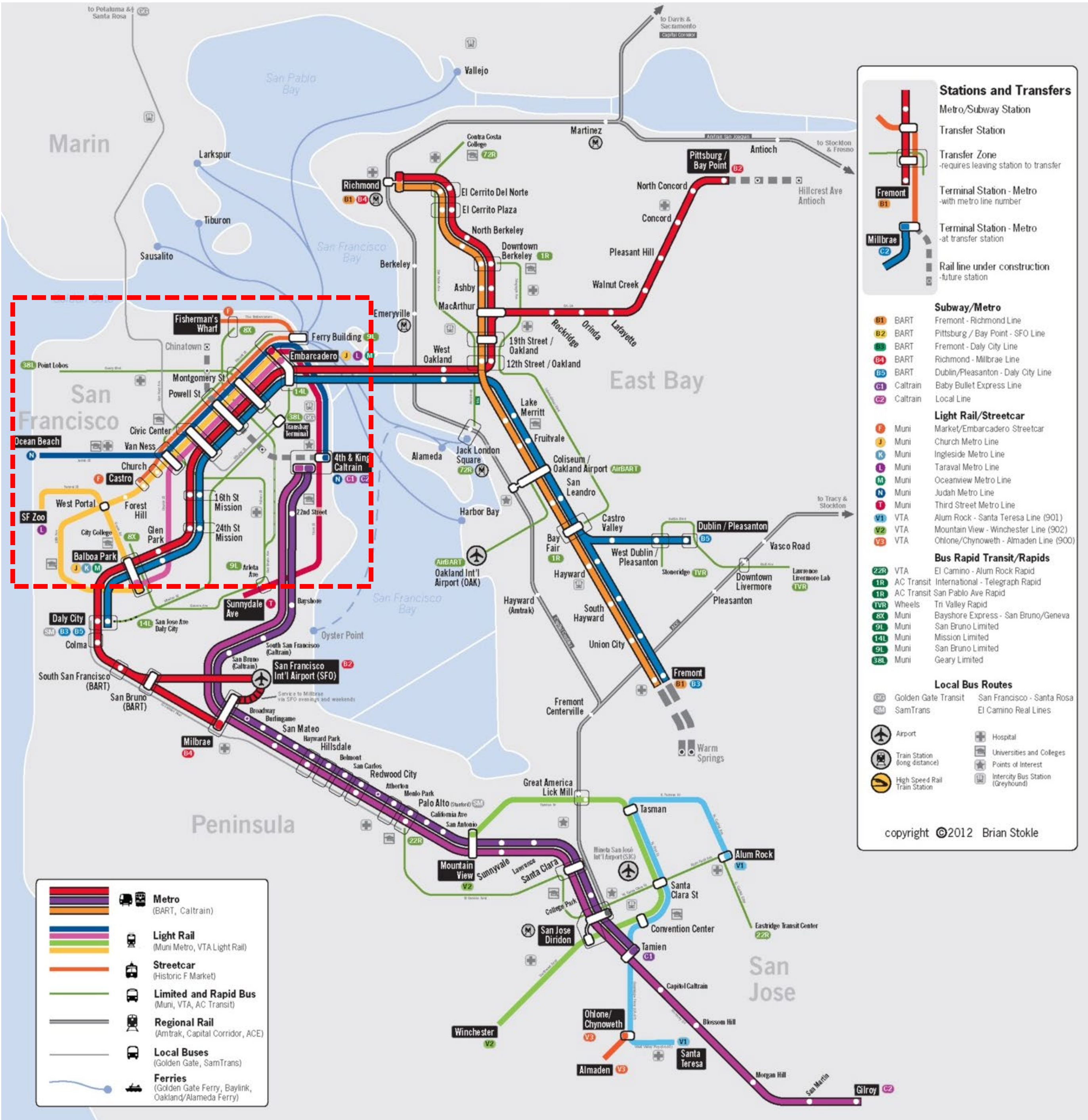


Figure 9 Bay Area Transit Mobility Map (Source: SPUR/urbanlifesigns)

San Francisco. Overall, San Francisco and the adjoining Bay area makes one the most transit-accessible regions in the U.S (Cervero and Duncan, 2003). Fig.9 shows the regional transit connectivity in the Bay Area with San Francisco's extent in dashed line extent. The Bay area has the second-best transit score (80) after New York (86) amongst all U.S. metropolitan regions (Transit Score Methodology, n.d.). Fig. 10 shows the transit mode share hotspots in the city.

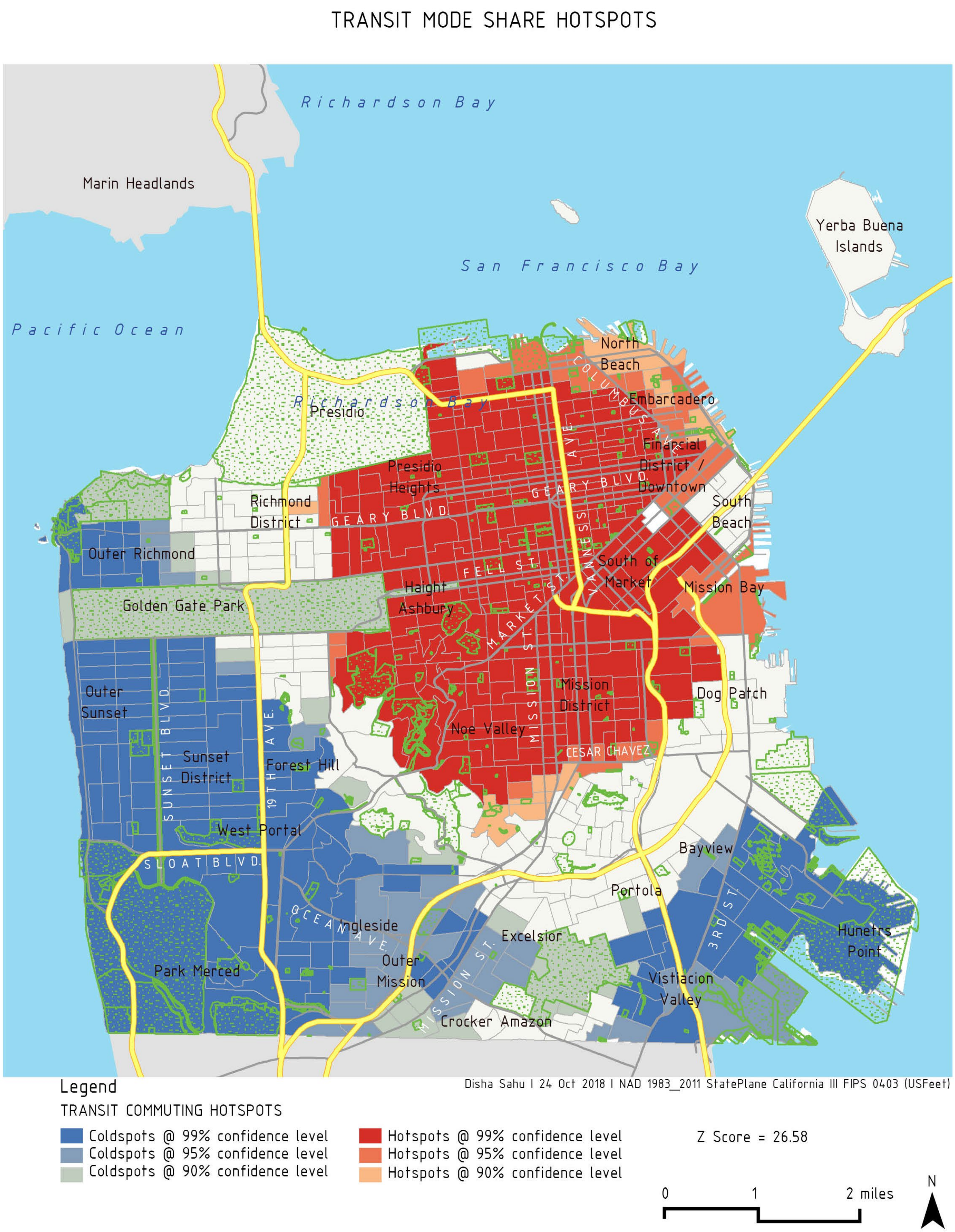


Figure 10 San Francisco's transit mode share hotspots **(Source: Author)**

Hotspots are statistically significant spatial clusters of high values and low values. The Fig. 10 shows the hotspots of transit mode share in San Francisco. The neighborhoods shaded in red represent the transit mode share hotspots at 99% confidence level. These neighborhoods include Financial District, South of Market, Mission District, Noe Valley, Haigh Ashbury, and Presidio Heights. The neighborhoods shaded in blue represent the transit mode cold spots at 99% confidence level. These neighborhoods include Outer Richmond, Outer Sunset, Sunset District, Ingleside, Park Merced, Vistacion Valley and Hunters Point. The hotspots and coldspots are calculated at bandwidth distance of 10000 feet (approximately 2 miles), which is the average transit ride distance within San Francisco.

The following section maps San Francisco's demography various indicators using American Community Survey data for 2012-16. Before diving deeper into San Francisco's biking characteristics, this study summarizes main observations related to various demographics factors like population density, residential density and employment density, household characteristics, and commute mode shares etc. In the later segments, the study will utilize this mapping's observations to understand how does biking in San Francisco relate to various other demographic factors.

Population density

As per American Community Survey (ACS) 2012-2016, San Francisco has an average population density of 18,131 persons/sq. mile (Social Explorer, n.d.). The densest neighborhoods are in the north-east part of the city, situated along Market Street and Mission District (Fig. 11). These neighborhoods have a density of almost 80,000 persons or more per sq. mile. Neighborhoods like North Beach, South Beach, Haight Ashbury, Outer Mission, Excelsior, Noe Valley, and Bay View are moderately dense and have population density in the range of 40,000

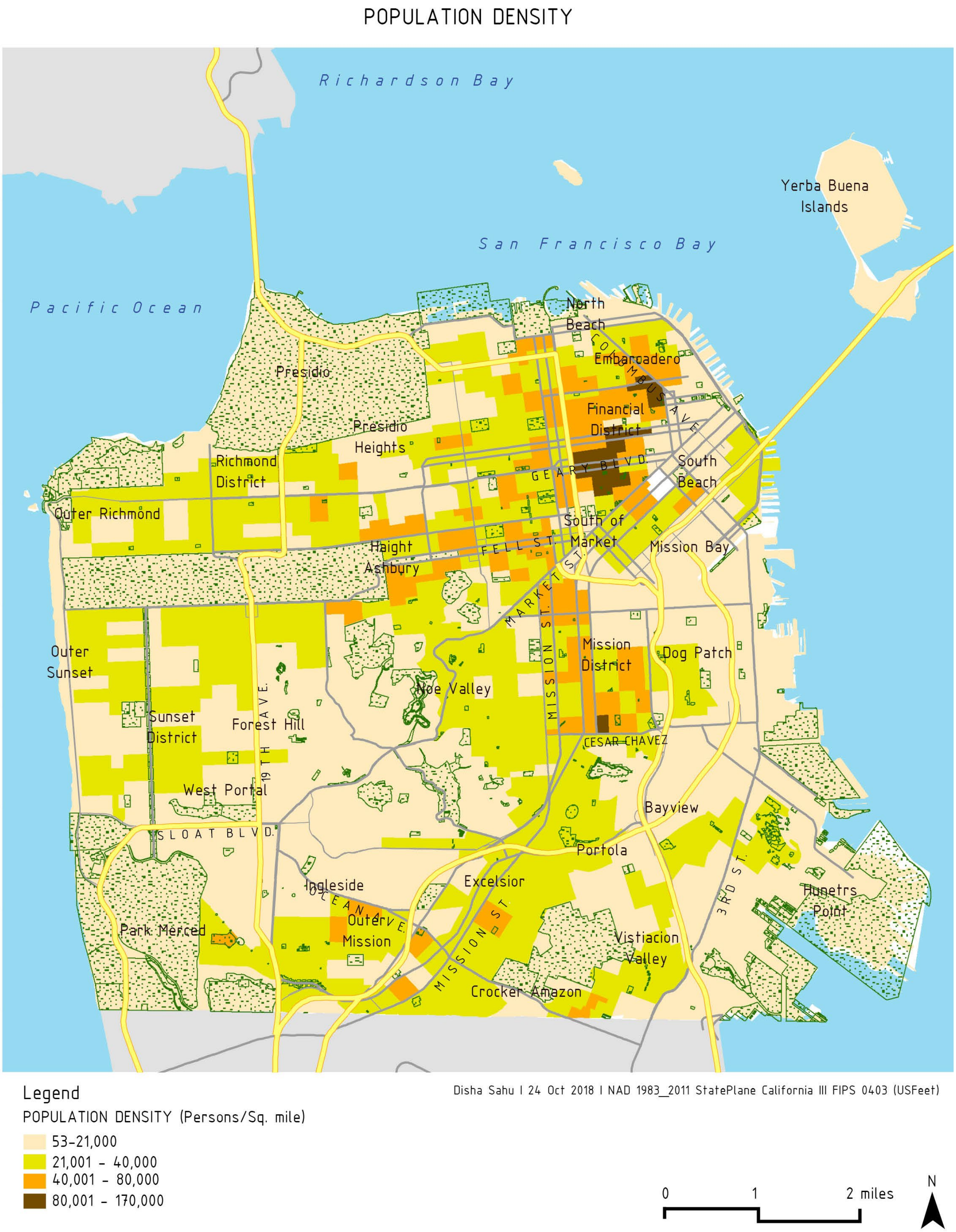


Figure 11 San Francisco's population density **(Source: Author)**

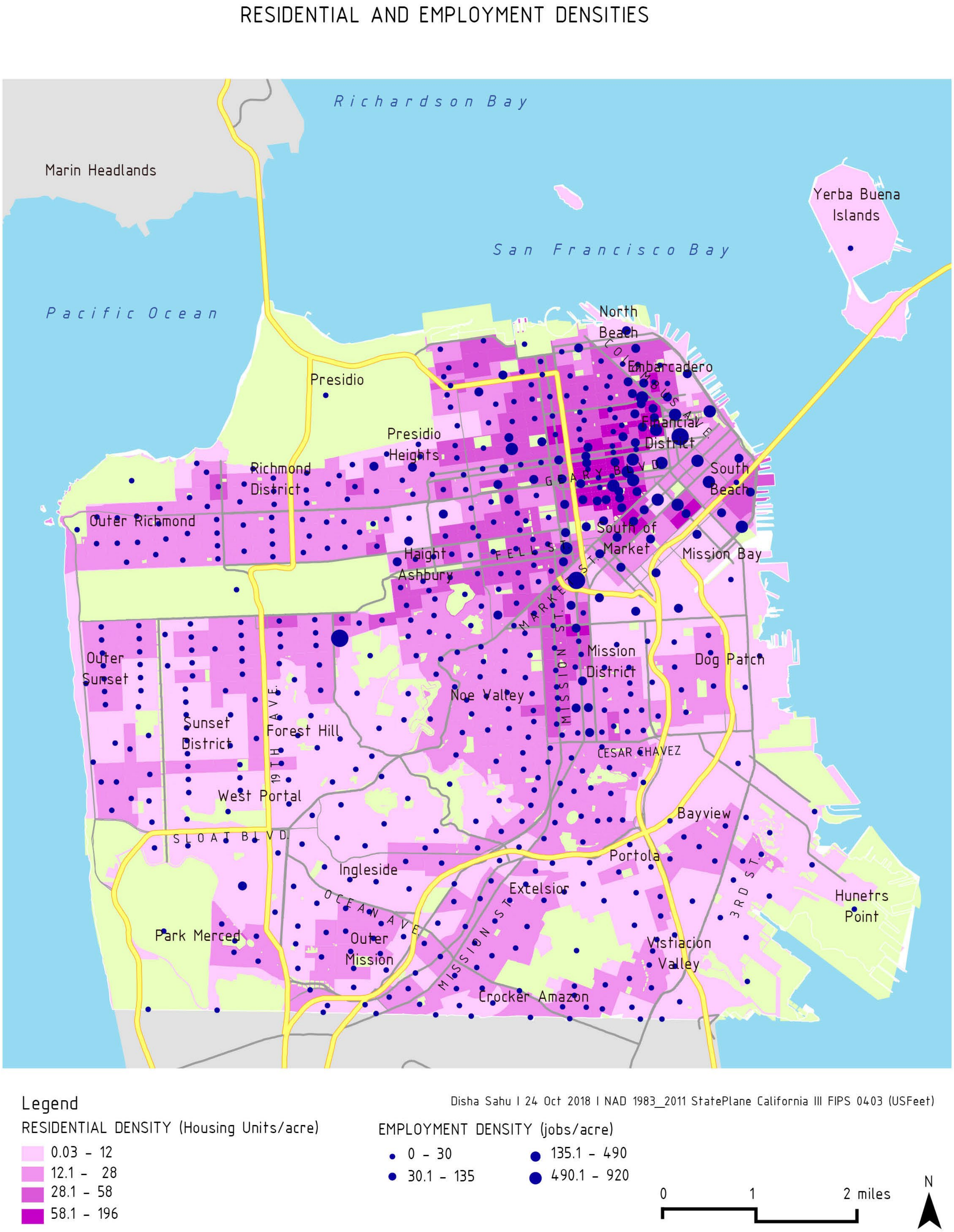


Figure 12 San Francisco's residential and employment densities (Source: Author)

up to 80,000 persons per sq. mile. Neighborhoods like West Portal, Park Merced, Presidio Heights, Forest Hill, Ingleside, Hunters Point, Sunset, Vistacion valley count as the sparsest in terms of population density.

Residential and Employment density

Most of San Francisco's residential density is concentrated in the north-east section of the city. South of Market, Financial District, Embarcadero, Mission District and Haight Ashbury exhibit the highest residential density (almost more than 60 Housing Units /acre) (Fig. 12). These neighborhoods also have the highest employment densities (around 130 or more jobs per acre on average) (Fig. 12). This co-location of highest employment and residential densities for almost one-fourth of San Francisco's geographical extent tells about the predominant mixed-use character of the city. This denotes a departure from the traditional form of an American city where the downtown/Central Business District is preliminarily used for employment purposes and the surrounding areas for residential dwellings only. The neighborhoods with high residential and employment densities are well served by regional and local transit lines (Fig. 9)

Average household size and household distribution

Marking northeast part of the city as the epicenter, the average household size continuously grows moving outward towards the southeast. The average household size within the city of San Francisco is 2.3 persons. Almost half of the neighborhoods in the city- North Beach, Embarcadero, Financial District, South Beach, South of Market, Mission Bay, Noe Valley, and Dogpatch have an average household size under 2.2 persons (Fig.13). Neighborhoods like Richmond District, Outer Richmond, West Portal, Park Merced, Ingleside, Portola, and Mission District preliminarily have a household size between 2.2 to 3.1 persons per household. Neighborhoods like Sunset District, Outer Sunset, Outer Mission, Crocker Amazon, Vistacion Valley, Excelsior and Bayview have average household size with more than 3.1 persons. Following the earlier logic of the northeast part of the city as epicenter growing out, one could observe that there is a greater concentration of non-family type households (households where the inhabitants do not comprise of a family but could be individual tenants, institutional tenants or other similar set-ups) in the northeast part of the city. Moving outward towards neighborhoods like Richmond District, Forest Hill, West Portal, Ingleside, and Vistacion Valley, there is a more pronounced visibility of family type households. (Fig. 13)

Commute Mode share – Walk, Bike Share

Comparing the relative catchment basin for commute mode of walking, biking and transit users, different neighborhoods with the city agglomerate different mode preferences. Neighborhoods in and around South of Market, Mission District, and Haight Ashbury demonstrate high walk mode share (Fig. 14). Bike mode share seems to be spread out far and wide with special concentrations around Mission Bay, South of Market, Mission District and western segment of Richmond District and Sunset District. Proximity to regional transit connections around Market Street and Mission District spine along with high residential and employment densities explain the high cycling rates in the northeast section of the city. Presence of steep hills around the central part of the city, North Beach and Vistacion Valley reduces bikeability. Most of the neighborhoods (including the ones in the south-east segment of the city) have a strong concentration of transit mode share (Fig. 10 and 14).

Average annual pedestrian volume and walk mode share

The northeast section of the city is a high pedestrian traffic zone. San Francisco Metropolitan Transit Authority (SFMTA) publishes average annual pedestrian traffic volume by each major

Figure 13 **San Francisco's average household sizes and distribution** **(Source: Author)**

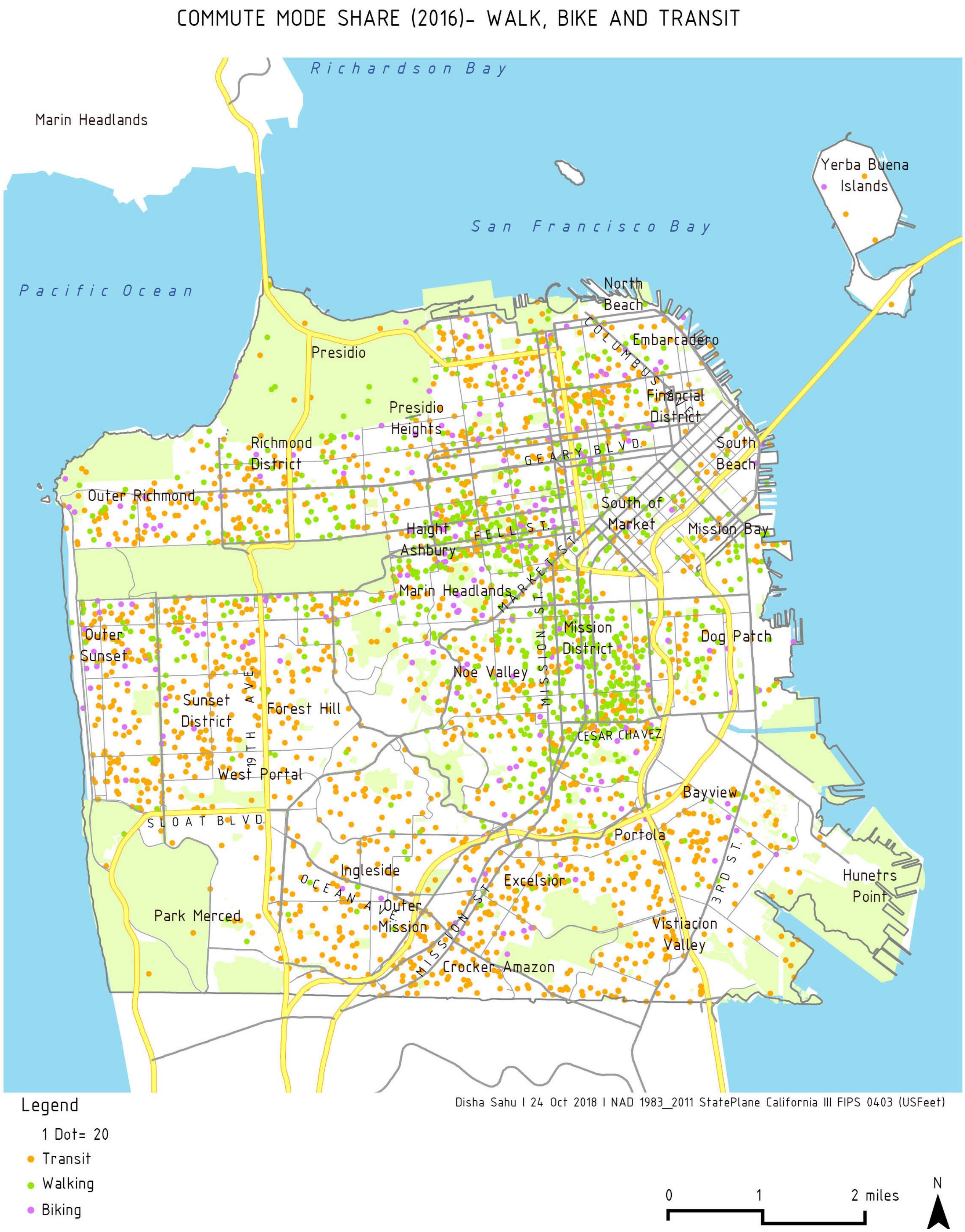


Figure 14 San Francisco's commute mode share - walk, bike and transit **(Source: Author)**

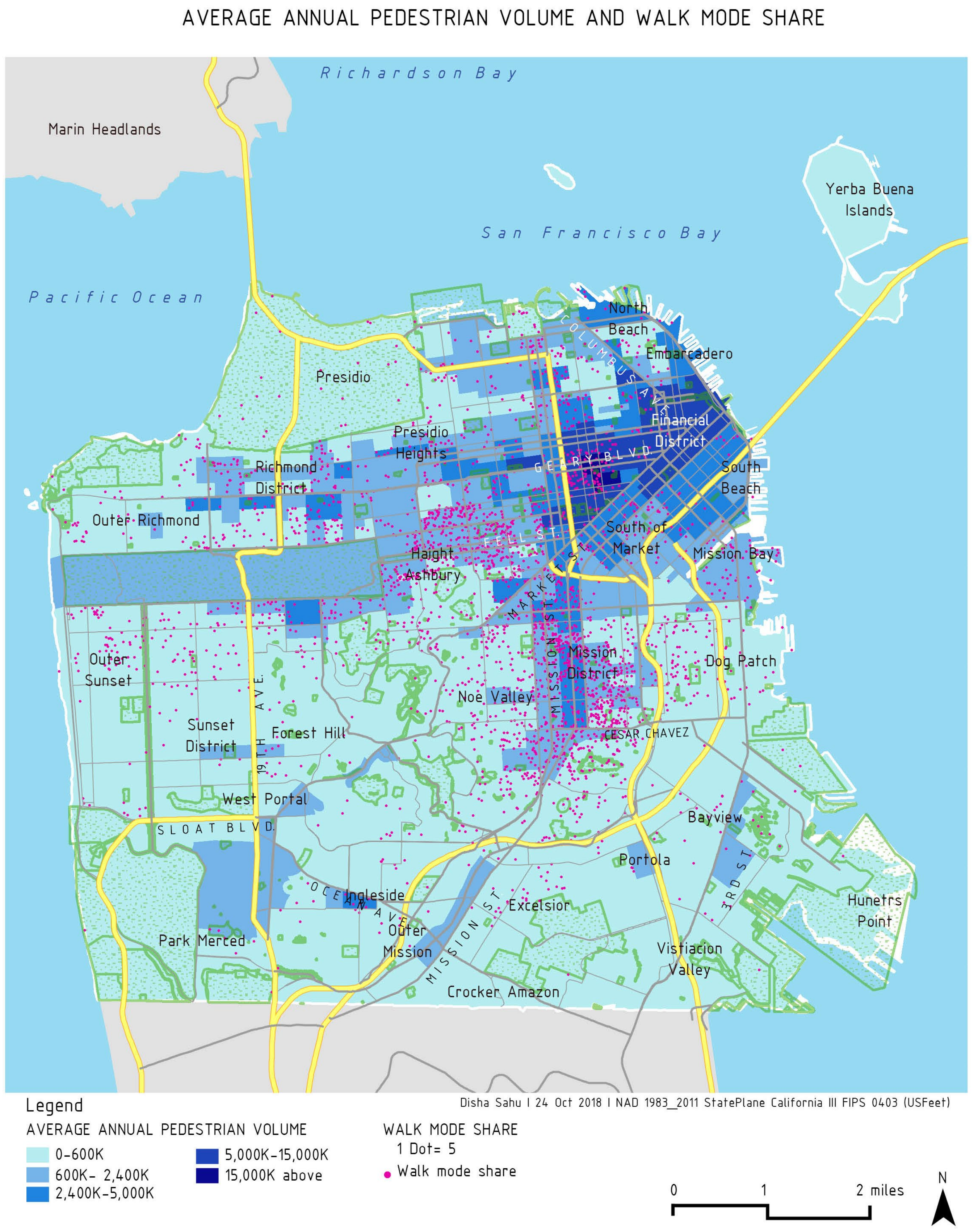


Figure 15 San Francisco's average annual pedestrian volume and walk mode share (Source: Author)

Figure 16 San Francisco' annual biking volume and bike mode share **(Source: Author)**

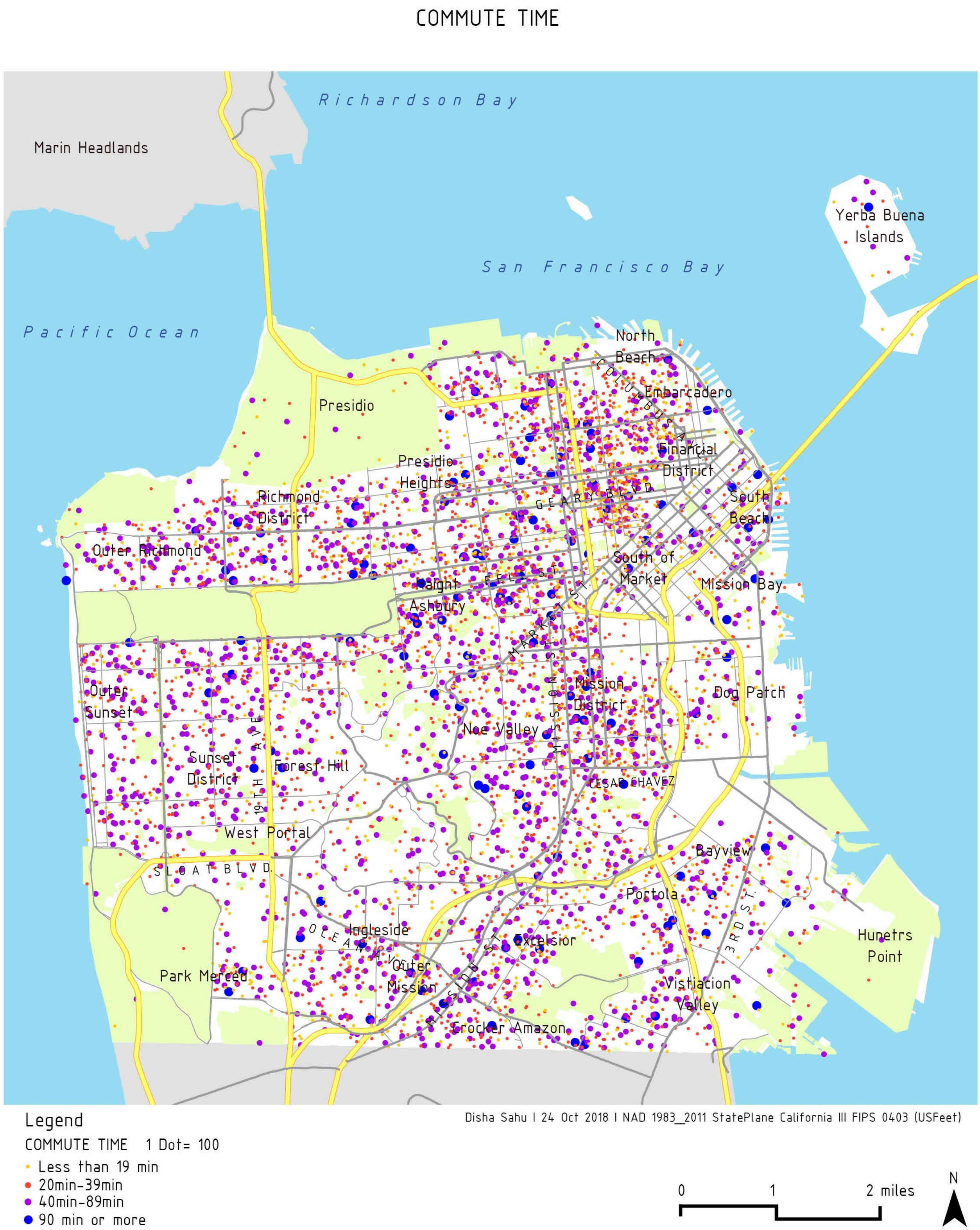


Figure 17 San Francisco's commute time distribution **(Source: Author)**

intersection. Fig. 15 shows the average annual pedestrian volume by block group and compares it with walk mode share (commute trips). While the pedestrian count is very high the northeast section of the city, the walk mode share statistic is really pronounced around Mission district, Haight Ashbury, and Noe Valley neighborhoods.

This trend can be explained on two facts- first, given that the Market Street (the diagonal street cutting the city grid in the northeast segment) is the main commercial and CBD area of the city, it is heavily frequented by people for employment, entertainment and shopping purposes which explains the high footfall trend. Second, the American Community Survey calculates walk mode share as a percentage of workers who commute by walking. Given the fact that neighborhoods like Haight Ashbury, Mission District, and Noe Valley are preliminarily residential in nature (although mixed-use) when compared to Market Street (mixed-use CBD) stretch. This explains why these neighborhoods exhibit particularly high walk mode share.

Average annual biking volume and bike mode share

San Francisco Metropolitan Transit Authority (SFMTA) publishes annual bike traffic volume. It relies on manual counts and bike counters tabulations in the designated locations for calculating total bike volume data. Fig. 16 shows the annual bike volume by block group and compares it with bike mode share (commute trips). There high bike volume concentration around South of Market and Upper Mission District. The bike mode share is especially pronounced in the eastern segment of the city. This slight geographic epicenter shift between bike traffic volume and bike mode share can be explained on two trends- first, as previously explained regarding the walking mode share and ped volume map, the eastern segment of the city has majorly residential neighborhoods compared to the northeast part of San Francisco. Therefore, it proportionally reflects high bike mode share just by the virtue of more people living and commuting from those neighborhoods.

Second, Fig. 16 shows an agglomeration of bike counters in South of Market and around Van Ness. This agglomeration is an outcome of SFMTA's long continuing efforts to collect fine-grained data and inform bike safety project on Better Marker Street (Bike Strategy Plan, 2009).

Commute time

As per the American Community Survey (ACS) 2012-16, within San Francisco city the average commute time is 32 min. Fig. 17 shows a dot density map of commute time across San Francisco in 20-min slots. The northeast part of the city along with the spine following Market Street and Mission District have an agglomeration of blue (denoting less than 19 min) and green dots (denoting 20-39min) referring to under 40 min commute time. The neighborhoods lying around the external periphery like outer sunset, Richmond District, Park Merced Ingleside, Crocker Amazon and Vistacion Valley. These observations were expected, given the spatial and land use characteristics of this part of the city in the preceding analyses.

Household Income

Fig. 18 shows median household annual income for 2012-16. Neighborhoods situated towards the southern external edge like Bay View, Excelsior, Vistacion Valley, Park Merced are preliminarily low-income neighborhoods. In addition, neighborhoods agglomerated in the northeast section of the city along Market street like Tenderloin, South of Market and the Upper segment of Mission District also qualify as low-income neighborhoods. These are the two low-income clusters of neighborhoods in the city. Gini index is a measure of income disparities within a given geographical extent. High Gini index indicates that the income levels are too

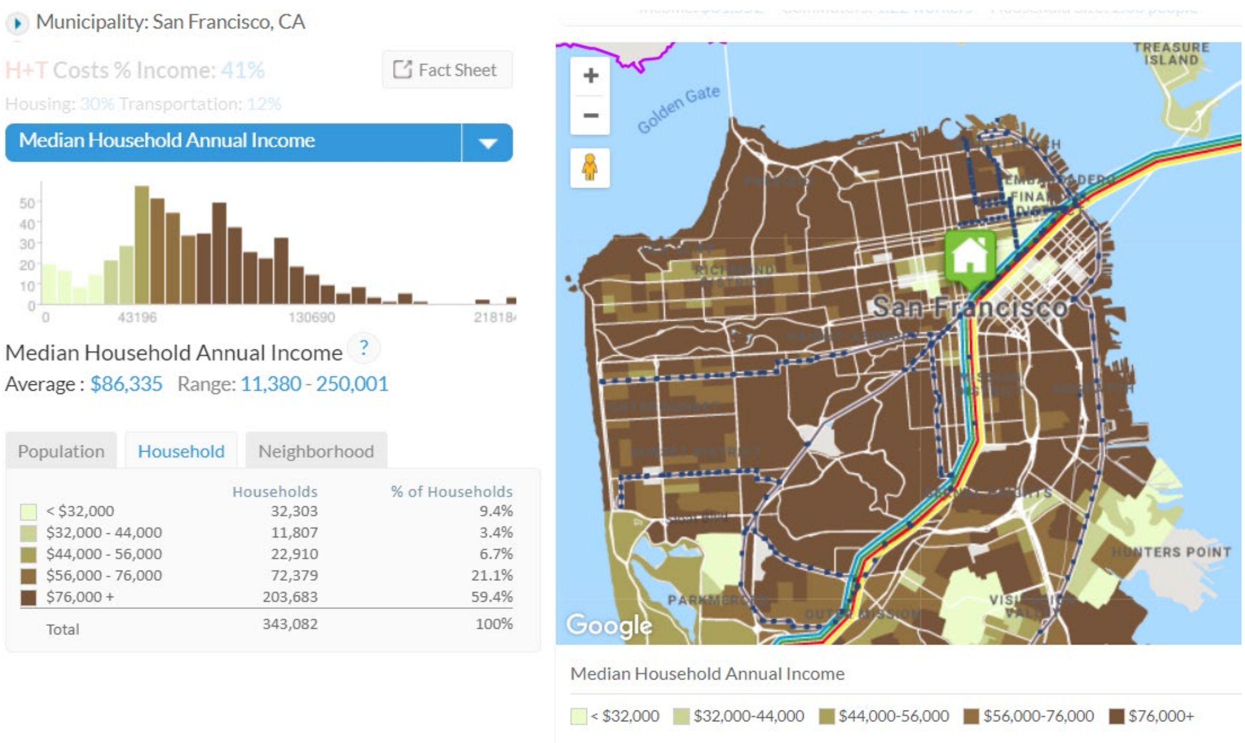
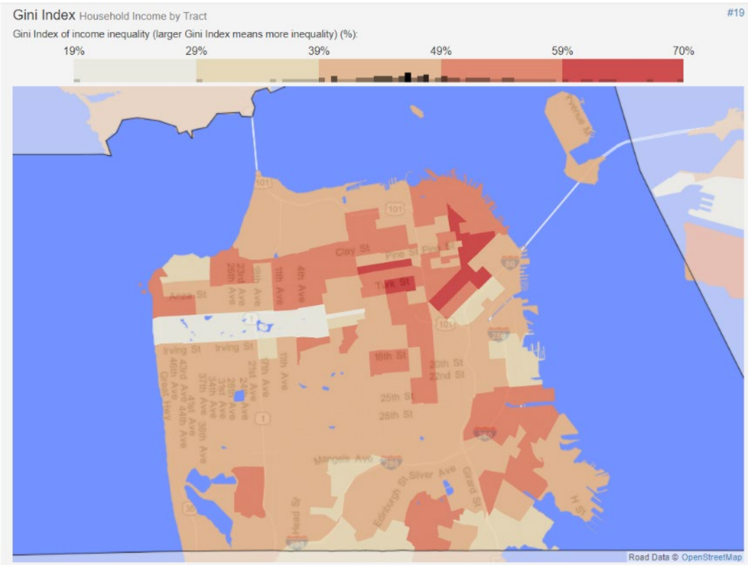


Figure 18 San Francisco's median household annual income (Source: H+T Affordability Index)

contrasting. This translates to a scenario where some households are wealthy while some are very poor. On the other hand, a low Gini index indicates that the incomes are uniform (either consistently low or consistently high). Fig 19. shows the Gini Index for San Francisco's census tracts. Neighborhoods of Tenderloin, SoMA and upper Mission District have a high Gini index values denoting that there is high level of income inequality in those neighborhoods. This trait is in contrast with the low-income neighborhoods of Bay View, Excelsior, Vistacion Valley and Park Merced which have low Gini index and demonstrate an overall expanse of poverty with a lack of economic diversity.



These above-plotted maps describe comprehensive characteristics of neighborhoods which affect walking, biking and transit use in the city. The following sections of the study refer back to these findings to explain San Francisco's spatial biking trends.

Figure 19 San Francisco's Gini Index 2016 by census tracts (source: Statistical Atlas)

3.2 Who bikes in San Francisco: A first-hand demographic data inquiry

The literature review found that bikers across the U.S. to be young (25-45 years of age), white, males and tend to have college or higher education levels and come from middle to high-income households (Pucher, et al, 2011) (Buck et al, 2013) (Shaheen, 2012). To inquire whether San Francisco's cyclist's demographics comply with this nationwide trend, the study ran scatterplots, OLS and Geographic Weighted Regression (GWR) on bike mode share (ACS 2012-16) and demographic variables. It should be noted that bike mode share as a cycling statistic does not portray the full picture related to biking in the city as it only accounts for biking for commuting purposes. Biking literature provides evidence that most of the cyclists nationwide pursue cycling for recreational and leisure purposes. However, this trend is soon changing as people are recognizing biking as a safe and reliable transportation mode (Pucher et al, 2011) (Shaheen, 2012). But even given these limitations, ACS bike mode share serves as the most consistent nationwide cycling statistic calibrated at the block group level and comparable for over 2 decades.

Mapping relationship between bike mode share and demographic variables

This research mapped bike mode share and percentage presence of 25 to 45 years old and found that the neighborhoods which showed high bike mode share did as well have a high percentage of young people (Fig. 20). The relationship between bike mode share and percent White presence seemed moderately pronounced, the census block groups which exhibited the highest bike mode share were mostly associated with 27 to 67% of white presence. The neighborhoods which had the most pronounced white population presence like Noe Valley, Haight Ashbury, Presidio Heights and western section of the Financial district were accompanied by medium levels of bike

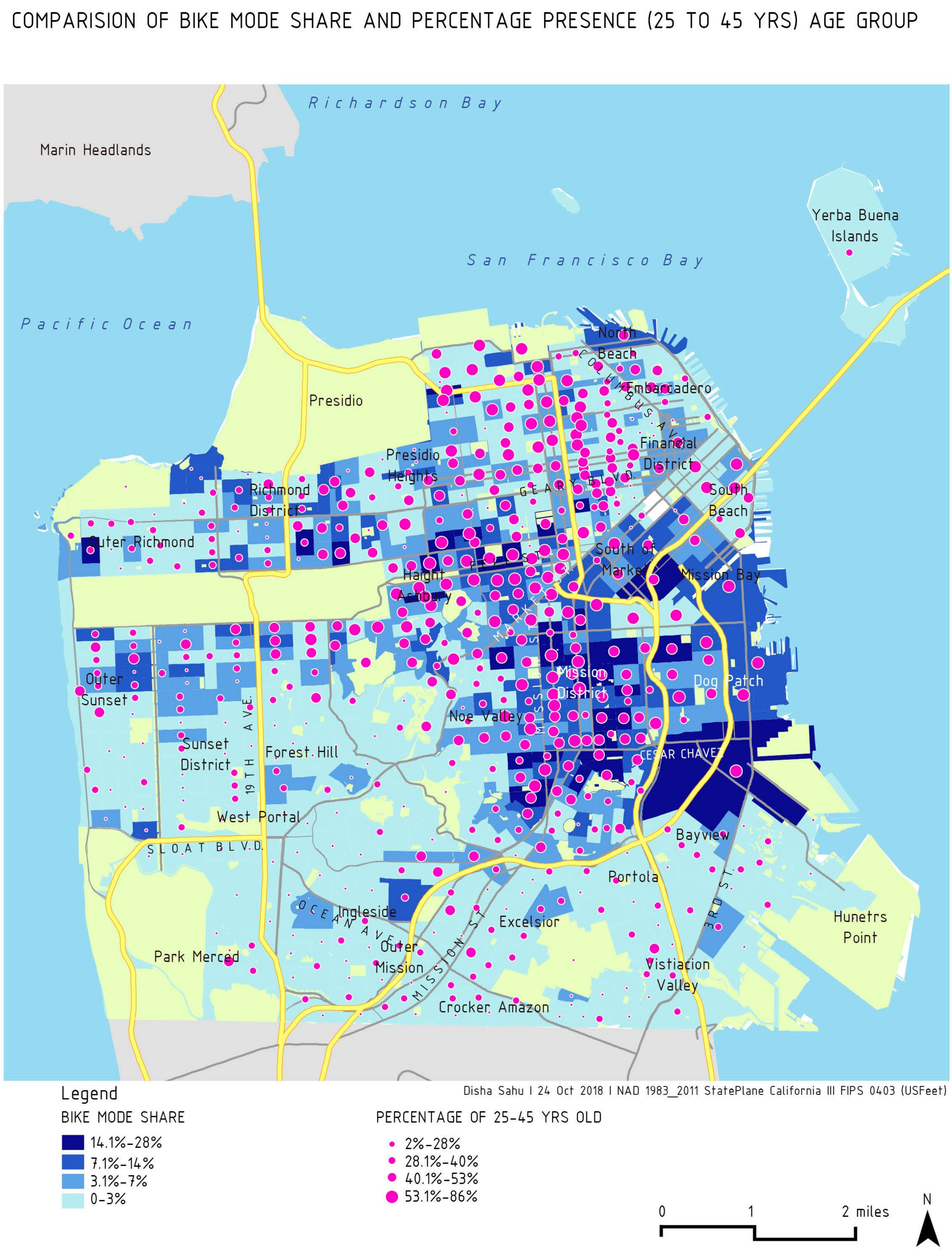


Figure 20 Comparison of San Francisco's bike mode share and percentage presence of 25-45-year-old (Source: Author)

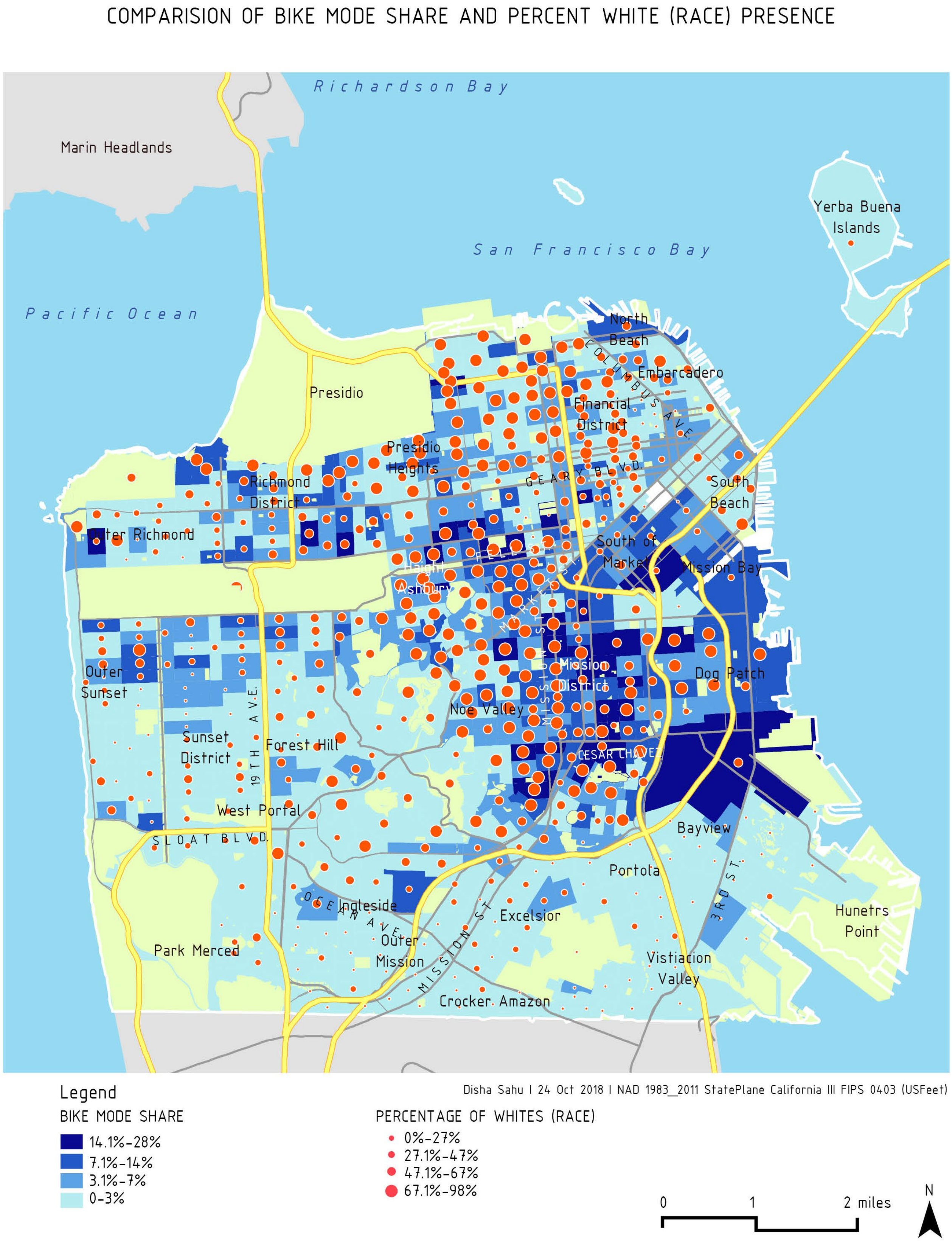


Figure 21 Comparison of San Francisco's bike mode share and percentage presence of whites (Source: Author)

COMPARISION OF BIKE MODE SHARE AND HIGHER EDUCATION LEVELS ATTAINMENT

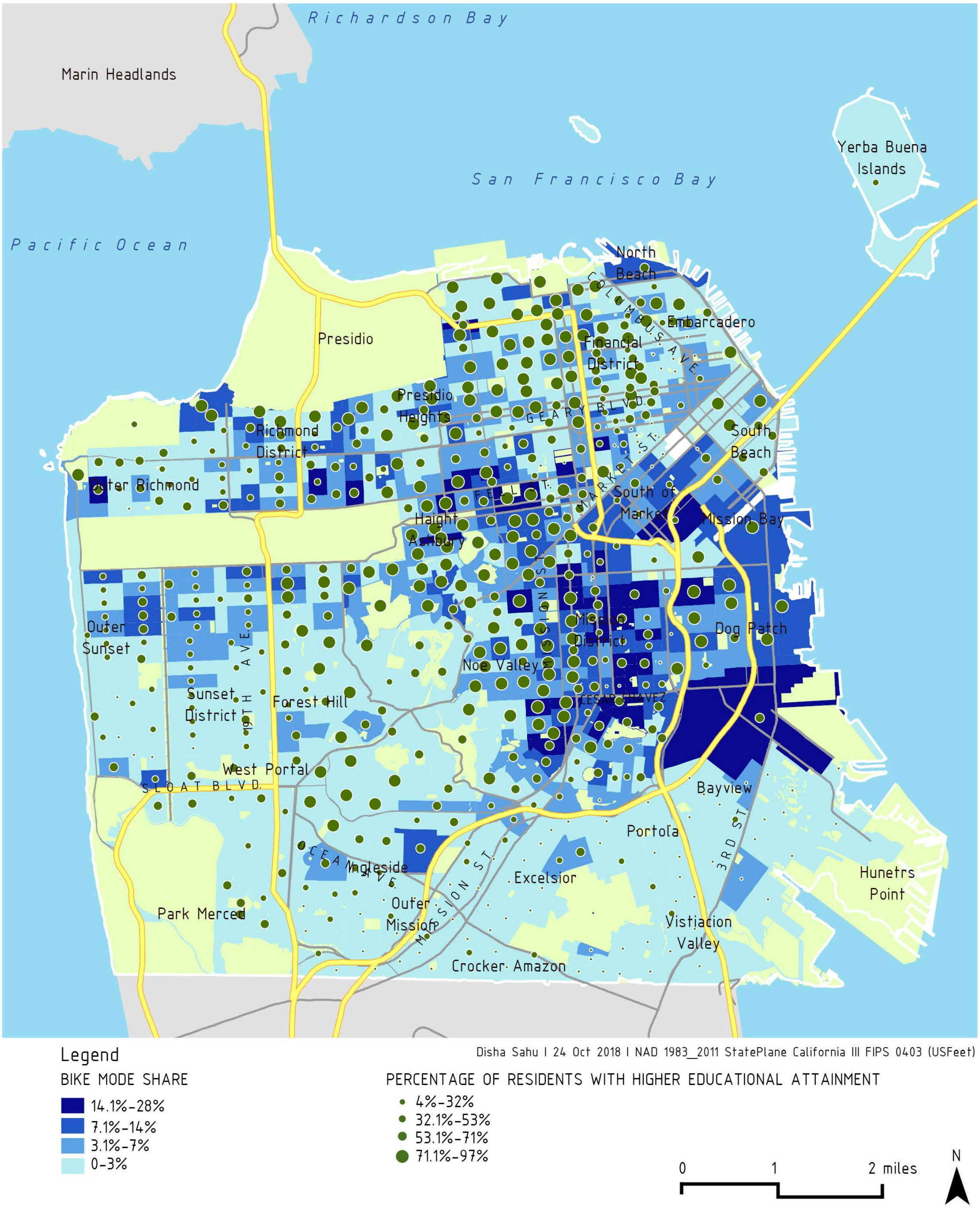


Figure 22 Comparison of San Francisco's bike mode share and percentage presence of higher education levels (Source: Author)

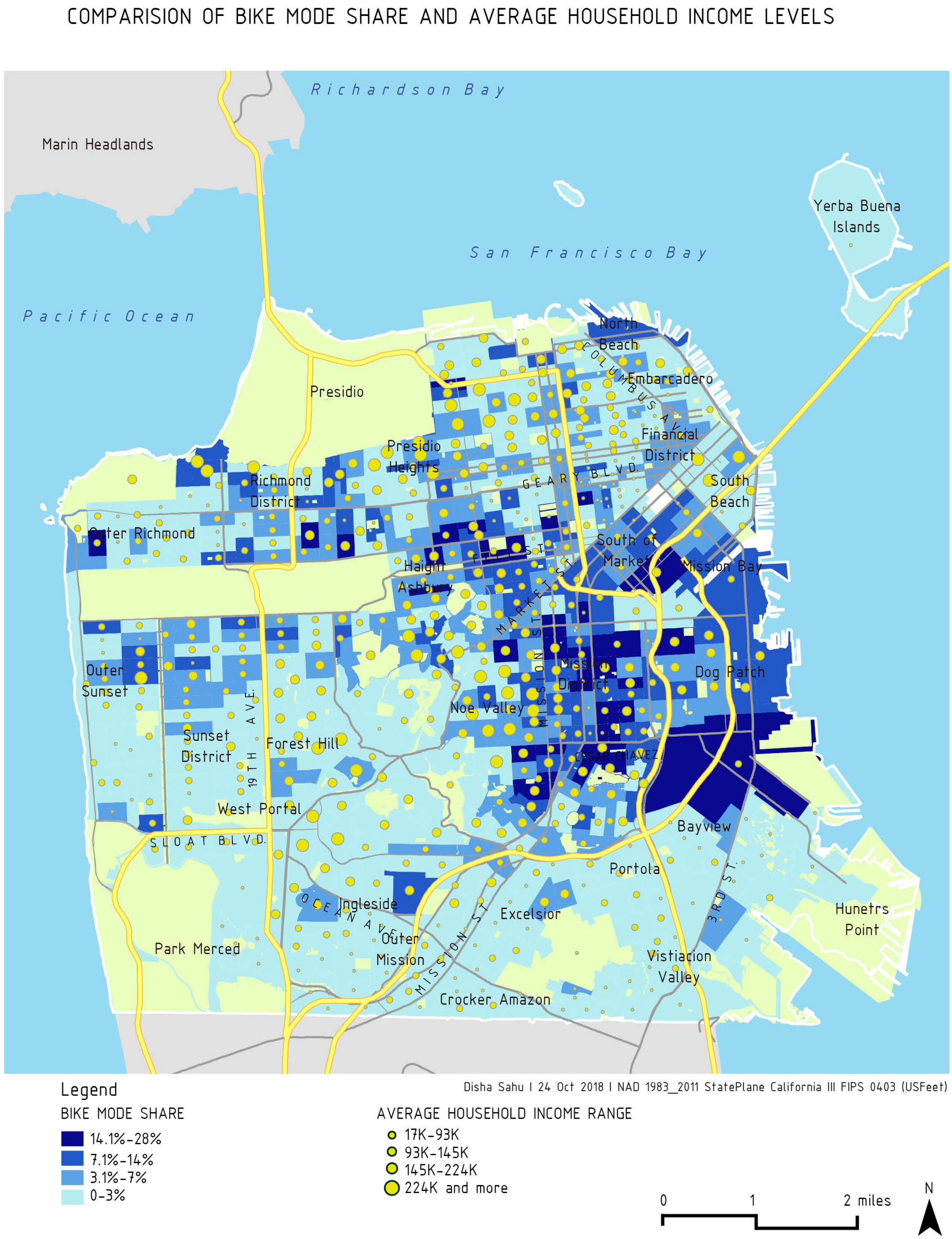
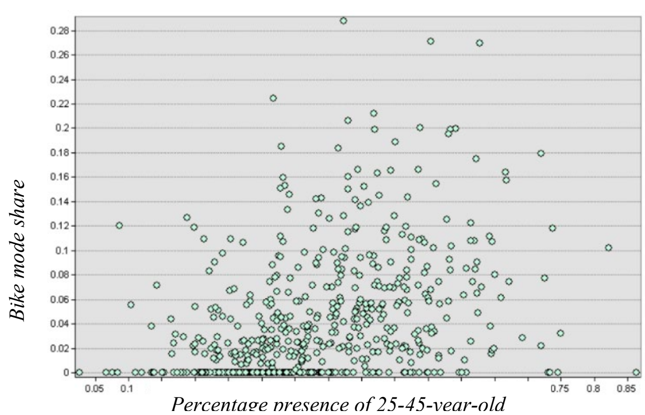
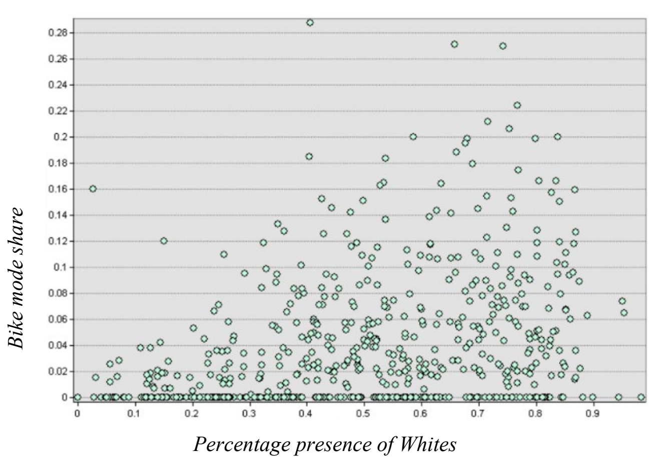


Figure 23 Comparison of San Francisco's bike mode share and average household income levels (Source: Author)

mode share (about 3-14%). (Fig. 21). The relationship between bike mode share and levels of higher education attainment were found to be weak. The neighborhoods which had high percentage (67% or more) presence of well-educated people were- Presidio heights, the northern section of Richmond district (close to Park Presidio), western segments of Financial District, Haight Ashbury, Noe Valley and some western segments of Mission District. And most of these neighborhoods had the bike mode share in the range of 3-14% (Fig. 22). The research found a negative relationship between bike mode share and average household income levels. Census block groups which had high bike mode share (more than 14%) consistently had the average household income below the region's average household earnings ($145,000) (Fig. 23). Thus, inquiring through the bike mode share, San Francisco's cyclist tends to be younger for sure with moderate chances of being white, with middle income or slightly low-income backgrounds but not necessarily holding more than college-level education.



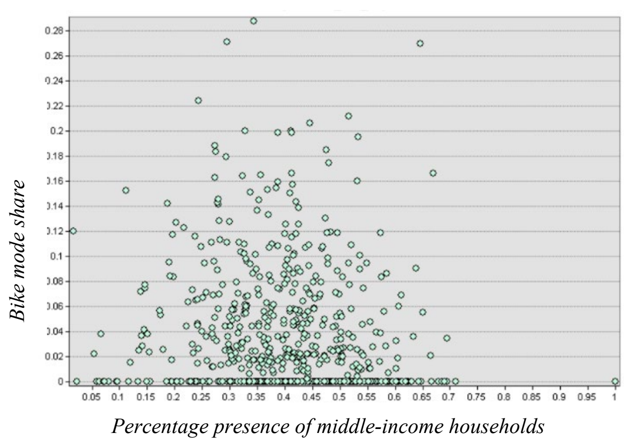


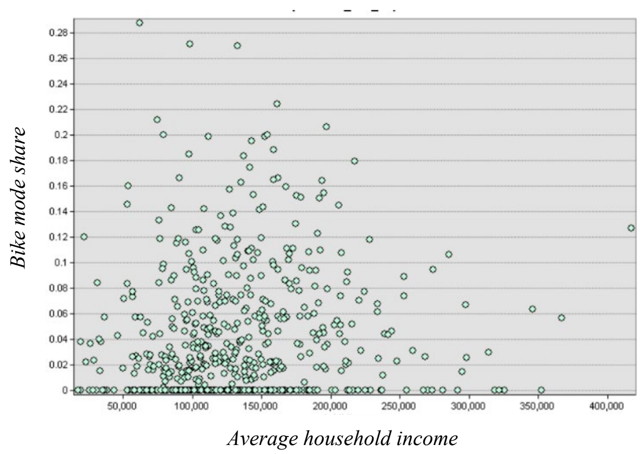
Ordinary Least Square (OLS) Regression

The study ran an exploratory regression, the following variables - *percentage white, the percentage of 25-45 years old, percentage household middle income, average household size, and average gross rent* were found to be the most significant variables related to the city's bike mode share. The OLS regression's adjusted r-square value was 0.2 indicating that these demographic variables show a weak relationship to bike mode share statistic for San Francisco. Of all the variables, age, race and income variables have the strongest coefficients. The signs associated with the coefficients affirm with earlier literature review and author's research hypothesis/GIS map findings. The regression equation was found to be:

Bike Mode Share = 0.07(Percent Whites) + 0.13(Percent 25-45 years old) – 0.04(Percent Middle Income) + 0.01(Average Household size) – 0.00016(Average gross rent) -0.027

Regarding OLS regressions results, since the Koenker (BP statistic) test was found to be significant, the robust probability should be considered instead of probability. All the coefficient's VIF values were found to be below 7 indicating that there was no instance of multicollinearity. Since the Jarque Bera statistic was significant, it indicated that there was some model bias and therefore the test results could not be considered globally accurate. The study tried various combinations of demographic variables as dependent variables, but this set was the most robust result yielding variables set. This model gave the least AIcc value indicating it was optimum enough amongst the given set of variable choices. The residuals were found to be clustered, when the study ran Moran's I test to account for spatial autocorrelation (Fig. 24). The Jarque Bera test was significant indicating there was model bias and therefore the spatial autocorrelation results being clustered was expected.





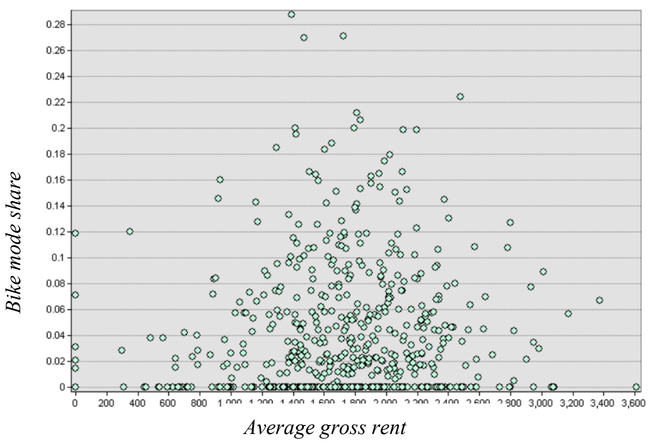


Fig. 25 shows the standard residuals for the above modeled OLS regression. The neighborhoods (block groups) rendered in blue were underpredicted, meaning the measure of bike mode share as a function of percentage presence of Whites, youth, middle-income households, average household size, and average gross rent was below the mean residuals. Another way to iterate this is that the neighborhoods which were rendered in red in the standard residual map were found to be overpredicted when seen as a measure of these demographic variables. Thus, in the neighborhoods of South of Market, Mission district, Bayview, Richmond District, North Beach, Dogpatch, and Mission Bay, bike mode share statistic is under-explained or represented when seen as a function of race, age, income levels, household size and gross rent. These neighborhoods are actually the ones where biking levels are enthusiastic and bikers most probably identify themselves as "*strong and fearless*" and "*enthusiastic and confident*".

Table 1 OLS results

Variable	*Coefficient*	*Std Error*	*T-Statistic*	*Probability*	*Robust Standard Error*	*Robust T-Statistic*	*Robust Probability*	*VIF*
Intercept	-0.027	0.013	-1.99	0.045*	0.015	-1.729	0.084	-
Percentage White	0.072	0.011	6.111	0.000*	0.012	5.702	0.000*	2.019
Percentage Higher Education	0.132	0.017	7.670	0.000*	0.019	6.884	0.000*	1.517
Percentage 25-to045 year old	-0.042	0.016	0.016	0.008	0.016	-2.577	0.010*	1.181
Percentage middle income	0.010	3.002	3.002	0.002*	0.003	2.706	0.007	1.790

Average Gross Rent	-0.000016	-4.01	-4.013	0.000*	0.000*	-3.928	0.000*	1.440

Table 2 OLS diagnostics

No. of Observations: 571	AICc: -1908.49
Multiple R-Squared: 0.214	Adjusted R-square: 0.207
Joint F-Statistic: 30.85	Prob(>F) (5,565) 0.000*
Joint Wald Statistic: 156.49	Prob (chi-squared) (5) 0.000*
Koenker (BP) Statistic: 37.77	Prob (chi-squared) (5) 0.000*
Jarque-Bera Statistics: 411.23	Prob (chi-squared) (2) 0.000*

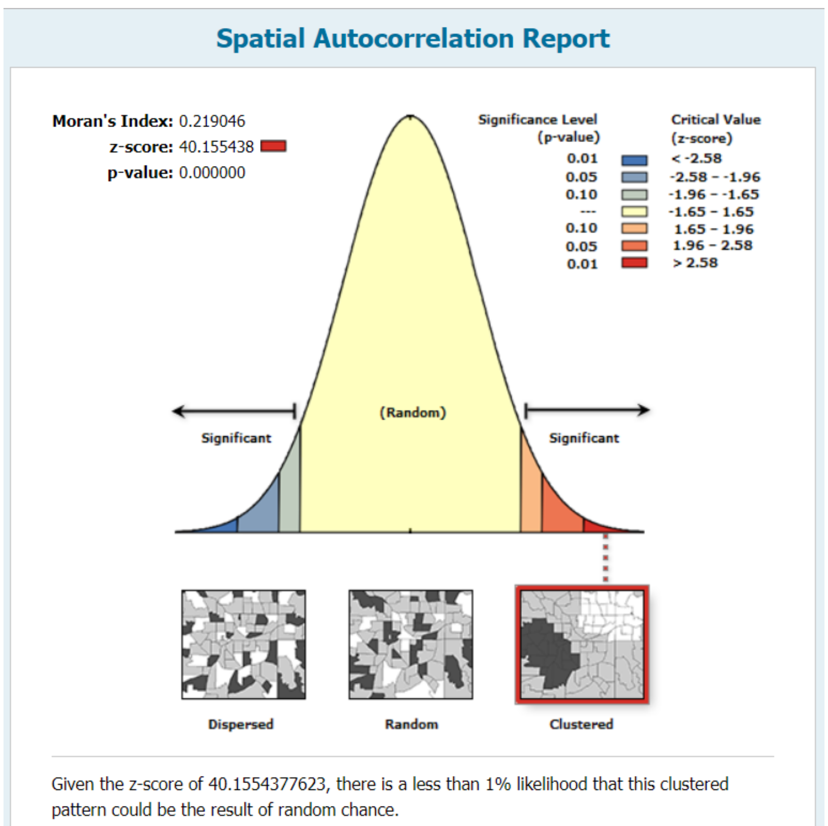


Figure 24 Spatial autocorrelation (Moran's I)

Geographically Weighted Regression (GWR)

The Geographically Weighted Regression (GWR) modeled on the same variables as of the OLS gave an r-square value of 0.32. This jump in r-square value from 0.20 in OLS to 0.32 in GWR indicates that a local model (GWR) explains the trend of biking rates better than a global model (OLS) for the given demographic variables. This reasoning of the local model behaving better than the global model can be attributed to residential self-selection in the Bay Area (Cervero and Duncan, 2003).

OLS REGRESSION - BIKE MODE SHARE AS A FUNCTION OF
INCOME, EDUCATION LEVELS, AGE GROUP AND RACE

Bike Mode Share = 0.07 (Percent Whites) + 0.13(Percent 25-45 yrs old) - 0.04(Percent Middle In-come) + 0.01(Average Household size) - 0.00016(Average Gross Rent) - 0.027

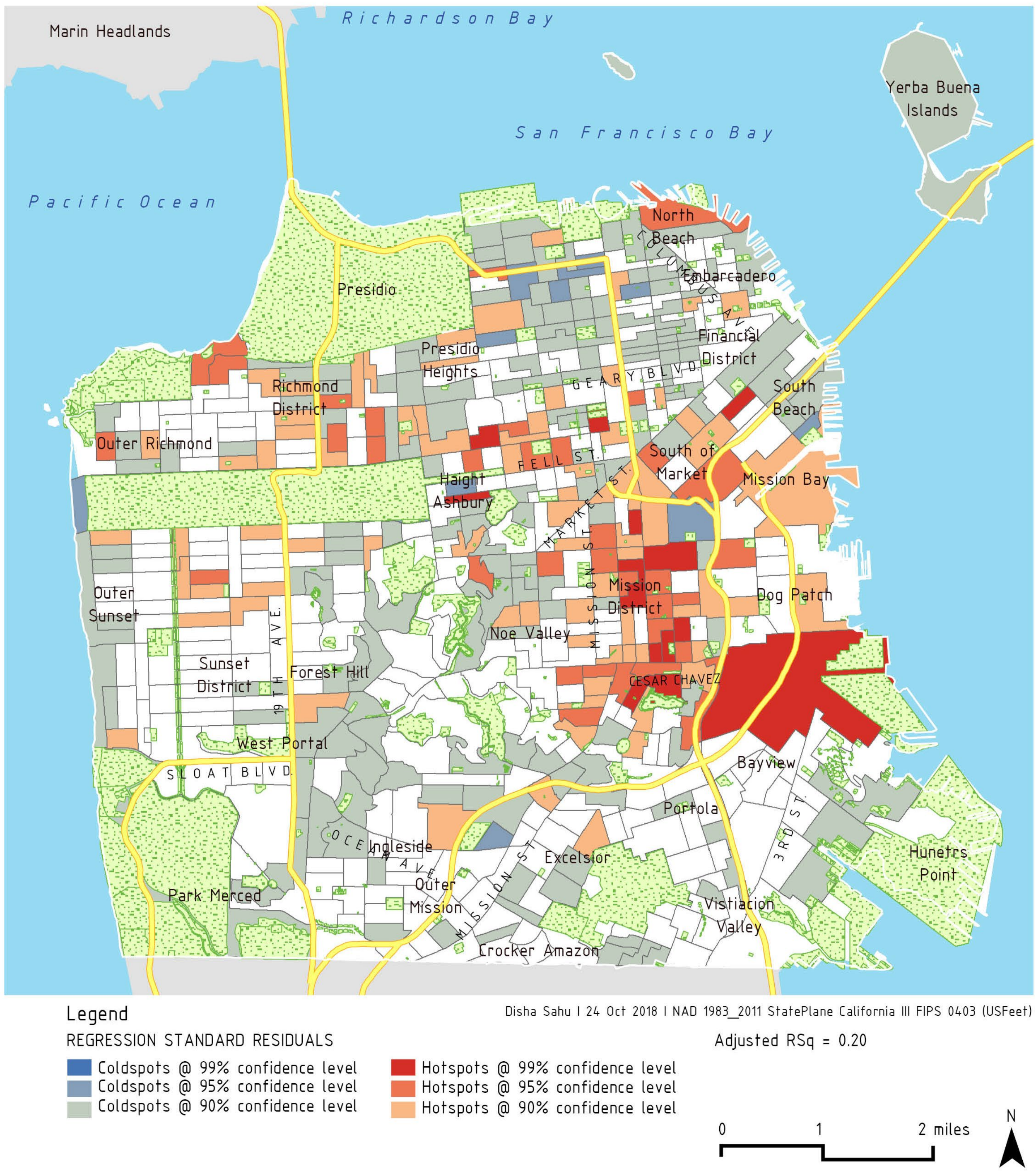


Figure 25 OLS regression residuals **(Source: Author)**

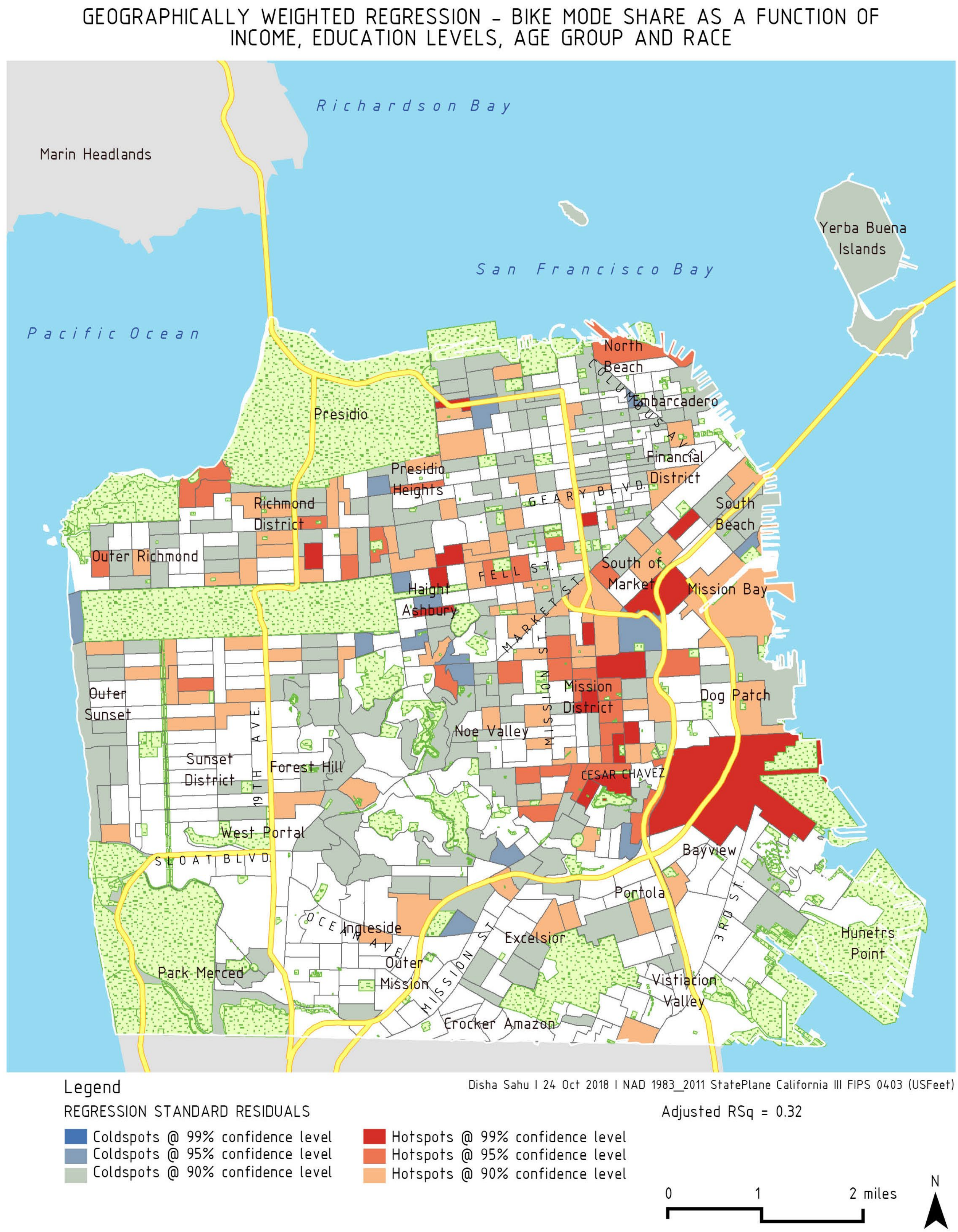


Figure 26 GWR residual results **(Source: Author)**

Figure 27 GWR- Mapping coefficients and R-sq. values **(Source: Author)**

The under and over-predictions were found to be similar to the ones observed in OLS (Fig. 26). Since the standard residuals were found to be clustered, these relationships should be interpreted with caution. Taking a look at the regression r-square results, the highest r-square agglomeration is found to be the south east segment of San Francisco (Fig. 27). Recalling the observation from bike mode share map, this segment of the city demonstrated fairly low biking rates (0-3%). Thus, the highest r-sq. values in the southeast segment of the city indicate that bike mode share as a function of demographic variables is strongest here. Although the neighborhoods of Bay View, Portola, Hunters Point, Excelsior and Crocker Amazon exhibit low bike mode share, this trend is adequately explained by the percentage presence of Whites (+), percentage presence of 25 to 45-year-old (+), percentage presence of middle-income households (-), average household size (+) and average gross rent (-).

The coefficient map of the percentage of middle-income household shows the darkest rendering towards the outer edge of the city (Fig. 27). The range of coefficient varies between -0.06 to 0.12. One could infer that neighborhoods agglomerated towards the northern edge like Embarcadero, Financial District and North Beach's share of middle-income households most strongly influence the bike mode share. On the other hand, neighborhoods agglomerated towards the east part of the city like Mission Bay, Dog Patch, Bay View, and Mission District demonstrate low bike mode share. Given the low-income stature of the communities the east part of the city and therefore the low presence of middle-income families; bike mode share's coefficient as explained by the presence of middle-income household is least and negative.

The coefficient map of average household size shows the darkest rendering in the northeast segment of the city (Fig. 27). Given the positive (OLS) global relationship between bike mode share and average household size, this coefficient rendering map implies that average household size as a measure of bike mode share is most positively explained in the northern neighborhoods of San Francisco. Recalling from the average household size distribution map (Fig. 13), this spatial pattern of decreasing strength of average household size as an indicator of bike mode share in San Francisco concurs to the previous literature findings that biking rates are positively correlated with smaller household sizes (San Francisco's average HH size is 2.3).

Table 3 GWR Diagnostics

Bandwidth	12086
Residual Squares	195
Effective Number	28.59
Sigma	0.04
AICc	-1982
Condition No.	16 – 28.5
R2	0.34
R2 Adjusted	0.32

The regression results on San Francisco's bike mode share corroborates biking literature's finding regarding across U.S. cities that higher cycling rates are positively correlated with presence of younger age groups (25-45 years old), majorly white ethnicity, smaller average household size. The study found a weak negative relationship between San Francisco's bike mode share and percentage presence of middle-income households and average gross rent. The study did not find any significant relationship between San Francisco's bike mode share and levels of educational attainment or average income levels.

3.3. Biking characteristics and trip purpose: Evidence from travel decision surveys

The Bay Area Travel Decision Survey 2017 shows that residential self-selection is more prevalent in San Francisco as compared to the rest of the Bay Area. This observation is well-noted

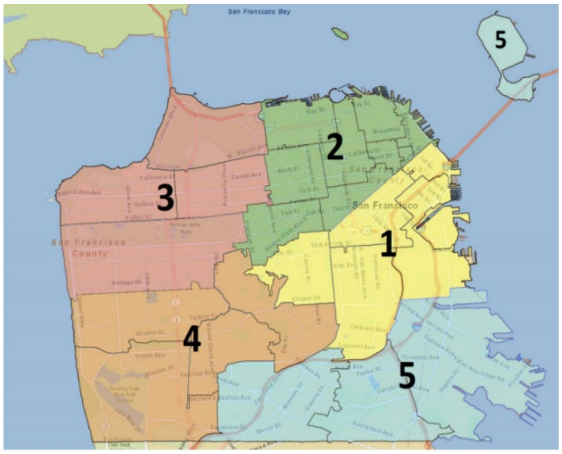


Figure 28 SFMTA Travel Decision Survey - residential zones (Source: SFMTA)

by the other Bay Area mobility studies (Cervero and Duncan, 2003) (Biggar and Ardoin, 2017). This study focusses mainly on automobile, transit and transportation network companies (TNC) use and has underrepresented data for reporting on biking trends in the city. 2013-17 travel decision survey data analysis shows that "*…bike trips have remained flat over time (around 2%), with minor fluctuations but no significant change since 2013. The bicycling data suffers from a small sample size. That said, other SFMTA studies indicate that although bicycle trips have remained steady between 2013 to 2017, it has increased substantially from 2006 levels…*" (SFMTA Travel Decision Survey Report, 2017). The survey maps out bike mode share by residential zones in the city and reports that biking rates are most prominent in (Zone 1, 2 and 5) eastern half of the city- North Beach, Embarcadero, Financial District, South of Market, South Beach, Mission Bay, Mission District, Dog Patch, Bay View, Portola, Noe Valley, Excelsior, Vistacion Valley and Outer Mission. The study reports the following statistics for bike trip purpose:

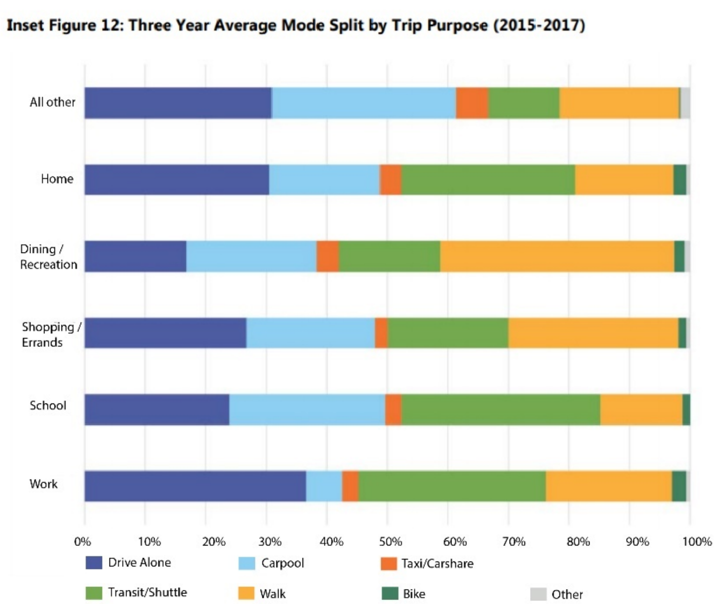


Figure 29 SFMTA's Travel decision Survey 3-year average mode split by trip purpose (2015-17) (Source: SFMTA)

Table 4 Extracting bike trip share by purpose (Source: Author)

Trip Purpose	**Overall trip share**	**Bike trip Share**
Home	34%	4%
Work	21%	4%
Dining/ Recreation	21%	3%
Shopping/ Errands	19%	2%
School	3%	2%
Other	2%	0.5%

The bike trip share from travel decision survey shows that most of the bike trips in San Francisco are purposed towards commuting (home and work bound). The study did not delve into fine-grained bike trip data analysis, but it recommends that "*…transportation focused interventions shown to increase the use of non-auto modes include …. and providing new or enhanced bicycle facilities including Class I and Class II bike lanes, secure parking and other such improvements*".

Another SFMTA study which preliminarily focused on biking trip destinations via intercept surveys found that 48% of San Franciscans bike for recreational purposes, followed by 14% for errands and 10% for work commuting, 6% for school/college and the rest 6% for dining and socializing (SFMTA, 2015).

The travel decision survey reports that most bike trip's purpose is related to commuting while the SFMTA intercept survey found that the most frequented bike trips are aimed towards recreation. This apparent discrepancy could be best explained by the methodology of the studies. Where the travel decision report's data is modeled on transportation models and frequented trips (with a certain degree of predictability), SFMTA intercept surveys were community-based deep-dives without paying attention to how frequently or predictably were those trips were generated.

3.4 Biking in San Francisco: The public perception

SFMTA conducted a bicycle usage and awareness study (intercept surveys) in the Fall of 2015 and concluded segment characteristics for different types of bike riders in the city. The segments division followed Roger Gehler's categorization – *regular riders, ready and willing,* *hesitant but interested* and *unlikely riders*. The following section paraphrases main characteristics about each segment:

Regular Riders

Regular riders make up almost 13% of San Francisco's cyclists. Regular riders were most likely to be under 40 and mostly students, minority, renters, well-educated, lower income and newer residents to the city. This segment bikes for commuting purposes and also use it for exercising and social activities. More than half of regular riders in San Francisco are choice riders and have access to at least one household vehicle and around 40% have a car share membership. They expressed a strong preference for bike paths that are separated from vehicles but are willing to ride on shared sharrows. This cohort uses biking for its lower transportation costs.

Recent nationwide planning literature elicits that traditionally whites tend to be the major ethnicity who bike in U.S. cities, but there is an increasing share of other races and ethnicities who are diversifying this trend. SFMTA's intercept survey findings on regular riders being the minorities corroborate this nationwide trend for San Francisco.

Ready and Willing

Ready and willing riders consists almost 14% of bikers in the city. Ready and willing are more likely to be male, students, under 50, middle income, educated, parents and newer residents. This segment uses bike preliminarily for exercising purposes. Around 33% of this segment have access to a household vehicle and less than 20% have access to car share memberships. They expressed a preference for separated bike paths too and support biking due to its lower transportation costs and positive environmental consequences.

Hesitant but Interested

Hesitant but interested consists around 17% of probable bikers. Hesitant but interested tend to be in their 50s and 60s, long-term residents, work in the city and live in southeast or central part of San Francisco. They rider bike rarely and when they do, it is preliminarily for exercise purposes in-and-around parks. Just one-third of this cohort have access to bike and bike parking. Like ready and willing, this cohort appreciates biking for its environmental benefits and not because of its low cost or convenience.

Unlikely riders

Unlikely riders make the majority (about 56%) of San Francisco's population. They tend to be female, 65 years or older, homeowners, long-term city residents and have well-to-do economic backgrounds. Only 25% of unlikely riders have ridden a bike and enjoyed the experience. Almost 70% of unlikely riders have access to an automobile and do not support biking in the city because they do not think that it is safe and there is sufficient space on streets to co-accommodate bikes, pedestrians, transit, and cars together.

The survey documented main reasons as to why people bike in San Francisco and found that almost 50% of people bike because it is cheaper transportation alternative (avoid car parking hassles), saves gas and automobile costs. The other 20% bikes because of health and fitness reasons. The rest 30% bikes because it is less damaging to the environment and avoids congestion and is a good form of exercise (SFMTA, 2015).

The survey also recorded other responses on what effective improvements will make people bike more. The study indicates almost 60% or more respondents wanted more physical separation between bikes and cars, clearer markings for drivers and bicyclists, more green-painted bike lanes and bike boxes, better signage directing bikers to bikeways and wider bike lanes (SFMTA, 2015).

Of all respondents, 23% said that they are only comfortable riding separated from vehicles, other 30% said that they can ride but are not comfortable riding in San Francisco and only 25% said they find biking comfortable in the city (SFMTA, 2015). With these responses, it is fair to extrapolate that as San Francisco plans to build more safe bikeways, people will bike in more numbers.

3.5 Bike sharing

Introduced in 2013, the Ford-Go bike share is Bay Area's regionwide integrated 3rd generation docked bike share system. It has over 500 stations spread across San Francisco, East, North and South Bay. It is well connected with the regional and local transit system. Ford Go bike share is in a rapid expansion phase and as of November 2018 phase I and II are completed. The bike share offers yearly, monthly and single-use passes. The number of rides per month between January and June 2018 has almost doubled. This rise can be attributed to: increasing network and station installation, better marketing of discounted rates for lower economic households, increasing no. of monthly and yearly subscriptions (Lin, 2018).

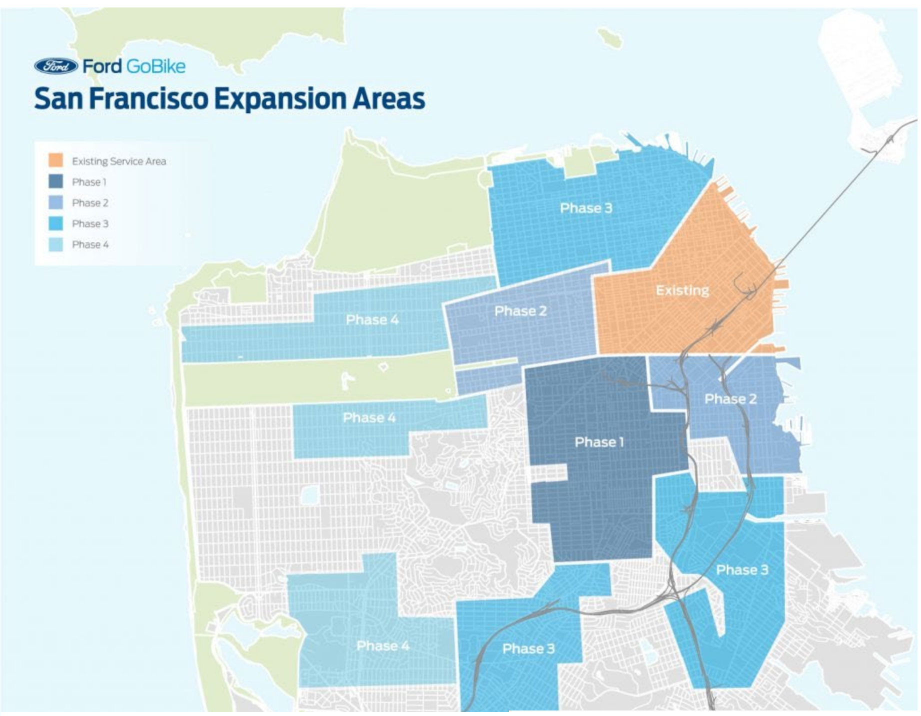


Figure 30 San Francisco bikeshare expansion areas (Source: Ford Go bikeshare)

Some key bike sharing indicators are as follows:

Tony Lin's data mining of Bay Area Ford Go bike share shows that users tend to be male, in their 30s-40s and use bike share for rides less than 30 minutes in the city (for distances of under 4 miles) (Lin, 2018). The study also notes that frequency of rides during the weekdays and the

BIKE SHARE STATION (START STATION) HOTSPOTS

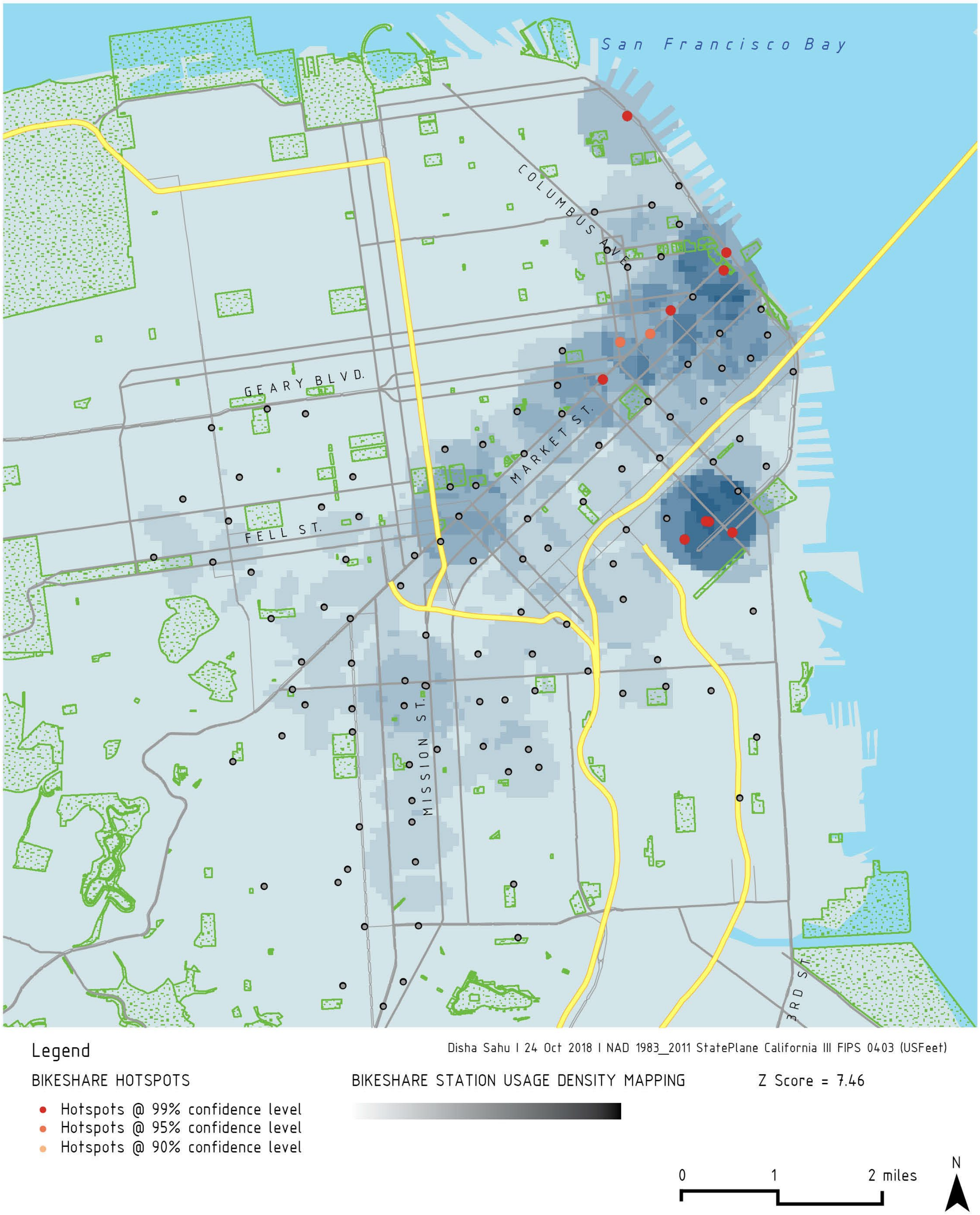


Figure 31 Ford Go Bike share hotspots (by start stations) **(Source: Author)**

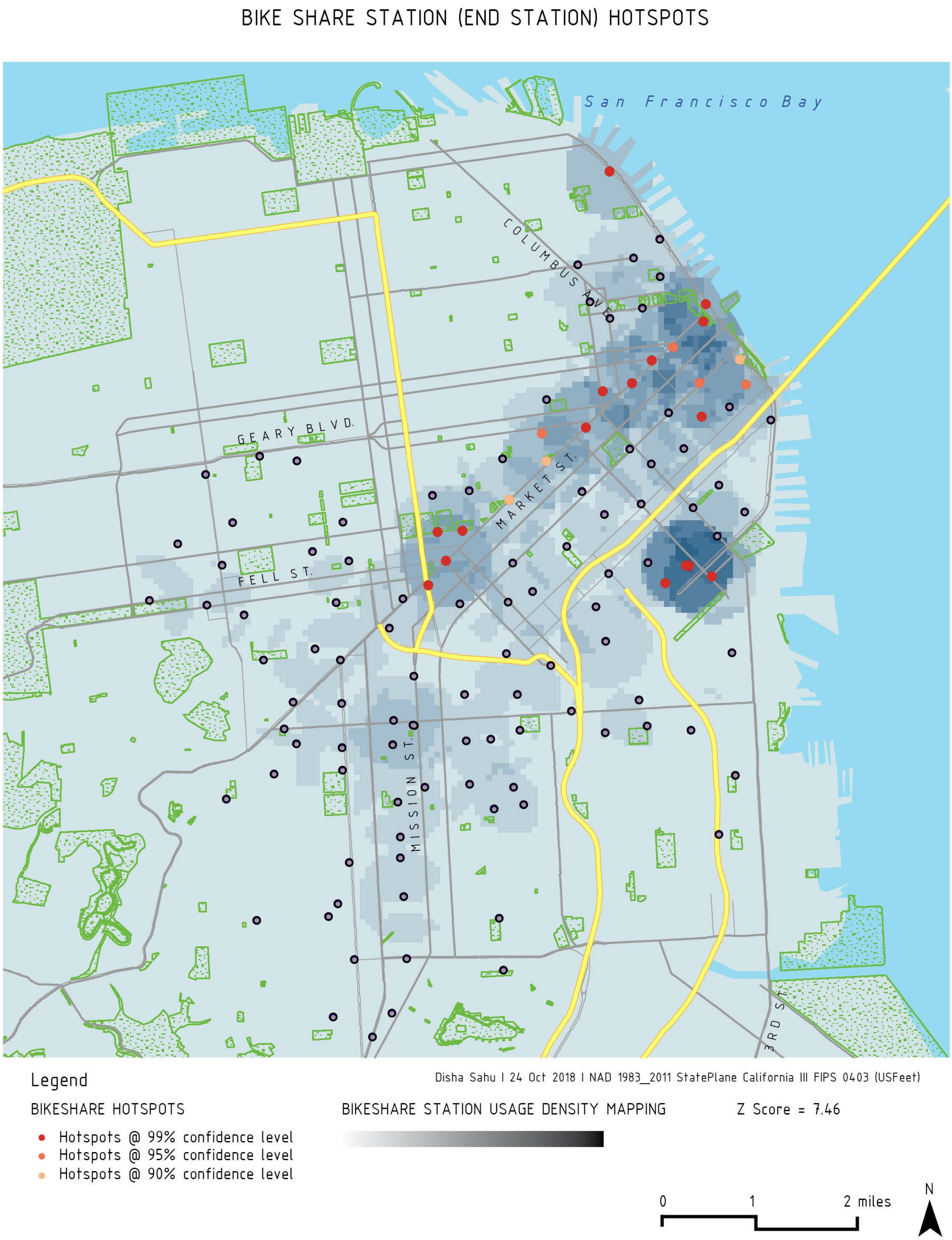


Figure 32 Ford Go Bike share hotspots (by end stations) **(Source: Author)**

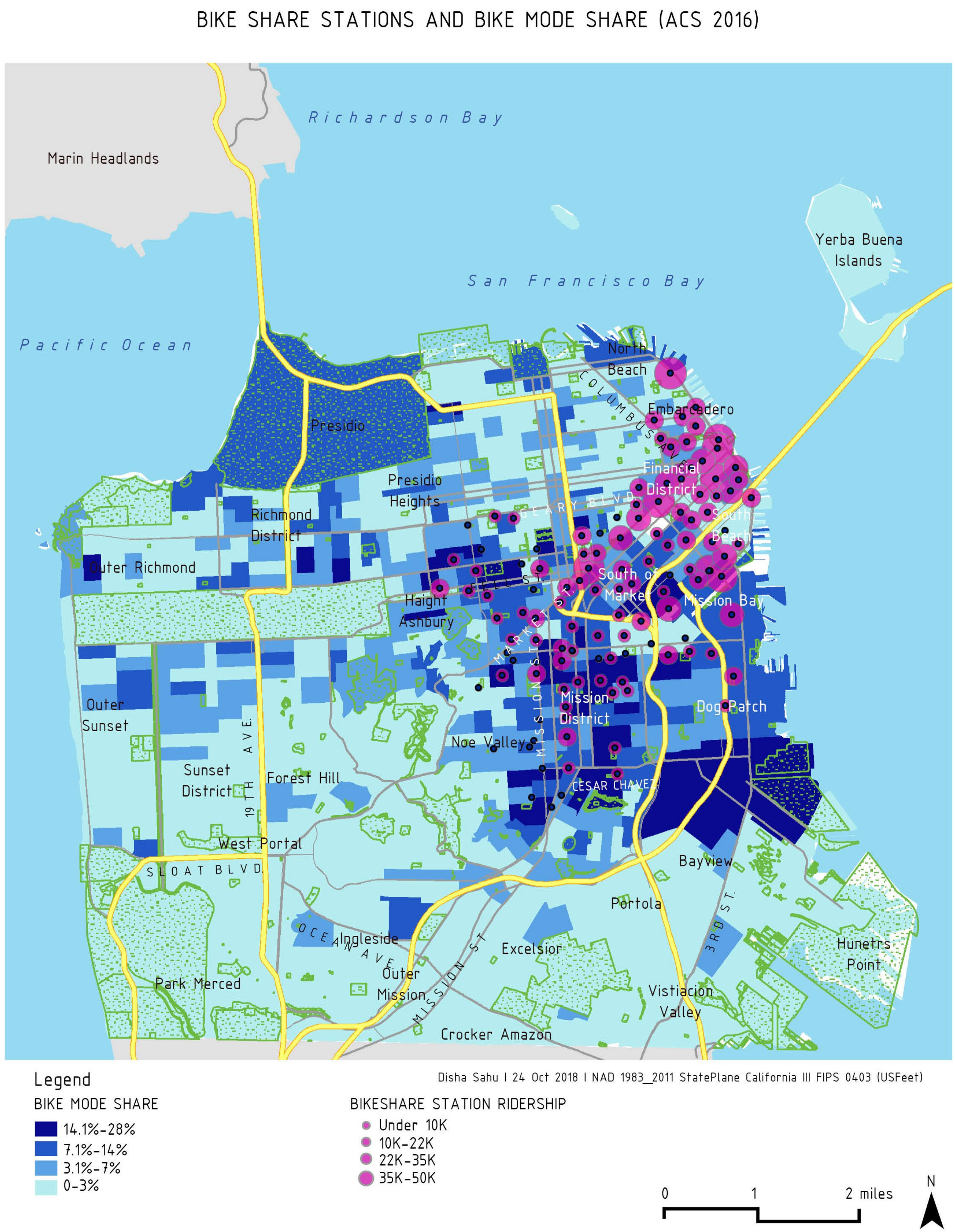


Figure 33 Ford Go bikeshare stations and San Francisco bike mode share **(Source: Author)**

observed peak of bike share trips around normal commute hours (8am-10am and 4pm-6pm) indicate that that the trip purpose is for the commute (Lin, 2018). Bike share start and stop station hotspots (Fig. 31 and 32) (around CalTrain stations and BART stations) indicate that bike share system is most commonly being used by commuters who travel from the rest of Bay into San Francisco. Most bike share ridership is agglomerated around the financial district (Fig. 33). Given that the financial district is the main employment center for the city and having established that For Go bikes are preliminarily being used for commuting, high ridership in Downtown seems logical. ACS bike mode share is high in some of the east segments of the city (Dog Patch, Mission Bay, Mission District, Noe Valley, and Haight Ashbury) which are majorly residential neighborhoods. Residents who commute by bike to work in the city or other bikeable locations in the Bay Area. These biking trips are either origin-to-destination biking or transit-

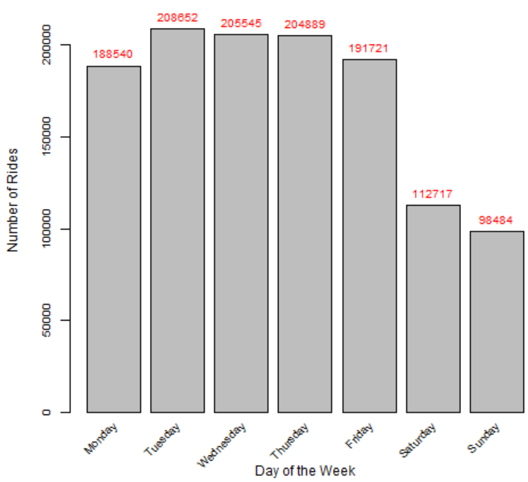


Figure 34 Bikeshare usage by day of the week (Source: Lin, 2018)

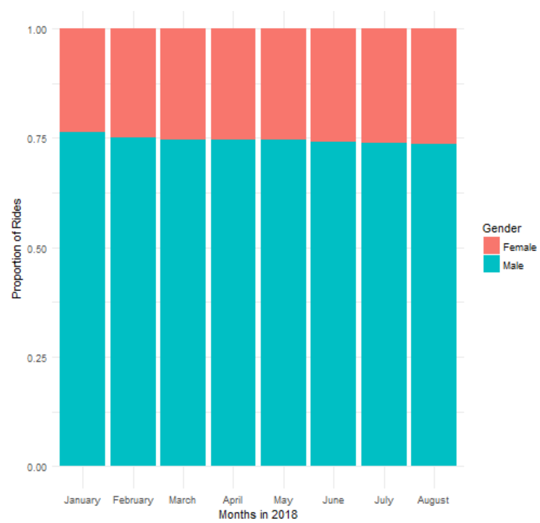


Figure 35 Bikeshare usage by gender (Source: Lin, 2018)

integrated first-and-last-mile biking. The Ford Go bike share ridership indicates that it is being used by the commuters who come to the city using CalTrain or BART and the bike share gives them the convenience of biking for a first-and-last mile (faster than walking) access without having to carry a bike in transit. This is convenient because of the lack of safe bike parking in the city and high rates of bike stealing events.

Other than For Go bike share, San Francisco has dock-less Jump bikes which are co-operated with Uber. Fig. 38 shows the service area of Jump bikes, if the rider parks the bike beyond this designated area, they are levied $25 fine. Jump bikes are in a pilot test till end of 2019 and have not made its data publicly accessible. But having used Jump bikes and studied the biking

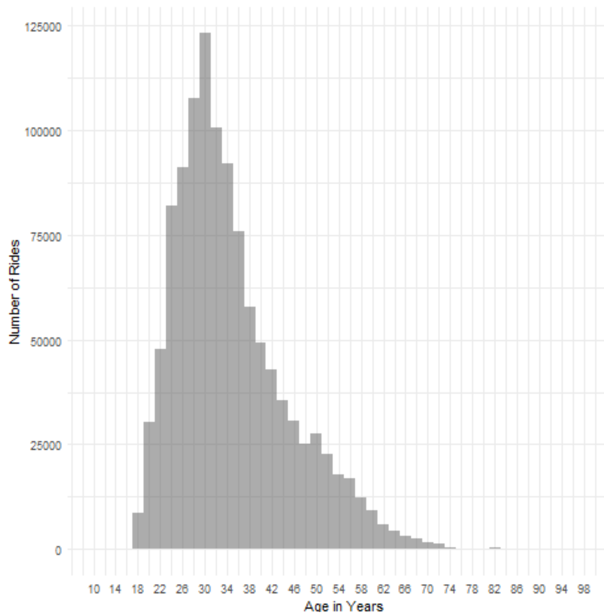


Figure 36 Total rides by age (Source: Lin, 2018)

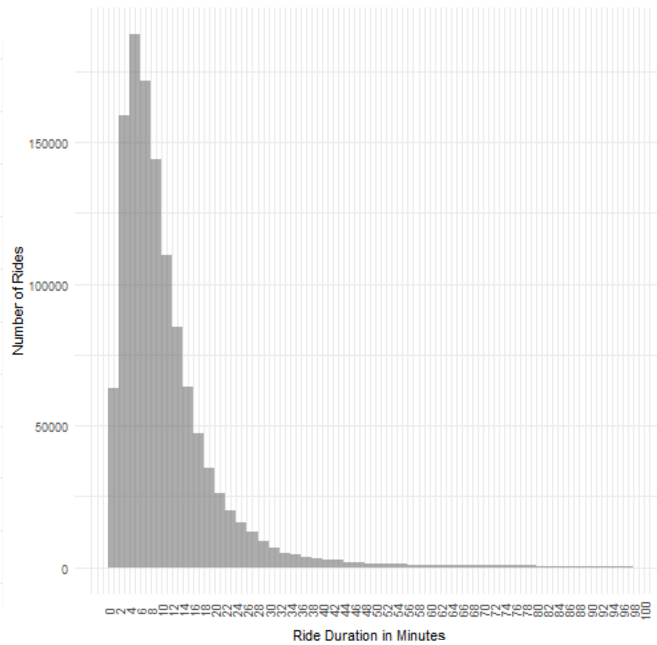


Figure 37 Duration of rides (Source: Lin, 2018)

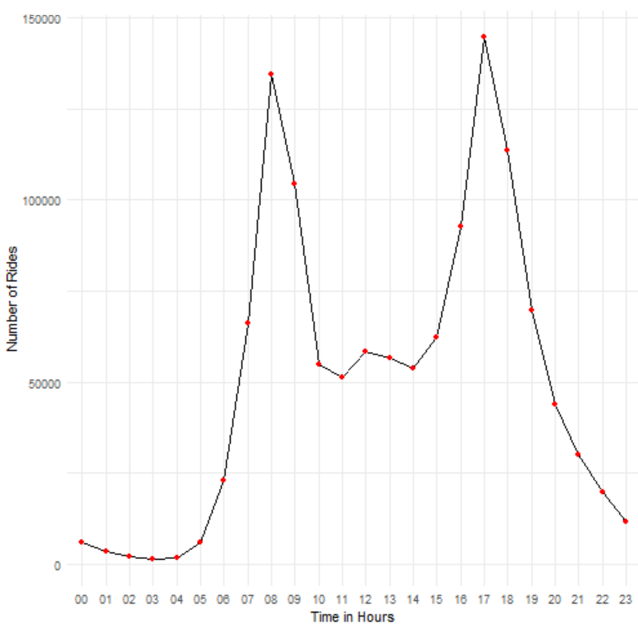


Figure 38 Total rides by hour (Source: Lin, 2018)

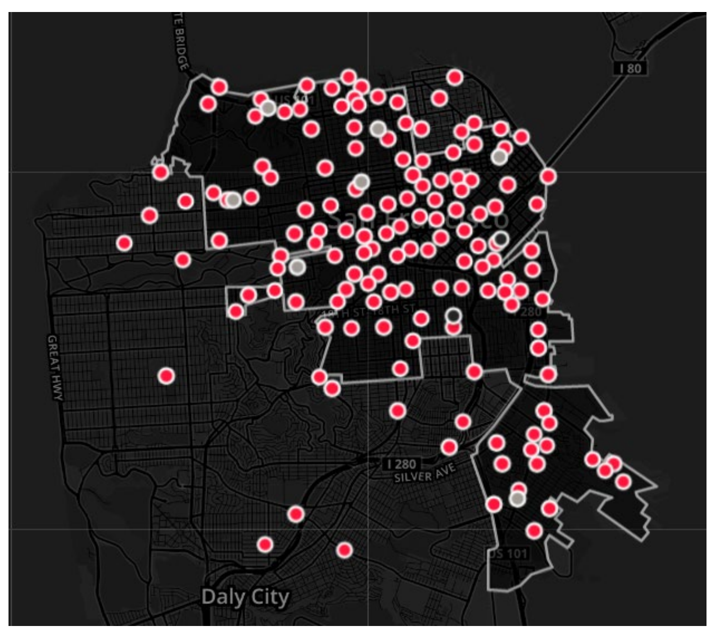


Figure 39 Coverage area of Jump bikes in San Francisco San Francisco

characteristics of the San Francisco, it is fair to assume that Jump bike rider's demographic profile is similar to Ford Go bikes. While Ford Go bike share has its epicenter around financial district and stretching south along the Mission District's spine, the Jump bike share extends much further south into low-income neighborhoods of Bay View and Hunters Point.

3.6 Need for recognizing the equity component of biking

The Bay Area cyclists recognize the expansion of Jump's dockless bike share catchment to the low-income neighborhoods is a crucial step towards improving the access of bike share in traditionally disinvested neighborhoods of San Francisco. The planners who understand the inside politics of bike share licensing and business rivalry view this as a pleasant outcome of bike share monopoly rights. Since Ford Go was the first bike share company on the West coast, during its establishment period, it signed an agreement with the City of San Francisco to not let any other bike share company establish its primary foothold in Ford Go bike share's competition. Since Ford Go targeted the floating commuter demographic who come to the city to work especially around the financial district, it focused its bike share network's epicenter on the northeast segment of the city. Being the first bike share company on West coast, Ford Go signed bike share monopoly agreement with the city of San Francisco. This agreement was crafted in a manner that ensured that no competing bikeshare company would find it feasible to co-locate docked bikeshare systems in the same geographical extent.

This report's analysis concurs that given demographic and land use characteristics of the northeast segment of the city, it was the most well-suited pilot neighborhood for bikeshare. In early 2018, when Jump bikes established its foothold in San Francisco against its competitor Ford Go bikes, it capitalized on two aspects- one, the electric biking technology which could go up the steep hills of city without manual labor and second, it demarcated its service area encompassing neighborhoods (preliminarily hilly) that had high bike mode share but were not served by FordGo bike share stations (refer Fig. 41 and Fig. 33). Thus, what was acknowledged as a step towards bringing more equitable bike share access to San Francisco was passively motivated by business model feasibility. Planning literature indicates that mere expansion of the bike share network in absence of safe and accessible bike infrastructure does not encourage these disinvested communities to bike (Haning, 2016). Although discounted bike share memberships to communities with low socioeconomic indicators or persistent disinvestment has shown encouragingly positive biking levels (Smith and Lei, 2015). Ford Go bike share under its Bike Share Equity Program has offered $5 first-year membership and cash transactions for low-income residents who qualify for Bay Area Utility lifeline program starting Spring 2018. Previous findings and literature suggest that this economic incentive and Ford Go's future phase expansion to southeast segments of the city will usher a considerable rise in bike share usage in the Bay Area. These results could be further improved if these neighborhoods have an increased supply of safe and convenient biking infrastructure. Next, this research tries to inquire whether San Francisco's biking infrastructure is equitably distributed across the city. As indicated by SFMTA's intercept survey, most of the *regular riders* and *ready and willing riders* come from lower to middle-income backgrounds and bike to save on transportation costs; the non-availability of safe and accessible biking infrastructure to those who use and need it the most might indicate a missed opportunity in San Francisco's biking renaissance.

4. Evaluating San Francisco's bike accessibility from socio-economic perspective

This chapter focusses on computing the perceived bike accessibility scores for San Francisco using GIS suitability analysis. Using Ordinary Least Square (OLS) and Geographically Weighted Regression (GWR), the study tries to derive a relationship between perceived accessibility measure (Bike Score) and literature sourced socioeconomic indicators. Perceived bike accessibility is a measure of people's choice to use a bike, given their ease and availability to access bike infrastructure (Scheepers, Wandel-Vos et al, 2016). Planning literature identifies numerous methods to quantify perceived bike accessibility, out of which bike score is one method. Bike score is a weighted measure of several factors that makes places easy to bike, like- *presence of bike lanes, bike share stations, topography, supportive land use variables and biking presence for commuting and recreational purposes*.

4.1 Measuring San Francisco's perceived bike accessibility

The lack of consistent biking data sources makes it difficult to map the origins and destinations of the bike rides. Travel decision survey for the Bay Area at best illustrates the shares of biking trips and percentage share of trip purposes. ACS data does not furnish any other statistic other than bike mode share for commuting purposes. Biking literature acknowledges this limitation and researchers have come up with many other ways to quantify biking accessibility without having to rely on origin and destination trip data. Perceived bike accessibility is a measure of people's choice to use a bike, given their ease and availability to access bike infrastructure (Scheepers, Wandel-Vos et al, 2016). This methodology computes perceived bike accessibility using a suitability matrix based on Bike Scores.

Computing Bikeability Index

Bike Score ® released a patented Bike Score Matrix based on the following equally weighted components: *Bike lanes, Hills, Destinations, and road connectivity and Bike commuting mode share* (Bike Score, n.d.) After consulting related literature, this research added the presence of bike share station as the fifth variable (McCormack and Rowe, 2014). This research did not weigh in all variables equally because biking related studies showed that all these variables contribute differently towards the biking experience. McCormack and Rowe conclude that double weighing the slope variable relative to other measures produces a realistic representation of biking experience (McCormack and Rowe, 2014). The study found that while riding downhill, three categories of riders- regular riders, ready and willing riders, and hesitant but interested riders seem ready to bike on downhill roads, however while riding uphill only regular riders and a small proportion of ready and willing riders choose to ride up the hill. The study noted that these observations stood valid if the riding slope was in range of one-in-eight to one-in-fifteen.

The destination and road connectivity variable in the bike score variable matrix represented land use variables. Cervero and Duncan (2003) work on bikeability in the Bay Area shows that density, diversity and design land use variables together give a comprehensive picture of the spatial form of land use scenario and therefore none should be missed. The following matrix formed the working basis of raster suitability analysis:

Table 5 Suitability analysis matrix **(Source: Altered version of Bike Score's methodology, tweaked as per author's research)**

Shapefile	**Data Type**	**Weight for suitability analysis**	**Logic**
Bike lanes	Line	5%	Distance people are willing to ride/walk to access a bike lane or in other words distance to the closest bike lane
		5%	People feel more safe biking or protected bike lanes rather than sharrows. Therefore, types of bike lanes encourage people to bike.

Bike share stations	Point	5%		Proximal accessibility to the bike share stations encourages biking. Walking -Half mile walking radius buffer from the bike share station as a measure of status-quo bike accessibility via walking. Driving- Half mile buffer from parking garages (preferably long term) Transit- Half mile buffer from CalTrain/Muni stops
		5%		Literature shows that people prefer to use bike share when there are numerous stations in proximity. Density of stations ensure that they can walk up to another bike station and either pick or drop the bike off
Hill slopes	Line/raster	40%		Steepness in topography inversely proportional to urban biking
Land use variables (Density Diversity and Design)	Census block group level data	20%		For biking, 3 d (density, diversity and design) variables at trip origin weigh almost equally to decide if the person will bike. Street grids (design variable) might be allocated a slightly higher value.
			Density (30%)	Density variable is an equally weighted output of: - Gross residential density (HU/acre) on unprotected land - Gross population density (people/acre) on unprotected land - Gross employment density (jobs/acre) on unprotected land - Gross activity density (employment + HUs) on unprotected land
			Diversity (30%)	Diversity variable is an equally weighted output of: - Employment and household entropy - Trip productions and trip attractions equilibrium index; the closer to one, the more balanced the trip making - Regional Diversity. Standard calculation based on population and total employment
			Design (40%)	Design variable is an equally weighted output of: - Total road network density - Network density in terms of facility miles of multi-modal links per square mile - Street intersection density (weighted, auto-oriented intersections eliminated) - Intersection density in terms of multi-modal intersections having four or more legs per square mile

Biking commute mode share	Census block group level data	20%	Higher commute mode share invites more biking in the neighborhoods. Concept of critical mass in bike commuting.

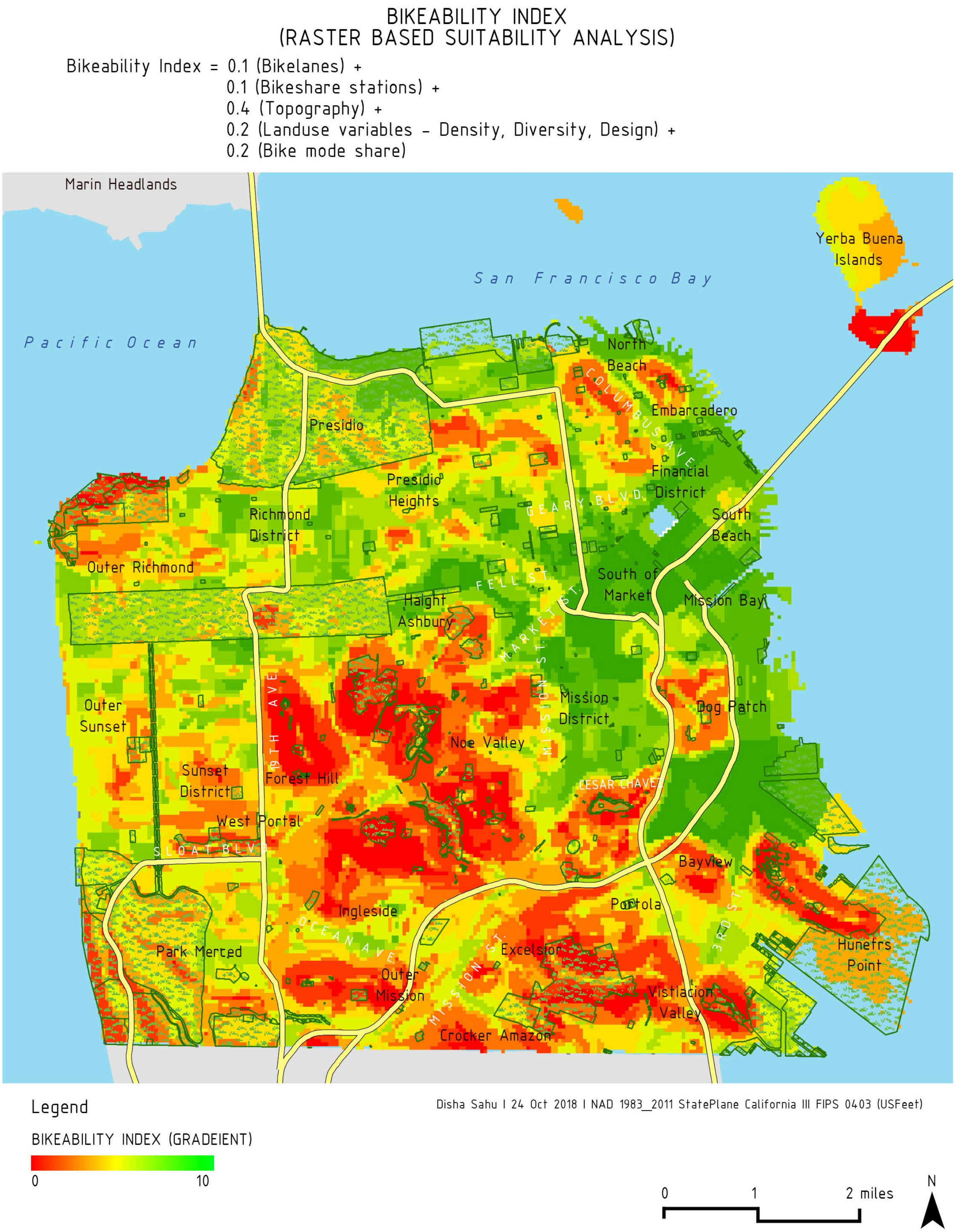


Figure 40 San Francisco Bikeability Index (Source: Author)

BIKING MODESHARE HOTSPOTS (ANALYSIS) AND BIKE SHARE STATIONS

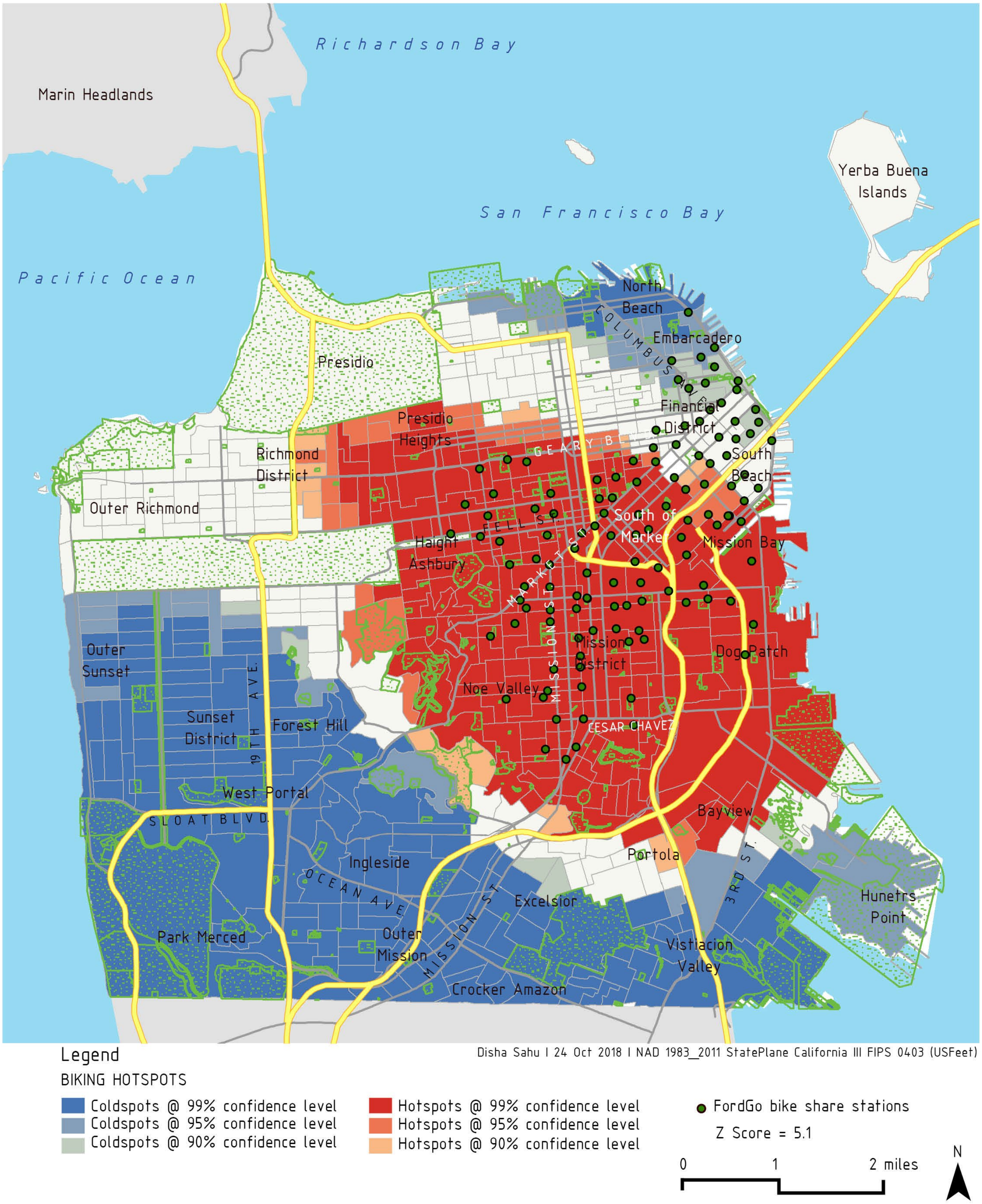


Figure 41 San Francisco's bike mode share hotspots and Ford Go bike share stations (Source: Author)

Fig. 40 represents the suitability raster output of the perceived bike accessibility score or bikeability index. The areas rendered in deep red are least bikeable and the ones rendered in deep green are the most bikeable. Since the slope variable was weighed at 40%, most of the hilly neighborhoods in the city were rendered un-bikeable by the suitability analysis. From the firsthand experience of biking in San Francisco, I agree with the literature's suggestion that double weighing the topography variable yields a more realistic bikeable experience and therefore a more accurate representation of how many bikers would likely to take those routes. Neighborhoods which very rendered highly bikeable were – *North Beach, Financial District, South Beach, Mission Bay, South of Market, Mission District, Richmond District, and Haight Ashbury*. Neighborhoods that were rendered moderately bikeable were- *Outer Richmond, Presidio Heights, Dog Patch, Outer Sunset, Sunset District, Portola, and Park Merced*. Neighborhoods which were rendered un-bikeable were- *Forest Hill, Outer Mission, Crocker Amazon, Excelsior, Bay view, and Dogpatch*.

Fig. 41 shows the bike mode share hotspot analysis (global distance n=9500 feet). The locations rendered in red overlaps with the bikeability index's most bikeable neighborhoods (discounting the red blobs- which appear because of high weightage of topography variable). It verifies the findings of the suitability analysis. The coverage of Ford Go bike share stations on Fig. 41 neatly fits onto the green rendered areas of the bikeability index map. This shows that Ford Go bike share's station siting acknowledges the bikeable locations of the city.

4.2 Deriving relation between perceived bike accessibility and socio-economic indicators

There are numerous ways to quantify transportation equity. This research borrowed its socioeconomic indicator matrix for quantifying biking equity from a biking and bike share equity study in Chicago (Scott et al, 2015). The study suggests the following 7 parameters as a measure of socio-economic hardship which is a strong indicator of disinvestment communities and continuing inequity:

1- *Unemployment rate - percent of civilian population over the age of 16 who were unemployed,*
2- *Dependency rate - percentage of the population that are under the age of 18 or above 64,*
3- *Lower educational status - percentage of population over the age of 25 who have less than a high school education,*
4- *Rent burdened households- percentage of households which spend more than 30% of income used as rent,*
5- *Crowded households- percent of occupied housing units with more than one person per room,*
6- *Lack of health insurance- percentage of adults' overs 18 years of age who do not have a health insurance,*
7- *Households receiving Public Assistance- percentage of households with public assistance income*

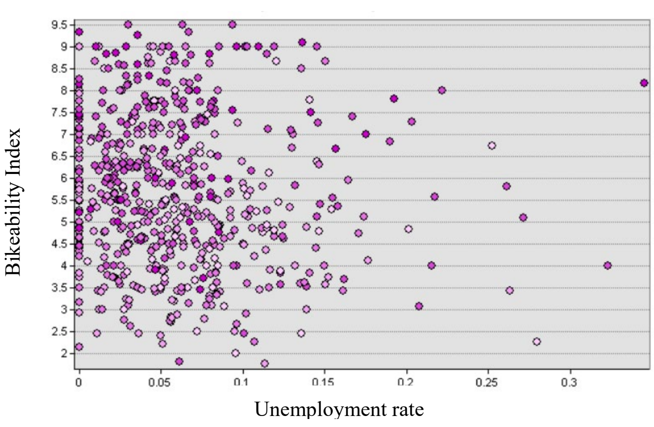
The research used raster calculator equally weighing the above factors to calculate a socioeconomic indicator for San Francisco. The neighborhoods rendered in low socioeconomic indices were found overlapping with MTA's community of concern (marked in the diagonal hatch) (Fig. 42). These findings support the previous efforts of MTA in improving access to transportation equity.

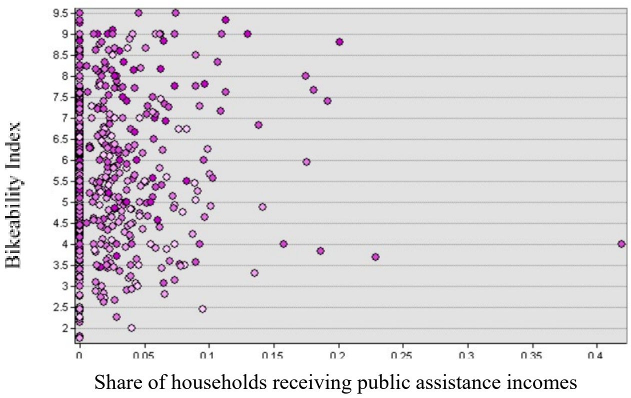
Instead of computing a descriptive statistic which amassed these 7 indicators, this research studies the relationship between bikebility index scores and the above mentioned 7 variables through scatterplots and regressions. This was done to understand which indicators most influences the bikeability index and by how much. Upon overlapping MTA's communities of concern (COC) polygon with Gini Index mapping of San Francisco, one could observe that the upper section of COC lies within the neighborhood where Gini Index is relatively high, and the low-income disinvested communities are pepper-potted in an overall high-income section of the city. The lower section of COC intersects with neighborhoods having low Gini Index. The introductory maps show that neighborhoods like Bay View, Outer Mission, Hunters Point are principally low-income neighborhoods. The southern segment of COC has been overall economically disinvested with little or no economic diversity around. As found in the succeeding research, the southern segment of COC has fared worse on fronts of biking infrastructure improvement projects. Next, the research explores the relationship between the bikeability index (BI) and each of the seven socioeconomic indicators by means of scatterplot, OLS, and GWR.

Ordinary Least Squares (OLS) Regression

Scatterplots of bikeability index with socioeconomic indicators

Of the above 7 variables, using exploratory regression, the following variables- *dependency rate, low education status, rent-burdened households, households with no health insurance and households receiving public assistance income* were found to be the most significant variables affecting the bikeability index. Unemployment rate and overcrowded household variables were eliminated because bikeability index raster suitability calculation used employment density and residential density as input variables. Therefore, by removing the unemployment rate and overcrowded household variables, we are eliminating any instance of double

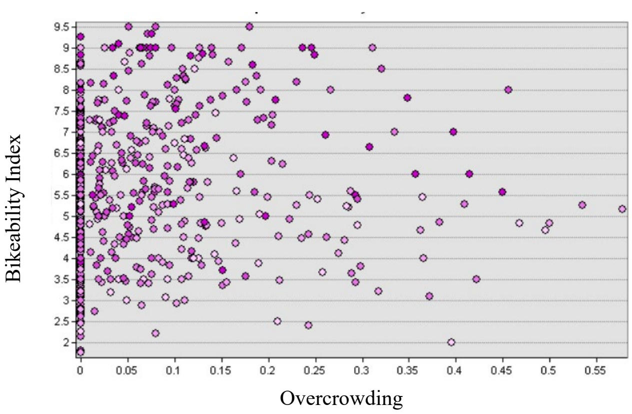


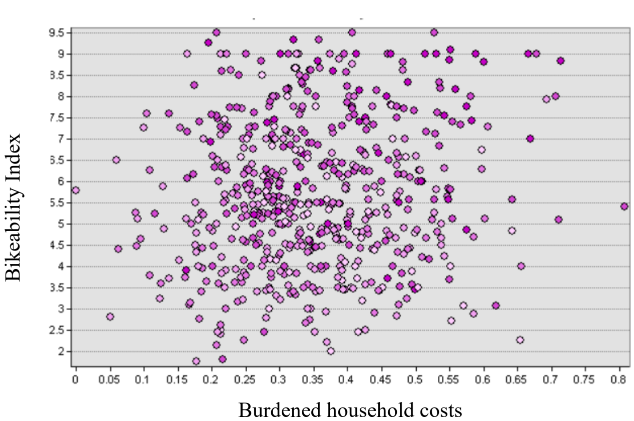


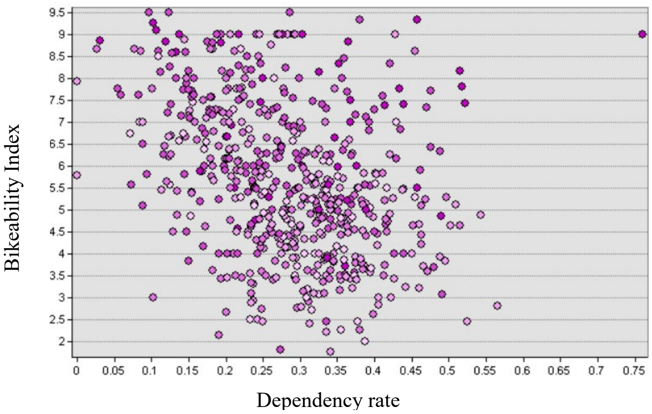
counting or cross-explanation. The adjusted r-square value was 0.14 indicating that these socioeconomic indicators have a weak relationship to the bikeability index. Of all variables, households with no health insurance, dependency rates, and lower educational levels have the strongest coefficients. The signs associated with the coefficients comply with earlier finding and biking realm’s literature. The regression equation is:

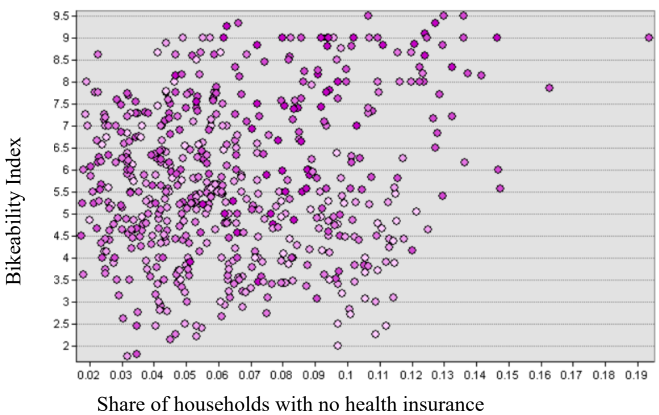
Bikeability index = -4.83 (Dependency rate) -2.3(Lower educational levels) + 1.6(Rent burdened households) + 10.58(Households with no health insurance) + 6.8

Regarding OLS regression results, since the Koenker (BP statistic) test was found not to be significant, the probability statistic could be trusted instead of the robust probability statistic. All the VIF values are below 7 indicating that all the variables are capturing a different segment of the story and there is no multicollinearity. Since Jarque Bera statistic was not significant, it eliminated any chance of model bias. Exploratory regression results showed that this combination of socioeconomic indicators had the least AICc values and the model was optimized. The Moran’s I spatial autocorrelation test gave a clustered residual which was surprising given that Jarque Bera test statistic









was not significant. Clustered Moran's I residuals indicate two trends- First, either the local model explains tendencies better than that global model. Second, the results concluded by OLS are not consistent and oscillate. Fig. 44 shows the standard residuals for the above modeled OLS regression. The blue neighborhoods represent underprediction while the red ones indicate overprediction. The results of underpredicted neighborhoods like Noe Valley, Forest Hill, Park Merced, Outer Mission, and Excelsior show that bikeability index as a measure performs lower when considered as a function of *dependency rate, low education status, rent-burdened households, households with no health insurance and households receiving public assistance income* variables. Recollecting from the suitability raster map, one could observe that these neighborhoods were rendered least bikeable (mostly due to their hilly terrain). The results of overpredicted neighborhoods are generally clustered in the northeast segment and it can be inferred that bikeability index as a measure performs higher when considered as a function of *dependency rate, low education status, rent-burdened households, households with no health insurance and households receiving public assistance income* variables. Given that this segment of the city has a robust bikeability index and mixed socio-economic indicators, the underprediction level was expected (Fig. 43 and 44).

Table 6 Summary of OLS results

Variable	*Coefficient*	*Std Error*	*T-Statistic*	*Probability*	*Robust Standard Error*	*Robust T-Statistic*	*Robust Probability*	*VIF*
Intercept	6.898	0.308	22.338	0.000*	0.340	20.252	0.000*	---
Dependency Rate	-4.836	0.738	-6.552	0.000*	0.856	-5.643	0.000*	1.276
Lower Educational Levels	-2.313	0.948	-2.439	0.014	0.955	-2.421	0.015	2.081
Percentage of Rent burdened Households	1.161	0.649	1.786	0.074	0.666	1.742	0.082	1.436
Percentage of households with no health insurance	10.592	2.919	3.627	0.000*	2.981	3.552	0.000*	1.734

Table 7 Statistic of OLS results

No. of observations: 578	AICc: 2199.95
Multiple R-Squared: 0.149	Adjusted R-Squared: 0.143
Joint F-Statistic: 25.14	Prob(>F): 0.000*
Joint Wald Statistic: 77.65	Prob(>F): 0.000*
Koenker (BP) Statistic: 23.09	Prob(>F): 0.000*
Jarque Bera Statistic:2.45	Prob(>F): 0.293

Geographically Weighted Regression (GWR)

The study modeled a Geographically Weighted Regression (GWR) on the same variables as of the OLS. The r-square value went up as 0.51. This jump in r-square value from 0.14 in OLS to 0.51 in GWR indicates that a local model (GWR) explains the scenario much better than a global model (OLS). The standard residuals of the OLS were clustered despite a non-significant Jarque Bera statistic. The under and over-predictions are a little more scattered than OLS with the difference that the northeast segment still remains as the epicenter of over-prediction and central and southwest segments remain as the hub of underprediction. Since the standard residuals are clustered, these relationships may not be entirely consistent (Fig. 45).

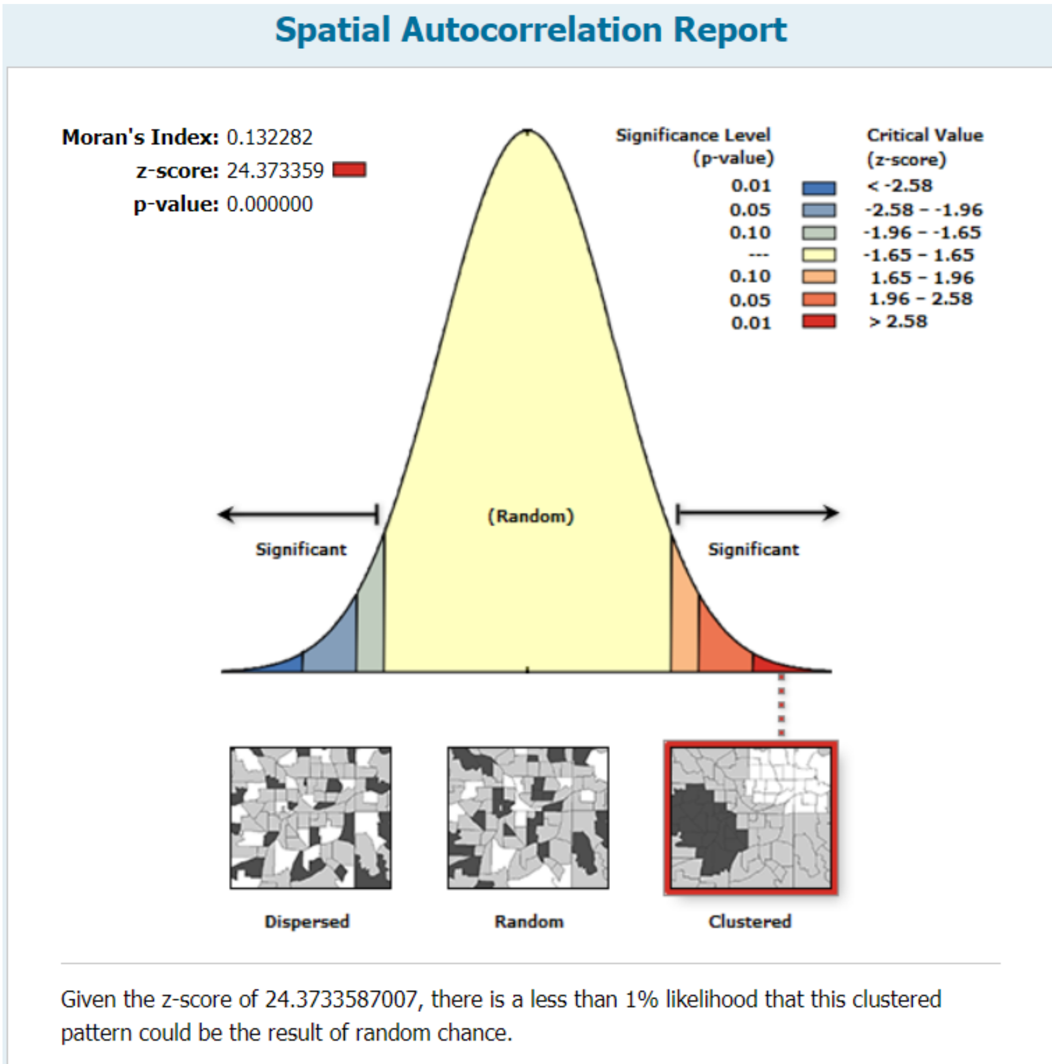


Figure 42 Spatial autocorrelation (Moran's I)

Table 8 GWR Diagnostics

Bandwidth	10817.14
Residual Squares	849
Effective Number	33.55
Sigma	1.20
AICc	1925
R2	0.53
R2 Adjusted	0.51

Taking a look at GWR's r-sq. results, the highest r-sq. agglomeration is found to be in the southeast segment of the city (Fig. 46). Recalling from socioeconomic indicator map (Fig. 43), this segment houses the most disinvested neighborhoods of the city and shows low bikeability index values. **This finding verifies our hypothesis that low-income neighborhoods (especially in the southeast segment) of San Francisco have inequitable access to biking infrastructure.** The dependency rates have a negative relationship with bikeability index (BI) and are at the highest in the southeast segment of the city. This observation was expected given that high dependency rates relate to larger household sizes with a lower number of earning hands and mostly are mobility restricted.

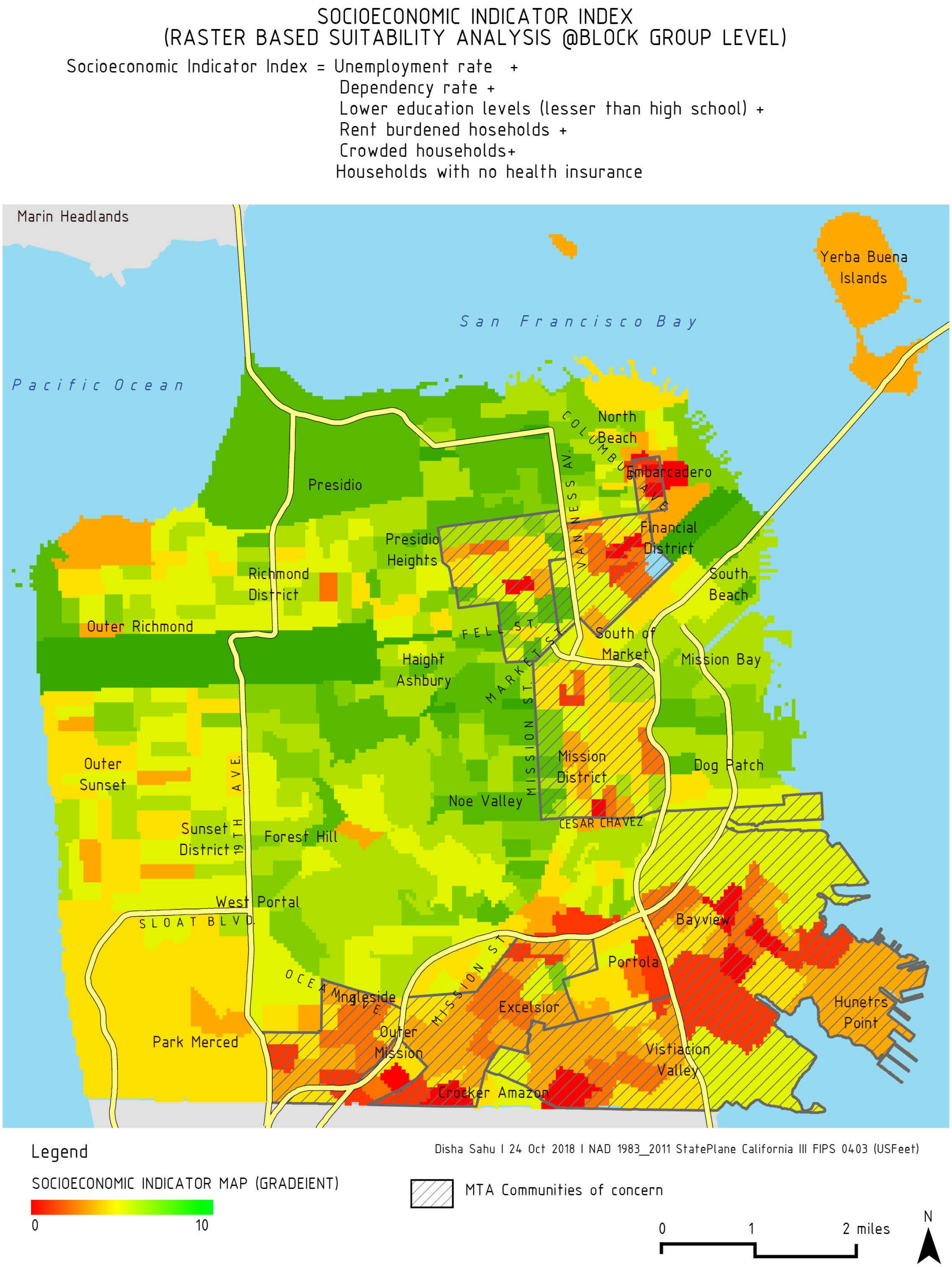


Figure 43 San Francisco's socioeconomic index (Source: Author)

OLS REGRESSION – BIKEBILITY INDEX AS A FUNCTION OF DEPENDENCY RATE, EDUCATION LEVELS, RENT BURDENED HOUSEHOLDS, PUBLIC ASSISTANCE AND HOUSEHOLDS WITH NO HEALTH INSURANCE

Bikeability Index = -4.83 (Dependency rate) - 2.31(Lower education levels) + 1.6(Rent burdened HH) + 10.58(Households with no health insuarnce) + 6.8

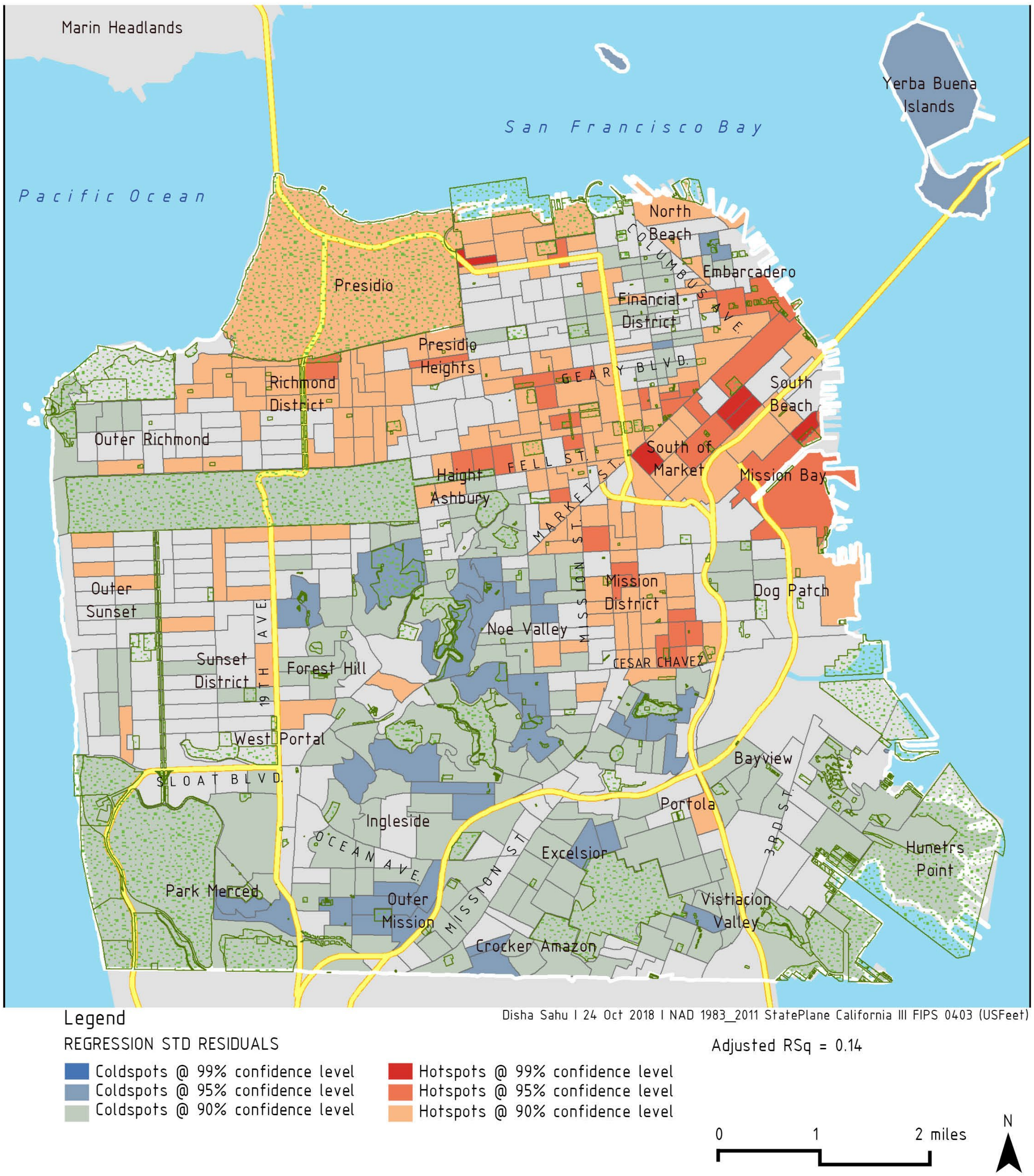


Figure 44 OLS regression residual results **(Source: Author)**

GWR REGRESSION - BIKEBILITY INDEX AS A FUNCTION OF DEPENDENCY RATE, EDUCATION LEVELS, RENT BURDENED HOUSEHOLDS, PUBLIC ASSISTANCE, AND HOUSEHOLDS WITH NO HEALTH INSURANCE

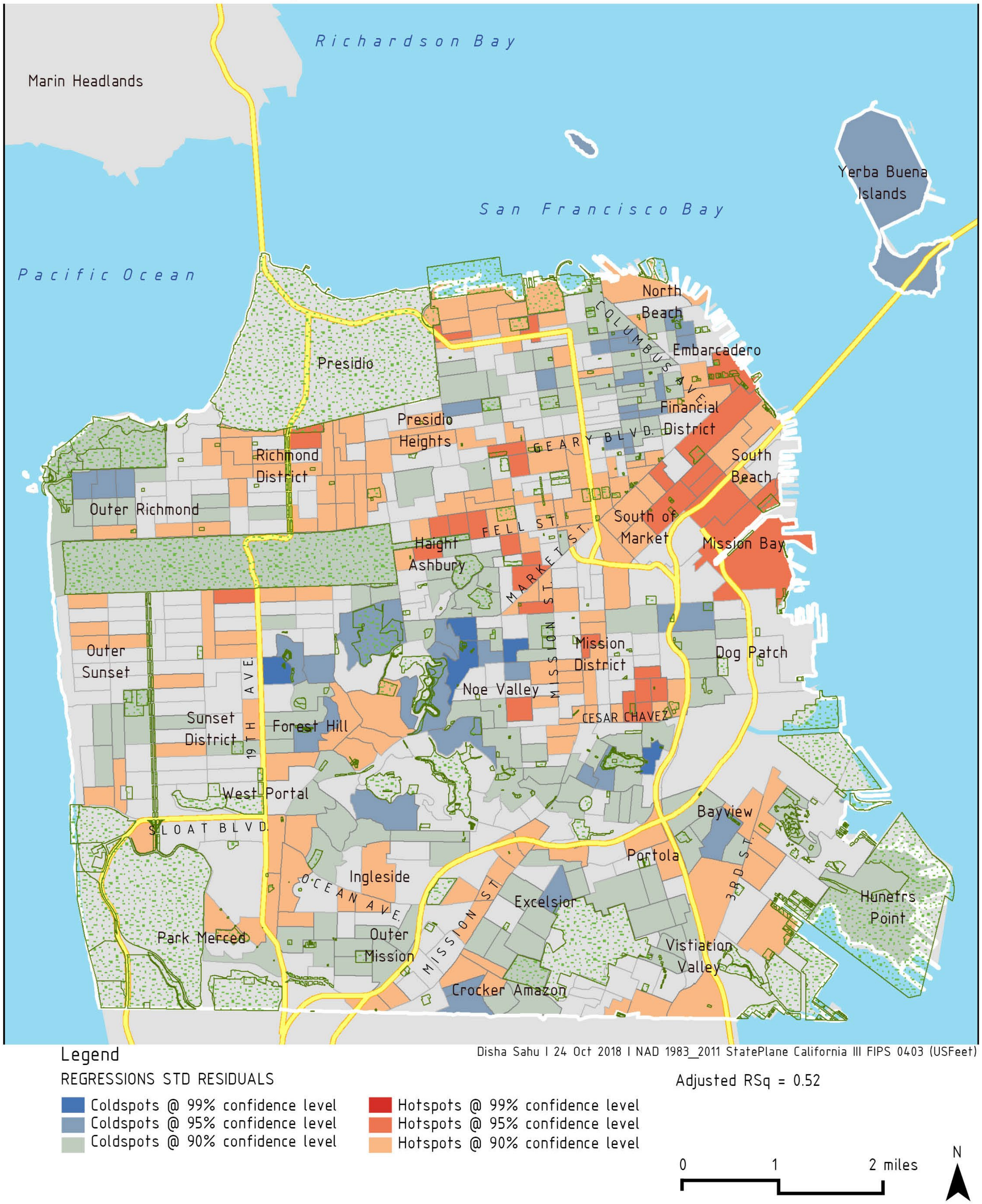


Figure 45 GWR residual results **(Source: Author)**

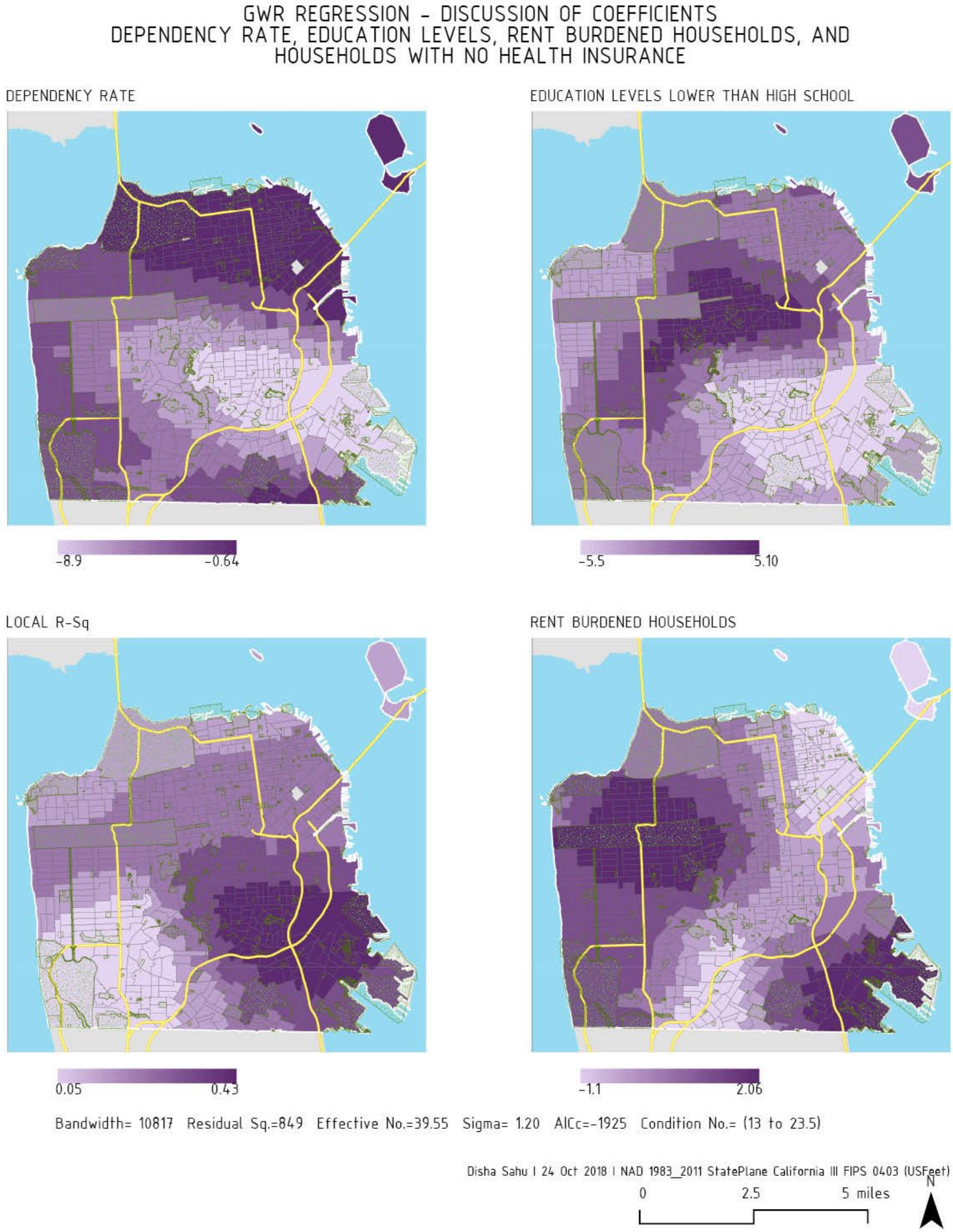


Figure 46 GWR coefficients and r. square results **(Source: Author)**

These attributes negatively affect Bikeability Index (BI). The rent-burdened households in comparison of BI have two high epicenters - one towards the Bay View and Hunters Point neighborhood and the other towards the Outer Richmond. The educational level has a bi-directional coefficient gradient when explained as a function of BI. The southeast neighborhoods negative educational levels relate to low BI index while Haight Ashbury and Presidio Height's positive educational levels relate to moderate to low BI score in those neighborhoods.

5. Evaluating the equity consequences of SFMTA's biking infrastructure expansion projects

5.1 City's biking infrastructure expansion plans

This chapter explores various biking infrastructure plans and capital improvement projects that were undertaken in the past decade by the San Francisco Metropolitan Transit Authority (SFMTA). This segment inquires what share of the planning and capital improvement biking projects have been planned or implemented in the MTA communities of concern (COC) area in the past decade?

SFMTA rolled out its Bike Strategy Plan in 2009. The project consisted of "*the San Francisco Bicycle Plan Policy Framework (Policy Framework), the draft San Francisco Bicycle Plan Network Improvement Document and Proposition K 5-Year Prioritization Program (Network Improvement Document), and the phasing of implementation of near-term, long-term and other minor improvements to the bicycle route network, as well as amendments to the San Francisco General Plan (General Plan), the San Francisco Planning Code (Planning Code), and the San Francisco Traffic Code (Traffic Code)*" (San Francisco Bike Plan, 2009). The project preliminarily proposed two type of implementation projects- first, near-term bicycle route network improvement projects that were targeted to be constructed with next 5 years. Second, the long-term bicycle route network improvement projects that were targeted for future years and have been actively under planning review. Minor improvements would include pavement upgrades, marking upgrades, installation of sharrows, minor parking configurations and other alike. Major improvements were mostly planning intensive projects which needed envisioning exercises and a lot of inter-agency coordination to break grounds. Fig. 46 (source: SFMTA) shows the demarcation and extent of the projects undertaken by the Bike Strategy Plan 2009.

Figure 47 San Francisco's Bike Strategy Plan 2009

One can observe that within the Communities of Concern areas, towards the southeast segment most projects qualify as long-term and or bike route improvement network projects (see legend of Fig. 47). While the northwest segment of communities of concern areas have their bulk of projects as near-term and functional bike route improvement projects. This demonstrates the city's ideology of investing public dollars to improve biking infrastructure with quick fixes in parts of the city where there is a critical mass of biking already happening. And save the big dig, capital-intensive projects which could transform the biking equity for biking deserts of the city for later. Although economically sound, this ideology does not address the equity component of biking infrastructure. This presents the classic causal-nexus dilemma regarding how to broach equity in planning given that the alternative way of spending public dollars (in this case, encouraging other biking infrastructure projects in not so disinvested parts of the city) will be financially more effective.

Fig. 48 shows the existing bike network; MTA communities of concern overlay, and socioeconomic indicator map of the city. The sparse and disconnected nature of the bike network is very apparent in the southeast segment of the city along with the meager mileage of separated bikeway. From personal experience, biking in those neighborhoods in absence of able bike infrastructure paired with steep topography and a high number of vehicles on roads is stressful.

Fig. 49 shows the minor improvements that have occurred in the existing bike network since 2012. And within the extent of COC, there has been a total of 11 projects undertaken in the past 6 years. Fig. 50 shows the major improvements that have been added to the bike network since 2012 and the southwest segment of COC has received 4 major bikeway makeovers only. These maps show the slow implementation side of the city's bike improvement projects with COC extent.

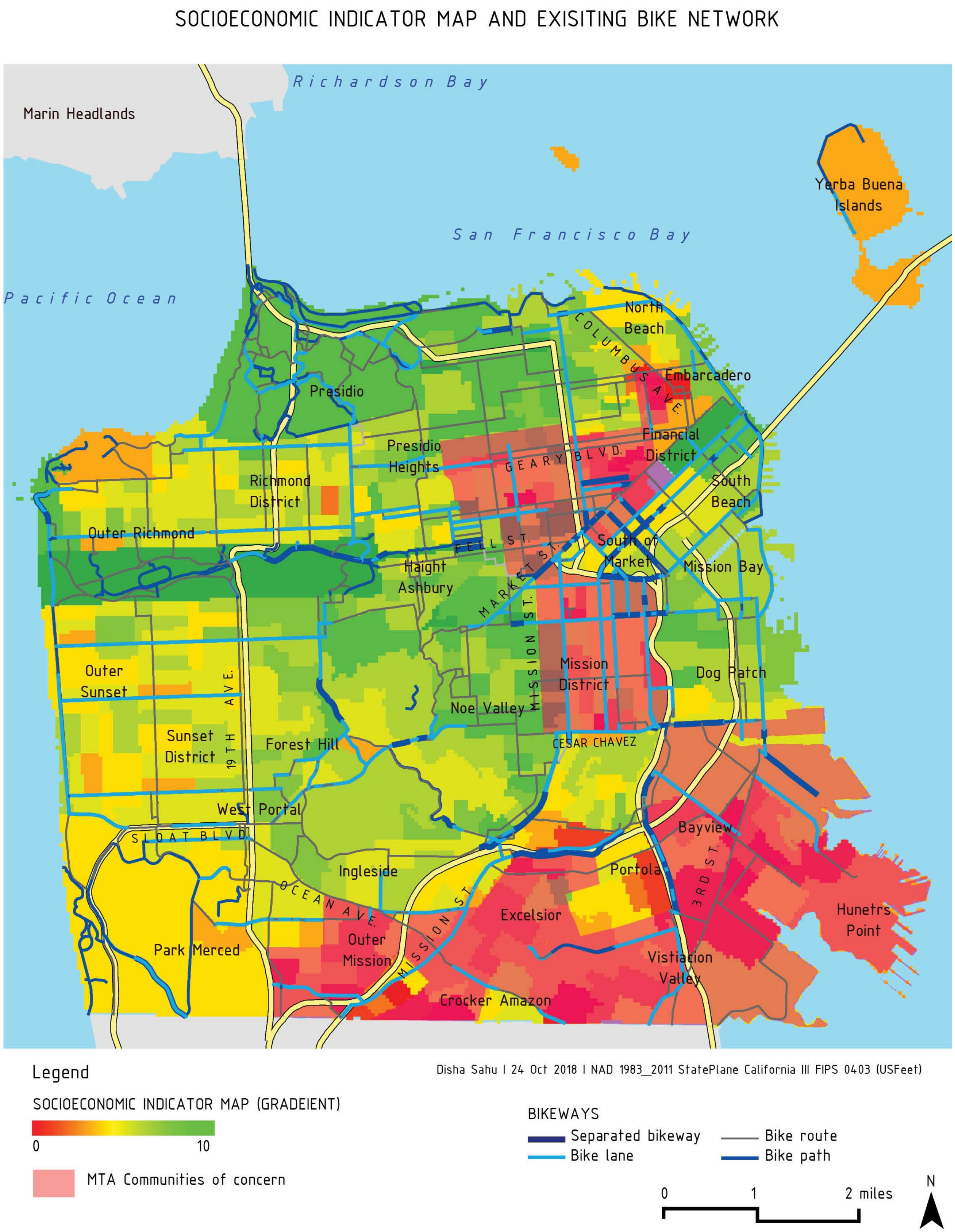


Figure 48 San Francisco's socioeconomic indicator map and existing bike network (Source: Author)

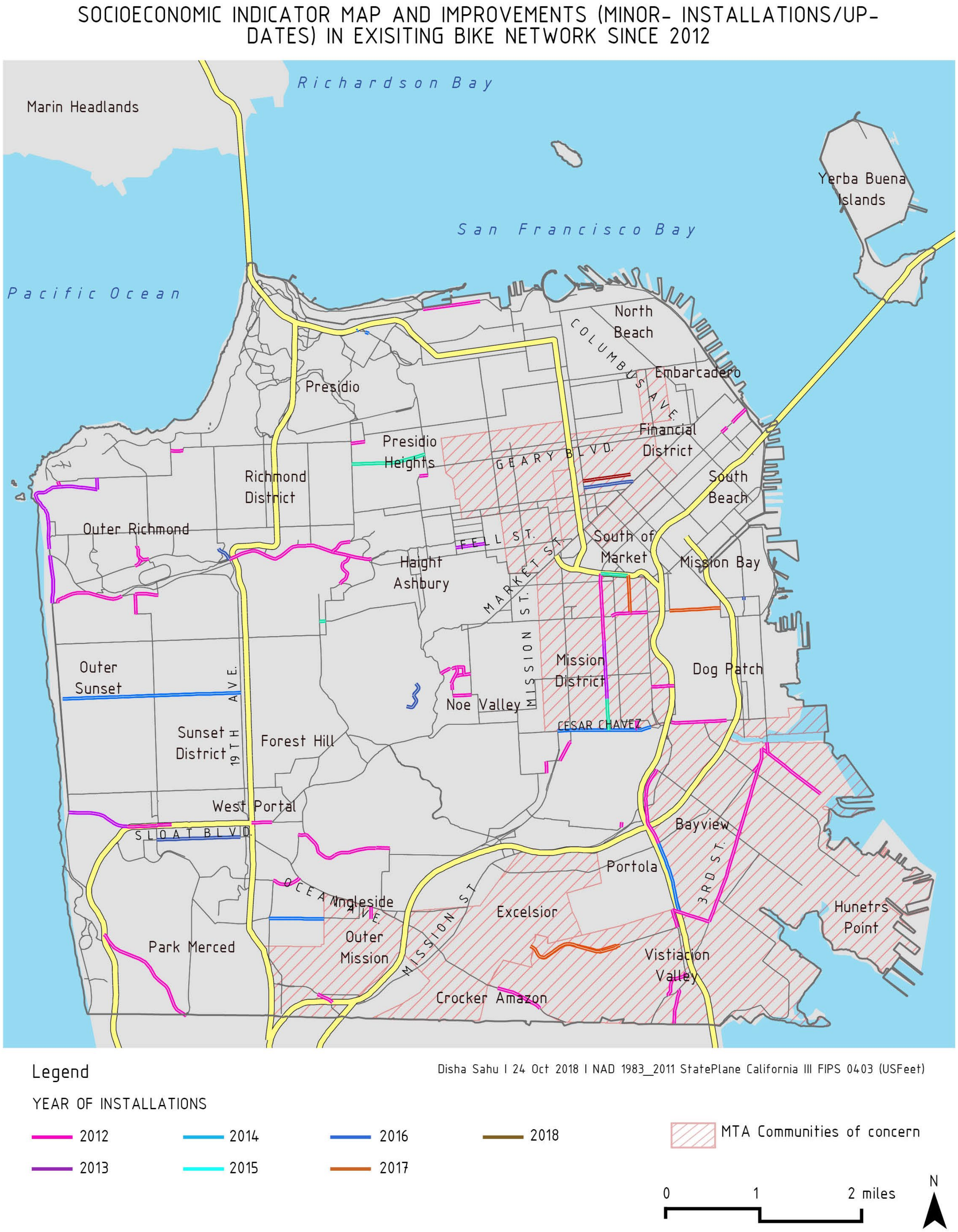


Figure 49 San Francisco's socioeconomic indicator map and minor improvements in bike network since 2012 **(Source: Author)**

Figure 50 San Francisco's socioeconomic indicator map and major improvements in bike network since 2012 (Source: Author)

5.2 San Francisco's infrastructural strides for improving the biking equity

The city of San Francisco launched Green Connections Plan in 2014. It is a long-term planning project which prioritizes and re-envisions 115 miles of San Francisco streets for active transportation and recreational needs. These streets connect various important parks, open spaces, and waterfronts within San Francisco. Green connections' is an umbrella plan which calls for "*coordinating existing initiatives such as traffic calming, stormwater management, with the goal of creating a cohesive network of improved neighborhood walking and bicycling routes*" (San Francisco Planning Department, 2014). The plan refers to three distinct street typologies to engage and invite more active transportation use. These are- *bicycle boulevard, neighborhood greenways, and green streets*. The Plan refers to bicycle boulevards as a means to provide distinct, easy-to-navigate bike routes that limit conflicts with vehicular traffic and enable low-stress biking experience. The plan does not create bicycle boulevards as added bike facilities but is designated to those streets on which most riders feel comfortable riding because of high bike level of service (LOS). These generally run parallel to high traffic arterial streets. The neighborhood greenways are pedestrian counterparts of bike boulevards and entail almost similar design considerations. Green streets entail low-impact development strategies that percolate water and improves water quality and reduces the load on local wastewater treatment facilities.

Fig. 51 shows the green connections network overlaid with the socioeconomic indicator map and COC demarcation. It is encouraging to see that much of the green connections' lay within the COC demarcation. Unfortunately, the GIS database does not give attribute to these connections on their relative type, whether they are *bicycle boulevard, neighborhood greenways or green streets*. Almost 32% of the green connections' mileage falls within COC extent.

SOCIOECONOMIC INDICATOR MAP AND PROPOSED GREEN CONNECTIONS

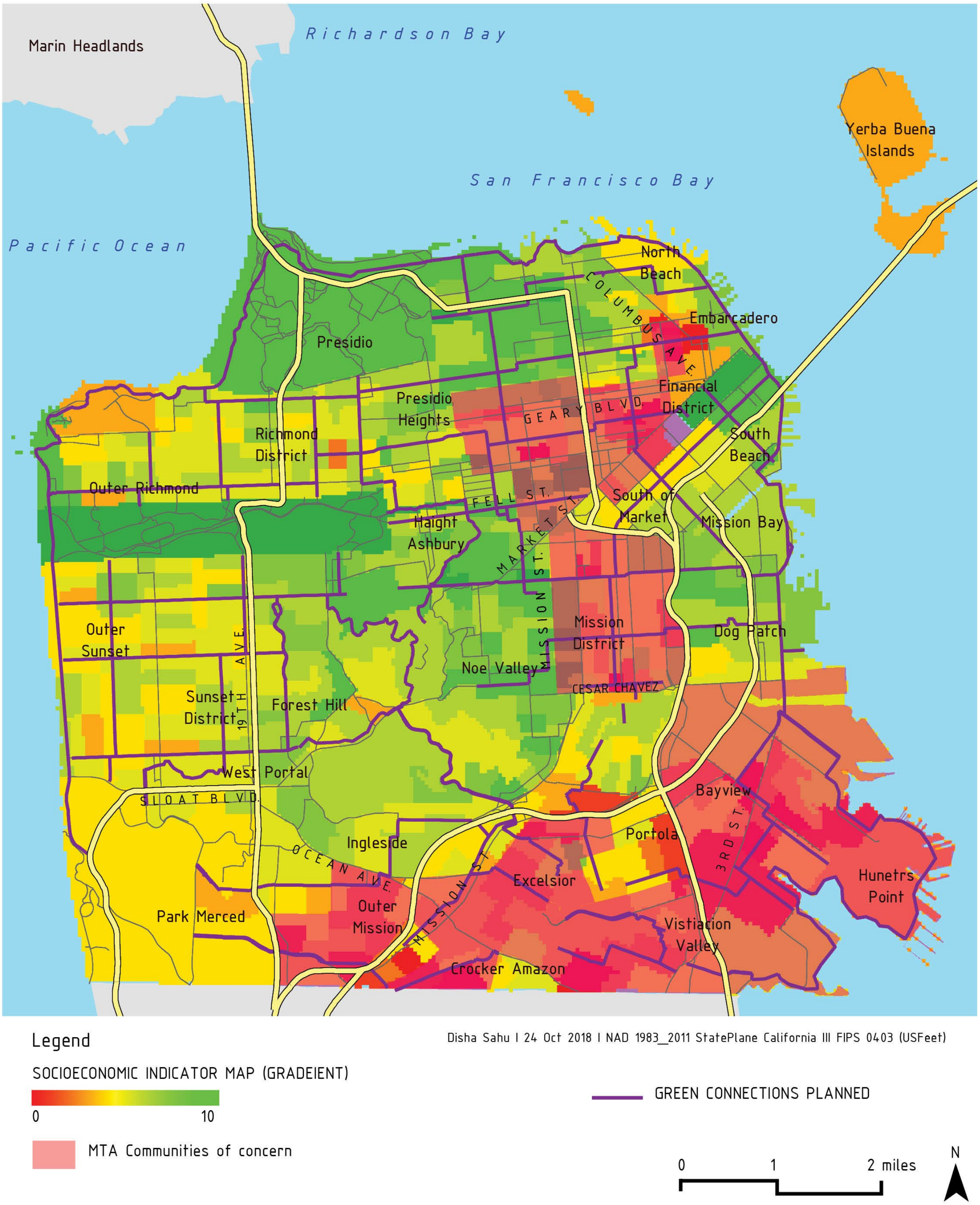


Figure 51 San Francisco's socioeconomic indicator map and Green Connections 2014 (Source: Author)

To evaluate whether the planned Green Connections improve the accessibility for these COC and if yes, by how much, this research ran a service area analysis of 5- and 10-minutes access isochrones in the COC neighborhoods which indicated an optimal biking demand. To scrutinize which neighborhoods (block groups) have an optimal biking demand and for which providing biking infrastructure will prove fruitful, I calculated a raster equivalent of equally weighted density, diversity, and design variables and reclassified the output in the score range of 0 to 10, with 0 being the least and 10 being the highest value. This reclassified output was spatially joined to San Francisco's block group level shapefile. The block groups' whose density, diversity, and design scores were lesser than 4 were removed. This was done because the score of 4 or below was considered insufficient to induce biking demand in the neighborhood. This methodology was referenced from Salon's and Cervero and Duncan's prescription, that "…*density, diversity and design land use variables weigh in equally at trip origin to determine if the person will bike or not*." (Cervero and Duncan, 2003) (Salon, 2016).

The resultant shapefile was then clipped to the COC extent. By running polygon to point operation in Arc Map, I had the centroids of the block groups (fine-grained neighborhoods) which had an optimum biking demand. These were the points from which the 5-and-10 min isochrones were drawn. The service network analysis shows that with the existing bike network, COC has 81 miles of bike lanes accessible to them within 5 min of biking distance and 216 miles within 10 min of biking distance (Fig. 52). The biking distance refers to the first-or-last-mile connection ridden on low-stress level neighborhood streets without a designated biking infrastructure. For San Francisco Bay Area, 5 to10 min of first-or-last mile biking connection is considered quite convenient (SFMTA Bike awareness, 2015). Fig. 53 shows that the introduction of green connections plan improves this mileage to 101 and 272 miles respectively. This shows

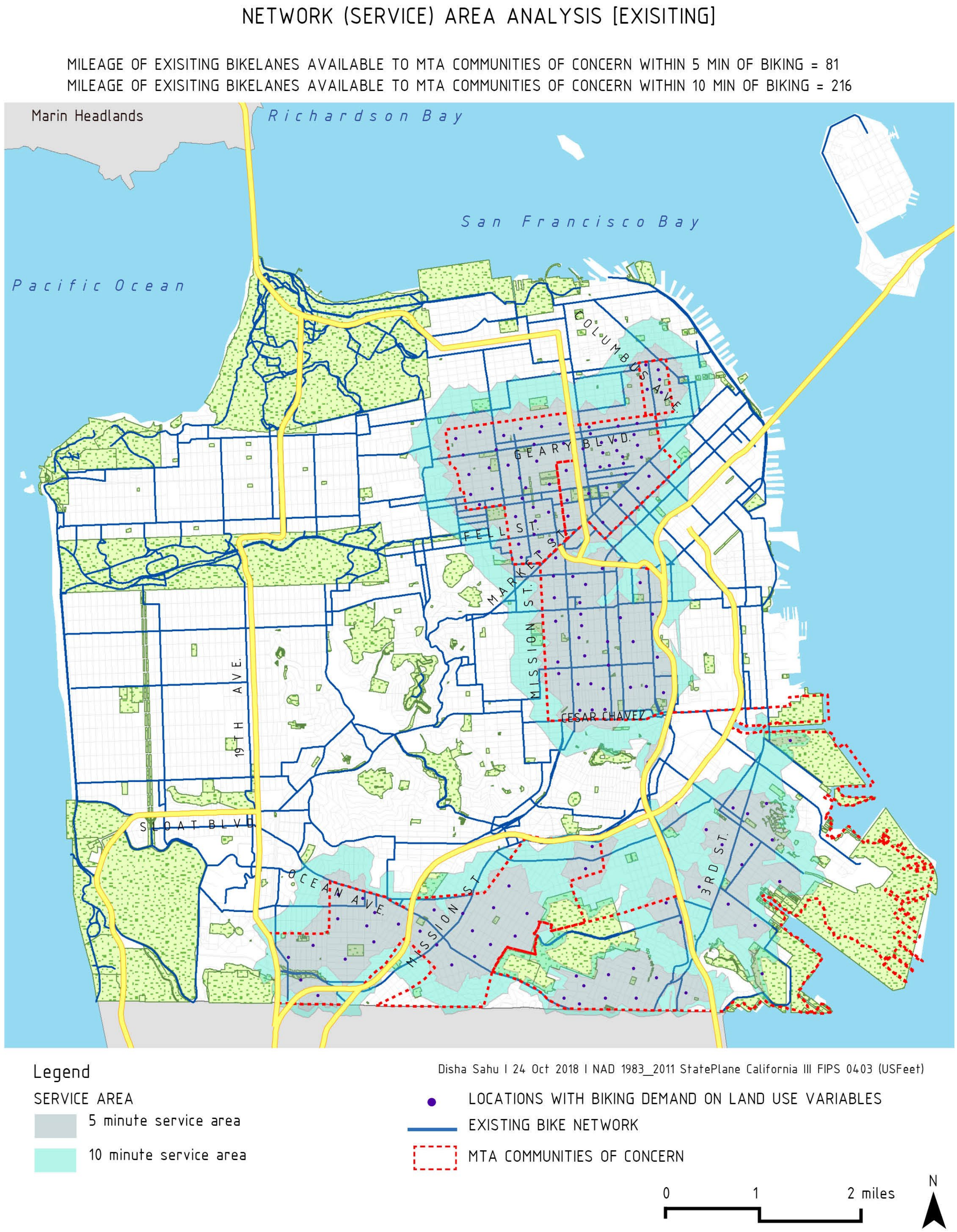


Figure 52 Network analysis of the existing bike network in San Francisco's Communities of Concern **(Source: Author)**

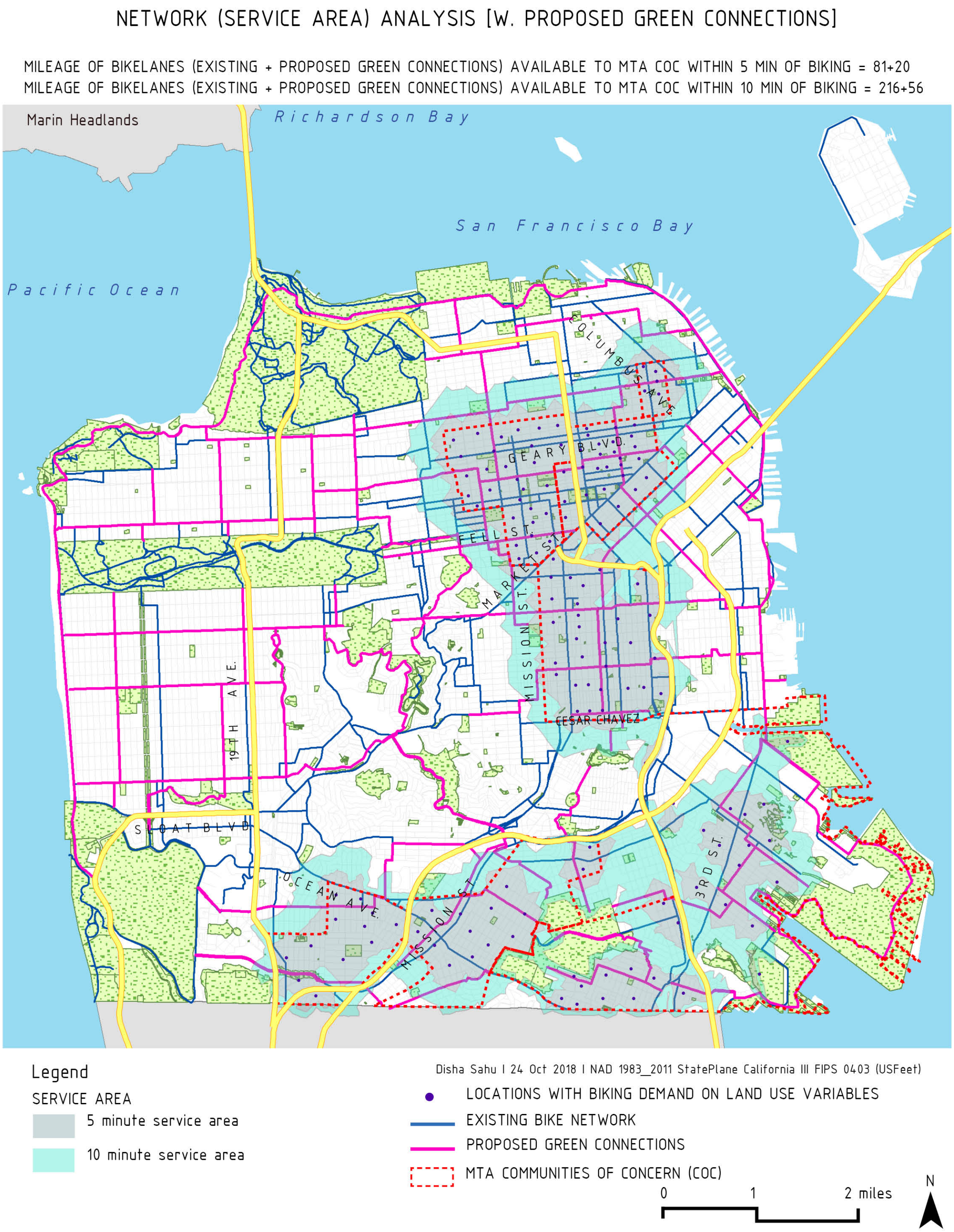


Figure 53 Network analysis of the existing bike network and proposed Green Connections 2014 in San Francisco's Communities of Concern (Source: Author)

an almost 20% and 25% increment in the access to safe biking infrastructure, assuming that the Green Connections Plan undergoes implementation. Although the projected improvements seem enthusiastic at first, given that this planning document is an umbrella document and does not have a prescribed implementation deadline, chances are grim that these improvements will manifest earlier than a decade.

6. Discussions and conclusions

This chapter is the summarizing section of the study. It is divided into four sections, namely- discussion, study findings, recommendations, and limitations. Discussion borrows shreds of evidence from other U.S. cities on promoting equitable biking and bike share programs' best practices. Can bike shares bridge the equity gap in a manner that traditional bike planning and infrastructure improvements haven't been able to provide for? This section summarizes the main observations of this study followed by certain recommendations on how to lower various kinds of barriers related to equitable biking in the city. This chapter concludes by identifying the limitations of the study and offers directions for further study in this realm.

6.1 Discussion

SFMTA's focus group intercept surveys (SFMTA, 2015) noted that among the regular riders' savings on transportation costs in one of the principal motivations for using a bike. The survey also showed that more than half of the low-income segment of *ready and willing* and *hesitant but interested* riders do not have access to working bikes and bike parking (McNeil et al, 2018). Ford Go bike's equity program in the Bay Area offers bike access with just $5 membership fee for the first year followed by $60 per annum thereafter. The expansion of the bike share to more residential locations might improve bike access for *interested but hesitant* low-income households in the city. A nationwide study on bike sharing operator practices found that "*Placing stations in the most densely populated areas of the city is viable to attract a maximum number of users and therefore robust yield ridership. However, this method of allocating stations has resulted in unintended consequences including limiting access to bike share for traditionally disadvantaged groups"* (Urasaki and Aultman-Hall, 2015) (Haning, 2016). SFMTA mandates that at least 20% of the bike share stations be located in low-income communities to ensure equitable distribution service. Ford Go bike share targeted its first three phases of expansion on commuters (as described in Chapter 3) to build a critical mass of users and the consequent phases are targeted to reach out to more low-income neighborhoods and establish an economically sustainable and equitable bike sharing system for San Francisco. By the culmination of phase V due in the end of 2020 in San Francisco, Ford Go would have complied by SFMTA's equity mandate.

James Haning's equitable bike sharing research in Mid-West cities found that the physical and financial barriers form only the tangible and a smaller segment of hinderances to equitable bike sharing systems. He argues that cultural barriers which include but not limited to- "*informational barriers prevent potential low-income users from understanding the benefits and ways to use it, discomfort with shared mobility systems, preference of a more culturally appropriate mode like cars, distrust of authority for inappropriately charging them for broken or misplaced bikes"* form the more nuanced yet essential tandem cultural barriers which discourage low-income households from fully tapping into the potential of bike shares. He suggests that active bike sharing advocacy, community outreach, and informational campaigns are the most effective way to overcome this cultural barrier towards biking and bike sharing.

Increasing number of creative financing schemes like – *cash-based payments for accessing low-income annual memberships (in San Francisco), installment payment plans (in Chicago), payment mode integration with regional transit pass (in San Francisco), access to free helmets to qualified low-income riders (in Chicago), provision of accessing credit cards for solely bike share usage with local credit unions (in Washington D.C.)* and *subsidized membership to public housing residents (Chicago)* have proved beneficial in addressing some of the financial barriers of bike share usage (Buck, 2013).

Haning's research concurs with most of the available literature's perspective on the issue of physical barriers that, "*the complexity associated with establishing a bike sharing network that* *reaches an optimal number of riders within a sustainable operating budget. The resulting network is often small covering higher density downtown and adjacent residential areas at cost of no bike share stations in disinvested communities*" and Chicago's case found that low-income communities are interested in bike share from a recreational perspective rather than for running errands and commuting (Haning, 2015) (Buck, 2013). Thus, the station siting and destinations covered by the network preliminary designs who will use the bike share and for what purpose. Intensive community input is necessary to capture these community riders. This learning is important for San Francisco's case because Ford Go's current bike share network most ably serves commuters. Given the agency's plan to expand the network to cover almost half of the city's geographical extent encompassing the other residential neighborhoods, community input regarding siting of docks, transit connectivity, possible destinations, and routing will be crucial in determining bike share's success for consequent phases.

Buck in his research "Encouraging equitable access to public bike sharing systems", elicits that there are two schools of thoughts on promoting equitable biking – first, to invest extensively in biking infrastructure, improve access and subsidize membership for underserved communities and this will slowly but steadily result into bike sharing's stronghold in the community. The second school of thought which is advanced by National Association of City Transportation Officials (NACTO) suggests that for the sustainable and equitable promotion of the bike shares, they should be optimized on cost and convenience model. Following Chicago's example, Haning's research offers case in point as to how bike shares offer a cheaper and quicker way for customers to move around the city in comparison to transit for under 3-mile distance.

From the policies and planning implementation strategies, the City of San Francisco's efforts seems to be aligned with the first school where the city is investing in expanding the network area and subsidizing low-income users to proliferate use of bike share more without any targeted outreach on focus-groups or membership media integration. San Francisco's case is distinct from Chicago in the manner that the steep topography in certain sections of the city needs transit to relive choice riders from riding steep sections in bike ways and therefore cannot always compete with transit but be supplemented by it for under 3-mile bike trips. Focusing on increasing the convenience of bike sharing trip for residents in non-CBD areas would ensure that after expansion into neighborhoods the bike share ridership remains robust. And as the network expands, following the economy-in-numbers principle Ford Go might re-consider reducing its bike ride costs. Appropriate sequencing of the above trends will ensure that bike share programs contribute their due equity to San Francisco's biking renaissance.

6.2 Study findings

Through Geographically Weighted Regression (GWR) analysis, the study establishes that San Francisco's bike mode share has a positive relationship with presence of younger age groups (25-45 years old), majority white ethnicity, smaller average household size and negative relationship with percentage presence of middle-income households and average gross rent. Recent SFMTA surveys suggest that San Francisco's cyclists' ethnic and racial backgrounds today tend to be more diverse than half a decade ago and this trend is on a rise nationwide. The GWR did not find any significant relationship between San Francisco's bike mode share and levels of educational attainment and average income levels. In San Francisco, commuters tend to be young, male, predominantly white (but increasingly becoming more diverse), and from lower to middle-income small households.

Most of the regular bike trips (more than a frequency of twice a week) in the city are made for commuting purposes. This trend is consistent for bike and bike sharing trips. Most of the city dwellers enjoy biking but do not consider it to be safe for commuting or running daily errands and therefore limit it for leisure and recreation-related activities. Savings in transportation costs, environmental benefits, and health benefits are the principal motivations for biking in San Francisco.

The study found that the measure of perceived bike accessibility varies substantially across the city. The northeast segment of the city the is considered to be most bikeable while the central and the southeast segments are considered the least bikeable. Steep topography in the central segment is the strongest indicator for explaining low bike accessibility. The study establishes that San Francisco's biking infrastructure is inequitably distributed across the city. Low-income households (especially in the southeast segment of the city) do not have access to safe and convenient biking infrastructure. Through Geographically Weighted Regression (GWR) analysis, the study elicits that San Francisco's perceived bike accessibility in especially low in disinvested neighborhoods of southeast segment. Neighborhoods with low bikeability index are often associated with poor socioeconomic indicators like high dependency rates, lower education level and lack of access to health insurance.

Within the past decade, most of city's near-term bike improvement projects have been focused around the northeast part of the city. Bike Plan (2009) designated most of the projects falling in the southeast segment of the city as long-term projects and since 2012 these projects have received little attention regarding implementation. The Green Connections Plan offers ambitious network improvement for the southeast parts of the city. For Communities of Concern (COC), the study assesses that the Green Connections Plan improves the mileage of available bike lanes within 5-and-10 min of biking from 81 miles 101 miles and 216 miles to 272 miles respectively. This marks an overall improvement of 25% approximately. Thus, San Francisco's active transportation plans acknowledge the need for equitable biking infrastructure and offers enthusiastic provisions for the same, but the city's implementation of these plans has been sluggish.

Active advocacy followed by persistent community participation will catalyze equitable access and distribution of planned bike infrastructure. San Francisco's inequitable biking stands at a very opportune moment with the Ford Go bike share's rapid expansion phases to residential neighborhoods along with the pilot testing phase of Jump Bikes.

Evidence from other U.S. cities has shown that bike share systems have encouraged newer demographics (mostly women and lower-income households) to bike and have reported back with improved environmental and health indicators. Appropriate strategy implementation like station siting with least access barriers, community-specific outreach, offering financial assistance and incentives to targeted communities, and strong advocacy on Ford Go's part might encourage more diverse users to use bike share in San Francisco. This might address the missing equity and access components in a manner that traditional bike infrastructure planning has not engaged with before.

Biking for commuting and running errands can save transportation-related household spending. Access to safe and convenient biking (and subsidized bike share access) for low-income households can let them escape a share of their transportation costs. Even a meager share of saving is meaningful for these low-income households which are most often rent-burdened given the high cost of the overall housing market in the Bay Area. Improving access to safe and convenient biking infrastructure through physical planning and design is a model traditional model of addressing inequitable distribution of civic amenities. As Ford Go bike share is set to expand its network in the east and southeast segment of the city which are mainly low-income neighborhoods and will offer reduced annual membership to economically strained households, this can catalyze biking interest in those communities which have traditionally shown very low bicycling rates. Convenient and cost-effective bike sharing program might as well relive transit overcrowding, reliance on transportation network companies short distance trips and reduce overall automobile congestion on San Francisco's streets. Most American regions struggle with maintaining an optimum transit ridership but cities like New York, San Francisco and Washington D.C. whose transit ridership rates are robust, but the peak commuting hours' demand remain underserved, good bike share network will improve the avenues of non-car-dependent modes of transportation.

6.3 Recommendations

Borrowing from case and point examples from bike share programs across the U.S. cities, this section offers recommendations for improving San Francisco's bike share equity in the given aspects:

- Station siting – Although SFMTA mandates that 20% of the bike share stations should be located in low-income communities, it does not offer any further guidance or the fine-grained recommendations on this. For Ford Go bike shares, it might be beneficial to place the expansion phases' bike docks in and around public housing and affordable housing and prioritize expansion to minority communities that qualify as *ready and willing* and *hesitant but interested*. Given the city's crunch of affordable housing, public agencies are rolling out plans and project proposals to fill in need for missing-middle-housing in the city. Ford Go's expansion plans might benefit from looking at these opportune new housing developments which mostly tend to align their development schemes as bottom retail along with condominium style housing with parking premiums. Siting bike share stations next to these new affordable units which are generally designed to be low car dependency might help build a critical mass of riders in those communities.

- Community-specific marketing and outreach – Ford Go's bike share equity program is not well-advertised in low-income communities. The households who are registered for Bay Area Utility Lifeline Program are eligible to enroll bike share equity program. But because there are eligibility mandates and accompanying paperwork, many low-income households find it cumbersome to get enrolled and use the facility. In absence of due marketing and outreach, it is difficult to tap into the latent demand who might find bike shares convenient because of the accompanying economic incentives. Ford Go should set up targeted outreach events and awareness campaigns at grocery stores, utility payment kiosks, subsidized healthcare providers and alike to invite more ridership under equity program.
- Economic contribution to the communities – "*Beyond reducing household vehicular transportation costs for low-income families, Ford Go might look at avenues to directly contribute to low-income neighborhoods by recruiting employees from low-income communities, locating facilities in places easily accessible to those neighborhoods, and partnering and sub-contracting with community-oriented nonprofit agencies*" (Buck, 2013). Strategies like this will serve two purposes simultaneously, first- contribute economically to the low-income neighborhood by creating jobs and second- overcoming cultural barriers associated with biking in low-income communities. As noted earlier, many low-income communities communicate their preferences for manned bike share docks, at least during the initial implementation phases. Partnering with local non-profits to provide bilingual assistance (in Chinese and Spanish), pilot demonstration rides, maintenance, and rebalancing labor will help to ground a for-profit bike share like Ford Go in these communities of San Francisco.
- Safe places to ride -Bike share and biking infrastructure have a symbiotic relationship, each benefit from one another. As articulated earlier, the more traditional way of improving

biking equity has been associated with physical planning and infrastructure design but given the restraint of strict environmental review of transportation-related projects in California under CEQA and NEPA, these bike improvement projects implementation has been slow. As bike share becomes popular in San Francisco (especially in residential neighborhoods) backed by strong advocacy and community interest, one might expect that the City might undertake short-term improvement projects like creating parklets, restriping and road diets using planters to catalyze a more bike-conducive environment as compared to relying on long-term big dig infrastructural projects. This incremental strategy will continue to positively influence the bikeabilty of San Francisco. Ford Go bike share could also pursue partnership programs like Safe Routes to School and other such grants to prioritize bike-friendly destinations and routes in the city.

- Overcoming biking barriers – Ford Go could partner with community non-profits (like SF Bike Coalition) to provide subsidized helmets, safe riding workshops to targeted communities. An increased presence of bike workshops or repair facilities in-and-around the bike share network will improve functional bike availability rates.
- Rebalancing and incentivizing – As the bike shares are currently being used for commuting purposes, there is a substantial rebalancing pressure on the system. With the upcoming expansion of the bike network to the surrounding residential areas other than CBD, Ford Go could incentivize rides into opposite direction of peak flow during commute times to promote self-rebalancing flow. This redistribution strategy might motivate tourists and leisure bike share users who use the system for recreation and exercising purpose during off peaks and in opposite direction of the peak flow.

6.4 Limitations

The study identified the following limitations:

First, the study used perceived bike accessibility to quantify which neighborhoods were most bikeable and which were the least. This was done to assess where are people biking the most. This intention could have been best fulfilled if there was a bike-focused travel decision model data on trip origins, destination, routes, and other such characteristics. In an absence of such a fine-grained inventory, the research resorted to perceived bike accessibility methodology which assumes that more bike accessible places generate more trips. On one hand, where the rationale seems good enough for this study's purpose, but on other this methodology has been criticized for its over-generalized assumption.

Second, the study could not find any longitudinal survey which documents how has people's perception of biking changed over the past five years in San Francisco. The study based its observation about biking perception from an intercept survey which was conducted in 2015. Since then, SFMTA has not published any more studies on the related matter.

Third, while calculating for the bikeability index through GIS raster calculation, the hill slope variable was double-weighted compared to the other variables based on literature evidence. This was an assumption and moving the weights around for raster calculation will yield different results. The otherwise output will have a different measure of relationship with the socioeconomic indicators.

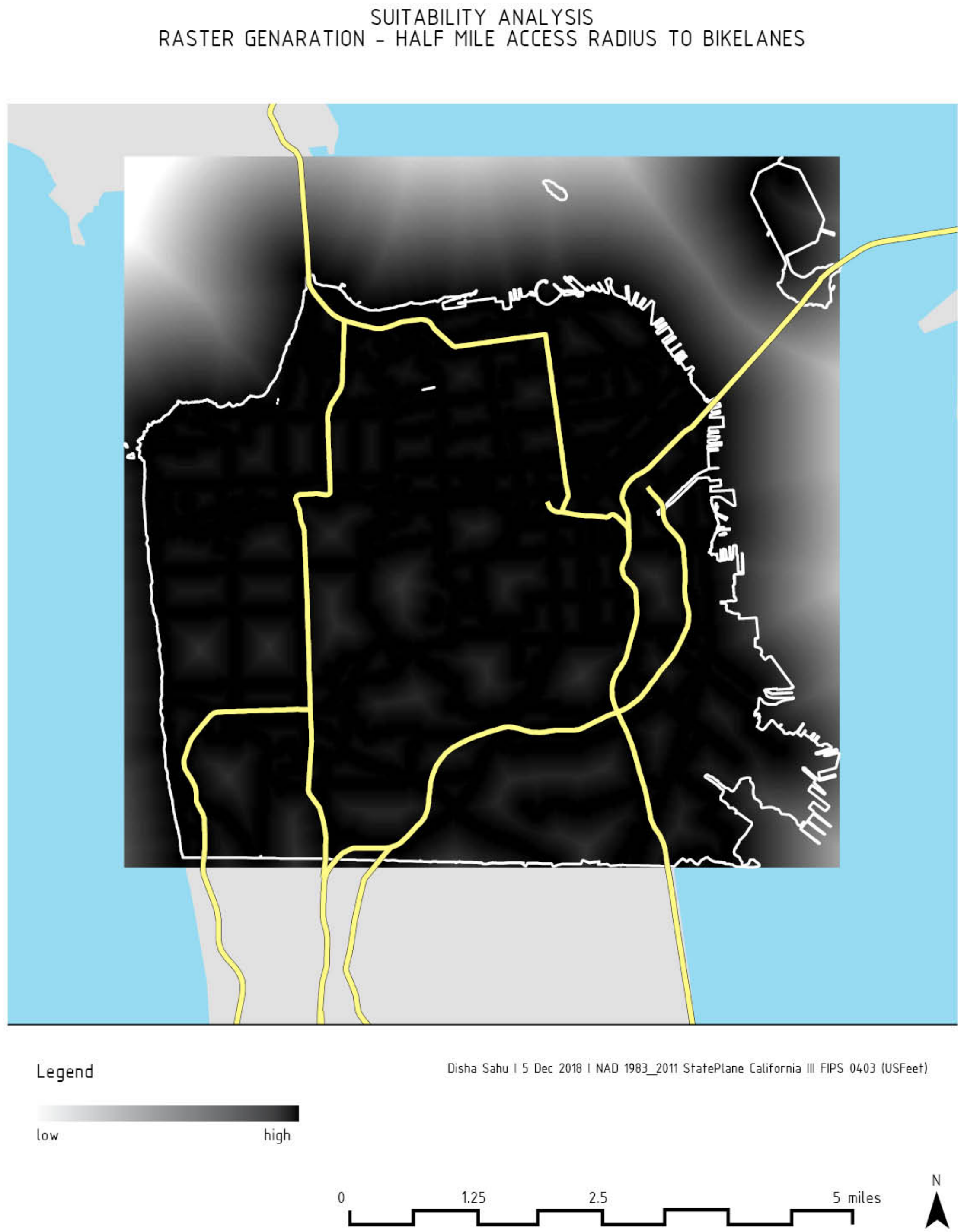
With the onset of electric biking technology, steepness of topography might not affect biking as much. Although the proliferation of electric bikes in the market will take time and given that a good one-third of San Franciscans use the bike for exercising purpose, electric bikes might not do very well in the market. This shows that the bikeability indices for neighborhoods are also partly subjective and fluid data-points.

Fourth, the study did not inquire about the share of the city's spending on the bike projects in the Communities of Concern area. The study concluded that SFMTA's slow pace of implementation is one the barriers to improving access to equitable biking infrastructure. But the study did not delve deeper to see what the share of spending on the long-term projects in the southeast segment of the city is. Communities those have been disinvested for long generally research- and capital-intensive makeovers to transform the scenario as usual. Planning evidence suggest that in absence of well-funded deep-rooted strategies, the proposed quick fix solutions don't fare well. Thus, analyzing this problem from a financial perspective could unravel different opinions.

Fifth, the residuals of OLS and GWR models were found to be clustered upon running Moran's I statistic. Clustering of residuals indicates the possibility of model bias. Given the VIF less than 7, condition numbers below 30 and coefficients being significant, the OLS and GWR modeling results are meaningful but not fully explored. In terms of directions for further study, it might be worthwhile to explore these relationships further. Planning literature indicates instances where variables were not found significant at census tract levels but were found to be significant at County or MSA levels. Geographic calibration of data points can vary the predicted output results.

Sixth, the data sources used geo-spatial mapping were plotted from different timelines. The smart land use database was most recently updated in 2013 while the ACS Data was 5-year tabulations for 2012 to 2017. The SFMTA bikeway network file was last updated in 2015 but had many attributes missing and had to be extrapolated to assign values for missing attributes.

Appendices


SUITABILITY ANALYSIS
RASTER GENARATION - HALF MILE ACCESS RADIUS TO BIKELANES
Legend
low
high
Disha Sahu | 5 Dec 2018 | NAD 1983_2011 StatePlane California III FIPS 0403 (USFeet)
0
1.25
2.5
5 miles
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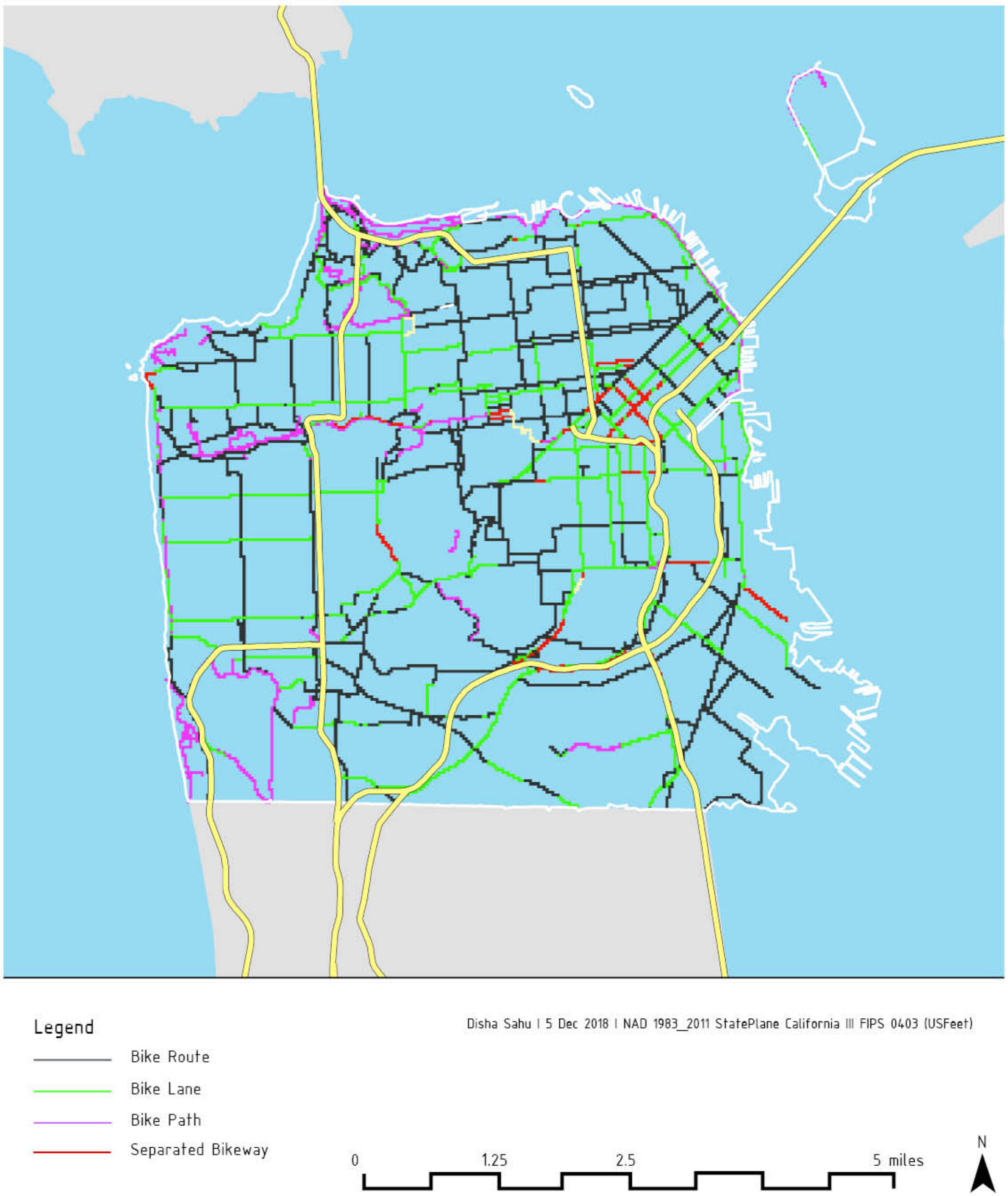
SUITABILITY ANALYSIS
RASTER GENARATION - CLASSIFICATION OF BIKELANES



SUITABILITY ANALYSIS
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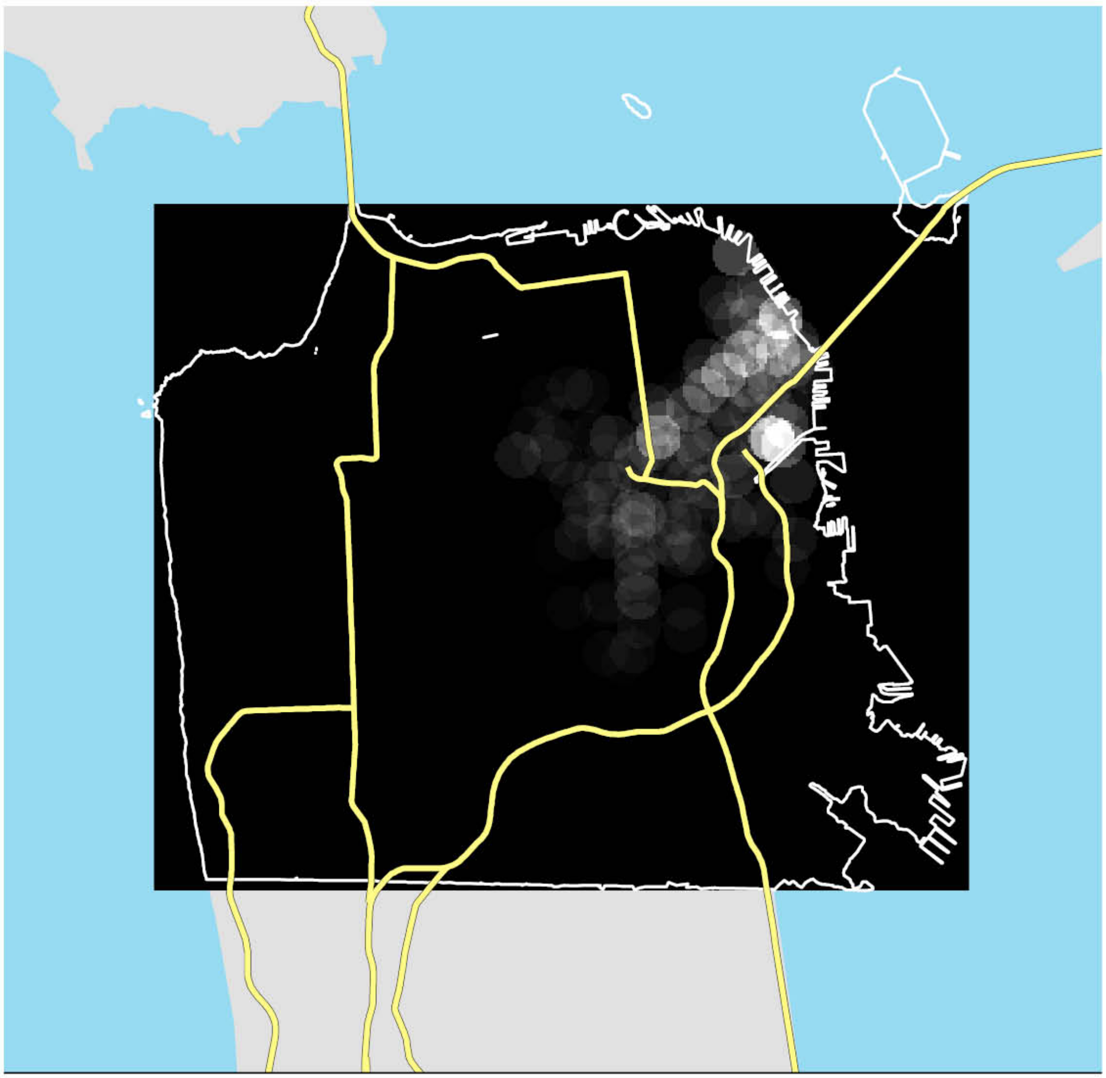

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high low

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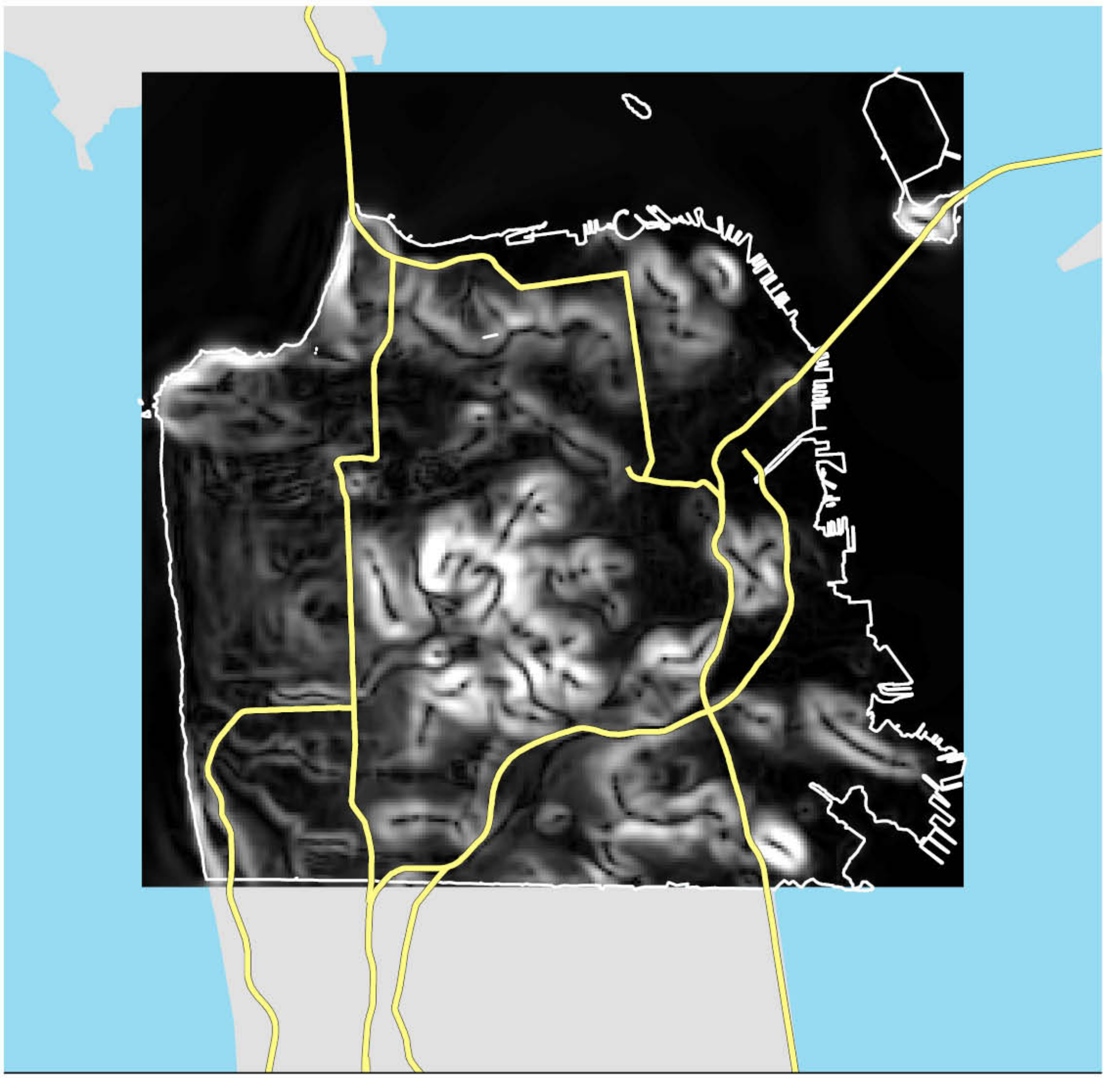
SUITABILITY ANALYSIS
RASTER GENARATION - TOPOGRAPHY



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SUITABILITY ANALYSIS
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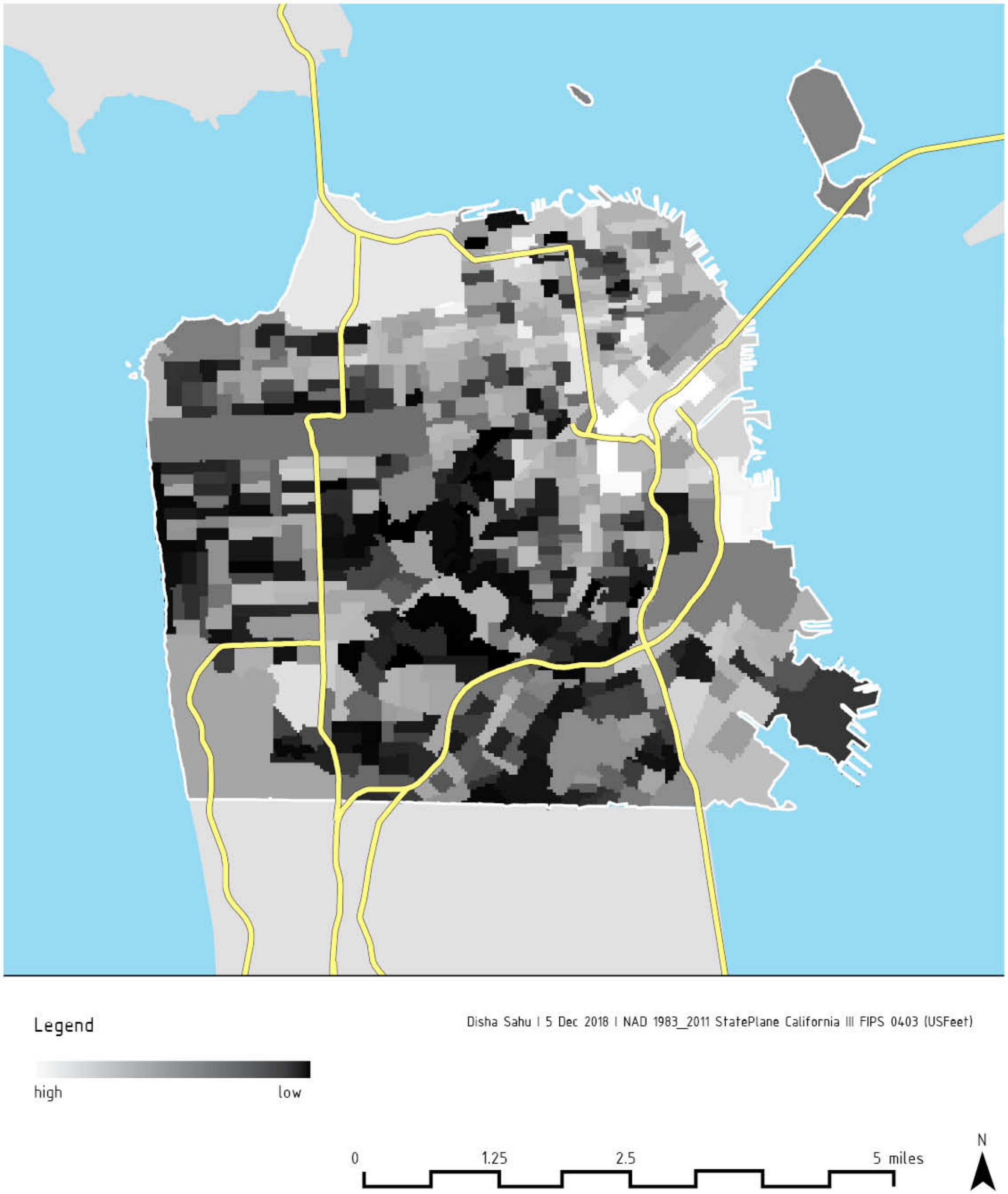

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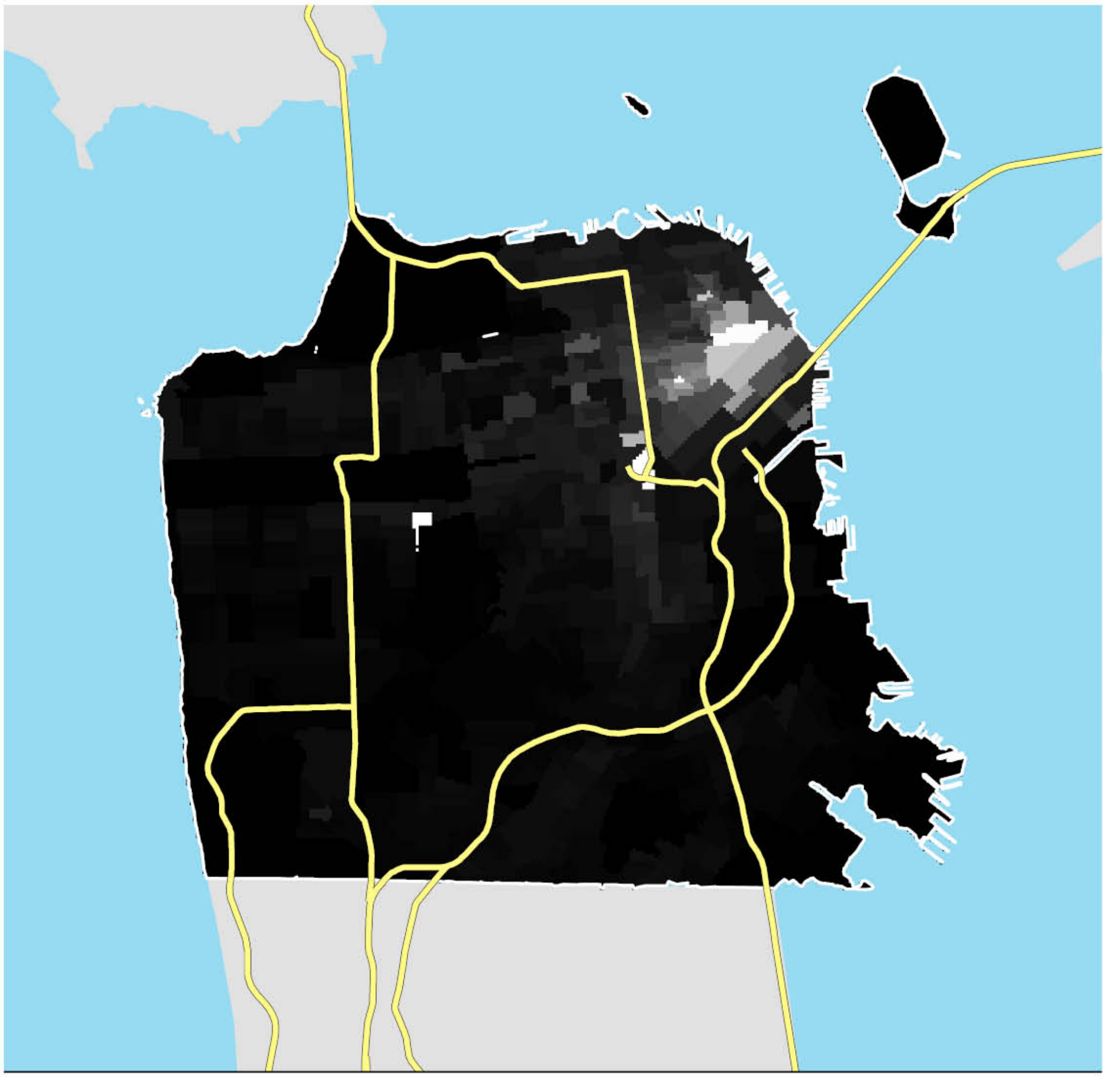

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high low

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SUITABILITY ANALYSIS
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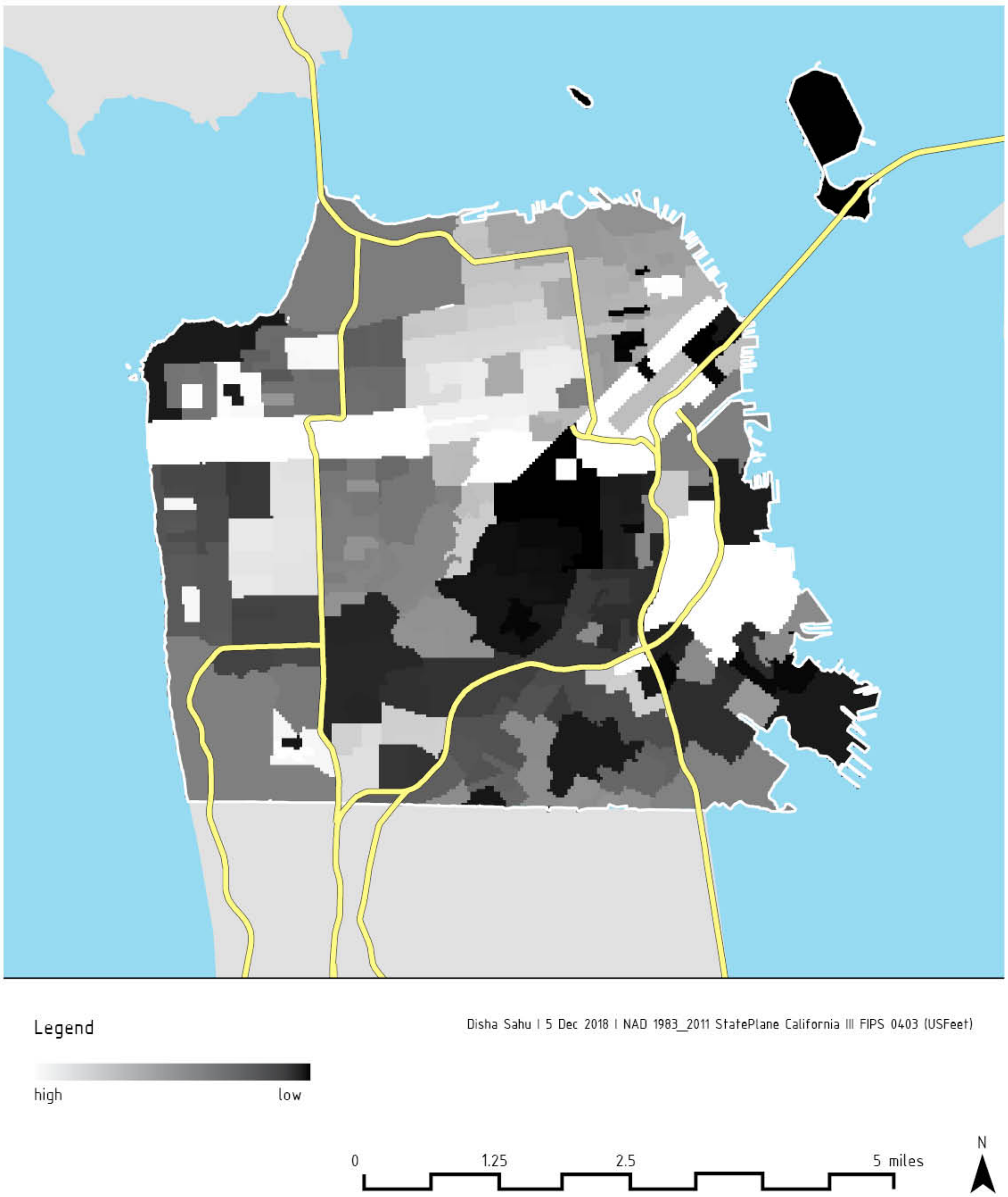
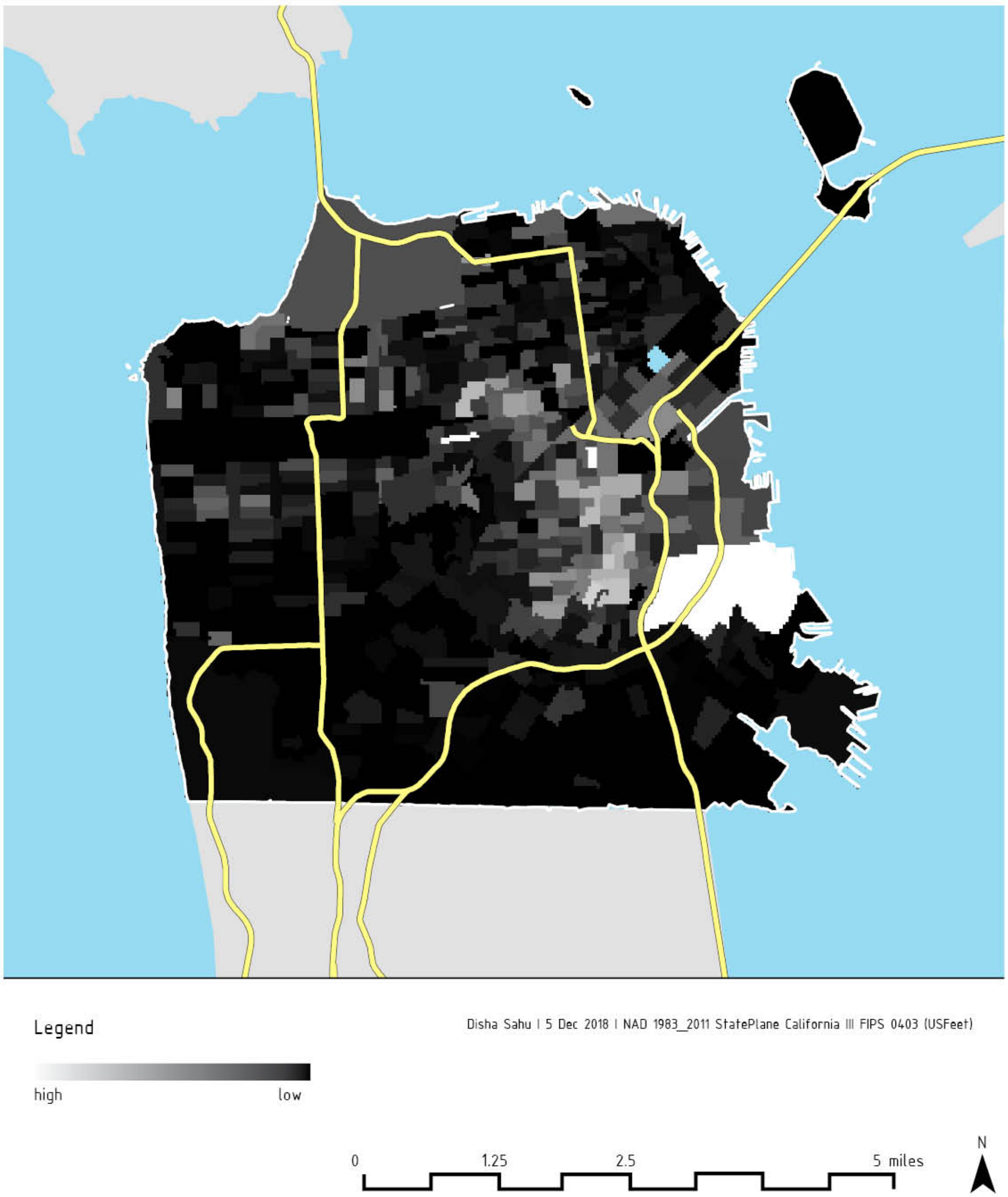


SUITABILITY ANALYSIS
RASTER GENARATION - BIKE MODE SHARE



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