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Massachusetts Complete Streets Program: An Exploratory Spatial and Social Equity Analysis

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MASSACHUSETTS COMPLETE STREETS PROGRAM: AN EXPLORATORY

SPATIAL AND SOCIAL EQUITY ANALYSIS

A Master's Project Presented

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ABSTRACT

MASSACHUSETTS COMPLETE STREETS PROGRAM: AN EXPLORATORY SPATIAL AND SOCIAL EQUITY ANALYSIS

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The effects of transportation planning on equity are often overlooked or not prioritized, sometimes resulting in an inequitable distribution of infrastructure investment with disparities in access. This paper examines the characteristics and distribution of approved Complete Streets projects across Massachusetts using social and spatial methods to analyze trends across socioeconomic demographic data. The methods applied include buffering techniques in GIS software to analyze population data within a half-mile radius of approved projects from 2016-2019. The half-mile measure of proximity is used as a proxy for access, in which descriptive statistics and regression models examine in detail.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Over the past several years, the state of transportation planning in North America has shifted from autocentric design toward active, multimodal streetscapes that enhance user mobility and access to places and resources. At the same time, equity has been increasingly incorporated into transportation planning from policy to project implementation. Complete Streets embody the vision for greater accessibility and equity through its design for all modes and users, with benefits that range from economic development to environmental justice (Smart Growth America, n.d.-e.). By enhancing road design that improves overall safety and further access by various modes of travel, Complete Streets have great significance for low-income and low-vehicle ownership communities, communities of color, people with disabilities, and people of older and younger age. However, while Complete Streets are intended to benefit diverse populations by design, it remains unclear how spatially accessible they are due to inconsistent project criteria, performance measures, and prioritization methods across state agencies and municipalities.

Despite increasing evidence and awareness of the importance of transportation equity, there remains a lack of consistent planning methodologies across various types of infrastructure and several studies have identified the presence of spatial and social demographic disparities. The National Complete Streets Coalition has published reports and presentations on the many benefits of Complete Streets and has stated that Complete Streets can benefit children, older adults, people with disabilities, and low-income neighborhoods and communities of color that have historically been disinvested in (Smart Growth America, 2015a). Complete Streets are differentiated from other transportation programs and funding due to their multimodal characteristics; they are designed and operated to prioritize safe access for all users, including pedestrians, bicyclists, motorists and transit riders of all ages and abilities with benefits pertaining to health, air quality, economic growth, and social opportunities (Smart Growth America, n.d.-d). This inclusivity is intended to provide equitable opportunity for vulnerable populations to access modes of travel that accommodate different needs. Equity is also an intended outcome due to the affordable and convenient nature of public transportation options which is particularly beneficial to low-income households. However, similar to transportation planning trends, there is no existing framework for prioritization and assessment.

Defining Equity

Transportation equity is theorized and conceptualized in various ways, and at a fundamental level it typically addresses the costs and benefits and the fairness to which investments are distributed among populations (Hertel, Roger, & Collens 2015; Garrett and Taylor 1999; Litman 2002; Mercier 2009; Pereira, Schwanen, & Banister 2017). A frequently cited definition of equity comes from the Standing Panel on Social Equity in Governance of the National Academy of Public Administration, who define it as "The fair, just and equitable management of all institutions serving the public directly or by contract, and the fair and equitable distribution of public services, and implementation of public policy, and the commitment to promote fairness, justice, and equity in the formation of public policy". The American Planning Association adds: "Unlike equality, which connotes sameness, equity is responsive to difference; equitable policies actively mitigate the disproportionate harm faced by certain communities" (American Planning Association, n.d.).

Transportation equity is commonly categorized into horizontal equity and vertical equity. Horizontal equity, also associated with fairness and egalitarianism, is concerned with the concept of equality and refers to the distribution of impacts between all groups and spaces considered equal in ability and need (Litman, 2012; Linovksi et al., 2018). According to this definition, equal individuals and groups should be treated the same in the distribution of resources, benefits and costs, implying that public policies should avoid favoring one individual or group over others (Safe Routes Partnership, 2017). Vertical equity, also associated with social justice, environmental justice, and social inclusion, is concerned with the basic level of access between all individuals and groups, as well as additional consideration and resources for those that differ by income, social class, mobility need and ability (Litman, 2020b; Linovksi et al., 2018). By this definition, transport policies are equitable if they favor economically and socially disadvantaged groups in order to compensate for overall inequities (Rawls, 1971). The "needs rule" as discussed by the Safe Routes Partnership (2017) also falls under this umbrella, which "seeks to level the playing field by providing the greatest benefit to those who are most disadvantaged". For instance, new bicycle lanes would target travelers who are mobility-deprived, low-income, or disadvantaged in other ways (Lee et al, 2017; Safe Routes Partnership, 2017).

Furthermore, equity is studied for social and spatial impacts. Social equity examines vulnerable or disadvantaged populations along socio-demographic lines. Approaches often include analyzing the usage of infrastructure or programs relative to specific populations. Spatial equity research focuses on geographic areas and how transportation policies and projects are spatially distributed (Safe Routes Partnership, 2017). Lee et. al. (2017) explains that "rather than exploring who stands to benefit more or less from a transportation policy or project, the spatial equity approach aims to determine where inequities are occurring" (p. 213). Spatial equity approaches are considered appropriate for and well-suited to assess distributional effects of public policies as they tend to cluster around specific physical locations (Lee et al., 2017; Stöhr & Tödtling, 1977). Equity indicators include socio-demographic attributes such as race, gender, age, and income that target vulnerable or disadvantaged populations.

Massachusetts is a unique state to study because of its successful 2016 Complete Streets Funding Program, which now serves as a model for the recently introduced Complete Streets Act of 2019. Before the state program started, only 25 municipalities had policies and as of 2019, there were 176 policies and 201 state-approved plans (Doyle, 2019; Complete Streets Act, 2019). However, the state agency responsible for funding allocation and the municipal planners responsible for prioritization do not have explicit equity objectives or assessment criteria for equity. This research paper aims to explore the existing locations, project types, and accessibility of approved Complete Streets projects in Massachusetts through GIS-based methods.

To the author's knowledge, such an effort has not been done with a focus on the following: a) mapping and analyzing the spatial distribution of a statewide Complete Streets program, or multimodal transportation infrastructure more broadly and b) analyzing the socioeconomic data associated with Complete Street project locations. This study applies various methods found within equity studies of active transportation and transit including descriptive and regression analyses.

Research Objectives

1. Examine the spatial distribution of Complete Street projects and their relationship to demographic data including population density, race, age, economic characteristics, vehicle ownership, commuting modes

Research Questions

1. Where have Complete Streets been implemented? (i.e., approved) within Massachusetts since the adoption of a statewide policy in 2016?
2. Who has access to Complete Streets? Is the distribution of projects equitable?

This research explores the spatial arrangements of Massachusetts Complete Streets and examines the extent to which disadvantaged communities experience differential access to transportation infrastructure. Descriptive statistics provide a comparative insight into how the demographic composition differs between service areas and block groups outside the service areas, while spatial regression models are employed to examine the degree to which socioeconomic characteristics describing disadvantaged populations explain variations in the distribution of Complete Streets.

CHAPTER 2: LITERATURE REVIEW

Transportation equity research has examined and analyzed spatial and social relationships between traditionally underserved communities and investments in transportation infrastructure using various theoretical foundations and methods. This chapter first presents an overview of spatial and social inequities of transportation infrastructure in the U.S. followed by a review of equity and justice theory and a discussion of how they are applied in research and practice.

Spatial Inequities

Spatial inequities are demonstrated in the unequal distribution of transportation infrastructure in the U.S. Historically, governments and agencies have favored more advantaged groups (i.e., white, upper-middle class neighborhoods) with the allocation of funding and investments in public infrastructure. Racial and social discrimination has existed within government transportation policies, projects, and programs, burdening communities of color and low-income populations with the associated costs while denying the benefits of investment (Buck & Buehler, 2012; Cradock et al., 2009; Day, 2006; Fainstein, 2005; Fruin & Sriraj, 2005; Golub & Martens 2014; Sanchez et. al., 2003). Despite more recent efforts to increase transparency and reduce disparities in planning processes and outcomes, such as the adoption of environmental justice initiatives, inequities across income, racial, and ethnic groups persist. (Brulle & Pellow 2006; Corburn, 2009; Forkenbrock & Schweitzer 1997; Hodge,1995; Litman, 2012).

Residential segregation from transportation policies remains commonplace in many communities, especially in low-income communities and communities of color where people are more dependent upon transit, bicycles, and walking to get around (Sanchez et al., 2003; Zimmerman et al., 2014). The lack of investment has led to unsafe and poor-quality infrastructure in these areas. Yu et al. (2018) found that neighborhoods with higher poverty and populations of nonwhites have greater exposure, more pedestrians, and less pedestrian infrastructure. For example, almost 90 percent of high-income areas in the U.S. have sidewalks on one or both sides of the street while the percentage in low-income communities drops to 49 percent. These disparities are also found among other types of street features including lighting, traffic islands, and crosswalks (Gibbs et al., 2012). Despite this, many programs and plans have still largely targeted middle- and upper-class communities for improvements (Day 2006; Mueller et al., 2015).

As a result of inadequate walking and bicycling infrastructure and unsafe conditions, these communities face a disproportionate number of pedestrian crashes resulting in the increasing toll of injuries and fatalities (Kravetz & Noland, 2012; Noland et al., 2013; Zimmerman et al., 2014). In the U.S., pedestrian fatality rates for Latino and African Americans are about twice that of whites (League of American Bicyclists, 2013). Pedestrian fatality rates have also been shown to be doubled in low-income metro areas compared to affluent neighborhoods (Maciag, 2014).

Physical inactivity-related ailments also occur as a result of these conditions. Poor quality infrastructure and road conditions discourages walking and bicycling, which has shown to contribute to rising obesity and diabetes rates (Zimmerman et al., 2014; Day, 2006). Studies have found a significant association between race, ethnicity, and socioeconomic status and access to physical activity settings; a 2004 study found that "moving from a community with a 1% poverty rate to a 10% poverty rate is associated with a decreased prevalence of bike paths from 57% to 9% respectively." (Powell et al., 2004 p.141).

Social Inequities

In addition to quality of infrastructure and access, low-income populations - who are disproportionately people of color - also face higher costs for transportation, spending a greater proportion of their income on transportation costs compared to wealthier people. In 2016, the lowest earning 20 percent of the population (earning an average of $11,922) spent 29 percent of their income on transportation costs (U.S Bureau of Labor Statistics, 2018). As income increases, the portion of expenditure going towards transportation decreases. Much of this is attributed to private vehicle costs which, in 2017, accounted for the largest amount of transportation expenditures, according to the Bureau of Transportation Statistics (Institute for Transportation & Development Policy, 2019).

Furthermore, transportation costs associated with private vehicle ownership have complex relationships with accessibility and mobility. Without reliable public transportation options, households are more reliant on private vehicles which have significant impacts on lower-income households. Zero-vehicle households have become increasingly concentrated among people with very low incomes and for many, living without a vehicle is a higher cost than owning one. King (2019) noted a "falling socioeconomic status" where households without vehicles are falling further behind households with vehicles and are poorer in absolute terms today than they were sixty years ago (p.2). However, in their study of socioeconomic status and private vehicle ownership comparing New York, Los Angeles, and the US overall, King found that unlike LA and the US, New York had a high correlation between vehicle availability and income. Notably, this was because households with cars are wealthier, and not because households without vehicles are poor. The author suggests this is attributed to the built environment of Manhattan and its lack of support for automobility, which is less present in LA and other areas of the US. From this study, one can assume that low vehicle ownership does not always imply or correlate with poverty, but rather indicates a relationship with density and non-autocentric design. Regarding vehicle ownership and *employment*, research has found that access to a vehicle increases the probability that poor people get jobs, and in one study even more so than with access to transit (Sanchez et al, 2004; Cervero & Radisch, 1996; Newman & Kenworthy, 1996; Sheller & Urry, 2000). However, similar to income, the increase in employment associated with vehicle access is also related to density and how the built environment privileges automobile use.

Urban living and housing costs are also discussed within vehicle ownership research. Relationships between density and housing with income and unemployment is unclear. The "spatial-mismatch" hypothesis claims that jobs have moved from central cities into suburbs, creating a barrier between urban workers and places of employment. A critique of this, which has developed into the "modal-mismatch hypothesis" suggests that the barrier to reaching distant places of employment is not geographic distance, but the lack of reliable personal transportation (i.e., personal vehicle ownership) (Grengs, 2010). Research on transportation and housing costs more specifically is extensive and complex, however some studies have found a positive relationship between transport accessibility and housing values (Du & Mulley, 2006; Kramer, 2014; Seo et al., 2014). Thus, there are different views of how vehicle ownership or lack thereof, indicates existing inequities and transportation needs depending on places of living and working.

Transportation Justice and Equity

Social and spatial inequities are often studied through the lens of transportation justice or spatial justice. Soja (2009) refers to spatial justice as the "fair and equitable distribution in space of socially valued resources and the opportunities to use them" and spatial *in*justice as locational discrimination "created through the biases imposed on certain populations because of their geographical location" (p.2.). Distributional inequities vary by unit and by logic of distribution, of which the latter is defined by various philosophical theories (Lamont, 2003; Taylor & Norton, 2009). In practice, these inequities are often a result of budget requirements, institutional inefficiency, personal greed, racial bigotry, and differential wealth and social power, that creates locationally biased and discriminatory geographies of accessibility (Soja 2010, p.47).

There is no clear definition in practice or theory of what constitutes a fair distribution of benefits from transportation investments, nor are there universal or commonplace standards, goals or performance measures that exist to measure progress or achievement in the distribution of transportation benefits. In a study reviewing justice theory, Martens et. al. (2012) found that distributional goals in current transportation planning practice are either 1. Not stated at all, 2. Implied but unclear, or 3. When stated explicitly, not based on a well-developed moral argument. From an activist standpoint, Enright (2019) argues that a more comprehensive view of transport justice would "take into account how mobility is a matter of many networked social relations and material processes at multiple scales" (p. 669).

Social and Spatial equity analyses of transportation infrastructure

Within research, social and/or spatial characteristics are often analyzed to help make visible the underlying structurally unjust aspects of societal and governmental organization (Pereira et. al., 2019). The social and spatial methods applied in the literature primarily focus on the quality, access, and usage of transportation amenities. It is more common to find that social and spatial characteristics are combined for a more holistic analysis; spatial equity analyses are typically conducted first to stratify by geographic group, followed by a demographic analysis of geographic groups (Delbosc & Currie, 2011; Delmelle & Casas, 2012; Grengs, 2001; Griffin & Sener, 2016). Analyses are conducted within Geographic Information Systems (GIS) programs and employ various spatial and statistical methods using social, economic, demographic, and transportation data.

Transportation equity research that employs both spatial and social methods include analyses on pedestrian facilities, bikeshare programs, transit stations and networks, Bus Rapid Transit (BRT) systems, and bicycle infrastructure. Research has found overall that transportation infrastructure often has skewed findings of access and distributions where low-income communities, communities of color, and low-income communities of color have less bikeshare and bicycle infrastructure access, less bikeshare usage, and poorer quality pedestrian facilities.

Pedestrian studies have analyzed crash data, distribution of projects, and quality of infrastructure with regards to low-income communities and communities of color. In a study using crash data to identify disparities, Kravetz and Noland (2012) found that neighborhoods with higher concentrations of low-income, African American, or Latino residents in northern New Jersey had increased rates of pedestrian crashes. On a similar note, Lu (2013) examined the distribution of pedestrian safety projects and found that communities of color and low-income groups disproportionately suffer from higher rates of pedestrian injuries. Studying infrastructure quality, Kelly et al. (2007) assessed differences in walkability in St. Louis, Missouri using neighborhood audits. Using Census block group level data, the study found that predominantly African American neighborhoods were significantly more likely to have uneven sidewalks and more sidewalk obstructions. Grant et al. (2010) studied accessibility and safety in Ottawa, Canada through focus groups and interviews with older residents. The findings indicated those living in lower socio-economic status (SES) neighborhoods had fewer active transportation facilities, a higher pedestrian-vehicle collision risk, and indicated a greater concern for traffic hazards.

The growing body of bikeshare literature assesses spatial and social equity through accessibility studies to explain disparities in their distribution and usage. Recent research has found that bikeshare station placement and thus bikeshare users tend to be more white, male, and affluent. A study of bikeshare programs across the US revealed that the distribution of stations in many systems captures only a small number of potential low-income users (Smith et al., 2015). Another analysis of bikeshare programs in several large U.S. cities found that minority, low- income, and less-educated communities tend to have poorer bikeshare access than other income groups (Ursaki & Aultman-Hall, 2015). Similar findings outside the U.S. show discrepancies in bikeshare access. Hosford and Winters (2018) assessed the spatial access to bicycle share programs in Canadian cities by comparing socioeconomic characteristics of dissemination areas inside and outside bicycle service areas. They found that advantaged areas have better access to bicycle share infrastructure in five out of the six cities studied. Goodman and Cheshire (2014) examined usage data of the London bicycle sharing system and found that women make fewer than 20 percent of all trips, and that users from highly deprived areas doubled across the program's first three years. In a case study of public bicycle and car sharing schemes in Glasgow, Scotland, Clark and Curl (2016) looked at the accessibility of public bicycle and car sharing schemes by examining how well they serve different population groups across the city. By analyzing the proximity to locations of bicycle stations and car club parking spaces, they found that in being designed from commercial and mode-shift perspectives, such a market imperative will be less likely to extend to populations at risk of transport-related social exclusion.

In addition to usage, bikeshare research has examined the relationship between station placement and low-income populations and people with health conditions. Using a spatial index that combines the potential for increased access to jobs and essential services, the level of bike infrastructure, and the disadvantaged population shares, Qian

(2019) found that existing bikeshare systems have been specifically designed to target certain ridership and that locating station in proximity to disadvantaged communities has the potential to increase accessibility. In a study of London's public bicycling sharing scheme, Ogilvie (2012) found that females and residents in deprived areas are underrepresented users and the scheme's expansion into more deprived areas has the potential to create more equitable usage. Downing (2013) looked at the spatial presence of health conditions and socio-demographic characteristics within service areas of a proposed bicycle share program in Philadelphia and found "target health groups" which included women, blacks, Latinos, and those living below 200% of the Federal Poverty Level. These findings suggest that station locations more mindful of disadvantaged populations can help bridge equity gaps.

Transit studies have incorporated social and spatial methods to identify how rail and bus infrastructure are serving different populations. Griffin (2016) evaluated the equity of transit service in nine large US cities by comparatively studying percentages of low-wage workers and all workers in Core Based Statistical Areas and block groups. Through descriptive statistics and a local Moran's I analysis, they found variability among transit services to low-income populations, with different results at regional and local levels. The regional-level analysis of transit service was shown to hide significant variation through spatial averaging, whereas the new data employed in the study demonstrated a block-group scale equity analysis that could be used on a national-scale data set. Delmelle (2012) measured spatial accessibility of Bus Rapid Transit systems in Colombia by calculating accessibility to stops and stations and accessibility to activity opportunities. They explored the equitable distribution of accessibility patterns in relation to neighborhood socioeconomic strata, finding that walking access to the BRT system was greatest for middle income groups and most limited for neighborhoods in the highest and lowest socio-economic strata. Yeganeh et al. (2018) analyzed transit job accessibility in 45 U.S. Metropolitan Statistical Areas (MSA) using the Gini Index as a measure of equality, finding overall low transit ridership across race and income and highest job accessibility among minorities and low-income populations. They also noted that in certain MSAs, transit job accessibility was higher for high- and low-income populations but lower for middle income populations.

Much of the spatial equity transit literature pertains to new methodology to measure service areas and their respective population data. Welch (2013) proposed a methodology to measure transit equity from a graph theoretical approach for all levels of transit service coverage integrating routes, schedules, socio-economic, demographic and spatial activity patterns. Biba (2010) presents a method for determining the population with walking access to bus stop locations using the spatial and aspatial attributes of parcels and the network distances from parcels to bus stop locations. El-Geneidy (2013) developed new methods to generate service areas based on existing service ad neighborhood characteristics that include measured walking distances and detailed train and bus routes.

While many studies have examined both social and spatial equity of pedestrian facilities, bicycle (excluding bicycle share) infrastructure and multimodal facilities are less commonly addressed. Winters et al. (2018) examined income inequalities in spatial access to bicycling infrastructure by calculating the kilometers of bicycling infrastructure (e.g., cycle tracks, on-street bicycle lanes) per dissemination area (smallest standard geographic unit for census data in Canada). They found that in three mid-sized Canadian cities, two had greater access to infrastructure compared with higher income areas, and another had no infrastructure consistent across income quintiles. Multimodal transportation is even less common; most studies analyze a single mode or program such as bikeshare or pedestrian and bicycle infrastructure as discussed above. There is currently no existing spatial research on the combination of walking, bicycling, and transit infrastructure or its accessibility. However, Ozel et al. (2016) describes a geographic information systems-based methodology that can be used to evaluate and measure the accessibility to multimodal facilities including railway stations, ferry stations, public airports, and Greyhound intercity bus stations for aging populations.

Equity in transportation planning practice

The incorporation and prioritization of equity in transportation planning practice varies widely due to vague conceptions of transportation equity, lack of data and a lack of metrics. While many practitioners and decision-makers identify equity objectives in transportation planning, it can be difficult to evaluate due to the various types, impacts, measurement units, and categories of people to consider. Karner and Niemeier (2013) stated “One of the most significant gaps in transportation planning is the lack of a coherent and rigorous framework within which equity analyses can be conducted.” (p. 133). Transportation justice researchers have concluded that the ineffectiveness of traditional equity analyses stems from both a failure to account for displacement and current inequalities and the outdated nature of 20-year forecasting models used for transportation plans created every four years. They argue equity should be addressed in the near-term and that projects and plans meet community-identified needs that benefit low-income residents (Creger et al., 2018; Marcantonio, 2016).

Several studies have examined the incorporation of equity in transportation plans. Lee et al. (2017) found a wide disparity in the extent to which equity is prioritized in cities around the U.S. Through a review of citywide pedestrian and bicycle master plans, there was significant variation in the understanding, integration, and prioritization of equity in active transport planning. For example, the City of Seattle, WA has made equity a primary goal in its bicycle and pedestrian master plans while other cities such as Louisville, KY and Atlanta, GA, mention equity but don't provide specific, concrete strategies. In a study of 18 urban transportation plans in large North American metropolitan areas, Manaugh et al. (2015) evaluated how social equity is conceptualized, operationalized, and prioritized and found social equity objectives and measures in several plans but a lack of clearly specified objectives and measures to assess their achievement in a "meaningful, disaggregated manner" (p. 174). A report by Advocacy Advance (2015) highlights a survey of bicycle and pedestrian master plans from 38 U.S. communities that looked for explicit mentions of equity, including the word "equity" along with several associated terms describing race, family characteristics, and income. It was found that equity was mentioned in approximately half the plans, and where the term was found it was often undefined, poorly defined (providing little information on the process that created the definition) or left vague in the plans.

Equity is commonly measured with environmental justice principles that assess transportation issues by incorporating justice concerns into transportation decision making. Metropolitan planning organizations and transportation agencies, for example, have begun to adopt environmental justice as a key component within planning but equity norms remain marginal within practice and implementation (Gössling, 2016; Enright, 2019).

CHAPTER 3: COMPLETE STREETS MOVEMENT AND THE MASSACHUSETTS COMPLETE STREETS PROGRAM

Background

Complete Streets have emerged in North America as a movement toward multimodal and inclusive transportation design. Smart Growth America, a coalition of advocacy organizations for smart growth policies, created the National Complete Streets Coalition program defined as a "non-profit, non-partisan alliance of public interest organizations and transportation professionals committed to the development and implementation of Complete Streets policies and practices" (Smart Growth America, n.d.-e). The Coalition launched the Complete Streets nationwide movement in 2004 to promote the development and implementation of policies and professional practices that ensure "streets are safe for people of all ages and abilities, balance the needs of different modes, and support local land uses, economies, cultures, and natural environments." (Smart Growth America, n.d.-e).

Complete Streets are broadly defined as streets that can safely accommodate all road users, regardless of mode of travel or ability and their designs and policies often have social and environmental goals and benefits (Litman, 2012; U.S. DOT, 2015; Hui et al. 2018). They are typically viewed as corridors that provide choices for people who feel comfortable walking, bicycling, using public transit, or driving. Projects are of many scales and address a wide range of elements such as sidewalks, bicycle lanes, bus lanes, public transportation stops, crossing opportunities, median islands, accessible pedestrian signals, curb extensions, modified vehicle travel lanes, streetscape, and landscape treatments (USDOT, 2015). Complete Streets have large sets of potential competing priorities, where the importance of each priority will vary depending on the context of the street and its role in the network: not every street is intended or suitable for the accommodation of every user mode or street function (Sousa & Rosales, 2010).

Legislation

Since the Complete Streets Act of 2009, municipal level Complete Streets policies have proliferated throughout the country. A study of Complete Streets at a national scale found there to be a smaller presence of policies within smaller municipalities, municipalities in the South, and municipalities with lower median education levels (Carlson et al., 2017). While this study did not conclude the reasons for these findings, they suggested that a lack of resources, capacity or awareness of Complete Streets policies to prioritize, adopt, and implement such policies could explain the absence of Complete Streets policies. As of 2018, 29 states and Washington, D.C. have adopted Complete Streets policies with mandatory requirements; 16 of those states and D.C. have policies that include mandatory requirements with clear action and intent (Porter et al., 2019). Modeled after the Massachusetts landmark law, The Complete Streets Act of 2019 has recently been introduced in congress and is awaiting to be passed into law. This bill would A. Set aside federal funds to support Complete Streets projects (five percent of annual federal highway funds) B. Require states to create a program to provide technical assistance and award funding for communities to build Complete Streets projects and C. Directs localities to adopt a Complete Streets policy that meets a minimum set of standards to access that dedicated funding (Smart Growth America, n.d.-a).

Equity

Complete Streets are unique to transportation policy and funding because they represent multiple modes for greater accessibility. Whereas traditional forms of transportation projects focus on specific systems or facilities, Complete Streets embody a vision for a streetscape that promotes greater mobility of people "of all ages and abilities". Complete Streets are viewed as a mechanism for accessibility and equitable design; the Smart Growth America and National Complete Streets Coalition partnership published a brief on the benefits of Complete Streets titled "Complete Streets mean Equitable Streets" where "incomplete streets" are causal to pedestrian fatalities and poorer health of older adults, communities of color, and low-income communities. Further, they discuss that auto centric street design primarily affects children, adolescents, many older adults, people with disabilities, and low-income individuals who do not drive or have access to a vehicle. They imply that providing transportation options through Complete Streets ensures that people have "access to education, employment, religious and cultural institutions, and friends and family" (Smart Growth America, n.d.-b, p.2)

Despite the acknowledgment of barriers and disinvestment within these communities, there is no framework or policy to promote or incentivize states or municipalities to consider the spatial distribution of Complete Streets. A 2016 qualitative study interviewed planners, transportation-related professionals and advocates located in 8 jurisdictions with Complete Streets policies that included equity-related language to identify how equity was being implemented and prioritized in practice. The study found that despite communities including equity in their policies, in practice there were few procedures, standards, or measures to address equity in terms of distribution of resources, engagement of disadvantaged populations, or staff training. Additionally, most communities did not have a concreted project prioritization process, in part due to greater perceived need and priority in areas of existing deteriorating infrastructure (Thrun et al., 2016).

Similar to findings in other transportation equity research, studies on Complete Streets have found inequitable social and spatial outcomes. In a 2016 study, Smart Growth America found that Complete Street funding had often gone to whiter, wealthier areas rather than those areas where vehicle ownership is lower and the use of alternative modes of transportation, like public transit and bicycling, are higher (Smart Growth America, 2017). These findings suggest such trends may indicate low-income communities and communities of color are not receiving or being allocated the transportation infrastructure investments seen within other populations. Overall, there is a need for more research on equity, clearer indicators to establish consistency, and more buy-in from local governments, private sector bodies, and the public (Safe Routes Partnership, 2017).

Massachusetts Complete Streets Program

The Massachusetts Complete Streets Program, administered by the Massachusetts Department of Transportation (MassDOT), provides technical assistance and construction funding to municipalities to plan for and implement Complete Streets projects. Similar to the broader vision of Smart Growth America and the National Complete Streets Coalition, MassDOT's Complete Streets are intended to provide accessible travel alternatives for all modes including walking, biking, transit, and motorized vehicles while promoting safety, health, and economic viability to be enjoyed by people of all ages and abilities. Street improvements are of varying scales, including corridor-wide improvements, and projects focusing on the needs of a single mode such as a bus shelter for a highly used bus stop. The program objectives include: "ensuring that underserved municipalities are served equitably by the program as anticipated by statute" and "facilitating better pedestrian, bicycle, and transit travel for users of all ages and abilities by addressing critical gaps in pedestrian, bicycle, and transit infrastructure by funding Complete Streets projects in cities and towns that have already adopted policies and undertaken planning" (MassDOT, 2016b p.7).

Prioritization Application

To be eligible for Complete Streets funding, municipalities apply to MassDOT with a prioritization application. The prioritization process, sometimes outlined in Complete Streets prioritization plans, is conducted through various methods including the analysis of crashes, level of traffic stress, demand, and socioeconomic data. It is often unclear what methods are used and they tend to vary by the agency responsible for prioritization. Many municipalities have existing Prioritization Plans or plans of highly desired projects (i.e., Capital Improvement Plans, Master Plans) already developed, which can often be modified to fit the MassDOT Complete Streets Prioritization Plan format and then ranked based on the municipality's desired evaluation criteria (See Appendix B for eligible project types and Appendix C for non-eligible projects). Not all municipalities have published reports or plans; at the time of this paper, only twelve documents were available for download online. Thus, it is unclear what methodologies were applied across the state.

Equity

The inclusion of equity within program objectives, policy, and project funding allocation are vague and lack explicit measurement of accessibility and distribution. The objectives for the Complete Streets Program include "achiev[ing] equity in program participation and award distribution" (MassDOT, 2016a, p. 2). It is implied that the participation and award distribution are achieved through technical assistance and by allocating a percentage of funding to lower-income municipalities.

To receive project approval and funding, municipalities must have approved policies that meet the MassDOT guidance and scoring system criteria. To meet requirements, policies must meet 80 points from within the guidance and scoring system. The "Complete Streets Ten Policy Elements" listed in the Complete Streets Funding Program Guidance details the policy elements recommended by MassDOT with corresponding points. The only element listed relating to equity is core commitment two, number two: "Specifies that the transportation system services '**all users'** including pedestrians, bicyclists and transit passengers of **all ages and abilities**…" (p. 17). This section explains "Beyond the type of user is a more nuanced understanding that not all people who move by a certain mode are the same. The needs of people—young, old, disabilities, without disabilities-are integral to great Complete Streets Policies.". Four additional points are awarded if the policy references the "needs of users of all ages" or "needs of users of all abilities". However, there is no further information on how needs based on age and ability are identified or planned for.

Funding awards depend on the overall number of municipalities seeking funding and are based on several criteria of (a) how well each project accomplishes complete streets goals (i.e., safety, connectivity, mobility, accessibility); (b) equity (i.e. municipality median household income at or the below statewide average, gateway community, environmental justice/Title VI area); (c) geographic distribution of funding; (d) number of submitted projects; and (e) available funding (MassDOT 2016b, p. 13-14). To achieve equitable funding allocation, the 2014 Transportation Bond bill states that thirty-three percent of the grants awarded for Complete Streets must be issued to municipalities are at or below the average of the Massachusetts median household income (Transportation Bond Bill, 2014).

According to MassDOT, the equitable distribution of funding is dependent on technical assistance and construction costs. MassDOT states "to assist achieving equitable distribution of funding" they will emphasize the availability of technical assistance funds to assist municipalities in developing a Prioritization Plan (MassDOT, 2016c, p.2). The technical assistance for analysis and the prioritization plan is a "targeted investment strategy to improve safety, mobility or accessibility" and will identify the streets and infrastructure as well as determine the estimated costs and timelines for the improvements (MassDOT, 2016b, p.8). The assistance provides funding for planning studies or analyses and can be used for third-party consultants or assistance from regional planning associations. Furthermore, the funding program guidance states "to insure a fair and equitable distribution of available funds, construction costs will be a critical factor in the final selection of Complete Streets projects." (MassDOT, 2016b, p.15). However, costs for pedestrian bicycle safety infrastructure often vary greatly among regions (MassDOT, 2016b).

Furthermore, Environmental Justice criteria are included in applications that require identifying whether a project is "within or serves a designated Environmental Justice population cluster". The U.S. Department of Transportation explains that Environmental Justice in Transportation planning incorporates three principles: (1) avoid, minimize, or mitigate disproportionate burdens of transportation; (2) ensure the full and fair participation by all stakeholders; and (3) prevent the denial of, reduction in, or significant delay in the receipt of benefits by minority and low-income populations (U.S DOT, 2016). Other guidance from the Federal Highway administration (FHWA) mentions distribution of benefits but no explanation is provided for what the appropriate distribution would entail. Likewise, MassDOT does not explicitly state what a fair distribution of investments would look like or how this criterion is used to determine funding allocation.

In conclusion, the Complete Streets program lists equity as an objective, implies equity requirements for policy approval, and in practice aims to achieve equity by emphasizing available funds and allocating a percentage to lower-income municipalities. It is unclear what meeting the needs of all users and abilities means to MassDOT and municipalities creating their Complete Streets policies. Furthermore, while technical assistance and the thirty-three percent allocation of funding will provide greater access for cities and towns across the state, it does not ensure the projects they prioritize will be approved or funded, and nor does it ensure that the projects they prioritize will have an equitable outcome. Similarly, in allocating a certain percentage of funding to lower income municipalities, the outcomes of prioritization plans are unclear because MassDOT does not require other criteria for equity to be met. Lastly, environmental justice principles are often mentioned by transportation agencies and authorities within programs and policies, but rarely are they used to define or measure distribution of infrastructure. The environmental justice criteria are included in the Complete Streets applications but its weight for approval is unclear.

CHAPTER 5: METHODOLOGY

In the US, authority for major transportation investments is typically at the state level while everyday impacts of transportation are occurring and are felt at regional and local levels (Griffin & Sener, 2016; Bond & Kramer, 2010; Bullard, 2003). The research methods applied in this study aim to identify patterns of project distribution at state-wide and smaller scales by analyzing the locations of Complete Streets projects and the populations that have access to them.

As described in Chapter 1, this study takes a spatial and social equity approach to evaluate the geographic distribution of active transportation infrastructure implementation. To measure equity, this study compares the characteristics and locations of Complete Streets projects with key socioeconomic indicators of historically disadvantaged populations that have greater need for investment. As a proxy for access, this study applies a half-mile radius around all Complete Streets projects in Massachusetts to study the demographic data within this distance. Due to the multimodal design of Complete Streets, this analysis applies to a variety of transportation infrastructure including facilities for active modes and transit. This study also includes a more comprehensive set of population data (in comparison to Gini index studies, for example) and addresses overlooked transportation-disadvantaged groups including vehicle-deprived travelers. To the authors' knowledge, there are no existing studies that address the spatial distribution of Complete Streets projects in relation to disadvantaged populations. Because MassDOT does not provide explicit prioritization or evaluation criteria, the methods discussed in this chapter attempt to explore statistical qualities and spatial patterns on varying scales.

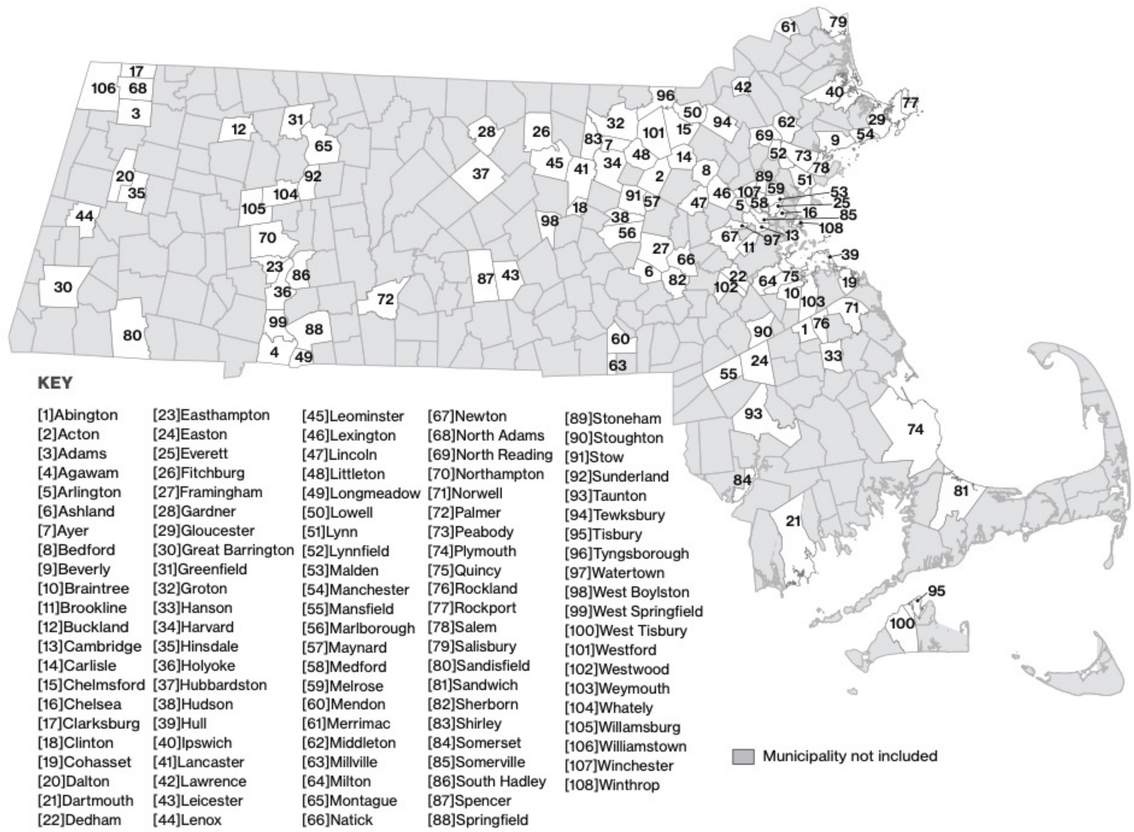
Data: Complete Streets

Data for the Complete Streets approved projects were obtained from the prioritization applications within the Massachusetts Complete Streets Funding Program Portal. The portal provides Tier 3 project construction funding applications (also referred to as prioritization plans) from each municipality per fiscal year (See Appendix A for example). Files are in Microsoft Excel format available for download per municipality and fiscal year. At the time of data collection, applications were only available for fiscal years 2017, 2018, and 2019.

I downloaded each individual approved Complete Streets applications and consolidated them into a single spreadsheet which included municipality name, median household income status, project name and type, location related to Environmental Justice populations and fiscal year. Some municipalities and projects were omitted in the process due to unavailable applications. The following twenty municipalities were included in the portal for having approved projects but were excluded from this study because no application was provided for download: Amesbury, Ashburnham, Billerica, Concord, Dighton, Fall River, Goshen, Haverhill, Lunenburg, Millbury, Nantucket, Newburyport, Pittsfield, Topsfield, Wakefield, Walpole, Webster, West Bridgewater, West Brookfield and Whitman. Furthermore, some applications did not provide coordinates or sufficient project location descriptions. For example, some project descriptions were listed as “multiple locations in town” without providing coordinates or names for the specific start and end locations. For these reasons, I omitted projects within Everett, Marlborough, Sandisfield, Springfield, Holyoke, Groton, Easton, and Maynard. There were initially 450 total projects, and after sorting and cleaning the data 421 remained with 628 total individual locations across 108 municipalities in Massachusetts. Figure 1 illustrates the locations of the 108 municipalities included in the analysis.

After a robust data cleaning process, the project coordinates were geocoded in ArcGIS 10.7 using the NAD 1982 coordinate system. Projects that extend over a single point such as those pertaining to sidewalks or bike lanes were aligned to a MassDOT roads shapefile using the "Align Features" tool in the Arc Toolbox to improve the accuracy of these locations.

Figure 1 Municipalities included in analysis



Data: Measure of Socioeconomic Status

The socioeconomic indicators in this study can be found in various transportation planning research to describe “disadvantaged populations” or “traditionally underserved populations” that were previously discussed in Chapter 2 (Litman, 2012; Sandt et al., 2016). Most commonly used (individually or within indexes) are populations at the household or individual level with characteristics of racial/ethnic minority, low income/poverty, low vehicle ownership and young and older age groups. This study uses both socioeconomic data as well as the transportation-related data to better understand the need for multimodal transportation infrastructure. The data includes individual variables of population, sex, race and ethnicity, age, educational attainment, median household income, unemployment, poverty rate, no vehicle ownership, and means of transportation to work. Categories were also calculated for low and high educational attainment (i.e., at or below high school degree and greater than bachelor's degree, respectively), non-white (i.e., all race/ethnicity variables other than white), and commute by other (i.e., commute by public transportation, bicycle, and walking).

Environmental Justice shapefiles were downloaded from MassGIS. The neighborhoods are identified by the Massachusetts Executive Office of Energy and Environmental Affairs Environmental Justice Policy using 2010 U.S Census data. The indicators analyzed in this paper differ from Environmental Justice criteria by their characteristics and data source; the Massachusetts Environmental Justice data includes income, minority and English language isolation, whereas this research uses a broader scope of socioeconomic status including income, race, ethnicity, age, education, vehicle ownership, and commuting modes. Current Environmental Justice data is from the 2010 Census at the census tract level, and the socioeconomic data in this study was obtained from the U.S. Census Bureau's American Community Survey (ACS) 2013-2017 5-year estimates at the block group level.

Table 1 Variable definitions and sources

Socioeconomic variables *Source:* American Community Survey 2017 5-year estimates at the block group level		
Population	Population density	Total population per square mile
	Total population	Total population
	Total occupied household units	Total occupied household units
Economic characteristics	Median household income	Median household income
	Unemployment	Percent of individuals for the population 16 years and over not in labor force
	No vehicle ownership	Total number of occupied housing units (both owned and rented) with no vehicle tenure
	Poverty status	Percent of households with income in the past 12 months below poverty level
Educational Attainment	Less than high school	Percent of population 25 years and and over with less than a high school diploma or GED
	High school or equivalent	Percent of population 25 years and and over with a high school diploma or GED
	Bachelor or higher	Percent of population 25 years and and over with high educational attainment including Bachelor's degree, Master's degree, and Doctorate degree
Social Characteristics	Median age	Median age
	Over 60	Percent of total population over the age of 60
	18 and under	Percent of total population under the age of 18
	Non-white	Percent of individuals identifying as race other than "white only" and of "Hispanic/Latino origin"
Means of Transportation to work	Private vehicle	Percent of households who commute to work by private vehicle. Includes car, truck, or van
	Other modes	Percent of households who commute to work by mode other than private vehicle. Includes: public transportation, bicycle, and walking
	Public transportation	Percent of workers 16 years and over who commute to work by public transportation (excludes taxicab)
	Bicycle	Percent of workers 16 years and over who commute to work by bicycle
	Walking	Percent of workers 16 years and over who commute to work by walking

Service Areas

To assess spatial access to Complete Street projects across Massachusetts, this study draws from bikeshare and transit literature that characterize distributional effects of transportation infrastructure among demographic variables within a given distance from infrastructure locations. Transportation studies commonly apply a buffer from transportation infrastructure (e.g., bikeshare, bus, transit stations) based on a Euclidean distance to define what is referred to as service or catchment areas. The service areas are then studied to analyze population characteristics (Ursaki, 2015; Hosford & Winters, 2018; Fruin & Siraj, 2005; Winters, 2018; Duran et al., 2018; Galama et al., 2017; Yaghoobirad, 2016; Krykewycz et al., 2010; Gutierrez, 2008; Dill, 2007; Moudon, 2005; Buck & Buehler, 2012).

To measure a reasonable walking distance from projects, I applied a Euclidean, or "crow's flight" half-mile (804 meters) buffer from all Complete Streets project locations in ArcGIS. A half-mile distance has been applied in research pertaining to transportation investment distribution, bikeshare ridership, and light rail transit impacts on property values (Fruin & Sriraj, 2005; Buck & Buehler, 2012; Hess & Almeida, 2007). This distance has also been applied in methods employed by consultants for Massachusetts Complete Streets prioritization plans and by local agencies.

The population data is at the block group level to accurately reflect conditions within the half-mile of projects. However, due to the inconsistent sizing of block groups within Massachusetts, they did not fit neatly within the buffer boundaries. To avoid eliminating analysis on entire municipalities, the block groups that comprised the buffers within the 108 municipalities were selected to be used as "inside" data for populations living within the half-mile radius (see Figure 2). The locations of Complete Streets were mapped for every municipality with approved applications and integrated with the ACS block group data for underserved populations. To extract the ACS data associated with the half-mile buffer, the block groups comprising Complete Street buffers were assigned a value of “1” and block groups outside of this area were assigned a value of “0”. These will be referred to as “service areas” in the following chapters.

Figure 2 Block group selection

CHAPTER 6: FINDINGS

This chapter summarizes the primary findings from two statistical models. The first explores the comparison between population characteristics inside and outside of the half-mile service areas. The second explores local bivariate relationships and a generalized linear regression model to study how certain populations relate to service area proximity. Examining the spatial distribution of Complete Streets as well as the statistical relationships with socioeconomic characteristics of nearby populations provides both small- and large-scale pictures of access and spatial equity. This chapter will first illustrate the spatial distribution of Complete Streets, their project characteristics, and relationship to existing Environmental Justice populations. This is followed by statistical methods that a. compare the overall averages of block groups with complete streets to areas without and b. examine regression patterns between Complete Streets and socioeconomic indicators on local and statewide scales.

Descriptive statistics found the largest differences of means for commuting characteristics and vehicle ownership, suggesting that block groups with Complete Streets have fewer private vehicles and commute less by private vehicle and more by other modes. The local bivariate relationships tool identified areas of statistical significance between Complete Streets and income and between no vehicle ownership and poverty and income. Lastly, the generalized linear regression found that Complete Streets are associated with populations under 18, whiter households, no-vehicle households, lower unemployment, higher educational attainment, and higher income. The findings of the GLR model complimented those of descriptive statistics, overall indicating that Complete Streets projects are being distributed in areas with existing transportation infrastructure.

Project characteristics

Location, density, and project types

To visualize larger-scale spatial trends of Complete Streets, this section provides an overview of project locations, density, and project types across the commonwealth. Project density at the municipal level is shown in Figure 3. Complete streets appear to be denser within Middlesex, Suffolk, Norfolk counties in eastern Massachusetts, and within Franklin, Hampshire, and Hampden Counties in Western Massachusetts. There are fewer projects within the Berkshires, the remaining counties in the southeast region, and the northeast areas of Essex County and northern Middlesex. As shown in Figure 4, most projects are pedestrian facilities, followed by traffic and safety (24%), bicycle facilities (16%) and transit facilities (4%). Figure 5 illustrates the proportions of project types for the four categories within each municipality. These maps suggest pedestrian facilities are densest in Boston, Metro West, and the Berkshires; transit facilities are densest in Metro West, Franklin County and Hampden County; traffic and safety facilities are densest in Hampshire County, Hampden County, and in Metro West areas closer to Boston; and bicycle facilities have a less visible pattern with a more even distribution throughout municipalities.

Figure 3 Project density

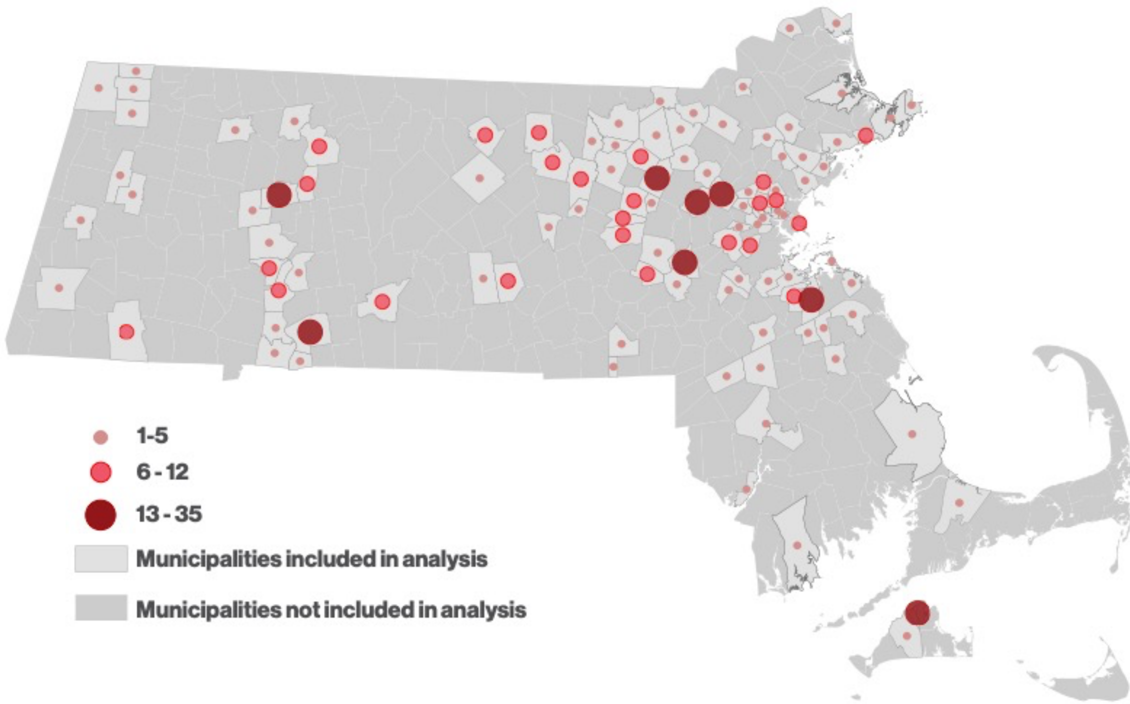


Figure 4 Project type

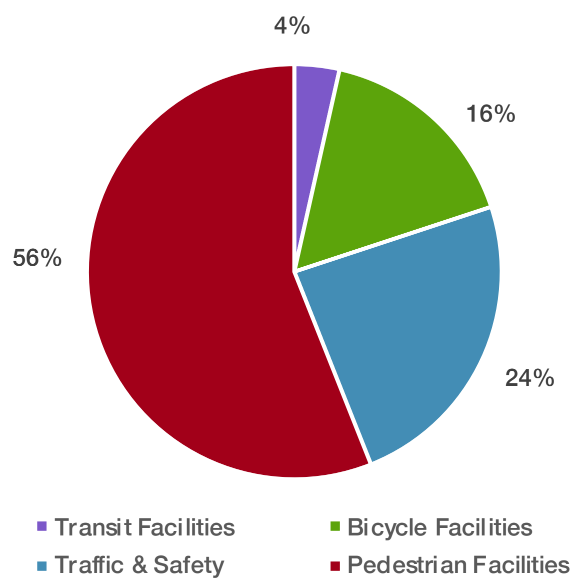
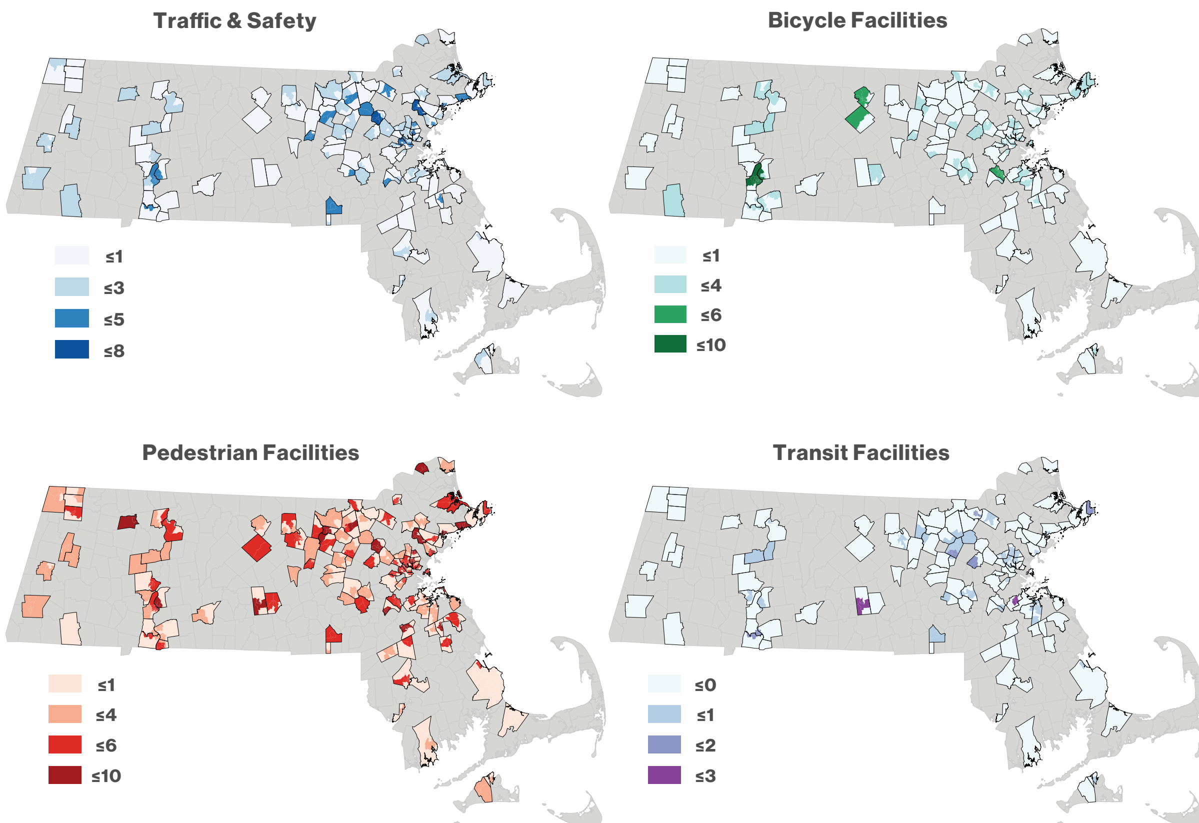


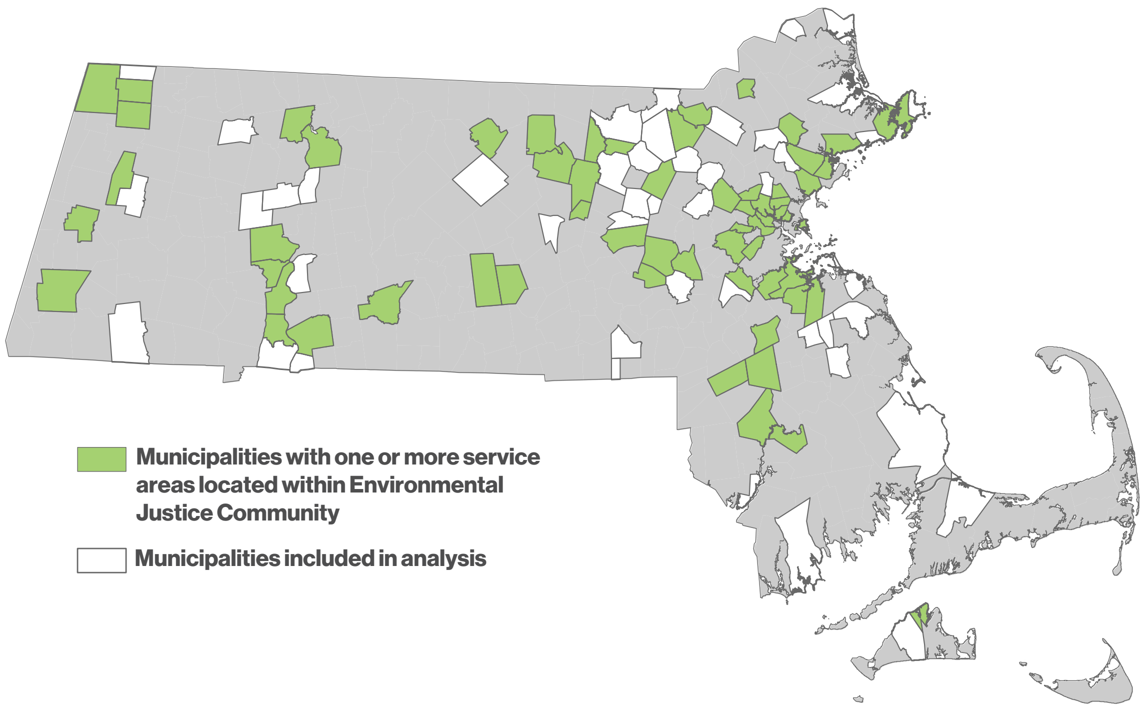
Figure 5 Project type by block group



Environmental Justice

More than half of the municipalities with complete streets projects used in this analysis have a census tract with an environmental justice designation (Figure 6). Forty-five municipalities have projects (i.e., points and segments) located within the designation boundary, and 61 percent have service areas within the designation boundary. The Environmental Justice population data is from the 2010 census based upon demographic criteria developed by the Massachusetts Executive Office of Energy and Environmental Affairs. A neighborhood is defined as an Environmental Justice population if any of the following are true: block group whose annual median household income is equal to or less than 65 percent of the statewide median ($62,072 in 2010), 25% or more of the residents identify as a race other than white, or 25% or more of households have no one over the age of 14 who speaks English only or very well (Massachusetts Department of Environmental Protection, n.d.)

Figure 6 Municipalities with service areas in Environmental Justice boundary

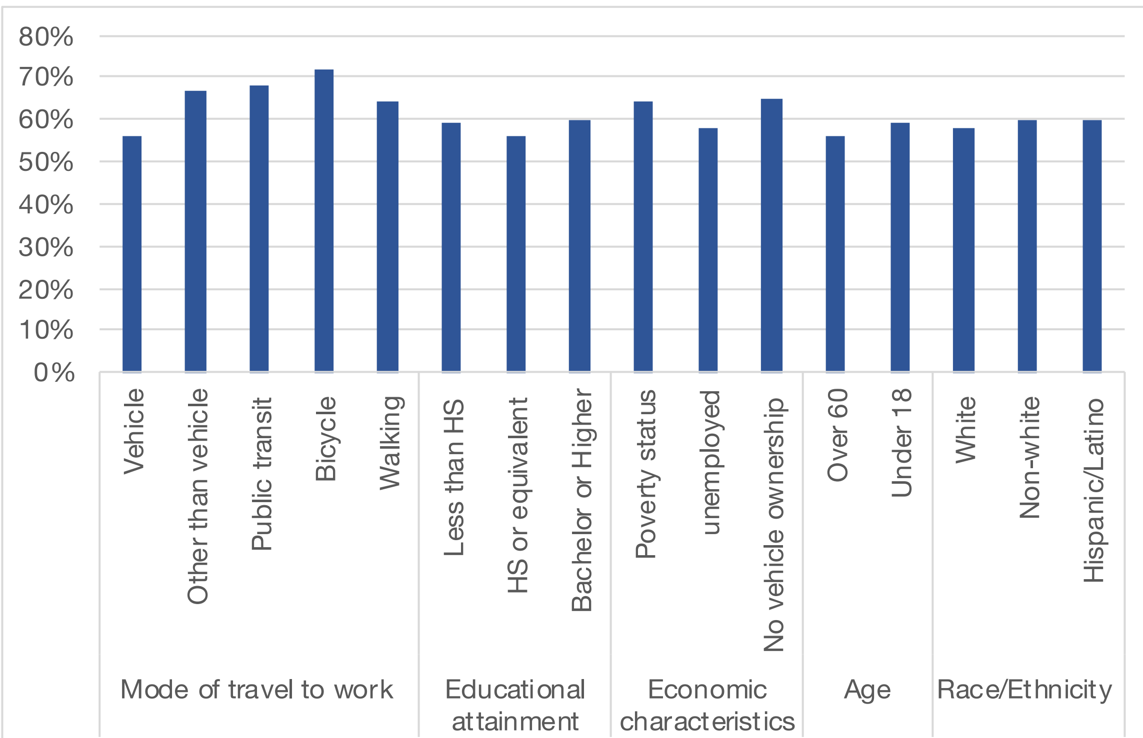


Population characteristics with access

The proportion of populations with access to complete streets is measured by the socioeconomic characteristics of block groups associated with service areas. Figure 7 shows that among the variables representing disadvantaged populations, the proportion of populations with access to complete streets are in order by greatest access as follows:

Bicycle commuters (72%), public transit commuters (68%), commuters by modes other than private vehicle (transit, bike, walking – 67%), no household private vehicle ownership (65%), individuals with poverty status (64%), walking commuters (64%), Hispanic/Latino populations (60%), non-white populations (60%), high educational attainment (60%), populations under 18 (59%), low educational attainment (59%), white populations (58%), unemployed populations (58%), populations over 60 (56%), commute by private vehicle (56%).

Figure 7 Proportion of the population who can access Complete Streets within a half-mile radius



Descriptive Statistics: Comparison of Access Across Socioeconomic Characteristics

When comparing disadvantaged populations within the half-mile service area to disadvantaged populations outside of the service area, the results show that the average compositions of the ‘in’ and ‘out’ populations vary by 5% of the respective totals at most. The socioeconomic composition within service areas appear to contain a higher proportion of disadvantaged populations that the composition outside of the service areas within the municipalities analyzed. It is important to note that the variables used to identify marginalized populations or historically underserved populations may be indicators of other factors requiring more context, especially considering that each variable is examined independently. For example, vehicle deprivation can suggest lower mobility and greater need for public infrastructure but depending on the setting it may indicate that households have greater access to existing infrastructure and thus, choose to not own a private vehicle.

Overall, the block groups associated with service areas are more densely populated with people who are more racially and ethnically diverse, have higher educational attainment, higher percentages of females, higher poverty levels, lower vehicle ownership, and commute less by private vehicle and more by other modes including public transportation. The largest differences between within and outside of the service area is of population density (1,358 person/ mi^2), commuting by private vehicle (5%), low vehicle ownership (4%), commuting by public transportation (3%) and high educational attainment (3%). The following sections detail the comparisons and point to areas for further investigation.

Service area distribution

The total area for the service areas of 588 projects in this study comprise 591 square miles, however due to the inconsistently large sized block groups, the 2078 block groups that were selected to be analyzed for ACS data have an area of 2078 square miles. 1063.9 square miles (n =831) are associated with proximity to service areas, and 1019 square miles (n=1247) are associated with the outside area in which there is low access to service areas.

The average number of service areas per block group are two, but some have as many as twenty-seven. Some towns and cities, especially in the western part of the commonwealth, have fewer block groups due to larger census boundaries. For example, the entire town of Sandisfield consists of only one block group. In denser areas of the selected municipalities, such as Springfield, there are 121 block groups. The municipalities in this study have as few as one service area and as many as ninety-six with an average of thirty-five service areas. The distribution of service areas per municipality and block group are shown in figures 8 and 9 respectively.

Figure 8 Service area distribution by block group

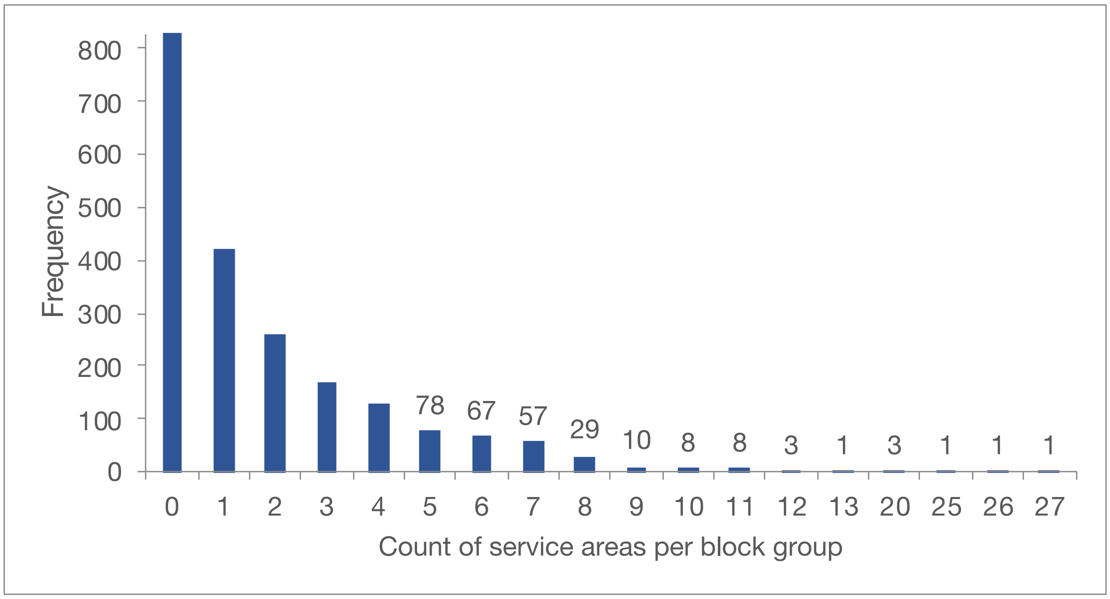
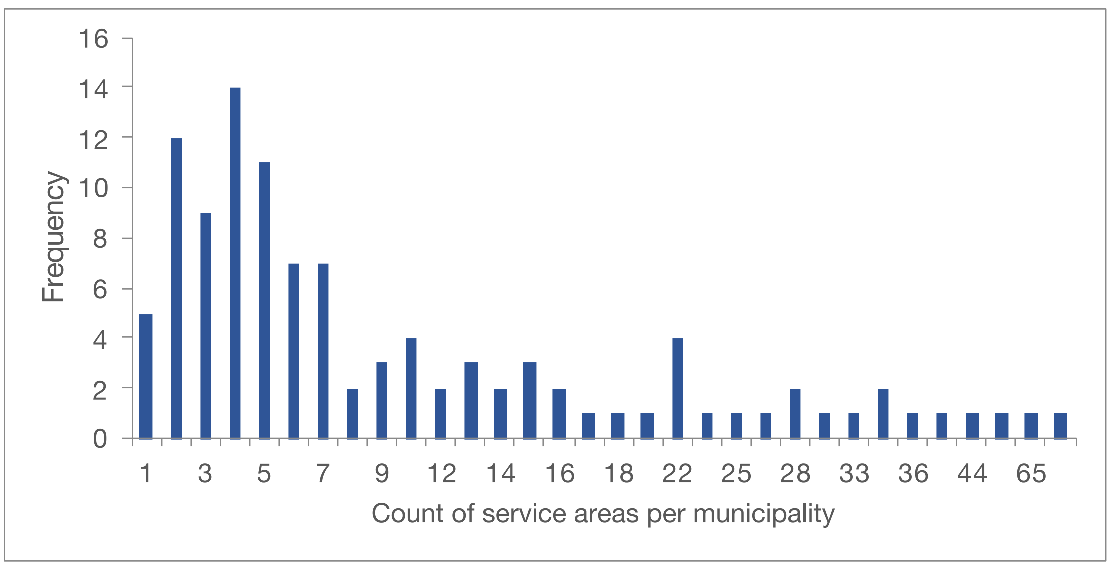


Figure 9 Service area distribution by block group

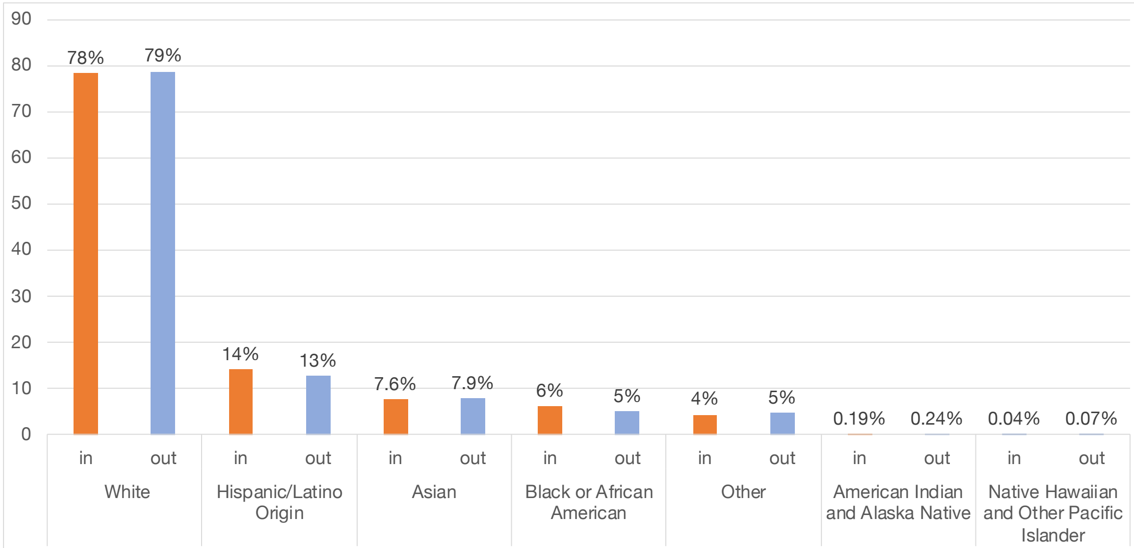


The service areas (i.e., 'inside' block groups) are more densely populated; the average block group has 1,358 more people per square mile, and the median value difference among block groups is almost 2,000 people per square mile. While there is higher population density within the service area, there are slightly more households and more people living outside of the service area (by mean, median and max values) within the municipalities. One can assume that these projects are in more urbanized, densely populated locations while the other remaining 831 block groups on average have slightly more household units and more people.

Race & ethnicity

The racial and ethnic composition of both groups are very similar with the service area having slightly more marginalized racial and ethnic populations; for both groups the White population is around 79 percent of the population and non-White around 21 percent with less than one-percent difference in averages per category. The non-White population in order are as follows: Asian (8%), Black or African American (5-6%), Other (4-5%), Two or More (3%), American Indian and Alaska Native (<1%) and Native Hawaiian and Other Pacific Islander (<1%). The Hispanic/Latino population comprises around 13-14 percent of the total population.

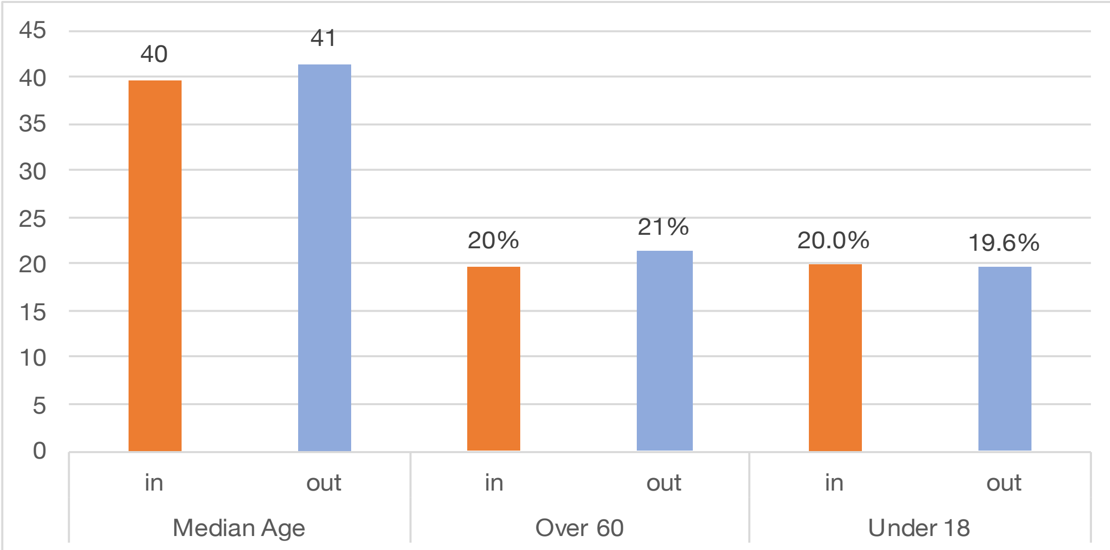
Figure 10 Race and ethnicity composition by mean values



Age

There are slightly larger percentages of people over 60 outside the service areas, however the service areas have a larger maximum value of 67 percent, which may suggest that there are highly concentrated areas of older adults that have access to Complete Streets projects. The maximum value for outside of the service area is at 58 percent, which may be useful to examine further. The under 18 population is nearly the same for within and outside of the service areas at 20 percent for mean and median values.

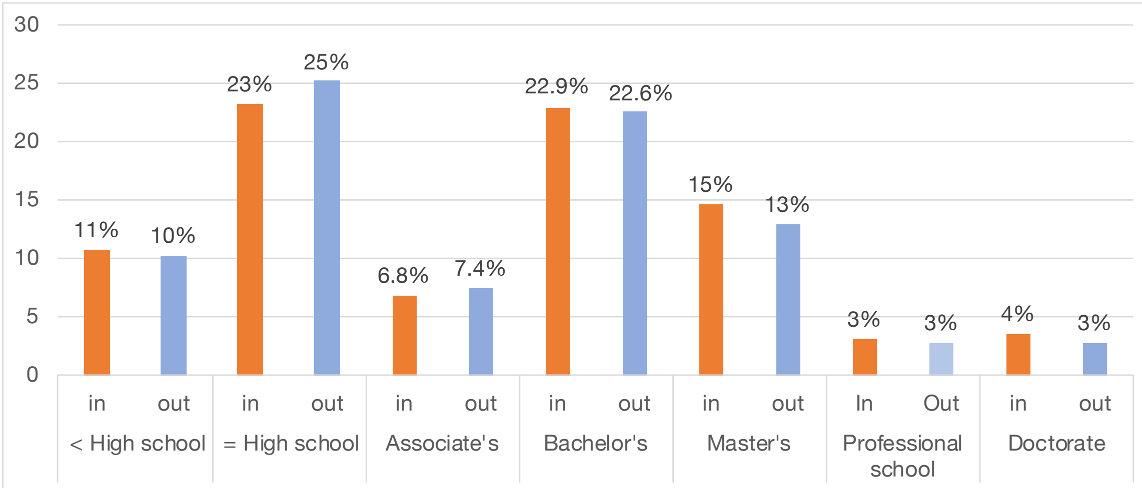
Figure 11 Age composition by mean values



Education

Educational attainment within the service area is slightly greater than that of outside populations. The percentage of attainment at the high school degree level or below is nearly the same for both groups, from around 10 percent below high school and around 23-25 percent with degree or equivalent. There are slightly greater differences among higher education variables with the greatest percentage gap at bachelor's degree or higher (2.8% difference). For both groups, the level of education is as follows: high-school degree or equivalent (23-25%), bachelor's degree (23%), master's degree (13-15%), less than high school or equivalent (10-11%), associate degree (7%), doctorate degree (3-4%), and professional school degree (3%).

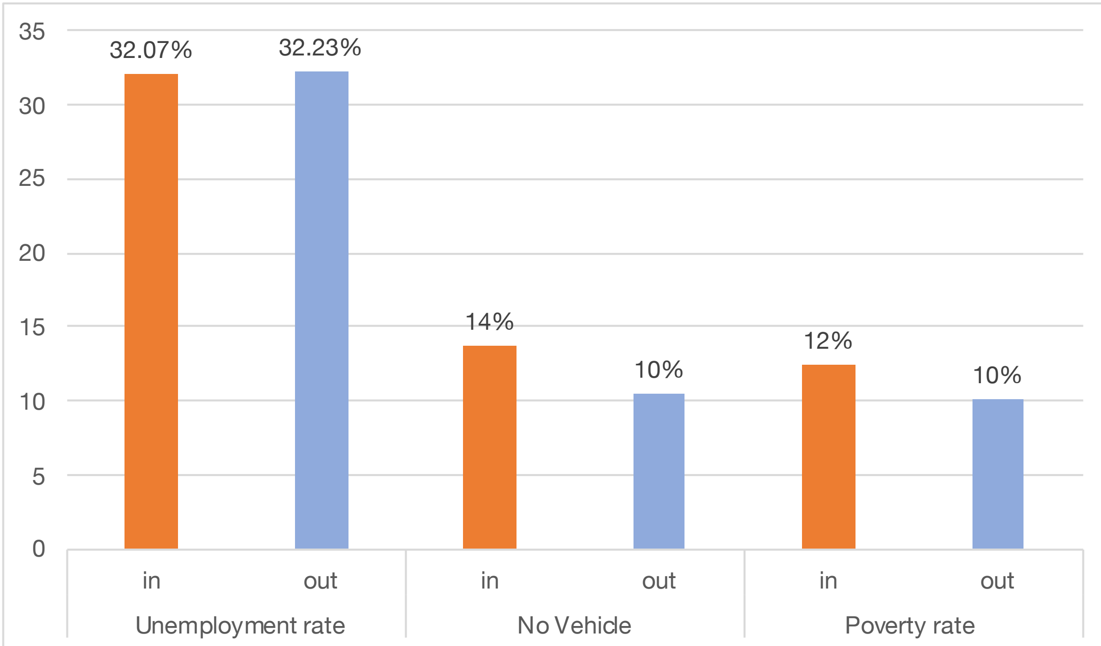
Figure 12 Educational attainment by mean values



Economic Characteristics

The service area has a lower median household income (difference of $2777 average), higher poverty rate (by 2%), and lower vehicle ownership (by 4%). The unemployment rate is nearly the same at around 32 percent. There are high maximum values (>= 80%) for poverty rate and low vehicle ownership among both groups which may prompt further research into whether these variables are significantly related to each other.

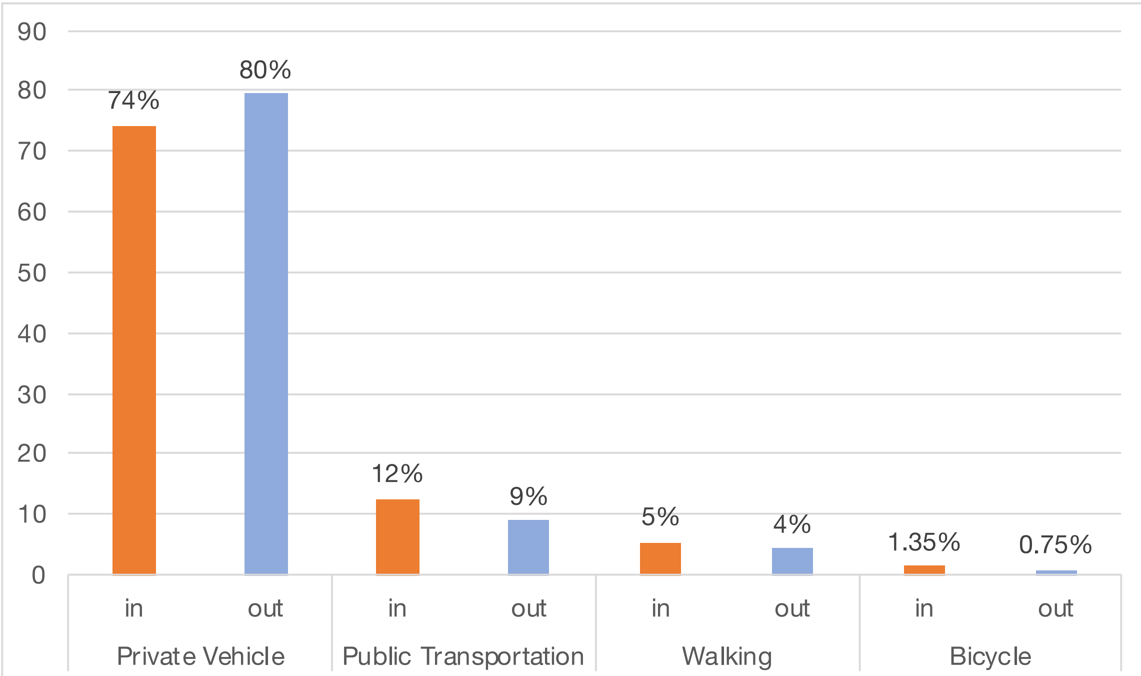
Figure 13 Economic characteristics by mean values



Commuting

The service areas have fewer people commuting to work by private vehicle, and more by public transportation, bicycling, and walking. This, in addition to greater population density and the lower vehicle ownership within the service areas may suggest that Complete Streets have been located in denser areas where it is more likely that people are living closer to places of employment and can commute by public transportation, bicycling or walking and/or people are living in areas with existing infrastructure to support public transportation, bicycling, and/or walking.

Figure 14 Commuting characteristics by mean values

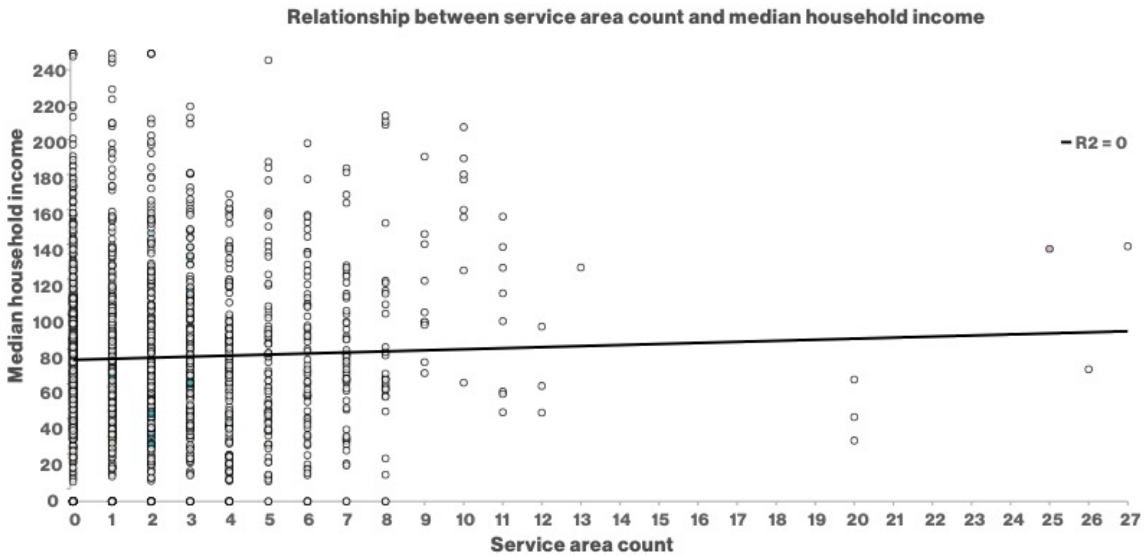


Local Bivariate Relationships

To explore the relationships between Complete Streets and the explanatory variables together, I used the Local Bivariate Relationships tool in ArcGIS Pro which analyzes two variables for statistically significant relationships using local entropy. I used the default parameter settings: a value of 30 for number of neighbors at a 90% confidence level with a False Discovery Rate Correction. After testing service area count with variables of over 60, under 18, no vehicle ownership, non-white, median household income, population density, bachelor or higher education, poverty, unemployment, female, male, and commute by other modes, the Local Bivariate relationships tool identified only one statistically significant relationship with income. While the descriptive statistics of the previous section found a lower average median household income among service areas compared to outside service areas, the local bivariate relationships tool found both negative and positive linear relationships. This suggests that Complete Streets are associated with higher income and with lower income varying across block group throughout the commonwealth.

As shown in Appendix E, the generated maps show Complete Streets are positively associated with income in areas of Bedford, Lincoln, Lawrence and Tewksbury. The negative linear relationships are found in areas of South Hadley, Palmer, West Springfield, Springfield, Plymouth, Tewksbury, Lowell, Lynn and Brookline. This may indicate that more Complete Street projects are located within higher income areas of Bedford, Lincoln, Lawrence and Tewksbury while the inverse is true for South Hadley, Palmer, West Springfield, Springfield, Plymouth, Tewksbury, Lowell, Lynn and Brookline. However, the identified significant areas have a small r-square value of .001 and are only within few block groups relative to the remaining block groups and municipalities without any significant relationships. The scatterplot in Figure 15 illustrates the strength of the relationship and shows that block groups with less than nine services areas have a more equal distribution across income, and block groups with greater count are mixed with high and low income.

Figure 15 Service area count and median household income scatterplot



To identify where low vehicle ownership may be indicative of need or existing infrastructure, I tested the variable of no vehicle ownership with economic variables of income, poverty, and unemployment. The tool found significant positive linear relationships with poverty and significant negative linear relationships with income. The scatterplots of Figure 16 and Figure 17 illustrate strong relationships with r-square values of 0.22 and 0.38, respectively. Figure 16 illustrates that there are for more block groups with low no vehicle ownership and high income than high no vehicle ownership and high income. Figure 17, which replaces the x-axis with poverty, shows that most block groups fall within low no vehicle ownership (less than 30%) and low poverty (under 40% of households), however the outliers of high poverty and no vehicle ownership demonstrate block groups may be useful to examine for project location.

Figure 16 No vehicle ownership and median household income scatterplot

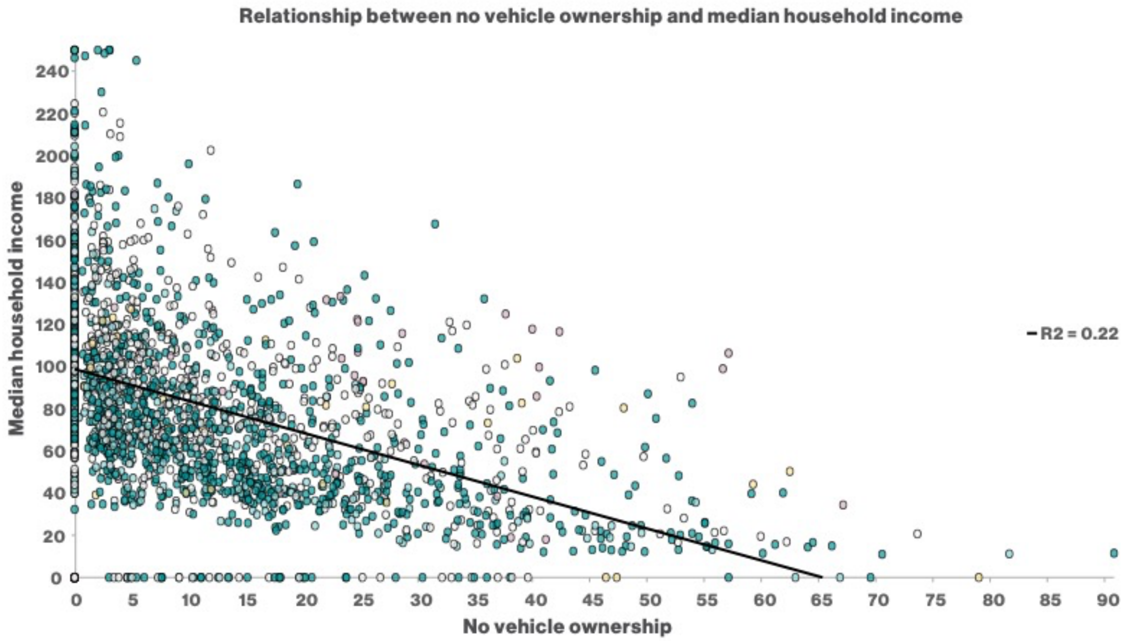
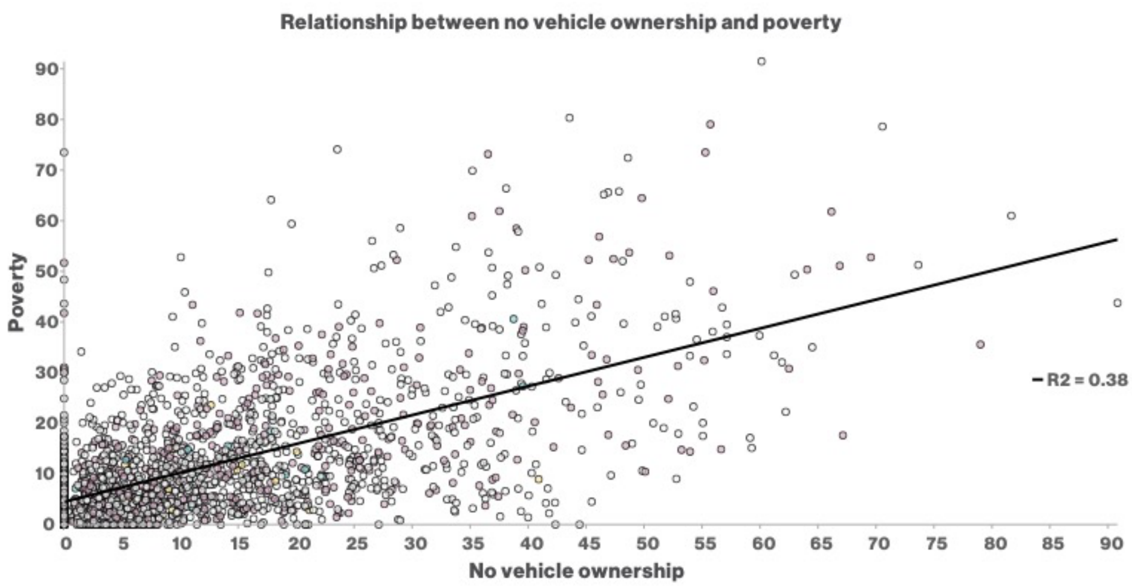


Figure 17 No vehicle ownership and poverty scatterplot



Multivariate Generalized Poisson Regression

To further explore the demographic variables and their explanatory relationship to Complete Streets, I ran a Generalized Linear Regression (GLR) with a Poisson distribution in ArcGIS Pro. Poisson regression methods are widely used within transportation research, particularly in the context of traffic safety for which the distribution of crash data often follows a Poisson or negative binomial regression (Washington et al., 2010; Dereli & Erdogan 2017; Ma et. Al. 2008; Ayati & Abbassi, 2014). Instead of crash data, this study measures a count distribution of non-negative integers by the number of Complete Streets service areas by block group. Further, there is an existing skewed distribution where there are greater numbers of service areas within fewer block groups (see Figure 9). The Poisson regression model assumes the dependent variable, or each observed count, is drawn from a Poisson distribution and assumes the logarithm of its expected value can be modeled by a linear combination of unknown parameters. The results are shown in Table 2 below.

Table 2 Summary of GLR results

Variable	Coefficient [a]	StdError	z-Statistic	Probability [b]	VIF [c]
Intercept	0.456107	0.093315	4.887837	0.000001*	
Over 60	-0.002778	0.002233	-1.244087	0.213468	1.733846
Under 18	0.003769	0.002189	1.721635	0.085136	1.225585
No vehicle ownership	0.012290	0.001577	7.793775	0.000000*	1.903981
Unemployment	-0.001642	0.001861	-0.882147	0.377698	1.574820
Median HH income	0.002013	0.000423	4.753823	0.000002*	1.402937
Population density	-0.008040	-3.496240	-3.496240	0.000472*	1.786017
Non-white	-0.003030	-2.669952	-2.669952	0.007585*	1.650992

Diagnostics

Number of Observations	2078	Akaike's Information Criterion (AICc) [d]:	9483
Average Count	1.85	Deviance Explained [e]:	0.012496
Joint Wald Statistic [F]:	76.05	Prob (>chi-squared), (6) degrees of freedom:	0.000000*

Using the dependent variable of service area count, the model results show varying statistical significance and correlation for the explanatory variables of over 60, under 18, no vehicle ownership, unemployment, median household income, population density, and non-white. Complete streets are positively correlated with no vehicle ownership, populations under the age of 18, and median household income and negatively correlated with unemployment, population density, populations over the age of 60, and non-white households. These relationships suggest that Complete Streets service areas are associated with greater no vehicle ownership, higher median household income, higher populations at age 18 or above, lower unemployment, lower population density, lower non-white households, and lower populations age 60 or above.

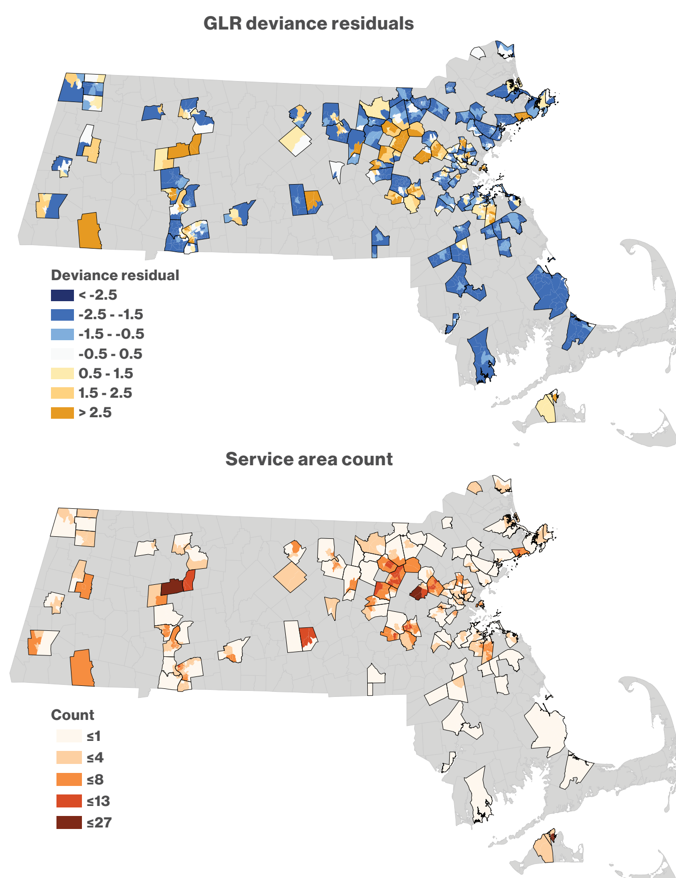
The significant relationships are found for no vehicle ownership, median household income, population density, and non-white. The strongest coefficient is 0.012290 for no vehicle ownership indicating that for an increase in one percent of households having no vehicle, the difference in the logs of expected service area counts would be expected to increase by .0129. The z-statistic, which is the ratio of the coefficient to the standard error of the predictor, is significantly high and indicates possible outliers.

The Joint Wald Statistic [f] is a measure of overall model statistical significance with a null hypothesis that states the explanatory variables in the model are not effective. With a 95 percent confidence level, the value of 74.575145 is not statistically significant and therefore the null hypothesis cannot be rejected. The percent deviance explained [e] value which describes the proportion of the count variable variance that is accounted for by the explanatory variables is 0.012252, in which only 1% of the data is explained.

Deviance residuals

The Generalized Linear Regression model output of deviance residuals is presented in Figure 18. It appears that the over-predicted residuals shown in dark blue are located on the periphery of project locations while the under-predicted residuals shown in dark orange are within block groups that have higher project density. The spatial relationship between the clustering of under-predicted residuals and the project density can be seen in Appendix G which illustrates a hot spot analysis of both service area count and deviance residuals.

Figure 18 GLR deviance residuals



Spatial Autocorrelation: Global Moran's I

Because the generalized linear regression model does not account for spatial autocorrelation between observations, I ran the spatial autocorrelation tool within ArcGIS Pro to apply the Global Moran's I statistic to the deviance residuals. This tool uses feature centroids of the block group polygons in distance computations. Using the default parameters of Inverse Euclidean distance, the results found that the residuals of the above model were significantly clustered, with a Moran's Index of 0.236414, a z-score of 59.578021, and a P-value of 0.00000. Because the p-value *is* statistically significant and the z-score is positive, the spatial distribution of high-count values and low count values in the dataset is more spatially clustered than would be expected if underlying spatial processes were random. Given these results, the null hypothesis, which states that the values associated with features are randomly distributed, is rejected. Thus, the clustered residuals indicate that there may be one or more key independent variables missing from the model. Further, while the spatial autocorrelation is evidence of underlying spatial processes within these models, there remains a question of overcounting bias that may create unreliable results. To address this, the model would have to be manipulated by resampling the input variables, isolating the spatial and nonspatial components of each input variable using a spatial filtering regression method, or incorporating spatial autocorrelation using spatial econometric regression methods, which have not been added to ArcGIS at the time of writing.

CHAPTER 7: DISCUSSION: LIMITATIONS, IMPLICATIONS, RECOMMENDATIONS

Socioeconomic characteristics including age, race, income, employment, vehicle ownership and commuting characteristics were examined to find social and spatial patterns in Complete Streets distribution across 2,078 block groups in 108 municipalities in Massachusetts. Findings within descriptive statistics, local bivariate relationships, and a multivariate regression model show that Complete Streets have greater association with areas of lower vehicle ownership, lower population density, lower unemployment, fewer adults over the age of 60, fewer non-white households, higher median household income, and greater population under the age of 18. The degree to which Complete Streets are associated with socioeconomic status and on what scale vary by analysis discussed in the following sections.

Discussion of findings

The descriptive statistics found slight differences in comparing block groups associated with service areas to block groups outside of the service areas. Averages for service areas were found higher among categories: population density, Hispanic/Latino origin, high educational attainment, non-white (<1% difference), female (<1%), and under 18 (<1%) and lower among total population, number of households, median age, and adults over 60. These findings suggest that on average, all service-area block groups throughout the commonwealth have greater population density, Hispanic/Latino population, high educational attainment, and fewer populations over 60.

The regression models provide different spatial scales with contradictory and complimentary findings. The local bivariate relationships tool provides an exploratory approach to spatially identify block groups with significant relationships and identification of outliers, while the generalized linear regression encompasses all key variables to predict the proximity of Complete Streets service areas to populations with greater need. These models are expected to have varying results due to the differences in statistical parameters and the inherent conditioning of variables in the multivariate model. However, the results of both provide greater insight into small- and large-scale findings.

The local bivariate relationships found both negative and positive relationships between project count and income and between vehicle ownership and economic deprivation. The service area and income relationships found that Complete Streets are significantly associated with higher income and lower income in different block groups. No vehicle ownership was found to be correlated with higher poverty and lower income. However, because significant relationships were not found for many of the block groups in each bivariate regression, the findings are only suggestive of specific areas, whereas the multivariate regression is indicative of relationships found across all block groups with additional variables. The multivariate regression found significant positive relationships with income, which suggests that the bivariate regression may be accurate in specific areas, but as a whole, and with variables of vehicle ownership, population density, non-white households, unemployment, over 60 and under 18, the more conclusive finding is that Complete Streets are associated with higher income. Further, because the bivariate regression found no positive associations of no vehicle ownership and income, it could be inferred that within this dataset, no vehicle ownership is more indicative of lower income rather than urbanity and density. However, as the scatterplot points indicate, the outliers suggest relationships similar to the statistics of the multivariate regression. For the GLR, income and no vehicle ownership were both statistically significant positive coefficients with no vehicle ownership having the strongest value and a significantly high z-score, also indicating extreme outliers. Thus, at the smaller scale local entropy modeling provides, greater need for Complete Streets and transportation infrastructure is identifiable within few block groups that may be worth investigating alongside other factors of equity measurements. At a larger scale, the multivariate model suggests that no vehicle ownership is more correlated with existing Complete Streets and higher income.

The multivariate model results also differ from the descriptive statistics of population variables. While the descriptive statistics show higher averages of non-white population and population density and lower averages for income, the multivariate model results show inverse directions; where the mean values are higher, the association of that variable to project count is negative, and vice-versa. However, the descriptive statistics show the largest differences in no vehicle ownership and commuting modes; no vehicle ownership is four percent greater in association to services areas – and service areas have greater multimodal commuting means. The negative coefficient of population density within the multivariate model likely suggests that service areas are located within places that have existing transportation infrastructure or the built environment to support commuting by public transportation, walking, or biking.

The deviance residuals of the multivariate model can be examined further to identify missing explanatory variables for the most accurate relationship between Complete Streets and their spatial and demographic attributes. Existing infrastructure would be a particularly useful variable to include in the generalized linear model; the association between complete streets and block groups with higher income, lower density, lower vehicle ownership, lower unemployment, and alternative modes of commuting suggest that: a. lower vehicle ownership does not necessarily indicate lower income or economic deprivation, b. lower vehicle ownership and greater averages of households commuting by public and active transportation suggest that these households are located in areas with a built environment that supports not owning or commuting by a private vehicle. Thus, including existing infrastructure such as bus routes or other facilities would provide more context between Complete Streets and a built environment that would support such projects.

The inclusion of property values or economic development attributes might also improve the model. Research has found that transportation infrastructure, including Complete Streets raises property values and increases local investments (Perk et al., 2015; Yu et al., 2018; Hadden Loh et al., 2019; Boarnet, 2017; Racca et al., 2006; Krizek, 2016; Bartholomew et al., 2011; MassDOT, 2016b). Smart Growth America also promotes the economic development benefits from Complete Streets and has reported that property values and investment have increased after project implementation (Smart Growth America, 2015b p.21). Further, in response to the Transportation Bond Bill requirements, MassDOT has encouraged municipalities to require private development to contribute to and integrate with the Complete Streets network through the municipal Complete Streets Policy (MassDOT 2016c, Appendix A).

It is possible that the combination of income and commuting statistics relate more to economic interests rather than equity; if households are not commuting by private vehicle but other modes, they are likely to be residing in areas where transportation infrastructure already exists. Thus, the projects being implemented in these locations may be adding to or improving existing routes or streetscapes where property values are higher – which also relates to higher income households. Additionally, Complete Streets will be located where new development is occurring if municipalities have included requirements within private development review. Inversely, the relationship between income, density, and vehicle ownership may also be a result of what Kramer (2013) found in affordable home ownership being connected to automobile dependency and subsequently separated from access to alternative less expensive modes.

Overall, these findings support the existing Complete Streets and bikeshare research that finds transportation infrastructure located in areas of whiter households, higher employment, and higher education (Smart Growth America, 2017; Hosford, 2018; Shaheen et al., 2012; Shaheen et al., 2015; Fishman et al., 2013). The inferences made of property values having a significant effect on model results may be suggestive Kramer's (2013) findings of affordable home ownership being linked to automobile dependency and lack of access to alternative, less expensive modes.

This research has, on a broad level, provided more understanding of the locations in which complete streets are located in compared to the rest of the population. The results show largest differences of vehicle ownership and commuting means and the largest significance between vehicle ownership and income. The trends across analyses suggest that Complete streets are approved in locations with higher income, fewer people of color, lower population density, greater means of commuting by modes other than private vehicle, and no vehicle ownership. The relationship between higher income, no vehicle ownership and lower population density may indicate that they are not located in dense urban areas, but in places with a built environment that supports no vehicle ownership and commuting by public or active transportation, which is likely in areas with higher housing costs/property values. Additionally, the methods used provide insight into how spatial analysis can provide large- and small-scale assessments of existing project distribution. The local bivariate relationships show there is more to learn from discrepancies in location within smaller regions and municipalities. As seen with no vehicle ownership and high median household income, outliers are suggestive of different stories varying at local scales. Unfortunately, this closer look may not be possible in municipalities with fewer/larger block groups as seen in Western Massachusetts. The lack of spatial granularity emphasizes the need for local knowledge of neighborhood characteristics.

Limitations

Lack of infrastructure context

It is important to note that this study analyzes the Complete Streets projects alone and does not use data for existing transportation infrastructure (i.e., transit and active transportation). For example, while some populations may not have 'access' to complete streets, they may have access to pre-existing infrastructure that was funded by program/s unrelated to Complete Streets, such as bus routes or bike lanes. Future studies would benefit from including this data to understand the broader context of need. Furthermore, this study does not consider equity performance measures of facility quality, safety, cost, level of Complete Streets funding, accessibility to employment or necessary services via active modes. For smaller-scale analysis, additional information would better inform conditions of accessibility.

Lack of spatial granularity and network considerations

While this study uses block groups as the smallest available census boundary, some block groups are larger than a given half-mile buffer and thus the block groups for which data is extracted does not fit neatly into the service area. This is not a completely accurate summation of data because it is characterizing land area outside of the appropriate half-mile distance. Furthermore, the buffers apply a Euclidean distance which does not take into account the real distance to projects; a network-based accessibility method, for example, would use existing road networks and routes to measure how close a household is to a given point or street.

Measure of equity

This study was primarily interested in examining the equity of the geographic distribution of Complete Streets projects in relation to indicators of potential deprivation such as the low-income, low-vehicle households. The variables included in this study do not represent all possible measures of equity including the differences among sociodemographic traits and equity concerns among bicyclists, pedestrians, and transit users. To draw inferences or make conclusions for where to prioritize projects based on equity objectives, these project types should be studied individually. Furthermore, public involvement in the planning process should also be evaluated.

MassDOT/ costs of projects

MassDOT states that costs for pedestrian and bicycle safety infrastructure often vary greatly among regions. This may suggest that more projects have been approved for areas or regions in which projects have been less costly (e.g., places with some level of existing investment). Therefore, project density maps may be indicative of local costs or existing networks and facilities and not solely based on need.

Implications and recommendations for planning

The methods applied in this research and their findings have implications for the processes of funding allocation, prioritization, and implementation assessment within transportation planning and planning more broadly. The rhetoric of equity within planning has become more prevalent within policies and objectives and particularly within Complete Streets language. However, the Complete Streets Program in Massachusetts does not explicitly state desired equity outcomes and thus there are differing measures of equity throughout Massachusetts towns and cities. These findings support similar research that has identified disparities in access to public infrastructure.

With projects having less association with lower-income, non-white, and over 60 populations, planners should investigate the existing infrastructure in these communities to ensure satisfactory conditions of transportation amenities. Furthermore, older populations, which are notably becoming increasingly diverse in terms of race, ethnicity and language, are expected to increase 21% in 2030 (Commonwealth of Massachusetts Executive Office of Elder Affairs, 2017). This projected increase of vulnerable populations indicates that the need for accessible transportation options will be even greater than modeled at present. To ensure equitable access to new infrastructure, these population groups should be engaged with for prioritization and proper outreach should be conducted for their inclusion in the planning process.

The findings of this paper also indicate competing planning interests between equitable outcomes and economic development. Both equity and economic development are promoted and researched outcomes of Complete Streets design and it is probable that communities face challenges maintaining equilibrium between the two. The model results that identify commuting patterns and income in areas of projects support other research findings of Kramer (2013), Frederick (2018) and King (2019) that suggest complex relationships between urban form, transportation infrastructure, and real estate. This further adds to the planning discourse of the intrinsic capitalist relationship between public investments and real estate market fluctuations. A basic and obvious expression of this dynamic is in the use of walk and transit scores to describe property listings; the walkability and transit access are highly valued and thus correlated with higher property values and rental costs. While these investments provide many public benefits, they may be located in areas where existing infrastructure systems already exist or in areas that later become too expensive for the vulnerable populations. Further, Smart Growth America, the organization that founded the National Complete Streets Coalition states that they "work with real estate developers and investors to capitalize on market demand for homes and offices in walkable neighborhoods" (Smart Growth America, n.d.-c). This leads to questions around housing affordability and gentrification which has been briefly discussed in publications by leading transportation organizations such as the Safe Routes to School Partnership. There remains a gap in research that examines how or to what success local governments have addressed such challenges through policy (Safe Routes to School Partnership, 2014).

Equity in prioritization

The results of this paper are not surprising given that transportation infrastructure planning existing is often not driven by equity considerations but rather ridership (e.g., bikeshare systems), traffic demand management, political context, or other priorities. There are increasing efforts in North America to prioritize equity in planning, including that of Complete Streets. However, it is difficult to measure how well or to what extent it is being prioritized if there are no consistent standards set by the agency responsible for funding and construction (in this case, MassDOT). To improve prioritization and evaluation of equity within Complete Streets it is imperative that equity first be defined by funding authorities and by planners responsible for prioritizing. More detailed guidance on how to incorporate equity, or what it means to support needs of all users and abilities, would encourage municipalities to incorporate equity into their prioritization plans, and ensure that projects are equitably distributed not just throughout the commonwealth, but within towns and cities at the neighborhood scale. Explicit language and detailed frameworks would also benefit evaluation and research of how equity is implemented.

It would be desirable to qualitatively analyze the inclusion of equity within Complete Streets projects by studying the planning methodologies and the MassDOT criteria, however at the time of writing it was not feasible due to inaccessible plan documents and unclear criterion. Subsequently, I chose to analyze the physical, quantitative results of the aforementioned background processes through social and spatial methods.

My recommendation for agencies such as MassDOT would be to require more specific and holistic prioritization methodologies of municipalities submitting applications as well as conduct a more robust application process that includes either a municipality's planning analysis or include criteria aside from the municipality's median household income and Environmental Justice applicability. Including additional characteristics aside from Environmental Justice criteria (i.e., minority, income, and English isolation) such as older populations and vehicle ownership, would also benefit an equity analysis. Within research design, this study would also improve by comparing the descriptive statistics between regions or cities within the commonwealth, rather than as a whole (Hosford, 2018; Duran, 2018; Griffin, 2016). This would be more applicable when there are more participating municipalities in the program.

Conclusion

This paper provides a new experimental and exploratory view on the spatial and physical outcome of a Complete Streets program and its relationship to equity in the field of transportation planning. The findings show that projects approved over 2016 – 2019 are located in areas of less vehicle ownership, less density, greater educational attainment, and whiter and wealthier populations. While the analyses are not conclusive, this study provides a combination of statistical and spatial modeling that provide small-scale and larger-scale patterns that suggest inequities in project distribution.

This study adds to the literature by employing a new data set integrating Complete Streets access and various socioeconomic indicators, allowing comparisons across the commonwealth and within municipalities. The descriptive summaries of differences in demographic compositions provide a broad-scale analysis of equity, while analysis of the same data within the regression models provide a nuanced view of equity. The methods applied in this study are not aimed to substitute for local analysis, but rather offer insight in identifying prospective equity opportunities at large and small geographic scales.

Methods such as the ones applied here can be improved and built upon to examine how the physical results of project location relates to their vision and goals according to Complete Streets policy and their prioritization methods. Furthermore, viewing these patterns at a statewide and regional scale may help identify missing gaps or factors that create an imbalance in distribution and/or funding allocation and subsequently provide locations to prioritize for investments.

This spatial analysis identified areas that have low infrastructure (i.e., less Complete Streets) and populations that have historically been underserved. While the Complete Streets program is relatively new in comparison to other transportation programs nationally and within the commonwealth, this analysis can provide as an update as to where investments can be targeted to increase spatial access for different demographic groups in the future. Analyzing patterns from the block group level through mapping clusters may help identify smaller-scale areas and boundaries to consider for investment. Additionally, the inclusion of data such as existing infrastructure and additional characteristics of the built environment could improve models.

Appendix A: MassDOT Complete Streets Application

massDOT – Moving Massachusetts Forward

...unding Program Tier 3 Project Application

...or FY19 Round 2 due to limited available funds.

FY 19

	Leicester	Total Request:		(Must match total of Exhibit B, Preliminary Estimate and not exceed $400,000)	
Name/Title Municipal Contact:	Michelle Buck, Town Planner/Director of Inspectional Services			FY17	FY18
MassDOT District	3	Previous Application (s)?		No	No
Housing Choice Community Designation (see instructions)	No	Previous Award Year(s)?		No	No
Below Median Household Income (US Census Bureau)	NO				

See Dropdown menus for answers Columns H - AD, AH

Municipal VERIFICATIONS	
Yes	Municipality has verified that projects are only on locally-owned roadways. MassDOT-owned roadways are not eligib
Yes	Has the Project scope/infrastructure changed from the Prioritization Plan? If yes, explain reason in Exhibit A.
Yes	Municipality has verified High crash bicycle or pedestrian crashes with MassDOT data, or has described RPA designati
Yes	Municipality has verified School, Seniors and Environmental Justice designations and identified schools/senior centers in Exhibit A.

Part 1: Project Details, Infrastructure Codes and Complete Streets Project Location

Rank	Project Name (Street and Infrastructure Improvement)	Project Description (brief narrative about the project need, condition of infrastructure, and how a network gap or safety issue will be addressed).	Complete Streets Project Type (refer to the Eligible Projects Worksheet)	Project Limits/Location	Project Start Location: X,Y Coordinates (MA State Plane meter)	Project End Location: X,Y Coordinates (MA State Plane meter)
2: Phase 1	Shared use path construction and bike lane on Paxton Street from Main Street to Winslow Avenuel- Phase 1 Northbound (1200 FT)	The construction or reconstruction of pedestrian accommodations is needed on Paxton Street from Main Street to Whittemore Street. On the northbound side of Paxton street from Main Street to Winslow Avenue, new pedestrian facilities are needed. The facility may be constructed in front of utility poles and steep grade in certain locations, narrowing the roadway width slightly (currently >25 feet). Pedestrian access from Town Center to Winslow Avenue is important because the Leicester Middle School and Senior center are located on Winslow Avenue. Paxton Street (Route 56) is a low comfort route for cyclists. For this reason, a 12' shared use path will be constructed on the northbound side of the road and a 5' bike lane will be provided in the southbound direction (roadway layout currently ~28' with additional ROW). A shared use path in one direction and a bicycle lane in the opposite direction would create a high to medium-high comfort loop of Paxton Street, Hyland Avenue, and Winslow Avenue, providing access to the Town Common Area, Primary School, High School, Middle School, Senior Center for cyclists and a high comfort connection for pedestrians. This project will complete the first phase of the full project; the full project would continue north to Whittemore Street. Although only the first phase of the project, it's completion will create a new, high comfort, safe, and ADA accessible connection from Main Street to the Town Commons and up to Winslow Avenue.	P10; B2; B10; P2; P3; P9	Paxton Street from Main Street to Winslow Avenue- Northbound	166448, 888491	166334, 888859
3: Phase 1	Crosswalks along Paxton Street at Winslow Avenue	The existing crosswalks at Paxton Street/Winslow Avenue will be reconstructed for ADA compliance and improved visibility. All new crosswalks and curb ramps will be ADA compliant.	P2; P3, P9	Paxton Street at Winslow Avenue	166337, 888856	
4	Sidewalk and path construction and maintenance throughout Town Commons	This project will reconstruct or provide maintenance to the existing sidewalks and paths that surround and cross through the Leicester Town Common, which is surrounded by the Town Hall, First Congregational Church, Becker College, and the Public Library. Reconstruction of the paths within the Commons on the western side will incorporate switchbacks to accommodate a more moderate grade down to Paxton Street. Sidewalk construction is needed on the eastbound and southbound sides of Washburn Square- this will need to be set back from the street to accommodate existing trees- and along the northbound side of Paxton Street from Main Street to Washburn Square. This project will provide pedestrian access all the away around and through the Common on both sides of all streets. The Town Commons area is within a census tract designated as Environmental Justice for income.	P1; P2; P3; P5; P10	Washburn Square and within the Town Common	166421, 888560	166606, 888501
5	Raised Crossings throughout Town Commons area	The Town Commons area (Main Street, Paxton Street, and Washburn Square) is a key destination in town as the Town Hall, First Congregational Church, Becker College, and the Public Library are situated around the Commons and the Commons itself is a destination for recreation and events. This project will provide a raised crosswalk across Washburn Square from the northern end of the main path through the center of the Commons to the Town Hall building, and will replace existing crosswalks with raised crosswalks at the southeast corner of the Commons across Main Street and east of the Commons at the Becker College entrance across Main Street. ADA compliant curb ramps will be provided for all crosswalks. Both Main Street crossings will be on the east side of the intersections to provide better visibility of pedestrians and adequate spacing between the two crosswalks. The Town Commons area is within a census tract designated as Environmental Justice for income.	P2; P3; P9; S8	Washburn Square at Town Hall, Washburn Square at Main Street, and Becker College at Main Street	166504, 888563; 166608, 888495; 166686, 888502	166648, 888634
6	Bicycle lanes around Town Commons	This project will provide bicycle lanes around the Washburn Square loop. The current roadway is oneway in the eastbound direction; the existing paved width is around 25 feet, which includes a parking lane along the eastbound direction. This project will provide a 6 foot contraflow bicycle lane, leaving 11 feet for the travel lane and 8 feet for parking. Shared use markers will be provided in the direction of vehicle travel. The Town Commons area is within a census tract designated as Environmental Justice for income.	B2; B8	Washburn Square	166423, 888553	166602, 888494
14	Bicycle parking at key locations	Install bicycle racks in Common across from Town Hall building, Middle School, High School, and Primary School. Racks will be installed in highly visible and convenient locations. Estimate assumes one large bicycle rack (10 bikes) at each location.	B3	Town Hall, Leicester Primary School, Leicester High School, Leicester Middle School	166356, 889361; 166505, 888555; 166531, 889248; 166644, 888980	

Part 2: Complete Streets - Safety - Mobility - Equity (Answer Y for Yes or leave Blank)

Rank	Network Gap: Is a Network Gap being filled? See Instructions	Modes Served: Bicycle	Modes Served: Pedestrian	Modes Served: Transit	Modes Served: Vehicle/Freight	Crash Location: Is the project located in a High Crash location? Further discuss the Safety Need in Exhibit A and indicate data source.	Roundabout/Mini Traffic Circle	Crossing Island	Pedestrian Hybrid Beacon (HAWK)	Pedestrian-Activated Warning Device	Road Diet	Lane Narrowing	Pedestrian Signal Upgrade	Sidewalk	Shared Use Path/Separated Bike Lane	On-road Bike Lane	Raised Intersection or Crossing	Intersection Reconstruction	Tighten Curb Radii/ Curb Extension	Transit Improvement	SRTS: Does this project improve safety or accessibility within one mile of a school?	SRFS: Does this project improve safety or accessibility within 1/4 mile of a Senior destination?	EJ: Is an Environmental Justice Population Served?
2: Phase 1	Y	Y	Y												Y						Y		Y
3: Phase 1			Y																		Y		Y
4			Y											Y							Y		Y
5			Y																		Y		Y
6		Y														Y					Y		Y
14																					Y		Y

Part 3: Funding Request, Design Stage, Construction Schedule and Award

Rank	Total Estimated Project Cost	Funding Requested (Must match Exhibit B Preliminary Estimate)	Other Funding Source(s) and Amount (if applicable)	Design Stage: If Design is needed, what stage of design is the project in?	Anticipated Construction Duration (number of months)	Desired Construction Start Date (month/year)	Award: Funded
2: Phase 1	$208,500.00	$208,500.00	$0	Conceptual	9	1/1/19	Yes
3: Phase 1	$17,400.00	$17,400.00	$0	Conceptual	1	1/1/19	Yes
4	$97,200.00	$97,200.00	$0	Conceptual	1	1/1/19	Yes
5	$19,200.00	$19,200.00	$0	Conceptual	1	1/1/19	Yes
6	$8,040.00	$8,040.00	$0	Conceptual	1	1/1/19	Yes
14	$3,200.00	$3,200.00	$0	Conceptual	1	1/1/19	No

Appendix B: Eligible Project Types

Table 1

Eligible Project Types

Traffic & Safety	Ref.	Bicycle Facilities	Ref.
• Pavement markings or signage that provides a new separate accommodation for bicycle, pedestrian or transit modes	$	• Improvement of shared use paths (non-safety related)	$
• Removal of protruding objects (pedestrian path of travel, bicycle, vehicular or transit facility)	$	• Designated bicycle lanes	$
• Pedestrian signal & timing (minor updates)	$	• Bicycle parking fixtures and/or shelters at transit and other locations	$
• Changing pedestrian signal timing (i.e., lead pedestrian interval)	$	• On-street bicycle parking	$
• Radar speed feedback ("Your Speed") signs	$	• Provide bicycle-safe drain grates and other hardware	$
• Reducing corner radii to lower vehicle speeds and/or decrease pedestrian crossing distances	$	• Bicycle boulevards	$
• Additional regulatory signing (for existing regulations)	$	• Bicycle wayfinding signs	$
• Speed humps/speed tables	$$	• Shared lane markings (sharrows)	$
• Street lighting	$$	• Bike route signs	$
• Road diets	$$	• Elimination of hazardous conditions on shared use paths	$$
• Speed attenuation devices	$$	• Designated Separated Bicycle Lane	$$
• Roadway resurfacing or micro surfacing if restriping for new bicycle lanes	$$	• New shared use paths	$$$
• Traffic calming measures	$$	• Intersection treatments (bicycle signals, bicycle detection, bike lane extensions, turn boxes)	$$$
• New Curbing on uncurbed streets.	$$		
• Addition of or widening of shoulders	$$$		
• Roundabouts	$$$		
• Intersection reconstruction – reducing complexity and crossing distance	$$$		
• Intersection signalization (major updates/upgrades & new Installation)	$SS		
Transit Facilities	**Ref.**	**Pedestrian Facilities**	**Ref.**
• Improving transit connections for pedestrians, including: ramps, providing and/or moving crosswalks, signing	$	• Sidewalk repairs (tree roots, uplifted panels, etc.)	$
• Improving transit connections for bicyclists, including: providing secure bicycle parking, signing	$	• Providing ADA/AAB compliant curb ramps	$
• Transit shelter	$	• Detectable warning surfaces	$
• Transit signal prioritization	$$	• Pedestrian wayfinding signs	$
• Bus pull-out areas	$$	• Providing new sidewalks	$$
• Railroad grade crossings improvements (signs, flange way fill, etc.)	$$	• Providing pedestrian buffer zones	$$
• Transit contra-flow lanes	$$	• Pedestrian Refuge Islands	$$
• Park-n-ride facilities	$$	• Curb extensions at pedestrian crossings	$$
• Transit-only lanes	$$$	• Crosswalks	$$
		• Widening existing sidewalks	$$
		• Accessible pedestrian signals	$$
		• New or improved crossing treatments at intersections, midblock, etc. including RRFB's and HAWK signals	$$
		• New pedestrian accommodations at existing traffic signals	$$ $$
		• Interim public plazas	$$
		• Traffic re-routing to create pedestrian zones	
		• Providing medians with ADA/AAB-compliant design	$$$

$	$3-$25 per linear foot or $100 to $1000 per each. Minimal work, no right-of-way actions, environmental checklist only (i.e. signing and striping projects)
$$	$25 to $75 per linear foot; $1000 to $10,000 per each.
$$$	$100 to $250 per linear foot; $10,000 to $50,000 each.
$$$$	$250 to $1000 per linear foot; $50,000 to $100,000 each. Full reconstruction, right-of-way actions, environmental permits required (i.e. full depth reconstruction, new shared-use path)

If a project or element does not appear in the list in Table 1, it may still be eligible for funding. The applicant should provide justification for the decision based upon the classification of comparable projects.

Sources:

Complete Streets Local Policy Workbook; Smart Growth America and National Complete Streets Coalition, August 2012, updated Spring 2013.
http://www.smartgrowthamerica.org/guides/complete-streets-local-policy-workbook/

Accommodating Bicycle and Pedestrian Travel: A Recommended Approach; United States Department of Transportation Federal Highway Administration, May 7, 2012.
http://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/design.cfm

Appendix C
Ineligible Project Types[3]

The following project types are not eligible for Complete Streets funding:

- All projects on facilities where bicyclists and pedestrians are prohibited, such as freeways posted to exclude non-motorized transportation
- Projects done under Minor Vehicle Access Permit or Non-Vehicle Access Permits
- Routine roadway maintenance projects (e.g. pothole patching, crack sealing, joint repair, micro surfacing, chip seals, etc.) Micro surfacing eligible if restriping for bicycle lanes
- Non-roadway maintenance projects (e.g. catch basin cleaning, street sweeping, grass mowing, etc.)
- Bridge maintenance projects (e.g. joint repair, deck repair, superstructure repair, substructure repair, etc.)
- Emergency repairs
- Drainage only projects
- Guardrail only projects
- Landscape only projects
- Signage only projects. Bike wayfinding/bike route signing eligible
- Noise barrier only projects
- Shim/leveling projects
- Vertical construction. Covered bicycle parking shelters and covered bus shelters eligible

[3] Adopted from VTrans CS Program

Appendix D Descriptive Statistics

Category	Measurement Variable	Service Area	Mean	SD	Median	Min	Max	N
Population	Population density (persons/mi.^{2})	In	8,638	9,293	5,275	0	82,919	1,247
		Out	7,281	10,148	3,289	0	79,362	831
	Total Population	In	1,342	635	1,206	0	5,321	1,247
		Out	1,441	673	1,300	0	5,574	831
	Total Occupied Household Units	In	519.4	241.7	470	0	1,583	1,247
		Out	541.3	268.6	477	0	2,275	831
Sex	(%) Female	In	51.68	6.40	51.54	0	95.58	1,247
		Out	51.46	7.13	51.67	0	96.27	831
	(%) Male	In	48.16	6.36	48.45	0	80.59	1,247
		Out	48.42	7.10	48.32	0	100.00	831
Race/Ethnicity	(%) Non-White[a]	In	21.63	18.34	16.93	0	92.80	1,247
		Out	21.14	18.77	15.21	0	89.10	831
	(%) American Indian and Alaska Native	In	0.19	0.88	0.00	0	17.00	1,247
		Out	0.24	0.95	0.00	0	9.34	831
	(%) Asian	In	7.56	9.64	3.95	0	56.29	1,247
		Out	7.93	12.11	3.03	0	89.10	831
	(%) Black or African American	In	6.19	9.75	2.33	0	85.08	1,247
		Out	5.11	8.04	1.99	0	61.18	831
	(%) Native Hawaiian and Other Pacific	In	0.04	0.35	0.00	0	8.19	1,247
		Out	0.07	1.41	0.00	0	40.00	831
	(%) Two Or More	In	3.36	4.68	1.88	0	54.42	1,247
		Out	3.14	5.45	1.59	0	67.77	831
	(%) Other	In	4.29	8.80	0.45	0	71.62	1,247
		Out	4.66	9.80	0.35	0	56.98	831
	(%) White	In	78.21	18.59	83.00	0	100.00	1,247
		Out	78.74	18.95	84.79	0	100.00	831
	(%) Hispanic/Latino Origin	In	14.08	20.47	5.08	0	100.00	1,247
		Out	12.74	21.26	4.24	0	100.00	831
Age	Median Age	In	40	9	40	0	74	1,247
		Out	41	9	42	0	70	831
	(%) Over 60	In	19.79	9.48	18.66	0	67.07	1,247
		Out	21.35	9.88	20.53	0	58.06	831
	(%) Under 18	In	19.95	8.26	19.77	0	47.16	1,247
		Out	19.60	7.99	19.85	0	44.96	831
Educational Attainment	(%) < High school	In	10.78	11.57	6.68	0	83.54	1,247
		Out	10.30	10.56	6.91	0	72.04	831
	(%) = High school[b]	In	23.22	12.68	23.51	0	69.24	1,247
		Out	25.15	12.19	25.31	0	67.38	831
	(%) Bachelor or Higher	In	41.12	22.10	39.71	0	93.29	1,247
		Out	38.35	19.91	35.92	0	100.00	831
	(%) Professional school degree	In	3.17	4.16	1.77	0	32.43	1,247
		Out	2.80	4.00	1.36	0	27.83	831

Educational Attainment Cont.	(%) Associate's	In	6.85	4.73	6.13	0	32.32	1,247
		Out	7.44	4.62	7.07	0	26.18	831
	(%) Bachelor's	In	22.87	11.18	23.07	0	57.72	1,247
		Out	22.62	10.55	22.86	0	53.60	831
	(%) Master's	In	14.60	10.60	12.83	0	67.23	1,247
		Out	12.97	9.87	10.99	0	86.36	831
	(%) Doctorate	In	3.65	5.15	1.64	0	32.61	1,247
		Out	2.76	4.41	1.09	0	30.00	831
Economic Characteristics	($) Median HH income	In	79,029	46,374	72,263	0	250,001	1,247
		Out	81,806	40,169	80,379	0	250,001	831
	(%) Unemployment rate[d]	In	32.07	11.24	31.05	0	82.67	1,247
		Out	32.23	10.89	30.85	0	100.00	831
	(%) Poverty rate	In	12.47	13.19	8.20	0	91.49	1,247
		Out	10.11	11.63	6.33	0	80.33	831
	(%) No Vehicle[e]	In	13.63	14.13	9.30	0	90.83	1,247
		Out	10.41	12.79	5.67	0	79.01	831
Means of Transportation to Work	(%) Private Vehicle[f]	In	74.21	19.37	79.37	0	100.00	1,247
		Out	79.54	19.05	86.22	0	100.00	831
	(%) Public Transportation[g]	In	12.46	13.34	7.98	0	71.04	1,247
		Out	8.86	11.36	4.51	0	70.00	831
	(%) Bicycle	In	1.35	3.38	0.00	0	48.96	1,247
		Out	0.75	2.26	0.00	0	21.27	831
	(%) Walking	In	5.38	8.70	2.00	0	75.00	1,247
		Out	4.21	8.99	0.00	0	72.00	831

[a] All non-Hispanic races other than White including "two or more" and "other"

[b] Includes GED or alternative credential

[c] Includes degrees: Professional, Associate, Bachelor, Master, Doctorate

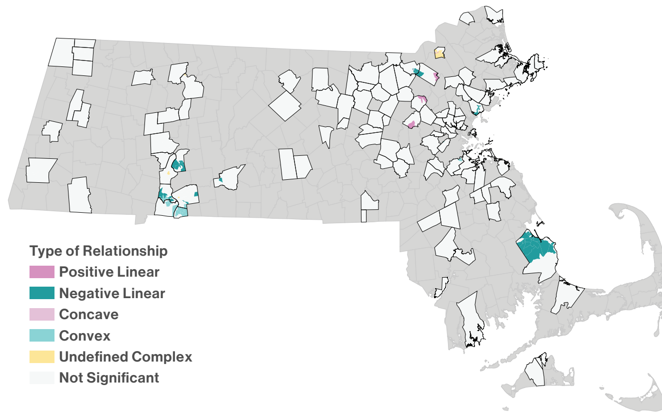
[d] Individuals with income in the past 12 months below poverty level

[e] Occupied households (rented and owned) with no vehicle available

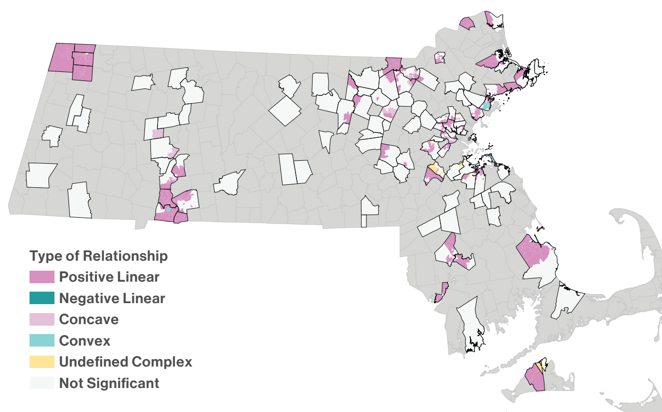
[f] Includes car, truck, or van

[g] Includes bus, streetcar, subway, railroad, ferryboat and excludes taxicab

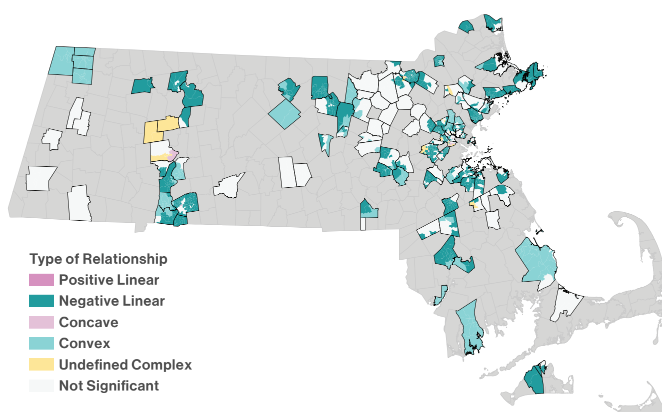
Service area count + median household income

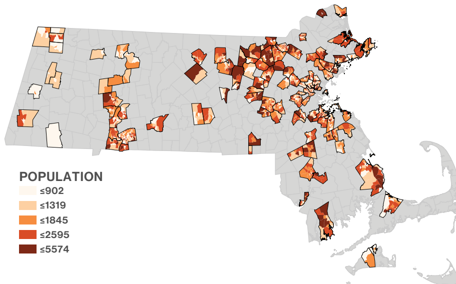


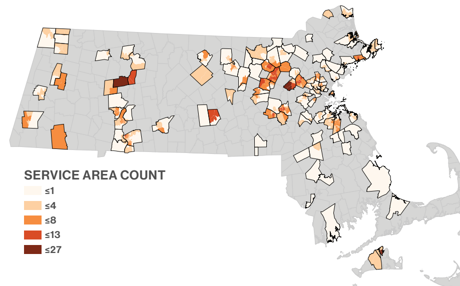
No vehicle ownership + poverty

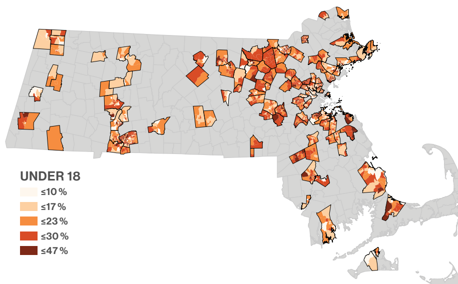


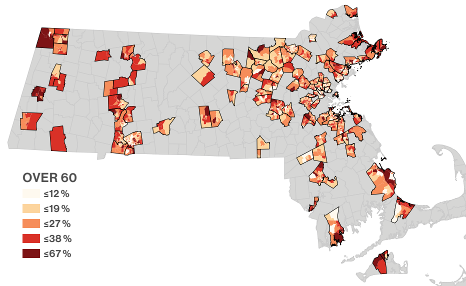
No vehicle ownership + income

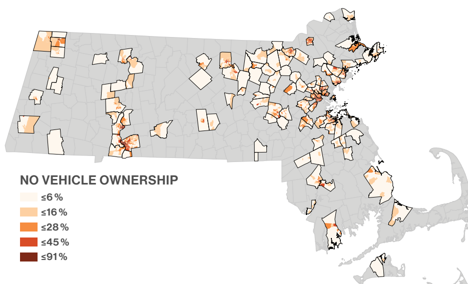


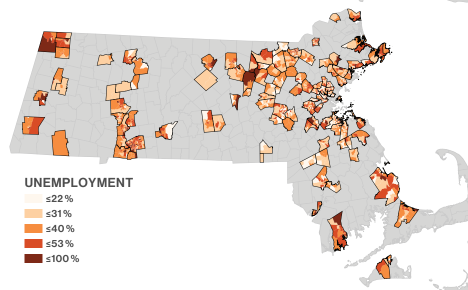

POPULATION
≤902
≤1319
≤1845
≤2595
≤5574

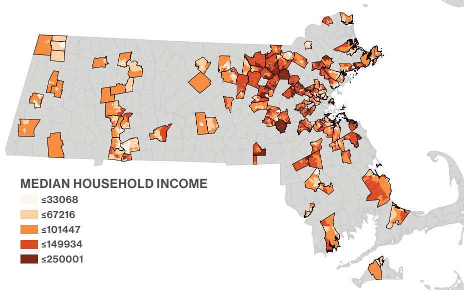

SERVICE AREA COUNT
≤1
≤4
≤8
≤13
≤27

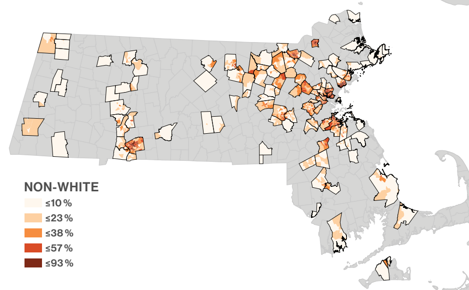

UNDER 18
≤10 %
≤17 %
≤23 %
≤30 %
≤47 %

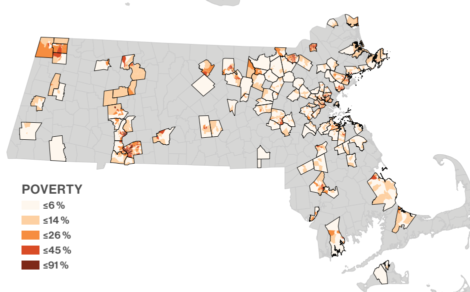

OVER 60
≤12 %
≤19 %
≤27 %
≤38 %
≤67 %


NO VEHICLE OWNERSHIP
≤6 %
≤16 %
≤28 %
≤45 %
≤91 %


UNEMPLOYMENT
≤22 %
≤31 %
≤40 %
≤53 %
≤100 %

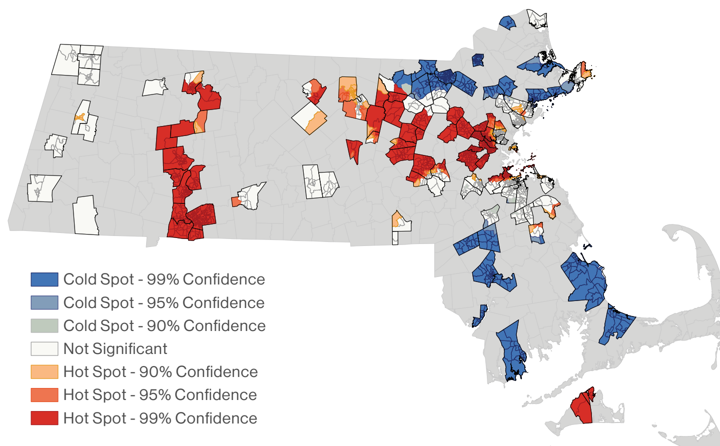

MEDIAN HOUSEHOLD INCOME
≤33068
≤67216
≤101447
≤149934
≤250001


NON-WHITE
≤10 %
≤23 %
≤38 %
≤57 %
≤93 %

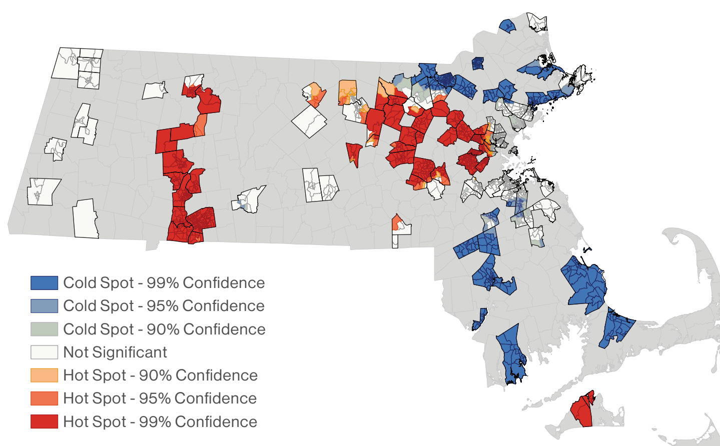

POVERTY
≤6 %
≤14 %
≤26 %
≤45 %
≤91 %

Appendix G Hot Spot analysis

GLR deviance residuals



Service area count



Using the GLR model to examine deviance residuals, I have identified over- and under-predictions and used the residuals in a hot spot analysis. Spatial clustering of low deviance residual values appears in southeastern Massachusetts while clustering of high deviance residual values appear in eastern Massachusetts outside of the Boston metropolitan area and along the route 91 corridor within the Pioneer Valley.

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