EVALUATING CARSHARING POTENTIAL: DEVELOPING TRANSPORTATION OPTIONS FOR THE FUTURE

By

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To my friends and family

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BBL	Borough Block Lot
DCP	New York City Department of City Planning
DoITT	New York City Department of Information Technology and Telecommunications
FHWA	Federal Highway Administration
GIS	Geographic Information System
NACTO	National Association of City Transportation Officials
NYC	New York City
NYCDOT	New York City Department of Transportation
PLUTO	Primary Land Use Tax Lot Output
POD	Point of Departure
SOV	Single Occupant Vehicle
TCRP	Transit Cooperative Research Program
TDM	Transportation Demand Management
TRP	Transportation Research Board
VMT	Vehicle Miles Traveled

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Carsharing, which is defined as the provision of hourly car rentals by non-profit or for profit organizations, has grown rapidly over the past decade, with 26 carsharing organizations (CSOs) reporting 560,572 members in 2011, compared to 5,377 in 2001. Carsharing has demonstrated that its members reduce automobile ownership, with 21% of carsharing members reporting that they gave up a primary or secondary vehicle after joining carsharing according to a Transit Cooperative Research Program (TCRP) report. This—along with the observation that members reduce their distance driven, reduce private vehicle costs, and use modes such as walking, bike, and transit more often than others—has started to convince transportation officials that carsharing may have a role in the management of transportation demand. However, carsharing's niche is limited typically to multimodal urban locations and college campuses where the ability to live without a car exists as a result of good transit service and the presence of walkable environments. In these areas, it still may not make sense to offer blanket incentives to carsharing organizations across an entire district or city, but to do so in specific overlay zones that offer a carshare-supportive environment. This thesis creates a carshare-

supportive zoning overlay that supports carsharing based on a suitability analysis done in Brooklyn, NYC. The suitability analysis informs the analysis of potential market sheds for carsharing, and provides the basis to create policy overlay areas for either the provision of on-street parking, parking reductions to developers, or other forms of municipal support in conjunction with carsharing.

CHAPTER 1
INTRODUCTION

In the North American context, conventional parking policies—such as minimum parking requirements for off-street parking and underpriced on-street parking—have operated as subsidies that often encourage the use of automobiles (Shoup, 2009; Weinberger, 2009; Guo, 2013). These conventional parking policies have created an oversupply of parking in many cities, contributing to climate change, congestion, higher development costs, and reduced urban densities—minimizing the feasibility of other modes of travel (Weinberger et al.., 2012; Shoup, 2009; Weinberger, 2009). While other parking policies such as alternative parking regulations and pricing policies that are more supportive of multimodal transportation patterns have emerged, they have been implemented fairly selectively (Shoup, 2009; FHWA, 2013; Engel & Passmore, 2010). One issue with new forms of parking management and even some transportation policies is that they tend to be politically controversial; they make automobile usage more expensive by pricing a good that many expect to be free (Litman, 2013; Shoup, 2009). Within the field of transportation policy, carsharing—the provision of hourly car rentals by non-profit or for profit companies—has gathered increasing attention as an element of parking and transportation demand management (TCRP, 2005; Engel & Passmore, 2013). Carsharing has been shown to have numerous benefits to both society and carshare members: reduced transportation costs; reduced parking demand, as carshare members give up vehicles; reduced vehicle miles traveled (VMT); and reduced greenhouse gas emissions and energy consumption (TCRP, 2005; Schwieterman & Bieszczat, 2012; Martin & Shaheen, 2011b). Additionally, carsharing has a complementary effect on other transportation demand management and parking policies by improving their effectiveness and working to accommodate transportation needs of transportation system users (FHWA, 2013; Ter Schure et al., 2012). Many municipalities have worked towards incorporating carsharing into their transportation policies by providing various levels of support for carsharing operators or their partners (TCRP, 2005). While various policy incentives can be provided to carsharing operators, one relevant to planners is the use of planning and parking support mechanisms, such as providing reduced parking requirements to developers who provide carsharing vehicles on their sites (Engel & Passmore, 2013). One concern with providing developers parking reductions in exchange for providing carsharing parking is that if carsharing service were discontinued in the development, then a parking shortage could result (Engel & Passmore, 2010). This type of concern spreads to other forms of carsharing support in that incentives could be abused if carsharing is incentivized in locations where the existing market conditions for carsharing do not exist, making tailoring carsharing policy to local conditions incredibly important (TCRP, 2005; Engel & Passmore, 2013). As a result, many municipalities have made the incentives provided to carsharing operators and developers tiered so that locations that have the sufficient conditions to support carsharing can receive higher levels of support, and those that do not have sufficient conditions receive less support or none at all (Engel & Passmore, 2013; TCRP, 2005; Shaheen et al., 2010). The idea that policy for carsharing should be tailored to locations where there are sufficient conditions to support its existence informs much of the basis for this thesis and its recommendations.

Research Question

One concern with the reduction of parking requirements is that if carsharing vehicles were to leave, parking shortages could result from developments being underserved (Engel & Passmore, 2013). This makes understanding the existing market conditions for carsharing very important before setting any carshare supportive policies in order to avoid abuse of incentives or to avoid unintended consequences such as parking shortages and spillover (Engel & Passmore, 2013; TCRP, 2005). This thesis uses existing literature to develop a suitability model designed to map the existing extent of the potential carsharing market to inform policy recommendations related to supportive parking policy in locations that can potentially support carsharing. The existing conditions of environments currently supporting carsharing are used to inform policy zone creation by limiting carsharing policy to locations where carsharing is likely to be successful or at least find sufficient conditions to prevent unfortunate relocation.

The Study Area: Brooklyn

Kings County (Brooklyn) was chosen for the study area because it is a relatively dense transit-served county that has both areas of high carsharing potential and areas that might not have the market conditions to support it (TCRP, 2005; Google Maps, 2013). Additionally, a sizable number of carsharing PODs, owned by the two largest carsharing operators used in this study—Zipcar and Enterprise Carsharing—are already located in Brooklyn (Google Maps, 2013).

CHAPTER 2
LITERATURE REVIEW

Parking supply and demand management provides a policy environment in which carsharing can be a part of the policy mix. Conventional parking policy, which ensures that adequate parking is available to all drivers, tends to provide incentives to drive and consumes large amounts of urban space. Carsharing can be seen as a part of parking supply and demand policies that—through the use of a variety of incentives and disincentives, including transportation demand management policies and alternative parking requirements—collectively improve the efficiency of parking supply and provide demand management. This literature review starts out with background relating to issues of parking and parking management in urban areas within the North American context. It covers conventional parking policy and alternative methods of parking management, and then transitions into what carsharing is and its role in the parking and transportation demand management toolbox. Within this review of carsharing, policies supporting carsharing are reviewed; specifically, supportive parking policies are reviewed in detail, along with the concerns and risks they pose.

Conventional Parking Policy

While the planning profession has been changing its outlook on parking within the last decade, planners previously adopted a paradigm that government intervention was required to ensure that destinations provided an adequate supply of parking (Guo, 2013; Shoup, 1997). Historically, justification for such policies has been to prevent spillover parking, where motorists park at nearby establishments or the street if a land use does not supply enough free off-parking (Shoup, 1999). This parking spillover and its associated problems can cause congestion on local streets when drivers cruise to find open parking spots (Shoup, 1999; Cutter & Franco, 2012). With increased congestion and parking that is difficult to find, businesses could lose customers, who may no longer visit due to congestion and a lack of parking (Shoup, 1999; Cutter & Franco, 2012).

To avoid spillover, many cities have set minimum parking requirements that require a certain number of off-street parking spaces to accompany each land use for new construction of redevelopment (Shoup, 1999). Studies that look into how most parking requirements are set find that the two most frequently cited methods are surveys of nearby cities and consultation of the Institute of Transportation Engineers (ITE) handbooks (Shoup, 1999).

When surveying the requirements of nearby cities, planners base their recommendations on what other cities have required for their parking (Shoup, 1999). However, as the Planning Advisory Service pointed out in 1971, this assumes other areas know what they are doing in setting parking requirements, introducing the risk of repeating another person's mistakes (Shoup,1999). In the case of consulting the ITE Parking Generation Handbook, more objective data is provided in the form or reported parking generation rates based on surveys of peak parking occupancy by transportation engineers (Shoup, 1999). However, as a source of information, ITE parking generation rates have been criticized as being inflated for a few reasons. The first reason is that the sites that are considered to have ideal conditions for observation tend to have ample, convenient, and free parking, automatically inflating survey results by making observations in almost exclusively automobile-served locations (Shoup, 1999; Shoup, 2009). Additionally, the survey data provided in the parking generation handbook does not provide key information about the context of the surveys, such as where and why they are conducted, how long the observation period was, or even how long peak occupancy lasted (Shoup, 1999). Finally, the surveys do not provide information about off-peak parking occupancy, leaving an important aspect of parking out of planners' recommendations (Shoup, 1999). Based on either other cities parking requirements or ITE parking generation rates, cities set their parking requirements for each land use by requiring some number of parking spaces per a unit of measure, such as the number of commercial square footage or the number of units in an apartment (Shoup, 1999; McDonnell et al., 2010). These requirements are based almost exclusively on the land use type combined with the building square footage or general capacity to determine the parking needs (Engel & Passmore, 2010). A severe shortcoming of these requirements is that they do not take into account other factors that impact parking demand, such as walkability, transit proximity, demographics, pricing, and other factors (Engel & Passmore, 2010; Steiner, 1998)

In the case of on-street parking in many major cities, a similar trend is found. On-street parking is often provided at little to no cost, relative to more expensive off-street parking (Shoup, 2006). In 20 major cities in the United States, on-street parking costs 20% of the cost of off-street parking (Shoup, 2006). One of the highest prices observed was only $2.00 (Shoup, 2006). While one would think that on-street parking should be the same price of off-street parking to correct this imbalance, this is incorrect because studies have shown that on-street parking and off-street parking are not perfect substitutes (Kobus et al., 2013). In fact, a parking study looking at data from the central business district of Almere in the Netherlands found that on-street parking had a price premium above off-street parking in the range of € 0.37 to € 0.60 (Kobus et al., 2013).

Consequences and Costs of Minimum Parking Requirements

The consequences and costs of these conventional parking policies, such as minimum parking requirements, have received a large amount of documentation and study within the last decade (Shoup, 1999; Litman, 2013). The first and most direct is the cost of providing parking for developers, businesses, and governments (Shoup, 1999). The costs in terms of land acquisition, construction, and maintenance for parking can vary by location and parking type (Shoup, 1999; Litman, 2013). Looking at parking at UCLA, Shoup calculated the cost of the garages constructed, finding the costs to be substantial, that they increased over time as the campus increased in density, and that the land became more valuable as it became more scarce (Shoup, 1999). For example, the average cost in 1994 dollars of parking structures in the 1960's was $12,400 per space of parking added to parking supply, while the average cost in 1994 dollars of structures built since 1977 was $23,600 per space added to parking supply (Shoup, 1999). This is consistent with Litman's estimates of the typical total annual cost of parking facilities based on their land costs, construction costs, and operation and maintenance costs in 2007 dollars annualized over 20 years for various types of facilities (Table 2-1) (Litman, 2013). The cost estimates shown illustrate that as the intensity of urban development increases and the types of parking facilities employed increase in size, the cost of parking generally increases as well (Litman, 2013).

If parking requirements are binding, they can increase the cost of development significantly, especially in high-density urban locations where each additional parking space has a higher marginal cost (McDonnell et al., 2013; Cutter & Franco, 2012). This higher development cost is bundled into the cost of units produced, so that each renter or homeowner faces the cost of parking, regardless of whether or not they utilize it (McDonnell et al., 2013; Cutter & Franco, 2012). For example, a cross-sectional study looked at non-residential property sales from 1996-2005 in Los Angeles County, using an analytical model looking at buildings built between 1976 and 2006 (a period where the understanding of parking regulations is well known) (Cutter & Franco, 2012). What they found was that the marginal value of land plus construction costs of parking were $21/square foot more than the marginal value added by parking (Cutter & Franco, 2012). Thus, while the value added by parking was positive, it was clear that minimum parking requirements imposed an opportunity cost on developers and supports the assertion that parking minimums significantly distort land use decisions (Cutter & Franco, 2012). Based on these results, the authors put the deadweight loss in development and other spending due to minimum parking requirements in Los Angeles County for suburban properties on the order of $1.5 billion during the study period (Cutter & Franco, 2012). This number assumes that externalities related to congestion, environmental externalities, and parking spillover net out to zero, because the calculation is simply based on the total square footage of parking provided for studied properties multiplied by the $21 opportunity cost per square foot of parking that the requirements imposed (Cutter & Franco, 2012). These requirements thus increase development costs, pushing up the cost of housing, and reducing its affordability (Cutter & Franco, 2012; Weinberger et al., 2009).

In addition to high development costs, minimum parking requirements increase driving and vehicle ownership through a reduction of the marginal cost of both driving and owning a vehicle, caused by increasing the transportation supply (Weinberger et al., 2009; Shoup, 2005; Guo, 2013). One study, which looked at how parking influences automobile ownership by corresponding local parking supply from 770 respondents from a regional travel survey in New York City, found that parking can heavily influence the decision to own a car, often outperforming household income and demographic characteristics (Guo, 2013). Another study looking at the influence of parking on travel behavior found that census tracts with a high availability of on-site residential parking in New York City had increased journey to work trips made by automobile even between origin and destination pairs that are well served or very well-served by transit (Weinberger, 2012). Another study looking at how parking ease effect (convenience of off-street parking access) influences travel behavior in New York City confirms the impact of parking on travel behavior (Guo, 2013). Based on the results from a travel survey and parking data, the author found that parking ease effect made up 7.5% of the VMT for all car-owning garage households who used cars on the survey day (Guo, 2013). The changes in travel behavior can have a large impact in the aggregate, as one study showed by modeling how parking requirements will influence travel behavior and car ownership based on existing data in New York City (Weinberger et al., 2009). With New York City projecting the city to grow by 1 million new residents between 2000 and 2030, the city projects there will be a need for an additional 265,000 housing units (Weinberger et al., 2009). Modeling New York City under a likely moderate and medium density scenario, the study found that the availability of off-street parking from parking requirements in New York City would lead residents of new developments to be 42% to 49% more likely to own cars than New York City denizens in 2000 (Weinberger et al., 2009). On the basis of that increased ownership rate, the authors estimate an addition 1.09-1.15 billion VMT, contributing an estimated additional 430-454 metric tons of greenhouse gas emissions (Weinberger et al., 2009). As a contributing factor, parking requirements contribute to decreased resultant residential and commercial densities by consuming more land per unit of development (Cutter & Franco, 2012). With lower resultant densities, auto-dependence is encouraged even further by increasing the distances between destinations, making other modes of transportation—such as walking, biking, and transit—less feasible (TRB, 2009; Shoup, 2005). With higher levels of driving and lower use of less impacting modes, energy consumption and transportation-related greenhouse gas emissions also increase (Weinberger et al., 2009; TRB, 2009). Higher levels of parking from parking requirements also contribute to increase land consumption, infringing on agricultural and conservation land (Davis et al., 2010). Additionally, parking lots are significant sources of non-point pollution as a result of its contribution to cities' coverage of impervious surface area, which contributes to storm water runoff (Davis et al., 2010). A study looking at county non-point pollution found that, in locations downstream from parking lots, phosphorus and nitrogen losses increased by 200%, while heavy metals, and other ecologically damaging contaminants increased by even larger percentages compared to predevelopment levels (Davis et al., 2010). The consequences of parking oversupply had led to new policy paradigms in terms of parking policy and management, with many of the tactics in the planning realm focusing on parking pricing, flexible parking requirements, and other demand management measures that are introduced in the next section (Shoup, 1999; FHWA, 2012; Engel & Passmore, 2010).

Consequences and Costs of Conventional On-Street Parking Policy

The underpricing of on-street parking creates a situation where on-street parking becomes an example of "tragedy of the commons," in which individuals will overexploit a "free, open access, yet rivalrous property without considering the effect on each other and society as a whole" (Gou & McDonnell, 2013, pg. 186). Consequently, drivers will often cruise in their vehicles until they find an open parking space (Shoup, 2006; Gou & McDonnell, 2013). Cruising for parking creates a mobile queue for a parking space, generating additional traffic and congestion (Shoup, 2006; Gou & McDonnell, 2013). Various studies have aimed to estimate how much time drivers spend searching for on-street parking and how much traffic can be attributed to it by looking at videos of traffic flows and by interviewing drivers (Shoup, 2006). Depending on the study and location, the resultant estimates range from 8 -74% of traffic; average search times to find an on-street space range from 3.5-14 minutes (Shoup, 2006).

In the case of residential on-street parking, specifically on-street parking in primarily residential neighborhoods, the parking is often reserved only for residences by residential on-street parking permits (Guo, 2013). For example, residential parking permits in New York City are given to residents to reserve the parking for them exclusively and to prevent the intrusion of non-residents, reducing residents' cruising for on-street parking (Guo, 2013). This does two things simultaneously: it reduces the shared nature of residential on-street parking by decreasing competition for on-street parking spaces and increases the certainty that the resident will find on-street parking by making it more convenient for them to find parking at a specific place and time (Guo, 2013). The same study, which looked at how parking convenience from off-street parking influences travel behavior in New York City, also looked at how the increased certainty of on-street parking influences travel behavior (Guo, 2013). Based on the results from a travel survey and parking data, the author found that parking certainty made up 10% of the VMT for all car-owning on-street households who used cars on the survey day (Guo, 2013).

Parking Management: Alternative Parking Requirements, Pricing, and Complementing Programs

As the problems associated with parking requirements and auto-dependent communities have gathered more attention, new methods of evaluating how parking policy should be set and determined have also gathered attention as well (Engel & Passmore, 2010; Shoup, 1999).

Alternative Parking Requirements:

Alternatives to setting parking requirements based on capacity and land use have seen increasing use, along with other measures that seek to increase parking facility efficiency (Litman, 2013; FHWA, 2013; Engel & Passmore, 2010). A variety of policies encourage more efficient parking policies through either reduced parking requirements, increased parking turnover, or reserved parking for higher value uses (Litman, 2013).

- Parking maximums: are upper limits that are placed on the parking supply by limiting the number of parking spaces at a development site per some unit of measurement, such as square footage or residential units (Litman, 2013; DCP, 2011). This is often done in downtown locations to support more pedestrian- and transit-friendly environments (Litman, 2013). For example, New York City removed its parking requirements and established parking maximums in the Manhattan Core (Community Districts 1-8) in 1982 in order to limit future parking provision in the business district (DCP, 2011).
- Area Based Requirements: this type of regulatory structure creates different zones created by the municipality, with each zone having different parking requirements (Engel & Passmore, 2010). A possible example of this type of regulations would be transit overlay districts, which provide reduced minimum or maximum parking requirement ratios for land uses located in special districts

along transit corridors, with the geography being determined by the municipality (DCP, 2011). The basis for this regulation is that because there are more transportation options, fewer parking spaces are needed, allowing the districts to often be employed to support transit oriented development (DCP, 2011). While this type of area-specific parking requirement is a blunt proxy for identifying factors that affect parking demand, they can be effectual and require little institutional change to implement (Engel & Passmore, 2010). Other area-specific parking requirements can complement transit overlay districts, but as more districts are added, the complexity of the zone system increases, along with the difficulty of managing it when changes become necessary (Engel & Passmore, 2010)

- Shared Parking: while technically a form of flexible parking requirements, shared parking reduces parking requirements by allowing parking spaces to serve multiple users or destinations that have different peak demands at different times (DCP, 2011; Engel & Passmore, 2010). This is one of the more commonly employed forms of flexible parking requirements (Engel & Passmore, 2010).

- Flexible Parking Requirements: aim to tailor parking requirements so that they reflect actual parking demand by creating adjustment factors for parking requirements that are linked to variables that influence parking demand, such as the presence of high densities, mixed-use development, transit accessibility, off-site parking availability, and the availability of carsharing vehicles (Engel & Passmore, 2010; DCP, 2011). An example of such flexible parking requirements is employed in Los Angeles, CA, which grants a reduction in the parking requirement of .5 stalls per affordable housing unit, with further reductions if the units are within 1,500 feet of high order transit (Engel & Passmore, 2010). These types of regulations provide detailed context sensitivity without developing unique parking standards for each of a city's neighborhoods (Engel & Passmore, 2010). One disadvantage is that more adjustment factors mean more system complexity; with additional complexity, requirements become more difficult to "understand, enforce, and predict" (Engel & Passmore, 2010, pg. 32). One example, provided by Engel and Passmore, is if parking reductions are offered for locations with nearby carsharing vehicle service, the service is something that the developer cannot control. If the carsharing service was to be discontinued, the development could be nonconforming and could face parking shortages (Engel & Passmore, 2010). Another concern is that these adjustment factors are based on existing conditions—if these conditions do not match the planned vision for locations in the city, then parking requirements may not align with long-term planning objectives (Engel & Passmore, 2010).

- Parking regulations: include a broad range of regulations that favor higher-value uses for parking spaces, such as for service vehicles or deliveries, or reduce the duration of an allowed parking period in order to increase parking turnover (Litman, 2013).These regulations control which vehicles may park at a particular location, and at what time and for how long, so that the efficiency of the parking space is increased (Litman, 2013). Some examples of how this could be done include having higher value users (rideshare/service vehicles), limiting parking with residential parking permits, commercial vehicle loading regulation and provision, regulations to prevent abuse of disabled parking, shorter parking duration periods, restrictions on larger vehicles, and even possible restriction of overnight parking to favor short-term parkers (Litman, 2013; DCP, 2011; FHWA, 2013).

Parking Pricing and Demand Management:

While alternative parking requirements help increase the efficiency of parking spaces by aiming to tailor parking requirements to parking demand, increased attention has been paid to parking policies that reduce parking demand to encourage modes other than driving, such as walking, biking, or transit (FHWA, 2013; Litman, 2013). These often come in the form of pricing policies or transportation demand management programs that accommodate other modes (Litman, 2013). Below is a list of a few methods of reducing parking demand that have gained traction and utilization for on-street and off-street parking (FHWA, 2013).

- Performance-based pricing: can be applicable to off-street and on-street parking; these types of pricing schemes for on-street parking set prices for parking relative to the demand for parking in order to better manage parking supply (FHWA, 2013). In general, parking experts set prices for these policies so that 10-20% (one or two spaces) of on-street parking should be vacant most of the time as a way to reduce or eliminate cruising for parking on most neighborhood streets (FHWA, 2013). One approach to performance-based parking is variable pricing, where the price of parking varies based on the time of day or the relative parking demand of high-demand locations (FHWA, 2013). These systems vary in sophistication from real-time monitoring of parking demand for on-street parking on the block level, with parking sensors in SFPark having prices change by location and time period, to the less sophisticated use of higher prices in time periods of high demand in two pilot neighborhoods in New York City (DCP, 2011; Shoup, 2009). Another method, often used for off-street parking, is the use of *escalating prices,* where the charge for parking increases with the time period for which the car is parked there (FHWA, 2013). This type of parking system is utilized to increase turnover in garages, so each user spends less time parked in each garage (FHWA, 2013).
- Parking Cash Out and Transportation Allowances: are economic incentives provided to employees so that they can make rational transportation decisions that are not biased by employer-paid free parking that is offered as a tax-free

perk (Shoup, 1997; FHWA, 2013). Parking cash out programs offer employees the option of having free parking or receiving a tax-free cash payment that can be used for transit passes or kept as cash (FHWA, 2013). Transportation allowances are similar, except employers offer a tax-deductible payment that employees can use for transportation expenses—such as paying for parking or transit passes—or even keep for themselves (FHWA, 2013). While parking cash out is more useful for employers that own parking facilities, and transportation allowances are useful for ones that do not, both are highly effective at reducing VMT and drive alone mode share (FHWA, 2013). One study looking at 8 cases of parking cash-out programs in California found that, after such a program was implemented, drive alone share dropped 17%, transit ridership increased by 50%, carpooling increased by 64%, walking and biking increased by 39%, and VMT dropped 12% (Shoup, 1997). The model developed by the study showed that congestion significantly reduced, with average speeds rising from 40 to 43 km/hour to almost 50 km/hour (Shoup, 1997; FHWA, 2013).

- Unbundled Parking: separates the cost of parking from the cost of residential and commercial developments, making parking a direct cost, as compared to an indirect cost that occurs when parking is included in the price of development (DCP, 2010; FHWA, 2013). While unbundling may have only a small direct effect on commercial developments, it does create the incentive to implement transportation demand strategies that decrease the number of employees driving to work (FHWA, 2013). However, an analysis of residential developments in New York City suggests that the provision of residential off-street parking influences commuting behavior by making residents more inclined to own vehicles and drive (Weinberger et al., 2009). This suggests that unbundled parking would have significant impact on residential development (FHWA, 2013). There is concern about the use of unbundled parking while minimum parking requirements are in place, because if parking utilization rates are lower than anticipated, it could impact developer's ability to repay loans if revenue from sold parking is lower than expected (FHWA, 2013).

- Parking Taxes or Fees: are charges that internalize the external costs of driving to influence travel behavior by decreasing parking availability, increasing the cost of parking, and creating the incentives for developers or employers to pass parking costs to drivers (FHWA, 2013; Feitelson & Rotem, 2004). A few cities have already placed parking charges or fees on users to increase their driving costs or on facility owners that will likely pass the cost on their users (FHWA, 2013). However, these taxes are only effective in changing behavior if they are implemented in locations that remove parking requirements, and the policies' success hinges on their removal (FHWA, 2013; Feitelson & Rotem, 2004).

While these policies of reducing parking demand and creating alternative requirements are effective, the costs they impose on users often make them politically difficult to implement and risk repeal if they do not make accommodations for users and do not have clear public communication (FHWA, 2013). While conventional methods of making these policies more viable through policies such as parking benefit districts, which allow local parking revenue to benefit local public goods in the neighborhoods they collected, these solutions do not necessarily support automobile access (DCP, 2011; Shoup, 1999). One complementary policy element that could be added to transportation demand management programs is the inclusion of carsharing support and allocation to support more multimodal travel, reduce vehicle ownership and parking demand, and reduce VMT (Shaheen et al., 2009, TCRP, 2005). Carsharing—along with its benefits, policies that support it, its market ranges, its role in transportation demand management programs, and policy targeting—is explored in the section below, in the context of its connection to parking policy.

Carsharing and the Role of Carsharing Policy in Parking and Transportation Demand Management Programs

What is Carsharing?

Traditional carsharing organizations (CSO) provide members access to a fleet of shared vehicles that are rented out by the hour, thus operating on a smaller time frame than traditional car rentals (Shaheen et al., 2009). In general, this pay-as-you-go system operates by having vehicles picked up and dropped off at unattended points of departure, or “pods,” which are dispersed throughout a general service area (Bieszczat & Schwieterman, 2012; Shaheen et al., 2012). Members reserve cars by booking their use online (often via smartphone), and once reserved, the vehicle can be accessed with a smart card (Bieszczat & Schwieterman, 2012). The fee structure is largely pay-as-you-go (hourly rented slots), but car share members pay a fixed annual or monthly fee to be part of the car share membership itself (Bieszczat & Schwieterman, 2012).

Early attempts at car-sharing can be traced to the “Sefage,” a carsharing program started by a housing cooperative in Zurich, Switzerland that opened in 1948 (TCRP, 2005). Europe would go on to see carsharing by fleet operators appear in the 1980s, with the first notable ones in 1987 in Switzerland and 1988 in Germany (TCRP, 2005). Just as Europe was seeing its first operators appear, North America was just experimenting with the concept as experimental programs during a Purdue University research experiment named Mobility Enterprise Program from 1983-1986 and San Francisco’s Short Term Auto Rental Service (STAR), a demonstration project that ran around the time from 1983-1985 (TCRP, 2005). The first modern operators appeared in North America in the 1990s, with Quebec City seeing the first program in 1994, to be followed by the US operators CarSharing Portland (later sold to Flexcar) in Portland, OR and Zipcar in 2000 in Seattle, WA (TCRP, 2005; Shaheen et al., 2012). In the last decade, car share operators in the US and abroad have expanded to other major cities in North America (Shaheen et al., 2012). Since the founding of these organizations, carsharing has experienced significant growth in vehicles and membership in the United States and Canada (TCRP, 2005; Shaheen et al., 2012). A large portion of this growth occurred in 2000 and 2001, during which time carsharing membership grew 1,174% and 81% respectively (these numbers, although large, likely account for the small size of the initial market) (Shaheen et al., 2009). While the growth rate reduced as the result of the number of vehicles and members growing in absolute terms, the total growth in the carsharing market has been very large in urban areas (TCRP, 2005). As of July, 2011, 26 US carsharing programs managed 10,019 vehicles and served 560,572 members, and Canada’s 20 carsharing programs hosted 2,605 vehicles for 78,840 members (Shaheen et al., 2012). Much of this growth has been facilitated by innovations in technology that make carsharing vehicles more convenient to access and reserve while also preventing theft (TCRP, 2005). For example, many of these earlier programs utilized a Lock Box model for accessing the vehicles where members could reserve a vehicle and then access a lock box with a key or code (TCRP, 2005). As the technology improved, reservations could be made online, and the cars were expected with smart card readers or other devices that would provide convenient access (TCRP, 2005). Additionally, GPS trackers have been equipped to some cars to prevent theft, find cars parked in the wrong location, or confirm that a car was returned past its reservation (TCRP, 2005). Considering the past role of changing technologies in making carsharing more convenient than car ownership in urban areas, it is expected carsharing will continue to play a role in the future (TCRP, 2005; Shaheen et al., 2010). Another factor contributing to the growth in carsharing is the cost savings it provides to users by providing access to vehicles without them having to pay the fixed cost of car ownership (Shaheen et al., 2010). As the numbers of carsharing members and vehicles have grown, so have the studies looking at the economic and transportation benefits, costs, and impacts associated with carsharing.

Benefits of Carsharing

Traditional carsharing has been under intensive study over the past few years, and several benefits from car sharing programs have been reported by a number of studies on the subject (TCRP, 2005).

The first of these is that car sharing is estimated to reduce vehicle holdings as car owners replace their cars with carsharing vehicles or forgo buying a new car (TCRP, 2005; Shaheen et al., 2010; Engel & Passmore, 2013; Schwieterman & Bieszczat, 2012). While the studies vary in results, they do so largely because of how they measure changes in auto-ownership (TCRP, 2005; Engel & Passmore, 2013). The Transportation Research Board (TRB) study only included members that gave up their primary or secondary vehicle after joining a carsharing program and found that between 1.4 and 6.4 private vehicles were replaced per shared car (TCRP, 2005). On average, 22 members participate per car share vehicle in the US, and 21% of members give up a primary or secondary vehicle, translating to an average car share vehicle leading to a reduction of direct private vehicle ownership of 3.9 per carsharing vehicle at the building level (Engel & Passmore, 2013). However, studies of specific locations have seen higher reductions depending on the percentage of members who give up a car and the members per carshare vehicle (Engel & Passmore, 2013). For example, one extensive study in San Francisco found that 29.1% of car share members substituted personal vehicles for City CarShare vehicles and 2/3 did not purchase another vehicle (Cervero et al., 2007). With 44 members per vehicle, this translates into a vehicle reduction of 13 vehicles per carshare vehicle (Engel & Passmore, 2013). Other studies that include private vehicles that members gave up and forgone vehicle purchases put the reduction at a much higher rate—between 4.6 and 20 vehicles per car share vehicle (Engel & Passmore, 2013; Shaheen et al., 2010). For example, in a research study, car share members were administered a web survey that found the average number of vehicles per household changed from 0.47 before carsharing to 0.24 after carsharing (9-13 vehicles per carshare vehicle), yielding an estimated aggregate removal of between 90,000 and 130,000 vehicles from the road in North America in 2010 (Shaheen et al., 2010). According to the TCRP report, 21% of carsharing members gave up a vehicle, but 40% reported avoiding purchasing one as a result of joining a carsharing program, which translates to an average of 5 vehicles shed per carsharing vehicle when the avoided purchases are included (TCRP, 2005; Ter Schure et al., 2012). However, such a reduction in vehicles does not translate to universal decreases in parking demand in all locations, such as shopping destinations (Stasko, et al., 2013). For example, one study of university carsharing in Ithaca, NY found that while parking demand near residences decreased an estimated 198 spaces (1 space per vehicle forgone) as a result of carsharing, shopping parking demand may have increased an estimated 2-3 spaces as a result of more shopping trips being carried out by car (Stasko et al., 2013). Some of the benefits from such reductions include the potential for fewer parking spaces and thus lower parking requirements, reclaimed street space that might go to on-street parking, and speculative benefits such as lower development costs from less parking, more open space, and less runoff (Shaheen et al., 2010; Richter et al., 2012; Schwieterman & Bieszczat, 2012).

Along with the net reduction in vehicles, carsharing has been reported to reduce vehicle miles traveled (VMT) in the widening body of literature, with the median reduction in average VMT of carsharing members being about 37%; however, this varies by study (Schwieterman & Bieszczat, 2012; TCRP, 2005). For example, in the same extensive study in San Francisco, members reported a non-statistically significant drop in VMT (adjusted for mode), but a statistically significant reduction of 67% over a 4-year period in Mode-Adjusted VMT (MVMT) (adjusts for mode and occupancy levels), contrasted by a 24% increase by non-members (Cervero et al., 2007). Overall, the range of VMT reductions across studies—according to one literature review—ranges from 7.6-80% (Shaheen et al., 2012). Much of these reductions in VMT occurred as a result of changes in mode share with an overall increase in public transit and non-motorized modes, shorter travel lengths, and higher occupancy levels of vehicles (Cervero et al., 2007, Martin & Shaheen, 2011a).

An additional benefit of carsharing includes reduced greenhouse gas (GHG) emissions from individuals participating in carsharing programs, according to a study's survey of carshare members (Martin & Shaheen, 2011b). While members who did not own a car before joining a carsharing program may have increased their emissions, the decrease in emissions from those who did own a vehicle and then shed one outweighs increases seen from other members (Martin & Shaheen, 2011b). This decrease in emissions is based on an average estimated reduction in VMT of 27% and the observation of the differences in mileage between vehicles of members before they joined the carshare program and then after with the carshare vehicles (Martin & Shaheen, 2011b). In general, the differences between carshare vehicles' average fuel economy and that of vehicles that are shed is expected to be an increase in efficiency of around 10 miles per gallon (Shaheen et al., 2010) The net estimated effect on the annual GHG emissions per household of joining a carsharing program was reported based their respective observed impacts, which look at the changes that actually occur in emissions, and then full impact that looks at the reduction of emissions and the prevention of emissions that would have occurred without carsharing (Martin & Shaheen, 2011b). The observed impact on GHG was reported to be -0.58 tons of GHG per year per household, while the full impact was estimated to be -0.84 tons of GHG per year per household (Martin & Shaheen, 2011b). With the share of inactive carsharing ranging between 15-40%, the authors estimate that in North America the aggregate observed impact on GHG emissions is between 109,000 and 155, 000 tons of GHG per year, and the full impact is between 158,000 and 224,000 tons of GHG per year (Martin & Shaheen, 2011b).

Several studies have reported that carsharing also benefits users by lowering the transportation costs of carshare members by several thousand dollars annually (Bieszczat & Schwieterman, 2012). The same survey of car sharing members showed the expenditures on carsharing to be fairly to be low, with the average per month expenditure on car sharing being $61.26 and the median per month expenditure being $40.50 (TCRP, 2005). This type of expenditure is low compared to the high fixed costs associated with car ownership and has been confirmed to yield significant savings to those who do not need to drive often (TCRP, 2005; Duncan, 2011). For example, the first year evaluation of CarSharing Portland found that members estimated they saved $154 per month in transport costs, and based on surveys from Philly CarShare members, average savings for those who could quantify their savings was $2,059 per year (TCRP, 2005). Based on a survey administered by the TCRP, 85.3% of respondents found the fact that carsharing was less costly than owning a car an attractive feature, while 31.9% reported the reduced cost of carsharing as its most attractive feature (TCRP, 2005). One study looking at cost savings potential of carsharing in San Francisco Bay estimated that, with current carshare pod locations at the time of the study, 7 % of vehicles and 9% of households would find carsharing to be a financially favorable alternative (Duncan, 2011).

Policies that Support Carsharing

In many municipalities around the world, different policies are used to support carshare use based on the benefits it provides to users and the city (Enoch & Taylor, 2006). In general, these support policies can be put into three categories: information-based policies, fiscal support, and supportive planning and parking policies (Enoch & Taylor, 2006).

Information-based policies aim to provide political, intellectual or institutional support for carshare operators and users (Enoch & Taylor, 2006). This can take the form of intellectual support from governments by disseminating information to policy makers to make them more aware of the role and benefits of carsharing (Enoch & Taylor, 2006). For example, in 1998, the Ministry of the Environment developed a national coordination and integration policy in Italy for car sharing through an organization known as "Iniziativa Car Sharing," which focused on developing fixed standards, creating co-financing strategies, providing operational fields and services (marketing, technical, and legal support to car sharing operators), and aiming to coordinate the promotion of carsharing (Enoch & Taylor, 2006). Additionally, this can also be provided by political support expressed through policy statements and measures (Enoch & Taylor, 2006). For example, the Dutch national Government directed "The Foundation for Shared Car" (national independent organization) with developing a national carsharing strategy that would aim to provide information and communication on carsharing, facilitate private carsharing, link private and business carsharing (car clubs for firms), integrate with development planning in new residential areas, and look at quality protection through research and monitoring (Enoch & Taylor, 2006). The last form is the integration of carsharing with other transportation providers, such as transit service providers, so that new ticketing and coordinated information and marketing products can be developed (Enoch & Taylor, 2006). This was done in Seattle, where Kings County Metro, WA integrated carsharing into its operations from the very beginning by offering $200,000 to potential carsharing operators to help with marketing, startup, and office space (Enoch & Taylor, 2006). As carsharing grew, Kings County Metro stopped providing direct financial support to operators, but continued to provide equivalent support by offering Flexpass (public transport pass offered by employers), discounted memberships or free carshare usage time (Enoch & Taylor, 2006).

Fiscal support mechanisms include providing public subsidies and financial assistance to carshare operators and their users (Enoch & Taylor, 2006). This includes the use of direct subsidies, such as the $20,000 loans the City of Toronto gave car sharing organizations to start up in the city and to facilitate the relationship between carshare operators and the Toronto Transit Commission (Enoch & Taylor, 2006). Additionally, cities can provide indirect subsidies by offering to stimulate carsharing services by having city agencies utilize carsharing vehicles as part of their fleet, as was done by New York City's Department of Transportation to remove ¼ of their vehicles from city streets (NYCDOT, 2013). Additional forms of fiscal support include tax breaks to carshare members or operators, such as the tax breaks provided by the State of Oregon that are used by carsharing organizations to acquire parking (Enoch & Taylor, 2006). Tax breaks are important to carsharing operators and users because they are often classified as car rentals, which is a business that has a very high taxation rate—well above local sales taxes (Schwieterman & Bieszczat, 2012). Based on a study conducted in 2012, average tax rate for a one-hour carsharing reservation across the

United States was 17.93%, 24-hour reservations were taxed at a rate of 14.08%, and it was estimated that these rates of taxation lead to an 11.7% reduction in carsharing (Schwieterman & Bieszczat, 2012). For example, the study reported that in New York City, in addition to the sales tax of 8.875%, carsharing faces a 6% state auto rental tax and a 5% metro commuter district auto rental tax, leading to a total effective tax rate of 19.91% (Schwieterman & Bieszczat, 2012). These auto rental taxes are often used to extract revenue from tourists and business travelers who require ground transportation; however, carsharing services are largely used by the local population, making the effective tax rates on carsharing a high cost to bear that could reduce carsharing use and membership (Schwieterman & Bieszczat, 2012). This makes tax breaks or the removal of the tax burden on carsharing very important in metropolitan areas that want to support carsharing use and development (Schwieterman & Bieszczat, 2012).

Planning and parking support policies aim to provide carsharing organizations with parking spaces for their vehicles at a discounted cost by either changing development regulations to provide neighborhood carshare services or to provide on-street parking for carsharing vehicles (Engel & Passmore, 2013, Enoch & Taylor, 2006, Shaheen et al., 2010). The provision of parking is one of the most appreciated forms of subsidy that carsharing operators get from cities like Seattle, WA, which provided Flexcar 30 on-street parking spots and Cambridge, MA, which provided subsidized off-street parking spaces to Zipcar (Enoch & Taylor, 2006). In the case of on-street parking provision, its main advantage is that it is highly visible and provides both marketing and parking for vehicles simultaneously (Enoch & Taylor, 2006; TCRP, 2005). Additionally, local authorities can provide parking to carshare operators by encouraging developers to offer neighborhood carshare services by reducing the parking they are required to provide if they host a carshare operator (Enoch & Taylor, 2006; Engel & Passmore, 2013). This originates from studies that show that the number of vehicles given up by carsharing members ranges from a reduction of 1.4 to 6.4 vehicles per carshare vehicle in estimates excluding forgone purchases, to a reduction of 4.6-20 vehicles per carshare vehicle in larger estimates that include forgone purchases (Engel & Passmore, 2013; Shaheen et al., 2010). Based on this data, many cities have started offering reductions in parking minimums for each carshare vehicle placed in a development, such as Seattle's reduction of 3 parking spaces for each carshare vehicle for developments requiring more than 20 spaces (for a max of 15% of required spaces) to Vancouver's reduction of 5 parking spaces for each carshare vehicle (up to a maximum of 1 carshare space per 50 dwelling units outside of downtown and 6 carshare spaces for each 100 dwelling units in downtown) (Engel & Passmore, 2013). San Francisco goes as far as to require 1 carshare space for dwellings with 50 to 200 units and an additional carshare space for every additional 200 units, in addition to other forms of support for carsharing operators (Engel & Passmore, 2013; Ter Schure et al., 2012).

Other forms of planning and parking support have taken different forms. In many regions, these carshare-supportive parking and planning policies have been integral to carsharing's success in numerous regions. However, each of these carsharing-supportive parking policies have several critical elements and potential benefits that are examined in detail in the next section.

Elements of Carsharing-Supportive Parking Policy

Carsharing parking policies in North America share a number of key elements (Shaheen et al., 2010). In a study looking at carsharing parking policy across North America, several key elements of carsharing parking policy were discovered after interviews with public officials and surveys of carshare operators, citizens, and literature (Shaheen et al., 2010). The basic elements include parking allocation, establishment of caps, development of fees and permits, signage allowances, enforcement, and the requirement in many cases of impact studies and public involvement before any changes in parking occur or regulation occur (Shaheen et al., 2010).

The first element that is typical in carsharing parking policy is parking allocation, where carshare parking is allocated either on-street or off-street through a series of informal (variances/special permits) and formal (ordinances/zoning) processes, such as providing on-street parking spaces to operators or providing incentives like parking requirement reductions to developers that host carshare vehicles (Shaheen et al., 2010; Engel & Passmore, 2013).

Another shared element is parking caps, where the number of locations of on-street or off-street parking spaces used for carsharing are limited by a public agency to a number determined by either the number of housing units, the number of stalls per membership level, or even the number of spaces allocated to a particular operator or location (Shaheen et al., 2010; Engel & Passmore, 2013).

Fees and permits given to carsharing operators for the use of parking facilities—either based on the value of forgone revenue, the cost of providing the parking space, cost of residential parking permit, or the market value of off-street parking—make up another element, along with the potential provision of parking either on-street or off-street at no cost (Shaheen et al., 2010).

An element common to almost all public agencies allocating on-street or off-street parking to carsharing operators is the regulation and allowance of special signage and the establishment of agreements that determine how the parking signs and spots will be maintained (Shaheen et al., 2010).

An important element of carsharing parking policy that is very important to carshare operators is parking enforcement where public agencies ensure that carshare parking spaces are reserved only for carshare vehicles, with some public agencies creating provisions for unique license plates and ticketing and towing authority (Shaheen et al., 2010).

Impact studies, wherein a few public agencies have required carshare operators to report the environmental, social, and transportation impacts of carsharing—both when considering carsharing policy, and at regular intervals after a carsharing parking policy has been implemented for continued monitoring—make up another important element of carsharing parking policies (Shaheen et al., 2010).

The final element observed in carshare parking policy is the requirement by some public agencies for public involvement, where carshare operators must work with neighborhood and community groups to gain approval for carsharing parking spaces before they can be installed (Shaheen et al., 2010).

Benefits of a Carsharing-Supportive Parking Policy

Cities that facilitate carsharing through targeted carsharing-supportive parking and planning policies could stand to see numerous potential benefits that are associated with reducing parking demand and enabling a lower parking supply to be required (Shoup, 1997; Ter Schure et al., 2012). Developers who can reduce their parking requirements by hosting carsharing vehicles can also reduce development costs by decreasing the resources spent on land acquisition and the construction of parking as the need for parking is lessened (Shoup, 1997; Litman, 2013). With the option to reduce parking costs from development and the provision of carsharing vehicles, developers can create more affordable housing options for low-income residents (McDonnell et al., 2010). In addition to this provision of affordable housing, the provision of carsharing enables low-income populations to have greater mobility, as access to a car provides carless households the ability to reach new destinations at a reduced cost (compared to owning a car) (TCRP, 2005). As parking requirements are reduced, developments can reach higher densities—as parking takes up less developable space, enabling more compact design (Engel & Passmore, 2010; TRB, 2009). Reduced parking, higher densities, and complementary carsharing services also act to encourage more multimodal forms of transportation, such as transit, bicycling, and walking (TRB, 2009; TCRP, 2005). With higher densities and more compact design, land consumption can be reduced, helping to preserve agricultural and environmentally-sensitive lands (Cutter and Franco, 2012; Davis et al., 2010). Additionally, the amount of impervious surface area dedicated to parking can be minimized, lessening its contribution to storm water runoff that is often contaminated with high levels of nitrogen, phosphorus, and heavy metals (Davis et al., 2010). Another potential benefit of such carsharing-supportive parking policies is that they beget more carsharing, past the incentives they provide to developers and operators, by encouraging the development of conditions that support carsharing: transit supportive densities, the encouragement of more mixed-use development, and increasing scarcity of the parking supply in the absence of carsharing service, for example (TCRP, 2005).

Developing Carsharing Partners and Markets

One of the first markets for carsharing was the neighborhood carsharing market, which offered carsharing services primarily in mixed-use, high-density residential neighborhoods where owning a car is optional (TCRP, 2005). This market developed primarily to give residents—and sometimes local businesses—a mobility alternative to vehicle ownership to assist with the occasional trip for a social visit, personal business, or shopping at a store (TCRP, 2005).

While neighborhood carsharing market niches were the first to appear, carsharing business models have evolved to provide variations of the neighborhood model in high-density residential areas, offering partnership-based carsharing services by establishing partnerships with university campuses, public transit operators, businesses, local governments, and developers (Shaheen et al., 2012; TCRP, 2005). While these new partners open up different markets for carsharing operators, these services are, in general, still offered in a similar context of multimodal urban locations (TCRP, 2005). Each of these partner types is discussed in detail below.

In the case of university partners, their goals are often to utilize carsharing as an element in their transportation demand management (TDM) programs in order to reduce the number of car trips to college campuses (TCRP, 2005). The scarcity of parking and the increased accessibility to destinations found on college campuses, combined with the fact that highly educated populations tend to be early adopters of carsharing services, make college campuses good markets for carsharing (TCRP, 2005). The carsharing operator Zipcar claims to have hundreds of university partners in a variety of settings, from university towns to urban areas like New York City (Stasko et al., 2013).

Transit operators also tend to partner with carsharing organizations because it is a complementary mode to transit (TCRP, 2005). By allowing carsharing operators to use some of their parking at their stations, transit operators improve the mobility of their customers (transit users) by providing options to reach destinations to which transit lines may not provide convenient access (TCRP, 2005). Carsharing's integration with transit can help transit operators unburden themselves of unproductive "end-of-the-line" routes that may see little customers because of their location, while still providing mobility options to users (TCRP, 2005).

Businesses partnered with carsharing organizations think of carsharing as contributing to multiple goals simultaneously (TCRP, 2005). By partnering with carshare operators, businesses gain access to a mobility option that is more economical than rental cars and can simultaneously serve as an employee benefit by increasing the mobility of staff who do not drive to work (TCRP, 2005). Additionally, it is often used as a parking management tool by helping employees use transit (TCRP, 2005). Since the year 2000, carsharing operators have increasingly developed this market segment by launching more targeted focus on business customers, extending their services to dense multimodal employment areas (Shaheen et al., 2009).

Local governments aiming to reap the social benefits of carsharing—such as reduced parking demand, reduced VMT and emissions, and increasing access to an automobile for the general population and low income households—are another common partner of carshare operators (TCRP, 2005). Cities often have different levels of carshare-supportive policies, but some cities will even replace some of their municipal fleet to yield cost savings and simultaneously support carsharing in the city by increasing demand for carsharing services (TCRP, 2005).

Carsharing has caught the attention of an increasing number of North American developers and property managers, especially in new housing and mixed-use developments (TCRP, 2005). To developers and property managers, carsharing provides several benefits, the first being that it is an additional amenity to tenants, particularly if they do not own a vehicle (TCRP, 2005). The next benefit is that carsharing helps promote sustainability and corporate citizenship, with some companies seeing it as an obligation as a good corporate citizen, but some also have used it to help achieve Leadership in Energy and Environmental Design (LEED) designation (TCRP, 2005; FHWA, 2012). Under the LEED rating systems, such as LEED Neighborhood Development, points are awarded to a development that has 50% of the constructed dwelling units within ¼ mile of a carsharing program (USGBC, 2009). An additional benefit to developers is the use of carsharing as a parking management tool, which reduces parking requirements and the overall cost of development (TCRP, 2005). This market segment has also been growing since 2000, with more apartment developers marking arrangements with carsharing operators (Shaheen et al., 2009).

The Role of Carsharing in Transportation Demand Management

A substantial number of studies have demonstrated that carsharing can help reduce vehicle ownership, reduce VMT, provide significant user savings, and encourage other modes of transportation, all of which are goals of transportation demand management programs (TCRP, 2005; FHWA, 2013). While the contexts in which it may be applicable as an option may be limited, carsharing has displayed that it can complement alternative parking and transportation demand management programs (FHWA, 2013; Ter Schure et al., 2012).

For example, a study in San Francisco looked at changes and effects of unbundled parking and carsharing employed together in a complementary fashion (Ter Schure et al., 2012). A 2008 ordinance lowered or eliminated parking requirements in downtown or transit-oriented districts, while requiring that parking be unbundled or sold separately from units and that residential and non-residential developments of a certain size provide carsharing vehicle spaces (Ter Schure et al., 2012). The study looked at the modal share, carshare membership rates, and average vehicle ownerships of transit-served sites that had unbundled parking and carsharing, unbundled parking only, or carsharing only, and sites that had neither carsharing nor unbundled parking (Ter Schure et al., 2012). The study found that transit-served sites with carsharing and unbundled parking created statistically significant reductions in vehicle ownership when compared to transit-served sites with neither carsharing or unbundled parking, with households with both unbundled parking and carsharing available in the building holding an average of 0.76 vehicles per household, while control sites with neither carsharing nor bundled parking held an average 1.03 vehicles per household (Ter Schure et al., 2012). The study recorded that, when unbundled parking and carsharing worked together, changes in vehicle ownership were large and statistically significant; by contrast, the results were not statistically significant when they each operated alone (Ter Schure et al., 2012). In addition, the study recorded carshare members having statistically significant reductions in vehicle ownership and statistically significant increases in non-automobile modal compared to non-carshare members in the same study area (Ter Schure et al., 2012). This provides evidence that carsharing may have a complementary effect with other parking and transportation demand management policies and while providing the option of automobility to urban residents (Ter Schure et al., 2012; TCRP, 2005). Carsharing serves as a method of accommodating transportation system users, assisting in making parking and transportation demand management programs not only more politically feasible, but more effective (FHWA, 2013; Ter Schure et al., 2012).

Risks of Carsharing-Supportive Parking Policy

While carsharing-supportive parking policies have their share of potential benefits, they also have their own risks that occur as a result of depending on multiple agents to achieve desired transportation objectives (Engel & Passmore, 2010). One concern is that such incentives could encourage the development of carsharing spaces where carsharing is not feasible (TCRP, 2005). If carsharing is allocated to an unsuitable location that would be abandoned by a carsharing operator in the long term, the city or development would have little recourse (TCRP, 2005). This is an additional concern because, while adjustment factors for parking based on the location of carsharing vehicles on-site may be under the influence of the developer, they are certainly not under its control (Engel & Passmore, 2010). If the carsharing vehicles were removed, the development would be non-conforming to zoning ordinances and could experience parking shortages as the option of using carsharing to supplement mobility is lost (Engel & Passmore, 2010; TCRP, 2005). This is why cities have aimed to tailor incentives for carsharing vehicles to existing market conditions, in order reduce the risk of relocation and increase the chances of carsharing being placed in a location based on these incentives that will stay for the long term (TCRP, 2005; Engel & Passmore, 2013).

Geographic Targeting of Carsharing Policy

Tailoring carsharing-supportive policies to existing market conditions ensures the success of the policy and its ability to avoid abuse that would lead to carsharing being allocated to locations where it will not be sustained in the long term (TCRP, 2005; Engel & Passmore, 2013). One method of tailoring carsharing-supportive policy to existing market conditions is to limit carsharing-supportive policies to specific geographic regions where carsharing could be supported (Engel & Passmore, 2013). Transit overlay districts that are drawn by the municipality around high-quality transit corridors or flexible parking requirements for transit-oriented development around priority transit stations are often examples of this type of spatial targeting of parking policy (DCP, 2011; Passmore & Engel, 2010). In practice, many cities have already included spatial targeting components as part of their carsharing policies in cities such as Vancouver, Canada, Denver, Colorado, and Austin, Texas (Engel & Passmore, 2013; Austin, 2008). In the case of Vancouver, the city allows larger overall reductions in parking requirements in the downtown area when carshare vehicle spaces are provided by allowing more carshare vehicles to yield reductions (Engel & Passmore, 2013). In this way, Vancouver has limited how much of an impact carsharing could have on parking requirements outside of the downtown while still providing it significant support (Engel & Passmore, 2013). In Denver, Colorado the rules for allocating on-street spaces to carsharing operators were drafted with limits on how many spaces may be allocated by the traffic engineer based on whether or not carsharing was downtown or outside of it (Public Works, 2013). In addition, Denver places requirements on operators to place at least 2 carsharing vehicles in any opportunity area (statistical neighborhood with at least a 30% poverty level) within the city limits if they request spaces elsewhere in the city (Public Works, 2013). In this way, Denver not only limits the geography of where carsharing could be located, but also sets the requirement that carsharing be placed where it would benefit other policy objectives, such as improving the quality of life of low-income residents (Public Works, 2013; TCRP, 2005). In Austin, Texas multifamily houses within the University Neighborhood Overlay District are allowed to reduce their parking requirement by 40% if they participate in a carsharing program that complies with certain administrative requirements (Austin, 2008). This limits the incentives to both the location where a market for carsharing exists around the University of Texas campus and to certain types of housing that would provide sufficient density (Austin, 2008; TCRP, 2005).

This type of spatial targeting of carsharing policy has a few potential benefits. For one, when policy is limited in geographic scope, it is easier to gain policy acceptance and communicate changes because the number of stakeholders is reduced, making coordination easier. An example of this type of policy-making includes parking benefit districts, which allow local neighborhoods to opt into a program that implements variable pricing for on-street parking in urban areas, and then lets a portion of the revenues benefit the local neighborhood (FHWA, 2013; Shoup, 1997). Additionally, limiting the geographic scope of carsharing-supportive policies limits the impact of one of the most important issues, which is the risk of carshare operators leaving a development once parking reductions are permitted (Engel & Passmore, 2013). Thus, this type of spatial limitations prevents carsharing operators from moving into locations that do not have mixed uses, transit access, or the sufficient densities required to support carsharing (Engel & Passmore, 2013).

Previous Studies on Carsharing Locations

In order to more accurately target carsharing policy, it is important to understand the general locations and environments where demand for carsharing service is sufficient enough to support it. In general, the large majority of traditional carsharing occurs in the urban cores of the principal metropolitan regions (TCRP, 2005). As of 2005, 94% of United States carsharing membership was located in San Francisco, Los Angeles, San Diego, Portland, Seattle, Boston, New York City, or Washington DC (TCRP, 2005). While membership has increased dramatically since this time period, carsharing services are still mostly suited to walkable, high-density, mixed-use urban neighborhoods that have access to public transit (Shaheen et al., 2012; TCRP, 2005). These environments have the neighborhood characteristics that help carsharing succeed by providing sufficient density to attract more customers, the ability to live without a car, parking pressures that increase the cost of car ownership, and a mix of uses that provide access to potential business and neighborhood carsharing members (TCRP, 2005). The populations in these locations are often defined by having low rates of vehicle ownership, low automobile mode share, and high population and employment densities that enable businesses and residents to access their services (Stillwater et al., 2007). In general, the variables that relate to carsharing locations can be broken down into three main categories: demographic variables, transport variables, and neighborhood variables. Each of the three main variable classes that are relevant to this study are discussed in detail below.

Transportation variables

Transportation variables are a broad class of variables that relate to transportation infrastructure and services, such as the provision of transit, parking facilities, and other multimodal facilities (such as bike lanes and pedestrian paths).

The first transportation variable of interest to carsharing vehicle location is the availability of transit, because carsharing vehicles tend to be deployed near public transit stations or in locations serviced by them (Shaheen et al., 2009; Stillwater et al., 2007;TCRP, 2005). This occurs likely as a result of transit service creating carshare-friendly environments by providing the ability to live without a car, and also as a result of many agencies and cities pushing for further integration of transit and carsharing services to provide options to reach destinations that transit lines may not provide convenient access to (TCRP, 2005; Enoch & Taylor, 2006). One GIS study investigating how built environment variables influence where carsharing vehicles of one operator are deployed in a single metropolitan area found that proximity (1/2 mile radius) to light rail stations was a statistically significant and positive explanatory variable of carsharing vehicle deployment (Stillwater et al., 2007). Additionally, in another study looking across 13 regions, transit mode share was found to have a statistically significant correlation between transit and carshare level of service (the number of carsharing vehicles within a half-mile radius), which can be seen in Table 2-2 (TCRP, 2005). Similarly, along with light rail stations, major bus hubs have been reported to be locations that carsharing vehicles are often placed near to (TCRP, 2005). In addition, in a web survey by the TCRP of carsharing members, 86.4% of respondents agreed or strongly agreed with the statement that their neighborhood is served by good public transit (TCRP, 2005).

Another variable that plays a role into whether or not carsharing succeeds is the availability of off-street and on-street parking (TCRP, 2005). Studies have reported that carsharing tends to succeed in locations where parking pressures drive up the cost of auto ownership (TCRP, 2005; Stillwater et al., 2007). This means that carsharing generally succeeds in environments where parking is expensive, inconvenient, and generally less available to would-be drivers (TCRP, 2005). For example, if people have to walk a block or two to reach their car because it is the only place they could park it, they might as well walk that distance to access a carsharing vehicle (TCRP, 2005). This is further supported by a web survey by the TCRP to carsharing members, where 47.5 % of respondents agreed or strongly agreed with the statement that on more than one occasion they had spent a long time searching for parking in their neighborhood (TCRP, 2005). This type of parking scarcity and inconvenience is typically observed in dense, mixed-use urban environments that have less on-street and off-street parking (TCRP, 2005).

A final transportation variable that plays a potential role in carsharing location is the availability of bicycle infrastructure, based on studies that suggest that non-motorized accessibility and bicycle mode share contribute to the conditions that facilitate carshare-friendly environments (TCRP, 2005; Celsor & Millard-Ball, 2007). As mentioned, carsharing hinges on the ability to live without a car, and bicycle infrastructure contributes to this ability by providing mobility options outside owning a vehicle (TCRP, 2005). Additionally, a geographic information system (GIS) study looking across 13 regions in the US found that bicycling had a positive Pearson Correlation coefficient of .202 to a significance level of .05 with carsharing level of service in New York City (Table 2-2) (TCRP, 2005). In addition, locations near carsharing PODs tended to have higher bicycle modal share than the rest of the region around them, but the relationship lessens in extent when adjusted for the number of carshare vehicles at each POD (TCRP, 2005). While some other North Eastern Metros like Washington D.C. had positive coefficients, it was generally found that, across all 13 regions, there was no statistically significant relationship (TCRP, 2005).

Neighborhood variables

Carsharing tends to locate in places that include mixed-use, walkable urban environments (Shaheen et al., 2012; TCRP, 2005; Celsor & Millard-Ball, 2007; Cervero et al., 2007). For example, in a web survey by the TCRP of carsharing members, 86.5% of respondents agreed or strongly agreed with the statement that their neighborhood has a good walking environment (TCRP, 2005). The neighborhood variables relevant to this study are those that describe the general land use and network connectivity characteristics of a location that make them more walkable, such as residential density, proximity to retail, employment density, and intersection density (TCRP, 2005; Stillwater et al., 2007).

The first neighborhood variable that serves as an indicator of a carsharing market location is the presence of high residential densities, where a high concentration of customers live within walking distances of a POD, acting as a proxy indicator of the multimodal nature of a location (TCRP, 2005; Stillwater et al. , 2007; Celsor & Millard-Ball, 2007). A GIS study looking at 13 regions across the US found that the average number of housing units per acre within ½ mile of carsharing pods was 17.1; when weighted to the number of vehicles at the pods, it was 21.7 housing units per acre (TCRP, 2005). Across all 13 regions, the Pearson correlation coefficient between carsharing level of service and housing units per acre was .174 and had a two-tailed statistical significance to the .01 level (Table 2-2) (TCRP, 2005). These results were confirmed in a report on City Carshare in San Francisco and other GIS studies looking at relationships between carshare and the built environment (Stillwater et al., 2009; Cervero et al., 2007).

An additional neighborhood variable to consider when evaluating carsharing market locations is the presence of high employment intensity that gives carsharing operators a higher potential to attract business carsharing members (Shaheen et al., 2009; TCRP, 2005). Carsharing operators aiming to cater to business carsharing members tend to launch their carsharing fleets toward dense employment centers, and to provide trip chaining opportunities to those near employment centers (Shaheen et al., 2009). Additionally, employment intensity further captures the high density of urban areas that carsharing thrives on to succeed (TCRP, 2005; Shaheen et al., 2009).

The presence of a mix of uses within the urban environment is another indicator of a potential carsharing market (TCRP, 2005). This synergy between locations with a mix of uses and carsharing has largely to do with the cycles of carsharing demand (TCRP, 2005). Carsharing demand periods tend to differ between different user groups, with business carshare members tending to even out demand for carsharing by using the vehicles during the work day, while members using the cars for personal trips tend to have peak demand in the evenings and weekends (TCRP, 2005). Thus, mixed-use locations have the potential to pair user groups with different demand patterns (TCRP, 2005). One way that research has tried to capture this behavior—along with other characteristics of walkable urban locations—is by looking at the percentage of units built before 1940 (TCRP, 2005). In one study, carsharing level of service and the percentage of units built before 1940 were found to have a positive Pearson correlation coefficient of .223, which achieves two-tailed significance to the .01 level (TCRP, 2005). Additionally, carsharing tends to locate in walkable urban locations, and a mix of uses contributes to that walkability by clustering origins and destinations together in close proximity (Cervero et al., 1997; Newman & Kenworthy, 1997).

The accessibility of local retail, which both contributes to the walkability of a location and is a feature reported in a survey of carsharing neighborhoods, is another indicator of a potential carsharing market (TCRP, 2005; Boarnet et al., 2011). In a web survey of carsharing members conducted by the TCRP, 67.7% of respondents agreed or strongly agreed with the statement that in their neighborhood it is easy to walk to a grocery store (TCRP, 2005). This survey strongly suggests that many carsharing members have local shopping opportunities within their neighborhoods and that it is a common trait found in carsharing neighborhoods (TCRP, 2005). In addition to this, in many cases the walkability of an area often depends on the availability of local shopping opportunities that the neighborhood unit provides to its residents (Boarnet et al., 2011; Azmi & Karim, 2012; Millward et al., 2013). For example, a study looking at walking behavior found that most common trip purpose for walking was traveling to shop at retail establishments and offices, making up 34.4% of all walking trips (Millward et al., 2013). Some important destinations included restaurants and bars, grocery stores, shopping centers, banks, and other services. Most people walking to these destinations have strong distance decay relationships, with most walks being shorter than 600 m, few further than 1200 m (Millward et al., 2013). In the study, many of these destinations tended to cluster in downtown cores or employment nodes where retail and offices are clustered (Millward et al., 2013). In addition, carsharing research across 13 geographic regions supports this connection, with carsharing pods having a positive Pearson correlation of .512 (the highest out of all variables listed) with a two-tailed significance to the .01 level (TCRP, 2005).

The final neighborhood variable that is an indicator of carsharing market location is the presence of good street connectivity, which contributes to the walkability of a location (Tal & Handy, 2012; TCRP, 2005). Street connectivity contributes to walkability as a quantity measuring the number of connections in the pedestrian network, and thus the directness and diversity of routes available (Tal & Handy, 2012). Intersection density, the measure of the number of intersections between 3 or more road links, is an accepted measure of street connectivity and contributor to walkability (Tal & Handy, 2012). A GIS study of 13 regions found intersection density had a positive Pearson correlation coefficient of .290 with a two-tailed significance to the .01 level (Table 2-2) (TCRP, 2005). However, one exception to this finding was New York having a negative Pearson correlation coefficient of -259 with a two-tailed significance to the .01 level (Table 2-2) (TCRP, 2005). While New York City has an odd relationship with this metric, it is still a generally good metric of street connectivity and one that is useful for identifying suitable locations for carsharing (TCRP, 2005; Tal & Handy, 2012).

Demographic variables

Demographic variables are largely limited to demographic characteristics of the populations that use carsharing, who largely are households that do not own many vehicles, use other modes other than driving to work, are small, have few kids, and are located in densely-populated areas (TCRP, 2005; Cervero et al., 2007).

Vehicle ownership is likely one of the strongest demographic indicators of carsharing market potential across a diversity of regions (TCRP, 2005; Cervero et al., 2007). Low rates of vehicle ownership are a trait that is consistent with most carsharing PODs, with the average car share vehicle being found in a location with an average of 82% of households having 0 to 1 vehicles, compared to the regional average of metropolitan areas with carsharing of 46% (TCRP, 2005). It is noted in many studies that the proportion of zero-vehicle households has a very strong relationship with car share, with the average car share vehicle being in a neighborhood where 40% of households have no vehicle, compared to the regional average of metropolitan areas with carsharing of 11.3% (TCRP, 2005). In a regression analysis of car share, households with 0 to 1 vehicles across all 13 regions considered in the study (including Boston, Los Angeles, Philadelphia, New York, Portland, San Francisco, Seattle, and Washington D.C.) had a Pearson correlation coefficient equal to 0.488, with a two-tailed significance to a p value of .05 (Table 2-2) (TCRP, 2005). The emphasis on zero-vehicle households could not be overstated in the same study as well, with zero-vehicle households having Pearson correlation coefficient equal to .399, with a two-tailed significance to a p value of .05 across all regions (Table 2-2) (TCRP, 2005). One of the reasons that zero-vehicle households are so significant to car share is that they are one of the major sources of early adopters (TCRP, 2005).

Another demographic variable of interest to carsharing markets is the travel behavior of the population, where households that use modes other than driving to get to work, such as walking and transit, are more likely to be amenable to using carsharing services (TCRP, 2005). The respective relationships between walking, transit, and single-occupant vehicles and carshare vary with strength, but the literature differs with its results For example, in one study looking at carsharing level of service across 13 regions shows that New York Metropolitan area had a small statistically insignificant significant relationship between carshare use and transit, but a stronger and more significant relationship with high walking modal share and low single occupancy vehicles modal share (Table 2-2) (TCRP, 2005). In the same research, the R^2 for transit use is stronger and statistically significant when looking across metropolitan areas (TCRP, 2005). In general, the locations where carsharing use is high tend to have a higher percentage of individuals using transit and walking to work, and lower percentages of individuals driving to work (TCRP, 2005).

An additional demographic variable that is a statistically significant indicator of carsharing market location is the presence of households with few or no children (TCRP, 2005; Cervero et al., 2007). A GIS study looking at carsharing level of service across 13 regions found that the percentage of households with children had a Pearson correlation coefficient of -.412, with a two-tailed significance level of .01 for all carsharing neighborhoods in the study area (Table 2-2) (TCRP, 2005). In NYC, the relationship is even stronger, with a Pearson correlation coefficient of -.593 with a two-tailed significance level of .01 (Table 2-2) (TCRP, 2005). Additionally, in a study in San Francisco, the percentage of members who were not carsharing participants had higher percentages of households with children than carsharing member households (Cevero et al., 2007). However, while these demographic relationships are strong, they do not mean that there are not households with children that are carshare members (TCRP, 2005). It is largely that younger professionals of working age are more likely to carshare, and, as such, demographic correlations alone may not be as useful as the transportation and neighborhood characteristics (combined with demographic characteristics) in predicting the locations for carsharing (TCRP, 2005).

In addition to this, another demographic variable that serves as an indicator for carsharing markets is the presence of populations with small family sizes—households of 1 to 2 people, specifically (TCRP, 2005). The TCRP found in its web survey that 64% of households participating lived with one other person, and the average household size was 2.02 (TCRP, 2005). Another study in San Francisco found that the mean household size of carsharing households was 1.93 individuals, compared to the 9-county Bay Area regional average of 2.63 (Cervero et al., 2007). Additionally, in a GIS analysis across 13 regions, the number of one-person households was a strong predictor for car share usage with a correlation coefficient of .478 that achieved a two-tailed significance to a p value of .05 (Table 2-2) (TCRP, 2005).

Another variable of interest to the presence of carsharing markets is the percentage of the population with a bachelor's degree or higher (TCRP, 2005; Stillwater et al., 2007). While a GIS study across 13 regions found varying relationships with percentage of population with a bachelor's degree or higher, it did find a positive and statistically significant relationship in New York City with Pearson correlation coefficient of .381 and had a two-tailed statistical significance to the .01 level (Table 2-2)(TCRP, 2005). However, while the GIS study had these results, other studies show that education is still a significant variable in the success of carsharing in a region (TCRP, 2005; Cervero et al., 2007). The TCRP web survey of car share members found 35% held a Bachelor's degree, 48% had some postgraduate work or an advanced degree, and only 2% had less than some college education (TCRP, 2005). In fact, some studies have shown that high levels of education seem to be the strongest predictor of whether an individual becomes an early adopter (TCRP, 2005). Based on data from one car share operator, the average percentage of the population in car share neighborhoods that had a bachelor's degree or higher was 48% (Stillwater et al., 2009).

A final demographic variable of interest to carsharing is population density, which is both a proxy indicator of multimodality and an indicator to the number of potential customers that carsharing requires to thrive (Celsor & Millard-Ball, 2007). For example, Zipcar sets a threshold of 10,000 people per square mile for its car share pod as an indicator of whether or not a station would be viable (Celsor & Millard-Ball, 2007).

Table 2-1. Estimated annual cost of typical parking facilities in 2007 dollars annualized over 20 years. Adapted from pg. 5.4-10 of: Litman, T. (2013). Transportation cost and benefit analysis ii – cost and mode definitions. In *Parking Costs*. Victoria Transport Policy Institute. Retrieved from http://www.vtpi.org/tca/tca0504.pdf

	Suburban: Surface	Urban: Surface	Urban: 3 level structure	CBD: 4 level structure
Annualized Land Cost per space	$215	$944	$315	$1,089
Annualized Construction Cost per space	$326	$543	$1,954	$2,171
Annual Operation and Maintenance Costs per space	$345	$575	$575	$575
Total Annualized cost	$885	$2,062	$2,844	$3,835

Table 2-2. Pearson Correlation Coefficients of different variables to Carsharing Level of Service adapted from pg. 3-35 of: Millard-Ball, A., Murray, G., Schure, J., & Fox, C. (2005). *TRCP: Report 108-car-sharing: Where and how it succeeds*. San Francisco: Transportation Research Board. http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_108.pdf

Variable	Boston	Los Angeles	New York	Philadelphia	Portland	San Francisco	Seattle	Washington DC	All Records
% households with children	-.548 (++)	0.106	-.593 (++)	-.627 (++)	-.729 (++)	-.552 (++)	-.646 (++)	-.303 (++)	-.412 (++)
% 1 person households	.619 (++)	.124	.699 (++)	.679 (++)	.822 (++)	.236 (+)	.758 (++)	.441 (++)	.478 (++)
% that carpool to work	-.503 (++)	.338	-.414 (++)	-.596 (++)	-.715 (++)	-.608 (++)	-.708 (++)	-.340 (++)	-. 363 (++)
% that drive alone to work	-.441 (++)	-.620 (++)	-.406 (++)	-.627 (++)	-.851 (++)	-.480 (++)	-.758 (++)	-.653 (++)	-.431 (++)
% that take transit to work	0.033	.492 (++)	0.043	-.626 (++)	.607 (++)	.477 (++)	.277 (++)	.198 (++)	.104 (++)
% that bike to work	-.149 (+)	-.425 (++)	.202 (+)	0.109	0.005	-0.046	-.318 (++)	.688 (++)	0.003
% that walk to work	.374 (++)	.337	.376 (++)	.718 (++)	.915 (++)	.281 (+)	.850 (++)	.538 (++)	.512 (++)
% of households with no vehicle	.427 (++)	.661 (++)	.551 (++)	.667 (++)	.902 (++)	.361 (++)	.832 (++)	.681 (++)	.399 (++)
% of households with 0 or 1 vehicle	.522 (++)	.485 (++)	.400 (++)	.735 (++)	.793 (++)	.422 (++)	.770 (++)	.633 (++)	.488 (++)
% with Bachelor's Degree or higher	.210 (++)	-.483 (++)	.381 (++)	.573 (++)	-0.028	-0.055	-.472 (++)	-0.04	0.063
Housing units per acre	.751 (++)	-.445 (++)	.379 (++)	.843 (++)	.636 (++)	.656 (++)	.671 (++)	.890 (++)	.174 (++)
Street Intersections per acre	.311 (++)	-0.024	-.208 (+)	-.26	.144	.583 (++)	.142	.475 (++)	.290 (++)

(+) denotes a correlation coefficient that has a two-tailed statistical significance to the .05 level.
(++) denotes a correlation coefficient that has a two-tailed statistical significance to the .01 level.

CHAPTER 3
METHODOLOGY

This study is a cross-sectional simulation using suitability analysis to gain insight into locations that have enough demand to support carsharing services in Brooklyn, New York City. The goal of this analysis is to determine what locations have minimally suitable environments to support carsharing services, in order to inform future carsharing policy. The benefit this provides is that, by understanding the geographic extent of potential carsharing demand, it is possible to reduce risks associated with providing incentives, such as reducing parking requirements in locations that cannot support carsharing services.

This section is organized into four general sections. The first section briefly reviews how information about the current state of New York City Parking and Carsharing policy was collected. The second section is the methodology for how the carshare suitability sub-models were created, looking at the demographic, transportation, and neighborhood characteristics that tend to support carsharing services. The third section looks at how carsharing pods are utilized with the suitability analysis to create carsharing market shed locations. The final section looks at how these market sheds are utilized to make policy zones and policy recommendations.

Policy Context Research Methodology

The research for the current state of parking policy and carsharing policy in New York City was retrieved by from three basic sources. The first was by searching New York City sponsored websites, specifically the Department of Transportation and the Department of City Planning. The second source of information came from searching libraries of academic journals in databases such as Science Direct and the University of

Florida library system. In the case of the Science Direct and the University of Florida Library system, this source was the primary source of data for the literature review, as well as providing information on New York City's policy context. The last source was searches on Google Scholar and Google itself. The search queries used typically for both the literature review and the policy context research had the following words and phrases: "New York City," "Carsharing Policy," "Carsharing," "Parking Policy," "Studies," "Parking," "Reports," "Waivers," "Minimum parking requirements," and "On-Street Parking." These basic searches often linked to other papers and reports that provided resources to find new research and studies to evaluate.

Summary of Suitability Methodology

The suitability analysis is broken up into three general categories: transportation, neighborhood, and demographic variables. All three of these categories are ultimately combined into different suitability surfaces that are used throughout the rest of the analysis. Tables 3-1, 3-2, and 3-3 briefly summarize the types of variables used, their weights, and justification. Figure 3-1 presents a summary diagram that shows how the variables are combined in the suitability analysis.

Transportation Sub-model Methodology

The GIS data for the Transportation Sub-Model is based on data collected from New York City's open data repository, which takes information from multiple departments, including the New York City's Department of Transportation (NYCDOT) and Metropolitan Transportation Authority (MTA) (DoITT, 2013). Additionally, PLUTO map data is used to provide parcel information taken from the NYC Department of City Planning website (DCP, 2013). The data used includes MTA bus lines and stops, MTA subways and stations, NYCDOT bike lane and sidewalk data, NYCDOT on-street parking regulation and off-street parking locations, and Department of City Planning (DCP) PLUTO data, which was retrieved from the DCP website (DoITT, 2013; DCP, 2013). This model attempts to capture elements of transportation and parking infrastructure that contribute to make urban environments more multimodal, thus contributing to carsharing's success in the area.

Subway stations surface raster

The suitability surface raster for subway stations was based on studies reporting that carsharing vehicles tend to be deployed near public transit stations or in locations serviced by them (Shaheen et al., 2009; Stillwater et al., 2007). Based on information from previous studies, the locations of subway stations were used to create a measure of transit proximity and level of service. The proximity raster was based on studies looking at the distances people travel to reach transit services (Gutiérrez et al., 2011; Untermann, 1984). In general, most catchment areas for rail service are approximately ½ mile, and for bus services are ¼ mile (Gutiérrez et al., 2011). In both of these cases, a distance decay relationship exists between distance away from transit stops and ridership, wherein the number of riders decreases as the distance away from a transit stop (the distance walked) increases (Gutiérrez et al., 2011). In many cases, this drop in ridership with distance can be very dramatic, with some studies finding near exponential decreases (Gutiérrez et al., 2011). For example, one study found that most people would walk 500 ft. to transit, 40% would walk 1000 ft., but 10% would walk half a mile (Untermann, 1984). While other studies of the distance decay relationship exist, Untermann is used in this paper because of its ease of application. The proximity raster is a Euclidean distance raster that is reclassified so that 0-500 feet is a 9, 500-1000 feet is a 7, 1000 -1250 feet is a 4, 1250-1750 is a 3, 1750- 2300 is a 2, and everything beyond 2300 is a 1. The next raster is the subway station quality raster, which is a point density on the stations, with a population field being the number of lines that serve the station and the search radius being ½ mile. Once the point density raster was generated, it was reclassified using geometric interval because the distribution had a skew to lower numbers and had a large number of repeated values. The basis for this density raster is that the number of lines represents options for destinations, and the more stations nearby or overlapping, the more generally well served the catchment area is. This assumes that each subway line has approximately the same level of service, and while this is not true, almost all subway headways are less than 10 minutes during the peak hour (MTA, 2010). While this measure is not perfect, it does capture high subway service nodes, such as downtown Brooklyn, Coney Island, and other locations that tend to have higher transit mode shares (Census Bureau, 2011). Once the proximity and subway quality rasters were created, they were put together with a weighted sum where each would be equally weighted (.5).

Bus stops surface raster

The surface raster for bus stops was based on studies' reports that carsharing tends to locate in multimodal locations that are served by transit (Shaheen et al., 2009; Stillwater et al., 2007). Similar to the subway raster, a proximity and quality raster are developed, but with a few more processing steps. The proximity raster was made so that its distance decay relationship reached its lowest value within ¼ catchment area observed for bus stops (Gutiérrez et al., 2011). Thus, the proximity raster was created by taking a Euclidean distance raster from bus stops and reclassifying the values so that 0-500 feet was a 9, 500-1000 feet was a 7, 1000-1500 feet was a 2, and everything past 1500 feet was reclassified as a 1. The quality raster was created by doing a spatial join between MTA bus stops and MTA bus lines so that bus stops were joined to every line within 50 feet of them. The join count is then used as the population field for a point density with a search radius of ¼ mile. The bus stop quality raster is then reclassified from 1 to 9 using geometric interval as a result of the left skew of the distribution and the occurrence of repeated values. Then the quality and the proximity rasters are combined through a weighted sum so that each raster has equal weight (.5).

Bicycle infrastructure surface raster

The surface raster for bicycle infrastructure was built based on research that gives indications that non-motorized accessibility and bicycle mode share contribute to the conditions that facilitate carshare friendly environments (TCRP, 2005; Celsor & Millard-Ball, 2007). However, while bicycling may contribute to the conditions that facilitate carshare, no clear-cut relationship exists; as such, this factor is given a low weighting. The bicycling surface raster was developed by taking bike lane data and creating a quality ranking based on whether it is a protected bike lane, bike lane, or sharrow (NACTO, 2011; DoITT, 2013). A protected bike lane refers to a right of way exclusively reserved for bicyclists that is buffered at least 2 feet from the street's driving/parking lane or even protected with barriers (NACTO, 2011). This type of lane is considered the highest quality type of bicycle infrastructure, with 7 out of 10 cyclists reporting they would go out of their way to ride on a buffered facility over a conventional bike lane (NACTO, 2011) A conventional bike lane offers slightly less protection and comfort by just consisting of an exclusive right of way for bicyclists, while a sharrow offers even less protection and comfort by consisting of a street with road markings indicating shared use of the road by bicyclists and automobiles (NACTO, 2011). While the data required some data-wrangling to rank bicycle facilities based on their quality, the ranking was set up numerically so their quality would be rated on a 1 to 9 scale. The final ranking was set up so a protected bike lane would be ranked a 9, conventional bicycle lanes were ranked a 6, and sharrows were ranked a 3. Then a kernel density was run on the bike facilities, with the population being the new bike ranking and the search radius being 4400 feet (5 minute bike ride at the urban average of 10 MPH)(NACTO, 2011). This kernel density raster is then reclassified from 1 to 9 using natural breaks.

On-street parking surface raster

The surface raster for on-street parking was created with NYCDOT street regulation data, which includes on-street parking (DoITT, 2013). This data regulation type field is very cumbersome—with approximately 3356 unique values (all unordered strings) and about 146,148 points located in Brooklyn alone, simple querying options were not available to select out relevant parking regulations (DoITT, 2013). The queries that were finally used aimed to select out metered or priced parking and locations where there is no parking allowed on more than two days. The final query for metered parking was “"SIGNDESC1" LIKE '%MUNI%' OR "SIGNDESC1" LIKE '%$. %' OR "SIGNDESC1" = '%METERED%' OR "SIGNDESC1" LIKE '%CEN”T%'”, and, when selected, a new field called park score was calculated to be equal to a 9. The final query for no parking for longer than 2 days was “"SIGNDESC1" LIKE '%NO PARKING%' AND "SIGNDESC1" LIKE '%THRU%' AND NOT "SIGNDESC1" LIKE '%SANITATION%' AND NOT "SIGNDESC1" LIKE '%BROOM%'OR "SIGNDESC1"LIKE '%NO PARKING%EXCEPT%' AND NOT "SIGNDESC1" LIKE '%SANITATION%' AND NOT "SIGNDESC1" LIKE '%BROOM%'”, and, when selected, the park score field was calculated to be equal to 7. All other field values are then calculated to be equal to 0 (assuming parking was generally more available). While these regulations and rankings are not perfect, they give an idea of where there is generally less parking available, and visual scans looking over the data selected found that only relevant regulation types were generally selected. The parking regulation data then served as the input for a kernel density, with the population field being the parking score field and a search radius of 1000 feet. This parking regulation raster is then reclassified from 1 to 9 using natural breaks. In an attempt to normalize the raster for the amount of activity each location may receive, a surface raster that reflected the approximate each location's value as a destination was created utilizing the employment intensity index (showing the square footage of employment activity in the neighborhood submodel). Once the index was created, it was converted to raster, and then reclassified 1 to 5 using natural breaks so that it would not have a large impact on the final raster. After the park index raster was created, cell statistics was used between the park index and the employment intensity index so that the maximum value would be the value chosen for each cell, further limiting the impact of the park ranking raster on the final employment activity index. The destination activity index is then multiplied by the on-street parking raster so that locations with high "destination" intensity and low availability of on-parking have higher values. This final on-street parking surface raster was then reclassified from 1 to 9 using natural breaks.

Off-street parking surface raster

The surface raster for off-street parking was built based on studies reporting that carsharing tends to locate in areas with increased parking pressures from a scarcity of parking (TCRP, 2005). The raster was built from two data sets, one a polygon file of parking lots larger than 2000 feet, provided by the Parks and Recreation department, and the PLUTO data set, provided by the Department of City Planning (DoITT, 2013; DCP, 2013). For the parking lot data set, parking lots are selected if they DO NOT intersect with any PLUTO lot that has any garage square footage. Then an additional field Parking_Val is calculated to 2000 (sq. ft.), and then the parking lots are converted to points. For the PLUTO data set, all lots with garage area greater than 0 are selected. An additional field Parking_Val is calculated to be equal to the garage area, then the lots are converted to points, and then merged with the parking lot points. A kernel density is then run on the points, with the population field being Parking_Val and the search radius set to ¼ mile. The kernel density raster is then reclassified from 1 to 9 using geometric interval because the distribution had a high skew to lower numbers and had a large number of repeated values. The reclassification had the new values reversed so that locations with a low density of available off-street parking were higher values. Once the off-street parking density was reclassified, the resulting raster was multiplied by the destination activity index raster so that locations with both higher traffic "destination" areas and a low availability of off-street parking had higher values. Once this was done, the off-street parking raster was reclassified 1 to 9 using natural breaks.

Final transportation suitability raster

The final transportation suitability surface for car share was constructed by utilizing a weighted sum on the subway station, bus stop, off-street parking, on-street parking, and bicycle infrastructure surface rasters, adding them all together with different weight values. The weights were chosen based on the strength and consistency of the variables' relationship to car share membership and neighborhoods that host car share locations. A summary table for the transportation sub-model showing the weights used for each variable and its justification are listed in Table 3-1. Once the final weighted sum was calculated, the output transportation suitability surface raster was reclassified using natural breaks.

Neighborhood Sub-model Methodology

The GIS data for the Neighborhood Sub-Model is based on New York City's Department of City Planning MAP Primary Land Use Tax Lot Output (PLUTO) data and Simplified NYS Street data (ITS, 2013; NYC DPC, 2013). The Map PLUTO data is lot level land use data that contains information about land uses, building square footage, zoning data, and other land use related information (NYCDCP, 2013). The Simplified NYC Street data is simplified street information that contains simplified polylines of relevant streets in New York State and contains information about street types, lengths, and names (ITS, 2013). This model was aimed to reflect the neighborhood characteristics that carsharing markets tend to locate in, which are dominantly mixed-use, walkable urban environments (Shaheen et al., 2012; TCRP, 2005; Celsor & Millard-Ball, 2007; Cervero et al., 2007).

Residential density surface raster

The suitability surface for dwelling units per acre was built based on studies that reported that carsharing locations tend to be located in residential neighborhoods with high residential densities (TCRP, 2005; Celsor & Millard-Ball, 2007; Stillwater et al., 2009). Based on this information, land use parcels with residences were selected and turned into points, and then a kernel density with a search radius of ¼ mile was applied. Once this was done, the raster was reclassified from 1 to 9 using natural breaks.

Retail proximity and density surface raster

The suitability surface for retail proximity and density was built based on studies reporting that carsharing markets are oriented toward walkable urban environments that provide the ability to live without a car and surveys showing carsharing members have access to retail in their neighborhoods (TCRP, 2005; Shaheen et al., 2012; Boarnet et al., 2011). Based on this information, the retail suitability surface was constructed by creating a raster that reflected both the relative concentration of retail and the relative proximity of retail to each residence. The rasters made to establish retail proximity were created by running Euclidean distance on all lots with more than 100 sq. ft. of retail, and then reclassifying it so that the highest value (9) would be below the average distance each residence was from retail and the next value (8) would be the mean +1/4 standard deviation, and then the next value (7) would be the mean +1/2 standard deviation and so on, till 1 was out more than 1 and ¾ standard deviations. The residence distances were calculated with zonal statistics on the retail Euclidean distance on multifamily and single family residences, each reclassified in the same manner as mentioned above, and then put together with a weighted sum that was weighted based on how many residential units were in multifamily (88% of units) vs. single family residences (12% of units). The surface that would reflect the relative concentration of retail was generated by converting the retail units greater than 100 square feet to points and running a kernel density on the points, with the population being the square footage of retail on each lot and the search radius being ¼ mile. Once the kernel density was run, the final raster was created by reclassifying the raster using geometric interval, because the distribution had a high skew to lower numbers and had a large number of repeated values, the exact circumstance that this reclassification method desired. The final step was a weighted sum between the retail concentration and proximity raster each with equal weight (.5) to make the final retail proximity and concentration raster designed to reflect shopping opportunities open to residents.

Employment intensity index surface raster

The surface raster for the employment intensity index was built to highlight locations of high employment intensity that would have a higher potential to attract business carsharing members (TCRP, 2005; Shaheen et al., 2009). Based on this information, the surface raster for employment intensity was created by selecting out all lots with office, retail, industrial, storage or other floor area greater than 0. Within this selection, parcel BBL 3085911500 was excluded because its building area was over four times larger than the second largest parcel (the Brooklyn Navy Yard) (DCP, 2013). This parcel caused significant distortions in the results and reduced the model's validity for nearby parcels. Once the relevant lots were selected, they were turned into points. After this was done, a new field was added for employment area, and was calculated by summing the total retail, office, industrial, other, and storage square footage for each lot. The raster for employment density was created by running a kernel density with a search radius of ¼ mile and with the total employment area as the population field. The final raster was reclassified 1 to 9 using geometric interval because the distribution had a high number of repeat values and a strong skew to lower numbers. While this lot level data does not provide the actual number of employees in each location, it does provide a strong indicator of the intensity of employment activity in each location, often serving as a metric on which to base trip generation estimates (MOEC, 2012).

Land use mix surface raster

The suitability surface for land use mix was built based on studies reporting that carsharing pods tend to locate in urban areas with a mix of uses, due to the cycles of carsharing demand and contribution to walkability that a mix of uses provides (TCRP, 2005; Stillwater et al., 2009; Cervero et al., 1997). Based on this information, the mixed-use surface raster was built by taking each of the lots and separating them into 7 categories: office, retail, industrial, public facilities, park land, single family, and multifamily. Then these parcels are converted to raster, and reclassified into values of 100 to represent the number of square feet of land area each cell represents. Focal statistics is then used to calculate the net area of each land use in each category, to then be divided by a focal statistic of all the selected land uses, creating a proportion of each land use. After the sums are created, they are plugged into a mixed-use entropy index (Shannon Index) being calculated in raster calculator with the following formula:

$$Land\ use\ entropy = \frac{\sum[(pi)(lnpi)]}{\ln k}$$

Where *pi* is the proportion of land use category I.

Where *k* is the number of land use categories.

This entropy index has been used in various studies to get a general understanding of how mixed land uses are within a study region, whether they are homogenous or heterogeneous (Cervero et al., 1997; Arafat, 2011). Once the land use entropy index is calculated, it is reclassified using natural breaks.

Intersection density surface raster

The final surface raster for intersection density was built based on studies looking at walkability's and carsharing's relationship to increased street connectivity (Tal & Handy, 2012; Celsor & Millard-Ball, 2007). Even with New York's odd relationship with intersection density, intersection density generally had a positive correlation to carsharing, and its use as a metric is addressed through its lower weighting (Table 3-3)

(TCRP, 2005). Based on this information, the intersection density surface raster was built by selecting out streets that pedestrians did not have access to, such as limited access thoroughfares and highways. The next step was selecting out their intersections by buffering the nodes in the network, creating a small buffer, doing spatial join on the buffer and links, and then selecting buffers whose join counts were greater than 3. Once this was done, a point density was run on the intersections with a search radius of ¼ mile, and then reclassified 1 to 9 using natural breaks.

Final neighborhood suitability raster

The neighborhood suitability model was constructed by utilizing a weighted sum on land use entropy, residential density, employment intensity, intersection density, and proximity and density of retail rasters. The weights for the various variables were based on the relative strength of the relationships for the variables and the literature's reports on what neighborhood variables are relevant to where carsharing pods locate. The weights used for each variable in the neighborhood sub-model and their justification are summarized in Table 3-2. Once the weighted sum was calculated, the raster was reclassified using natural breaks.

Demographic Sub-model Methodology

All of the demographic data utilized for the demographic sub-model—other than population density—is based on the 2007-2011 American Community Survey census tracts level data, retrieved from the Census Bureau TIGER Products website (Census Bureau, 2011). Census tracts were the chosen level of aggregation because the block group level data had a margin of error so large that it was unreliable as a source of demographic information; thus, the census tract level data was considered the best available data for the project. With the exception of population density information, 2010

Census Block data, retrieved from Minnesota Population center, was used (NHGIS, 2010). In the case of population density, the census data only relies on the number of people in the census block, which tends to be accurate at that aggregation, as opposed to American Community Survey data. This model was used to reflect the demographic characteristics that carshare locations tend to locate in, which are largely small households with low car ownership, low levels of automobile based commuting, and other demographic characteristics (Celsor & Millard-Ball, 2007).

Average household size surface raster

The surface raster for average household size was built based on the demographic literature that states that carsharing members' household size tends to be small households of 1 to 2 people (TCRP, 2005; Celsor & Millard-Ball, 2007). Based on this information, the average household size estimate was converted to raster, and then reclassified so that the highest value for the suitability surface (9) is an average household size of 0-2. After average household size of 0-2 was ranked a 9, the following ranks were set to decrease by 1 for every .2 rise in the average household size, and the lowest rank was set so that 3.4 to the max of 5.59 was equal to 1.

Population density surface raster

The population density surface raster was utilized because it is an indicator of multimodality and an indicator to the number of potential customers that carsharing requires to thrive (TCRP, 2005). For this raster, a kernel density of census blocks in NYC was utilized, which was then reclassified into natural breaks. This decision was based on the fact that Brooklyn's population density rarely goes below 10,000 people; thus, reclassifying on natural breaks was chosen to give an impression of relative population density in a manner that was consistent with suitability analysis reclassifications (NC DENR, 2005).

Mode share surface raster

The modal share surface raster takes into account travel behaviors associated with car share uses and is based on a constructed modal share index. The modal share index was constructed by creating a field that calculated using the follow expression: Modal share index= %Transit+%Walking-%SOV.

Where:

"%Transit" is the percentage of people who take public transit as their commute to work.

"%walking": is the percentage of people who walk as their commute
to work.

"*%SOV":* is the percentage of people who are driving alone, classified as single occupant vehicles (SOV), as part of their commute to work.

After the index was calculated, it was converted to raster, then reclassified using natural breaks in order to build this suitability surface layer.

The index was constructed based on the fact that, generally, carshare is more successful in locations that have a low single occupant vehicle modal share and higher shares of transit and walking (Celsor & Millard-Ball, 2007; TCRP, 2005). Most literature shows that transit use, walking, and generally low single occupancy vehicle share are associated with car share usage and uptake (TCRP, 2005). Thus, the index created reflects both high rates of walking and transit, with a negative relationship from a higher proportion of people occupying single-occupant vehicles.

Vehicle ownership surface raster

The surface raster for vehicle ownership was built based on the average vehicles per household, so that the highest values in the suitability surface favored low level of vehicle ownership. The basis of this index surrounds the fact that car share vehicles tend to be located in neighborhoods with low rates of vehicle ownership (TCRP, 2005). The index that was created gives more weight to 0 vehicle households because they are a strong source of early adopters (TCRP, 2005). The index was created to determine locations that had low rates of vehicle ownership was calculated based on the following expression:

Vehicle index=1.5*(%0 vehicle households) + (%1 vehicle households)

Once the index was calculated, the data was converted to raster, then reclassified with a natural breaks classification.

Educational attainment surface raster

The surface raster for educational attainment seen in carshare neighborhoods was created by taking the combined percentage of individuals who earned a bachelor's degree or graduate/professional degree, converting the data to raster, and then reclassifying it using natural breaks so that the higher percentage was rated more suitable. The use of educational attainment is based on the observation of higher levels of education in car share neighborhoods and membership programs, specifically those with a bachelor's degree or above (TCRP, 2005; Celsor & Millard-Ball, 2007).

Population with no children surface raster

The suitability raster for population with no children seen in carshare neighborhoods was created by taking the combined percentage of households with no children and converting the data to raster, and then reclassifying the output raster, using natural breaks so that the lower percentages were rated as more suitable. The basis for using the percentage of households with no children is that carshare neighborhoods tend to be in locations that have lower percentages of households with children (TCRP, 2005; Cervero et al., 2007; Celsor & Millard-Ball, 2007).

Final demographic suitability raster

The final demographic suitability surface for car share was constructed by utilizing a weighted sum on educational attainment, age, household size, vehicle ownerships, modal share, population density, and income surface rasters, having them added all together with different weight values. The weights were chosen based on the strength and consistency of the variables' relationship to car share membership and neighborhoods that host car share locations. Table 3-3 illustrates a summary table for the demographic sub-model, showing the weights used for each variable and its justification.

Once the weighted sum was calculated, New York City cemeteries were selected from the land use data with the following expression ""Owner Name" LIKE '%CEMETRY%' AND "Land Use" = '09'", and then turned to raster and reclassified to a value of 1. This cemetery raster surface used cell statistics set to minimum to mask out cemeteries from the suitability analysis so that they would not appear as suitable locations for car share pods. The final raster was reclassified using natural breaks.

Combined Suitability Rasters Methodology

The final step for the suitability analysis was to construct 4 combined suitability rasters from the demographic, neighborhood, and transportation suitability rasters (Figure 3-1 for conceptual model). This was done by creating 3 biased suitability rasters and 1 equally-weighted suitability raster through 4 weighted sum operations. The equally-weighted raster was created by giving each raster an equal weight of 1/3. The bias rasters were created by giving either demographic, transportation, or neighborhood suitability rasters a 50% weight and the other two rasters a 25% weight. There was a bias raster created for each of the 3 variable categories.

Market Shed Analysis Methodology

Once the final suitability rasters were finished for Kings County, the next task was to determine the average suitability values for carshare vehicles' "market sheds". In general, the literature shows that the typical market shed size for a carshare vehicle is ¼ mile from the point of departure (Shaheen et al., 2012). For example, studies have demonstrated that the profitability of carshare often hinges on the ability to have vehicles serve 25 members within ¼ mile, and is supported by the fact that, in San Francisco, 80% of carshare members live within ½ mile of the point of departure, and more than 50% live within ¼ of a mile (Shaheen et al., 2012). Based on this market shed size, focal statistics with a search radius of ¼ mile were utilized to create a market shed raster that represented the average suitability value ¼ mile in every direction of each raster cell for each of the combined suitability rasters.

After running focal statistics, Zipcar and Enterprise carshare locations were mapped as a representative sample of carsharing organizations serving Brooklyn within Google Map Maker (Google Maps, 2013). Google map maker was utilized using various search queries to limit the scope of the search to specific operators within the geographic scope of Brooklyn, and where they came up in google maps, markers were placed and labeled in the same location and then exported to XML and imported into ArcMap. In total, 61 carsharing locations were geocoded and mapped, with 7 Enterprise locations and 54 Zipcar locations. Once the file was converted into a point file, a ¼ mile buffer was created for each of the carshare locations (representing the market shed), and zonal statistics by table were run on the carshare suitability raster, with the feature zones being each independent buffer. It is based on this table that the suitability thresholds are generated for each car share market shed, by using the summary statistics of the mean values, the minimum value representing the minimum lowest market shed average value within the suitability raster, and the average value representing the average market shed average value within the suitability raster. In the case of the minimum field value, the field is recalculated so that, instead of using the lowest market shed value, the mean minus 2 standard deviations is utilized to reflect the minimum of the top 97.7% of observations within a normal distribution. While this change is not a drastic one, it does reduce the impact of outliers in the minimum threshold that would be created by using the actual minimum mean value. In the case of the average market shed average, it is simply an average of average suitability values within ¼ mile of each carsharing POD. These thresholds are then utilized to reclassify the market shed rasters made from the 4 combined suitability rasters, so that the locations that meet the minimum value threshold and the average market shed value threshold are displayed within Kings County.

With all four threshold rasters, cell statistics is utilized between the different minimum market thresholds and is set to minimum so that is takes the lowest values between all four rasters presented. To put this another way, it creates a surface where the minimum market threshold is only where there is 100% agreement between all four differently weighted rasters. This creates a conservative minimum threshold raster, because if any market threshold raster (transportation, demographic, neighborhood, or equal weighting) had a location that did not meet the minimally suitable environments for carsharing, it would be marked as being unable to support carsharing in the final raster. In the case of the different average threshold rasters, cell statistics is utilized to maximum, so it takes the highest value of all the average threshold rasters. In other words, the average market threshold requires only 1 of the rasters to agree that it meets the average conditions for carsharing. The combined effect of this is that the minimally suitable environments portions of the final threshold raster only classify locations as meeting the minimally suitable environments for carsharing if all four sub-threshold rasters mark it as meeting minimally suitable environments, and the average suitability conditions portion of the final threshold raster shows it as having average threshold conditions if only one threshold raster had a maximum. This procedure is meant to replace a sensitivity analysis between the combined rasters by having all four sub-threshold rasters be represented in the final raster.

The final step was the use of the thresholds and other rasters to build descriptive statistics that are reported in the results for areas of Brooklyn and The Inner Ring of Brooklyn, using the Inner Ring Polygon Study area utilized in the Inner Ring Parking study by the department of city planning.

Policy Zone Analysis Methodology

The end product for this section is a series of potential policy zones based on locations of relatively high poverty rates, areas with higher transit accessibility, locations within the Brooklyn Inner Ring, and general market conditions for carsharing established by the suitability model. The first step for all of these rasters was the conversion of the final market thresholds to polygons so that unions could be utilized to create combined zones.

The policy zones constructed for carsharing parking incentives to be targeted in low income areas were developed in case New York City wanted to incentivize, providing new mobility options to low income households that could either benefit from savings of the service or the option of using a car when they need them for certain trips (TCRP, 2005). The basis of these policy zones originates from the understanding that, while many low-income groups in New York City have good access to transit and other forms of transportation, carsharing could provide low-income residents with mobility options they did not have before (TCRP, 2005). As mentioned earlier, Denver aimed to conduct this type of incentive by allocating parking spaces to carsharing operators once they placed at least 2 vehicles in opportunity areas with poverty rates greater than 30% (Public Works, 2013). In a similar vein, the city of Seattle offered financial support to carsharing operators if they placed vehicles in “diverse neighborhoods” (TCRP, 2005). Locating carsharing vehicles in low-income neighborhoods can be difficult, with some cities experiencing problems related to these areas’ low saturation of population with drivers licenses, poor credit, or even language barriers to accessing services (TCRP, 2005). However, this makes policy support for low-income households’ access to carsharing critical if a city finds providing this mobility option to low-income residents to have social benefits. These zones were constructed based on a poverty threshold that was in turn based on the average and standard deviation of poverty rate in ACS Census Tract level data calculated with the summary statistics tool (Census Bureau, 2011). The average census tract poverty level in the ACS data was about 15%, and the standard deviation was about 13% (Census Bureau, 2011). Based on this, a poverty threshold of 28% was used to grab census tracts that had approximately the top 15% of high poverty census tracts in the study region. In addition, this threshold is similar to the level used to define Denver's opportunity areas (30%), so it seems a reasonable threshold to utilize (Public Works, 2013). Once these census tracts were selected, a union was run with the final market thresholds polygon, so that only census tracts that met the minimum market thresholds were kept.

The next policy zone constructed was a transit overlay combined with the minimum market thresholds polygon. The basis for this raster was that parking reductions or other incentives for development in transit-served locations if they provided carsharing near their development. While some cities offered blanket parking reductions in locations near transit, New York City has historically done this by allowing higher-density development near transit and having lower parking reductions per unit for higher-density zoning districts (McDonnell et al., 2011; DCP, 2011). The formal introduction of transit overlay districts, however, has not occurred in New York City, but has been recommended by a few studies as a formal way of reflecting changes in parking demand related to transit service (DCP, 2011; McDonnell et al., 2011). While New York City has not endeavored to create such zones yet, they might consider it if it was complemented by carsharing vehicle access to mitigate the impacts of demand for automobility that they are concerned will have spillover effects. These zones were constructed by creating ¼ and ½ mile buffers around subway stations, and then running a union between the buffers and the final market threshold polygon. These final zones limited carsharing incentives to areas that met the minimum market thresholds and were within a certain range of high-quality transit service.

The third was one that was established just by utilizing the minimum market thresholds established by the raster as policy zones themselves because they reflect locations where the incentives would not be abused to create carsharing spaces where carsharing is infeasible (Engel & Passmore, 2013). Taking into account the social benefits of carsharing, these zones would be considered geographies where the risks of reduced parking requirements for carsharing vehicles is decreased as a result of having the right conditions to support carsharing in the region. This final polygon is just the final market threshold, with those areas meeting at least the minimum requirements being selected.

The final one was established by selecting out locations that meet the minimum market thresholds from the suitability analysis that were within the Inner Ring of Brooklyn, a geography reflecting locations of higher transit accessibility and lower vehicle ownership created by the Department of City Planning from the Inner Ring Parking study (DCP, 2013). This geography was created by taking the polygon of the Inner Ring of New York city and clipping it out with the Brooklyn County boundaries. Then it was the union locations that at least met the minimum market thresholds and were within the Inner Ring that were selected out.

Table 3-1. Summary of Transportation Sub-model variables

Surface Raster Variable	Weight	Basis
Subway Service	.35	Literature showing correlations between carsharing and rail stations, and transit usage across regions.
Bus Service	.15	Literature showing relationship between carsharing and transit service, with carsharing vehicles often being deployed near major bus stops.
Bicycle Infrastructure	.1	Positive relationship between bicycle and carshare in New York city, contributes to the options available other than the automobile.
Off-Street Parking Availability	.2	Literature reports of carsharing vehicles being deployed with larger parking pressures, increasing the cost of the automobile.
On-Street Parking Availability	.2	Literature reports of carsharing vehicles being deployed with larger parking pressures, increasing the cost of the automobile.

Table 3-2. Summary of Neighborhood Sub-model variables

Surface Raster Variable	Weight	Basis
Residential Density-DU/Acre	.25	Significant correlation with neighborhood carshare and literature reports residential density to be a strong indicator potential membership.
Land Use Entropy	.25	Literature reports that carsharing tends to locate in urban mixed-use locations.
Employment intensity index	.25	Literature reports that business carsharing vehicles tend to locate in locations of high employment density and concentration.
Retail Proximity and Density	.15	Literature reports that carsharing tends to locate in walkable urban locations which access to retail for shopping trips contributes to (high walking mode shares in carsharing locations).
Intersection Density	.1	Literature reports that carsharing tends to locate in walkable urban locations which street connectivity contributes to (high walking mode shares in carsharing locations).

Table 3-3. Summary of Demographic Sub-model variables

Surface Raster Variable	Weight	Basis
Vehicle Ownership	.25	Strong correlations and consistent mean values in NYC and other regions.
Modal Share	.2	High walking, low SOV, and high transit show consistent correlations with car share in NYC and other regions.
Educational Attainment	.15	Consistent relationship and correlations with car share in NYC, but variation among regions. Other literature and surveys suggests it is strong predictor of early adoption of carsharing.
Average Household Size	.15	Consistent relationship and correlations with car share in NYC and other regions.
Population Without kids	.15	Consistent relationship and correlations with car share in NYC and other regions.
Population density	.1	Indicator of customer base and multimodality and an indicator used by one of the largest operators in North America.

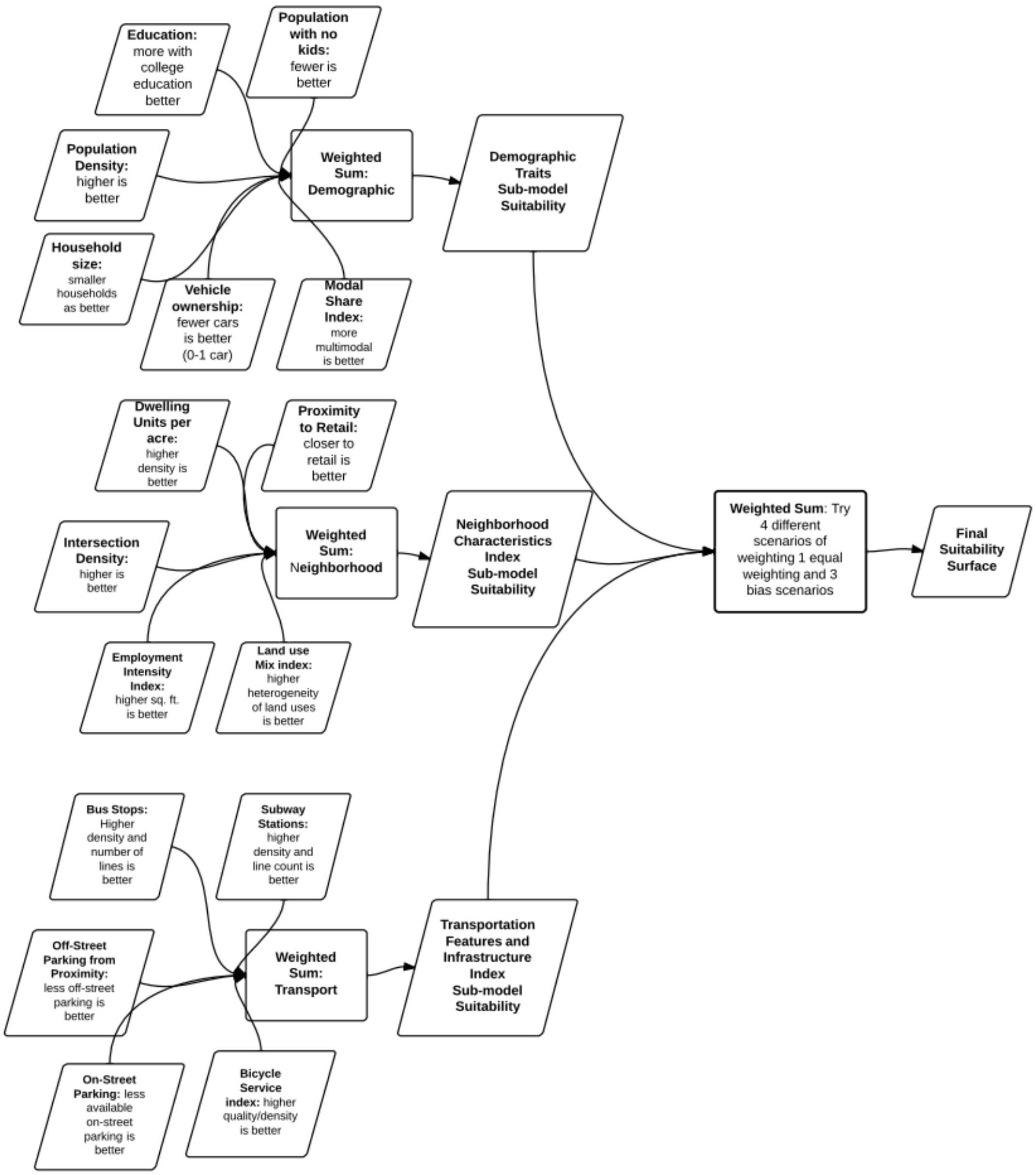

Figure 3-1. Suitability Model Summary Diagram

CHAPTER 4
RESULTS

Brief Profile of Study Area: Brooklyn

Brooklyn is 70.82 square miles in area and, as of the 2010 census, hosts a population of 2,504,700, making its population density approximately 55.26 people per acre of land (Census Bureau, 2010). This density, however, is not uniform, with most of the population located in parts of Brooklyn closer to Manhattan and along transit corridors (Census Bureau, 2011). In general, Brooklyn is very well served by transit, with 53.8% of the residential units within ¼ mile of subway stations based on PLUTO data and bus coverage that covers the entire borough (DoITT, 2013; DCP, 2013). This is reflected by Brooklyn's modal share for the journey to work, where 23.8% drove alone or carpooled to work, but 60.8% used public transportation to work, 8.9% walked to work, 2.6% used other means including bicycling to work, and 3.9% worked at home (Census Bureau, 2012). These modal shares indicate that Brooklyn is generally very multimodal; however, some locations have higher modal shares of transit and walking, while others have much higher rates of automobile commuting, such as areas within Brooklyn that are further from subways and are of much lower relative densities (Census Bureau, 2011). Additionally, this multimodality operates in this way as part of a larger region, where Brooklyn holds many residents who journey to Isle of Manhattan or Brooklyn's nearby Business district, where the bulk of employment and subway services are most heavily concentrated (DCP, 2013; Weinberger, 2012). However, even though a large portion of residents commute to the Isle of Manhattan, there is an increasing recognition of a need for options for inter-borough and intra-borough travel (DCP, 2013). Recent travel studies show that the further residents are from the Isle of Manhattan, the more likely they are to work in their own Borough, rather than to commute to the Manhattan Central Business district (DCP, 2013).

Brooklyn is one of the few areas that have incredible environments for carsharing (in locations closer to Manhattan and Downtown Brooklyn), and yet it also has environments that are less supportive of carsharing. For example, in South East Brooklyn, locations that may not have the correct conditions for carsharing have fewer mixed-uses, lower density, less transit service, and more automobile modal share, which together make carsharing infeasible (Census Bureau, 2011; TCRP, 2005). This makes understanding the market conditions for carsharing in Brooklyn important if any type of carsharing-supportive parking policies are to be developed in the region (Engel & Passmore, 2013). Based on data from Google, there is already a considerable presence of carsharing operators in Brooklyn, NYC, but there is room for considerable growth in service and coverage area (Google Maps, 2013). For context, a map of the study area (Figure 4-1) is provided below that shows existing land uses and the location of subway stations. It shows how much of Brooklyn has subway service and that it is largely dominated by multifamily development, served by mixed-use commercial corridors that provide goods and services to local neighborhoods (DCP, 2013; DoITT, 2013). In the walkable mixed-use areas with high densities of employment and population, it is expected that carsharing will have sufficient market potential to support carsharing if incentives were to be provided (TCRP, 2005). In addition to the map of land uses is a map displaying zoning districts and subway stations, based on data from the Department of City Planning website (Figure 4-2) (DCP, 2013). The zoning map shows that higher-density commercial and residential uses tend to be closer to the

Island of Manhattan, but even as the subway system moves south, higher-density residential and commercial zoning is provided in locations along transit corridors (DCP, 2011).

Study Area Policy and Carsharing Policy Environment:

Parking Policy in NYC

Even when adjusting for automatic waivers and reductions, New York City requires 50 parking spaces per 100 units of residential construction across all construction, but they vary based on different locations' zoning (McDonnell et al., 2013). While these parking requirements tend to be lower than in other parts of the country, the largely urban context of New York City and the price of land make any parking much more expensive per square foot (Litman, 2013; Shoup, 1999). For example, even in New York City—which is known for having low parking requirements—these parking requirements have been indicated in many cases as being binding, based on the observation from one study that most development in New York City had built the bare minimum of per-unit parking set in minimum parking requirements (McDonnell et al., 2013). When looking at new development in Queens, the study found that 22 out of 38 (57%) new developments built less than or equal to the minimum parking required, with those who built less acquiring waivers offered by the city (McDonnell et al., 2013). The authors suggest that many of these developments found the parking requirements binding, and that they might have provided less parking, thus building at less of a cost (McDonnell et al., 2013). Complementing this study, the Department of City Planning conducted their own study on parking requirements in the Inner Ring of New York City, encompassing locations that are dense, mixed-use communities served by transit lines, where the residents make trips by modes other than the automobile (DCP, 2013). This study found that the Inner Ring of New York City has, on average, lower rates of vehicle ownership when compared to the outer ring of New York City, and it found similar findings regarding how parking requirements can be binding (DCP, 2013).

In addition to studying specific developments to determine if requirements were binding, the McDonnell et al. conducted a GIS analysis with PLUTO parking data in order to determine the average parking ratio (parking spaces per housing unit) and the average required parking density (spaces per 1000 square foot of lot area) (McDonnell et al., 2013). Their study found that the city-wide required parking ratio, without adjusting for waivers, was 58%—meaning that, for every 100 units, 58 off-street parking spaces are required (McDonnell et al., 2013). However, this varies from borough to borough: the average required parking ratio for Manhattan is 10.6%, Staten Island is 134.4%, Queens is 76.9%, the Bronx is 56.6%, and Brooklyn is 68.5% (McDonnell et al., 2013). When considering parking density, New York City parking requirements become more complicated (McDonnell et al., 2013). Citywide, New York City has an average required parking density of .6 spaces per 1000 square feet of lot area, requiring 26 parking spaces per acre of lot area, but this varies by borough (McDonnell et al., 2013). The average required parking density for Manhattan is .53 spaces/1000 SF lot area, the Bronx is .84 spaces/1000 SF lot area, Brooklyn is .78 spaces/1000 SF lot area, Queens is .52 spaces/1000 SF lot area, and the lowest, Staten Island, is .47 spaces/1000 SF lot area (McDonnell et al., 2013). While initially counter-intuitive, this is the result of the interaction between housing unit density (related to maximum allowed building areas) and required parking ratios (McDonnell et al., 2013). Thus, even though zoning districts allow more unit density, the reduction in required parking ratio from low building density to medium-density zoning categories is not proportional to the increase in allowable units they permit (McDonnell et al., 2013). Built-out lots in medium-density districts will produce the most off-street parking spaces per land area on average when not including waivers (McDonnell et al., 2013).

The picture is more complex, however, when considering average required parking densities and parking requirements per unit in respect to whether or not they are within ½ mile of rail stations in NYC *without waivers* (McDonnell et al., 2013). The authors found that, while units near transit had less parking per unit, they did have more parking per square foot of lot area than other units (McDonnell et al., 2013). This means that developers building near transit must devote more square footage of lot area (most likely structured parking) than developers building further away from transit (McDonnell et al., 2013). This will typically mean that it is more expensive to provide parking near transit stations because it may typically be structured with higher opportunity costs for the land and higher construction costs associated with structured parking (McDonnell et al., 2013; Litman, 2013; Shoup, 1997).

However, when waivers for parking requirements from the provision of affordable housing, housing for the elderly, housing on small lots, and other exemptions are considered, the differences in required parking density disappear as required densities near transit reduce significantly (McDonnell et al., 2013). When waivers were included, the citywide average required parking ratio was 47.6%, or about 47.6 spaces per 100 units, and the average required parking density was .49 spaces/1000 SF of lot area (McDonnell et al., 2013). This reduces the citywide average required parking density for lots within ½ mile of rail stations to .5 spaces/1000 SF of lot area and those outside ½ mile of rail stations to .48 spaces/1000 SF of lot area (McDonnell et al., 2013). While this may be citywide average calculation, The Inner Ring Parking study found that the required parking ratio with waivers was 22%, or 22 spaces per 100 units for development in the Inner Ring (areas well served by transit) between 1998 and 2008 (DCP, 2013). Additionally, the Inner Ring Parking study found that parking within the Inner Ring shows that the effective parking ratio is lower for locations within ¼ mile of subway stations, with buildings with 1-4 residential units having an effective parking ratio of .14 spaces per unit, while buildings with 5 residential units or more have .18 spaces per unit (DCP, 2013). In comparison, 1-4 residential unit buildings that were further than ¼ mile from transit had effective parking ratios of .31 spaces per unit, and those with 5 units or more had an effective parking ratio of .36 spaces per unit (DCP, 2013). Both studies suggest that the New York City Parking requirements are fairly transit-sensitive when waivers are taken into account, compared to the unadjusted requirements (McDonnell et al., 2013; DCP, 2013). However, both studies also indicate that, while that includes parking requirements for all buildings near transit, denser multifamily housing that has more than 5 units generally tends to face higher effective parking ratios than buildings with fewer units, largely as a result of their inability to apply for small lot waivers (DCP, 2013; McDonnell et al., 2013). Within the Inner Ring of New York City Parking, buildings typically greater than 5 residential units are required to build largely structured or underground parking facilities as a result of the high opportunity cost of land (DCP, 2013; McDonnell et al., 2013). This makes parking requirements for larger multifamily buildings more cumbersome because of the expense of construction of structured parking, which will often be insufficient to yield any return on investment

(DCP, 2013; Litman, 2013; McDonnell et al., 2013). The Inner Ring Parking study further supports this claim by the fact that, when parking waivers were available for residential buildings in the Inner Ring with 11 or more units, 67% of developers elected to not build parking, in comparison to 53% of residential buildings with 1-10 units (DCP, 2013). Also, the burden was much more acute on multifamily buildings with 11 or more units because 77% of development was not eligible for waivers, compared to the scarce 32% of 1-10 unit residential development that were not eligible for waivers (DCP, 2013). In addition, buildings in the Inner Ring with 5 or more residential units tended to build only as many parking spaces as required—for developments built from 1998-2004, the difference between the parking spaces required and parking spaces built per unit deviated from one another only by .02 spaces per unit (DCP, 2013). While multifamily units may be able to spread the costs of parking across more units, these results suggest that the requirement of building structured parking for a multifamily development can be significant enough to make waivers fairly valuable (DCP, 2013; McDonnell et al., 2013; Litman, 2013).

This provides a mixed picture of parking requirements in New York City. While the requirements seem to be more transit-sensitive when adjusting for waivers, they still have requirements for parking that many large developments find binding (McDonnell et al., 2013). That said, the parking densities near transit are still close to the same to those outside ½ mile of rail stations (McDonnell et al., 2013). The authors suggest that, considering the density of parking near transit now, alternatives to per-unit requirements should be evaluated, looking at the importance of parking design and placement to ensure more transit-oriented development (McDonnell et al., 2013). In addition, the authors suggest that the requirement of relatively high parking densities near transit stations can impact the neighborhoods in negative ways by diminishing local air quality and increasing congestion in the area by attracting more drivers than there may have otherwise been (McDonnell et al., 2013). The Inner Ring Parking study found that buildings that had on-site parking had higher rates of vehicle ownership, with the effect decreases with increases in building size, suggesting that on-site parking availability has a smaller impact on the decision to own a car in larger buildings (DCP, 2013). In general, the report concludes that, while parking may have an influence on whether or not to own a vehicle, other variables are at play, such as transit access, neighborhood characteristics, and household characteristics (DCP, 2013). However, they do question the hypothesis of other studies that parking has a large influence on car ownership, and this is addressed in the findings of their report (DCP, 2013). Previous studies have pegged the additional VMT attribution to New York City's parking requirements from induced vehicle ownership to be in the range of 1.09-1.15 billion VMT, contributing an estimated additional 430-454 metric tons of greenhouse gas emissions (Weinberger et al., 2009). Researchers therefore argue that the minimum parking requirements in New York City stand in opposition of the city's sustainability goals and objectives (Weinberger et al., 2009).

New York City was among the first cities to make progress in parking policy when it removed parking requirements from the Manhattan core and Long Island City (McDonnell et al., 2013). Additionally, it was among the first to establish parking maximums in Manhattan and other locations, and other cities have subsequently established maximums of their own (McDonnell et al., 2013). With that, researchers and critics have pointed out that New York City's current parking policy risks countering their efforts toward their goals of pursuing sustainable development, as outlined in PlanNYC (McDonnell et al., 2013; Weinberger et al., 2009). The authors suggest the establishment of more flexible parking requirements, such as transit overlay districts employed in other cities, a practice recognized by the New York City Department of City planning itself (McDonnell et al., 2013; DCP, 2011). The recent Inner Ring Study aims to move the city forward in terms of how it treats the transit-oriented Inner Ring of New York City (DCP, 2013). The report includes 4 main recommendations, all of which aim to reduce the costs of development, increase affordable housing availability, and tailor the parking regulations to more closely match parking demand (DCP, 2013). The first recommendation was that off-street parking requirements should be evaluated on a neighborhood by neighborhood basis, suggesting that the cost of providing off-street parking and the demand for parking should be balanced based on neighborhood characteristics (DCP, 2013). The study suggests that if parking requirements are "higher than necessary, requirements can be reduced" (DCP, 2013, pg. 85). They make a similar suggestion with updating affordable housing regulations so that the parking requirements match affordable housing's actual parking demand, in order to reduce construction costs and enable more affordable units to be built (DCP, 2013). A key recommendation of interest also included expanding the transportation options within the Inner Ring of New York City, where carsharing is mentioned specifically (DCP, 2013). This recommendation was based on survey results showing that only 42% of drivers use their vehicles for commuting and that the most dominant use of vehicles was household errands, a task for which carsharing has a competitive advantage (DCP, 2013). The final recommendation is that the city should consider allowing accessory residential parking as public parking garages, both to increase parking utilization and to increase revenue from parking, making parking less burdensome (DCP, 2013).

Past minimum parking requirements, on-street parking in New York City neighborhoods is often free or largely underpriced, like in many other major cities (Shoup, 2006). The average monetary savings (excluding time wasted while cruising) in New York City from cruising for parking is about $12.88, based on the average cost differences in price between the costs of 1 hour of on-street parking versus 1 hour of off-street parking (Shoup, 2006). This is further confirmed by the Inner Ring Parking study, which surveyed residents in the Inner Ring, with one of the questions posed to residents who own vehicles and use on-street parking being if they use on-street parking relative available off-street parking (DCP, 2013). Of residents who owned vehicles and used on-street parking, 38% reported they did so because off-street parking was expensive, and 48% stated that there was no off-street parking available at the residence or nearby (DCP, 2013). In many cases, people chose on-street parking because it was cheaper in terms of availability and financial cost than off-street parking (DCP, 2013). As a result, cruising for parking often results from drivers searching for on-street parking that is either more expensive or reserved for residences (Shoup, 2006; Guo & McDonnell, 2013). Previous studies in New York City have pegged the average search time for on-street parking between 7.9 to 13.9 minutes, with one study estimating that 8% of the traffic on roads was due to cruising (Shoup, 2006). The concern about parking scarcity and cruising for parking has led the New York City Department of Transportation to pilot a PARK Smart Program to test performance-based parking, which is currently in operation in Greenwich Village, Upper East Side, and Park Slope (DCP, 2011).

State of Supportive Carsharing Policies in NYC

New York City has made several accommodations for carsharing in recent years as its benefits have become more formally recognized and its growth more noticeable (DCP, 2010; DOT, 2013). The first major change was the Carsharing Zoning Text Amendment passed in 2010 that allows carsharing spaces to be placed in public garages and accessory off-street parking spaces of developments (DCP, 2010). The amendment allows more carsharing vehicles to be substituted in accessory residential garages based on what density zoning allows (DCP, 2011). For example, high- to medium-density districts are allowed to allocate 20% or 5 accessory parking spaces—whichever is greater—to carsharing vehicles, while lower-density multifamily districts are only allowed to allocate 10% of total spaces, and 1-2 family residential districts are not allowed to allocate any accessory parking spaces to carsharing vehicles at all (DCP, 2011). In addition to residential units, carsharing can be substituted in up to 40% of public garages' parking spaces, and up to 10% total of commercial, community facility, and manufacturing parking spaces (DCP, 2010). While this does accommodate for carsharing, it does not offer parking requirement reductions for the presence of carsharing vehicles (DCP, 2010). The amendment does, however, attempt to tailor the amendment based on where market conditions for carsharing would most likely be met, such as high- and medium-density multifamily districts, which tend to be in locations served by transit (DCP, 2010).

In addition to the zoning text amendment, New York City has offered carsharing an indirect subsidy by utilizing their services (DOT, 2013). In 2010, DOT conducted a carshare pilot with Zipcar to reduce the agency's fleet size by removing 50 vehicles from its fleet and then providing carsharing access to 350 employees (DOT, 2013). As a result of the success of the pilot, DOT renewed and expanded its use of carsharing to 420 DOT staff in 2013 (DOT, 2013). The pilot program reported that it removed 25% of DOT vehicles from Lower Manhattan, reduced DOT's miles traveled by 11%, and, finally, reduced DOT parking impact in Lower Manhattan by 14% on weekdays and 68% on weekends (DOT, 2013).

GIS Processing and Analysis Results

Suitability Rasters

The first set of results include the carsharing suitability rasters, which highlight locations where sharing would be most likely to succeed, based on the presence of favorable demographic, neighborhood, and transportation-related characteristics (Figures 4-4 to 4-7). The suitability maps displayed are on a range from 1 to 9, with green locations being higher suitability and redder locations being lower suitability. While each of the different suitability rasters highlights some locations more than others, there are some patterns that are noticeable. The first trend is that the further away you get from the island of Manhattan, the less suitable carsharing locations tend to be. That said, there are often substantial clusters of high-suitability locations in mixed commercial or mixed-use high-density residential districts that are well served by transit. In addition, locations with low suitability scores tend to be in single-family districts with low residential densities and higher automobile modal shares.

Market Shed Rasters

The next set of maps of interest are the focal statistics rasters, which reflect the average suitability values of each location within ¼ mile of each cell represented on the map (Figures14-8 to 4-11). In essence, each point on the map represents the average values of all cells within the typical walking distance to a carshare pod. In general, none of the focal statistics rasters ever reach a value of 9, because there is no location on the map where, within ¼ mile of each point, all the suitability values are a 9. While there is some variance in the top values between the focal statistics raster, they tend to have high values in the same general locations. One pattern that emerges is that the focal statistics rasters tend to be vulnerable to edge effects from parks and cemeteries. For example, areas between Prospect Park and Greenwood Cemetery have moderately high suitability in some places, but the focal statistics raster records the lack of characteristics that does not support carsharing. These types of edge effects are reasonable in the sense that they reflect the lack of potential markets in terms of suitable population that could use the carsharing vehicles. In addition, the focal statistics raster tends to blend high0suitability pockets that are surounded by low-suitability locations so that they stand out less.

Threshold Rasters

These threshold rasters utilize the differently weighted suitability rasters to analyze the mean market shed values for each carsharing pod (Figures 4-12 to 4-16). The locations that have the average suitability environment set to the average market shed value are shown in green and reflect the areas that that have the average market shed suitability to support carsharing. The locations with minimally-suitable environments are shown in yellow and represent the locations that have the basic environmental characteristics to support carsharing markets. Locations that do not meet the minimum suitability threshold are shown in red, and these reflect areas in Brooklyn that do not have the basic characteristics to support carsharing. While the each of the first threshold rasters are reflecting each differently weighted raster, the final suitability threshold raster combines all of them to make a unique threshold raster that incorporates all the others, in order to make conservative estimates of the minimum suitability threshold (100% agreement between all threshold rasters) and liberal estimations of the average suitability threshold (only 1 threshold raster must agree). In total, 57% of Brooklyn's land area meets the minimum suitability requirements to support carsharing based on the methods employed in this analysis. When looking at the Brooklyn's Inner Ring as defined by the Department of City Planning in their Inner Ring Parking study, the percentage of land that qualifies as meeting the minimum suitability requirements to support carsharing jumps to 82%. This is not that surprising, considering Brooklyn's high population densities and high transit accessibility. The zones that were created have traits that very clearly reflect their general suitability. For example, the summary statistics for residential densities in the 3 zones show increasing signs of land use intensity between them. The average market environment (green) had an average gross residential density of 38.4 units per acre, the minimum suitability threshold (yellow) had an average gross residential density of 26.4 units per acre, and locations that do not meet the minimum suitability requirements had an average gross residential density of 9 units per acre. In addition, the gross employment square footage per acre in the average suitability environment is 15614.1 square foot per acre, the average employment square footage per acre is the minimum suitability threshold zone is 8191.2 square foot per acre, and in locations that do not meet the minimum suitability requirements for carsharing, the average employment square footage per acre was 3778.8 square foot per acre. As you enter more suitable locations, both residential and employment densities increase—an understandable result, considering that carsharing's success is linked to being placed close to high-density multimodal neighborhoods. The final suitability threshold raster is then utilized in the policy scenarios, as they represent the locations that have the minimally-suitable environments to support carsharing.

Policy Scenarios

The four rasters below represent different policy scenarios for which these threshold rasters could be employed in Brooklyn as part of a city policy to support carsharing. These "support zones" represent geographic locations that the city could target for planning support for carsharing operators. These zones are informed by the market conditions to support carsharing, and each intends to complement a policy objective. The first represents the city providing broad support for carsharing in locations that meet the minimally-suitable environments for carsharing, and is thus intended to support its penetration and growth in Brooklyn in multimodal locations. The second is intended to be part of a transit overlay district where, for example, reduced parking requirements could be offered to developments within a certain range of subway stops while meeting the suitability conditions for carsharing. The third is intended to provide incentives in locations that meet the minimum market requirements for carsharing while being in areas of relatively high poverty levels, in order to offer a mobility benefit to those who would not usually be given access to carsharing. The last is intended to reflect those areas that meet the minimum market requirements for carsharing and are within the Inner Ring of Brooklyn, which has higher transit accessibility, more mixed uses, and lower vehicle ownership than the outer ring of Brooklyn (DCP, 2013).

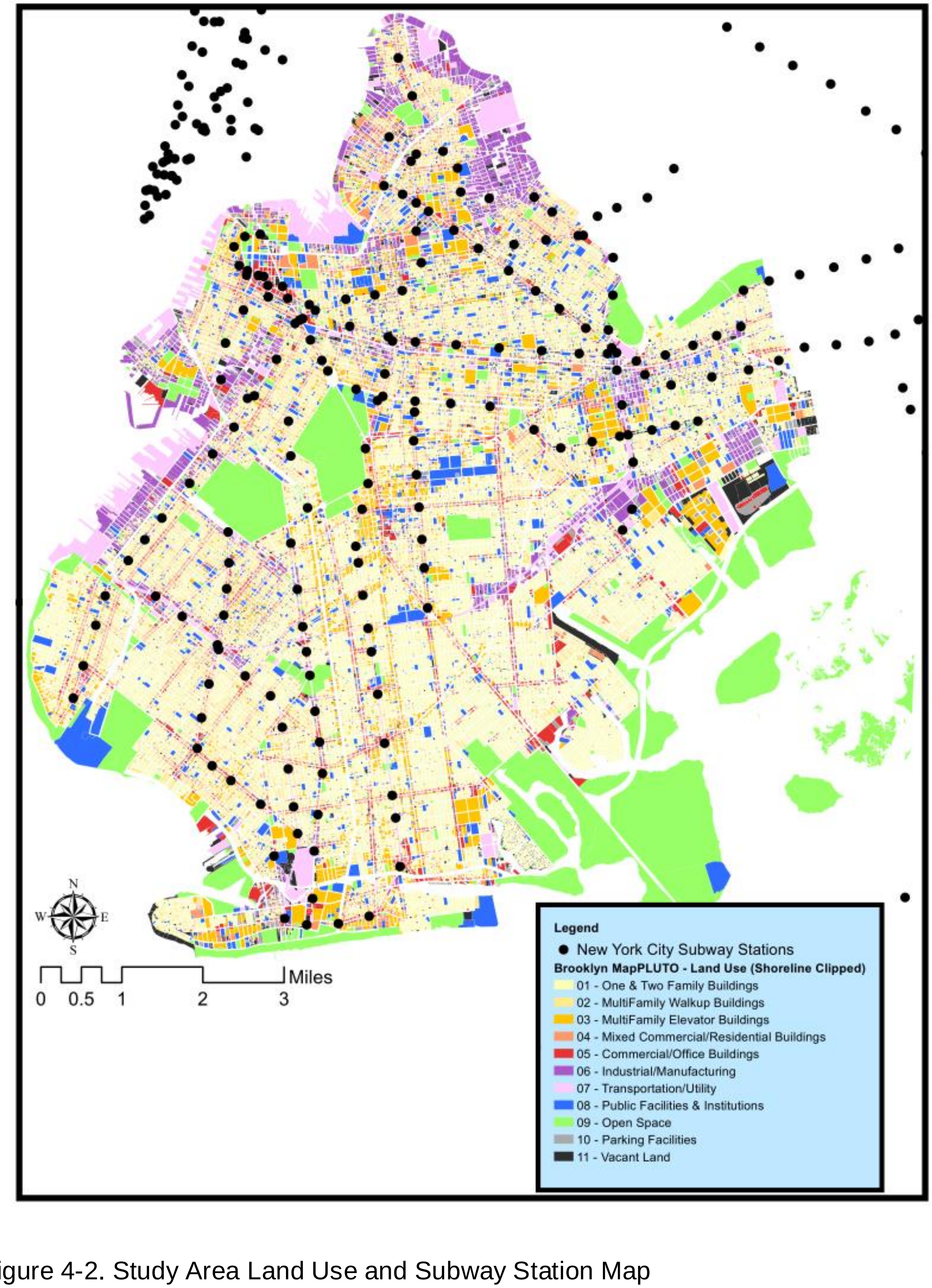

Figure 4-2. Study Area Land Use and Subway Station Map

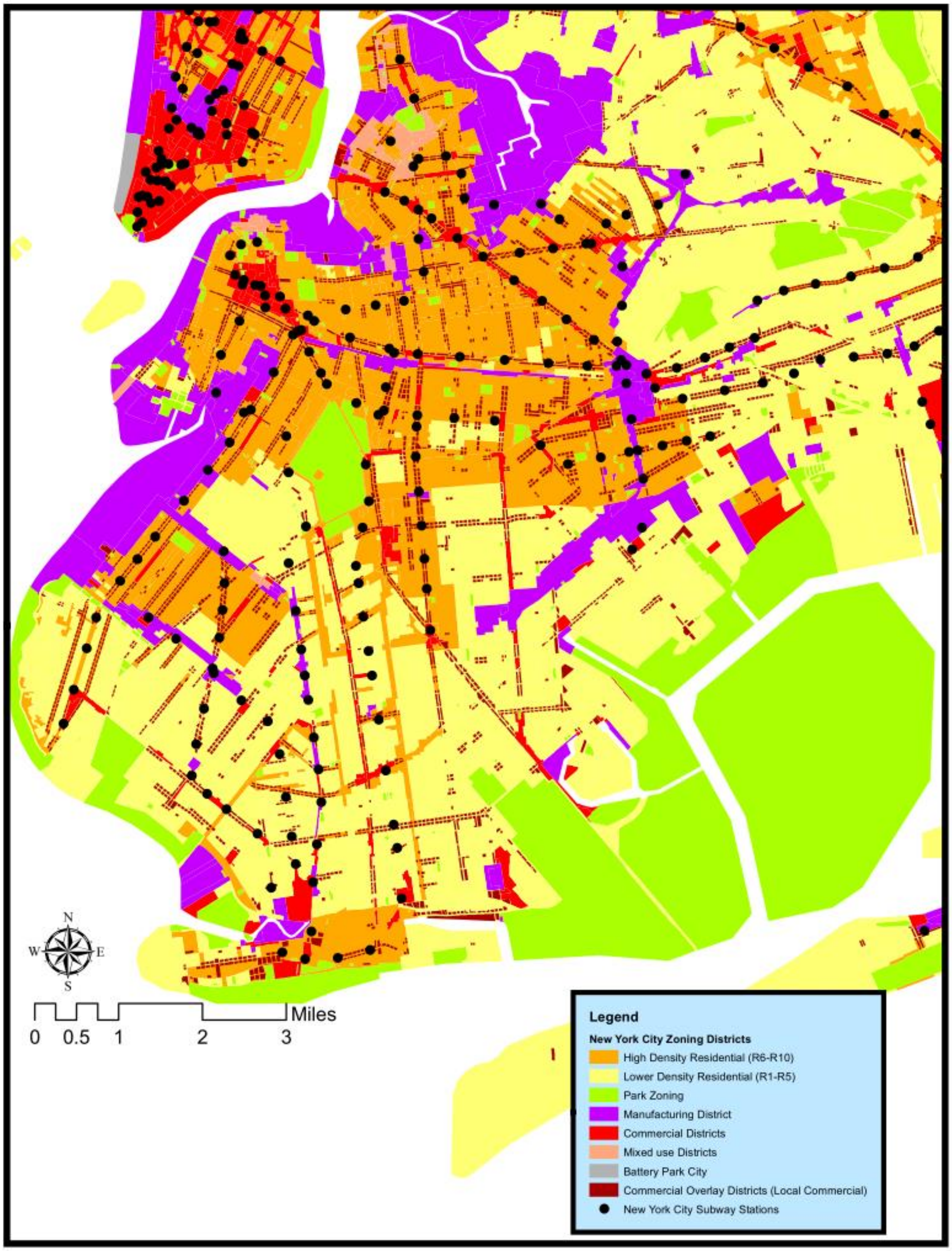

Figure 4-2. Study Area Zoning and Subway Station Map

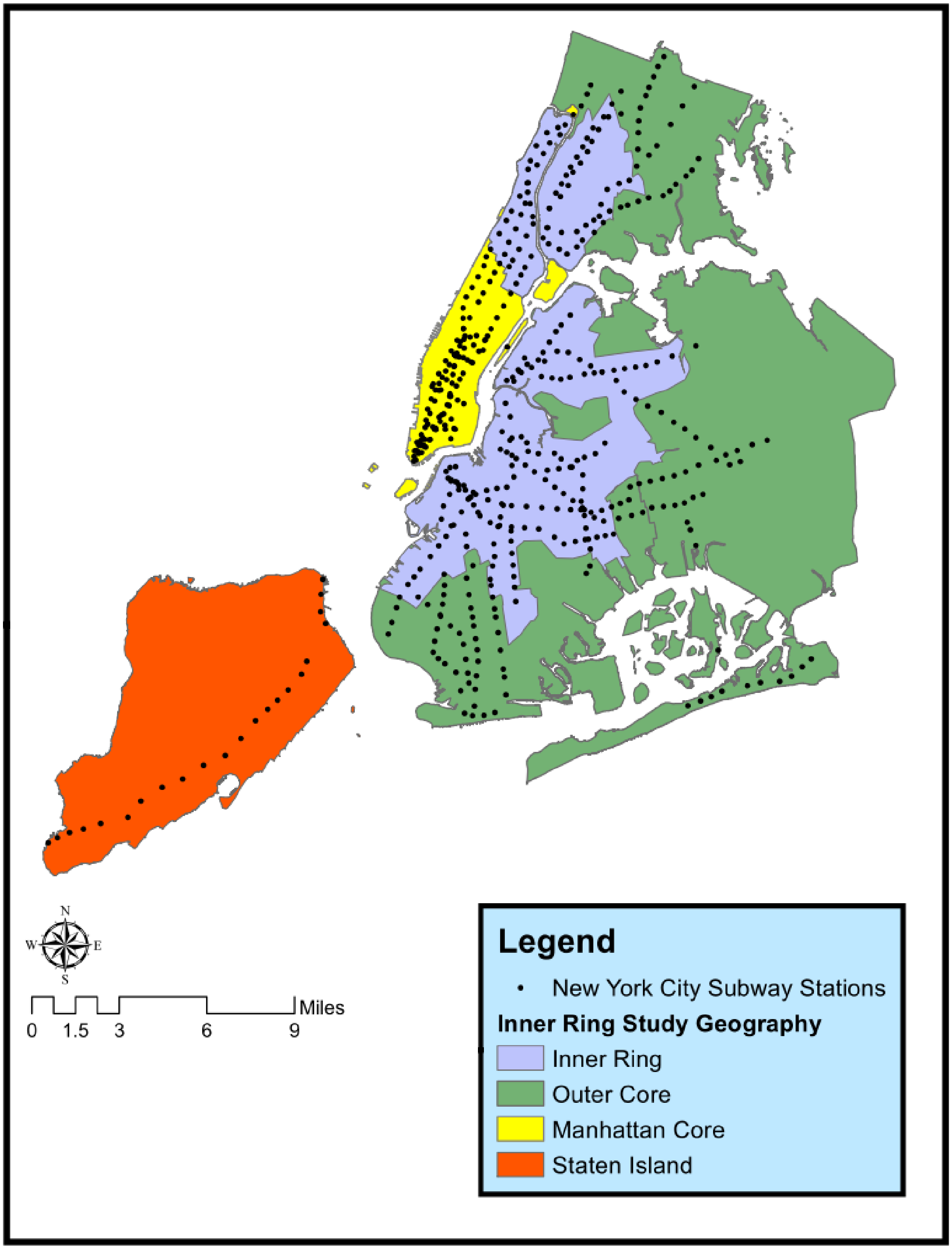

Figure 4-3. Inner Ring Study Area Geography and Vehicle Ownership adapted from: Department of City Planning, Transportation Division. (2013). *Inner Ring parking study*. Retrieved from Department of City Planning website: http://www.nyc.gov/html/dcp/pdf/transportation/inner_ring_complete.pdf, pg. 19.

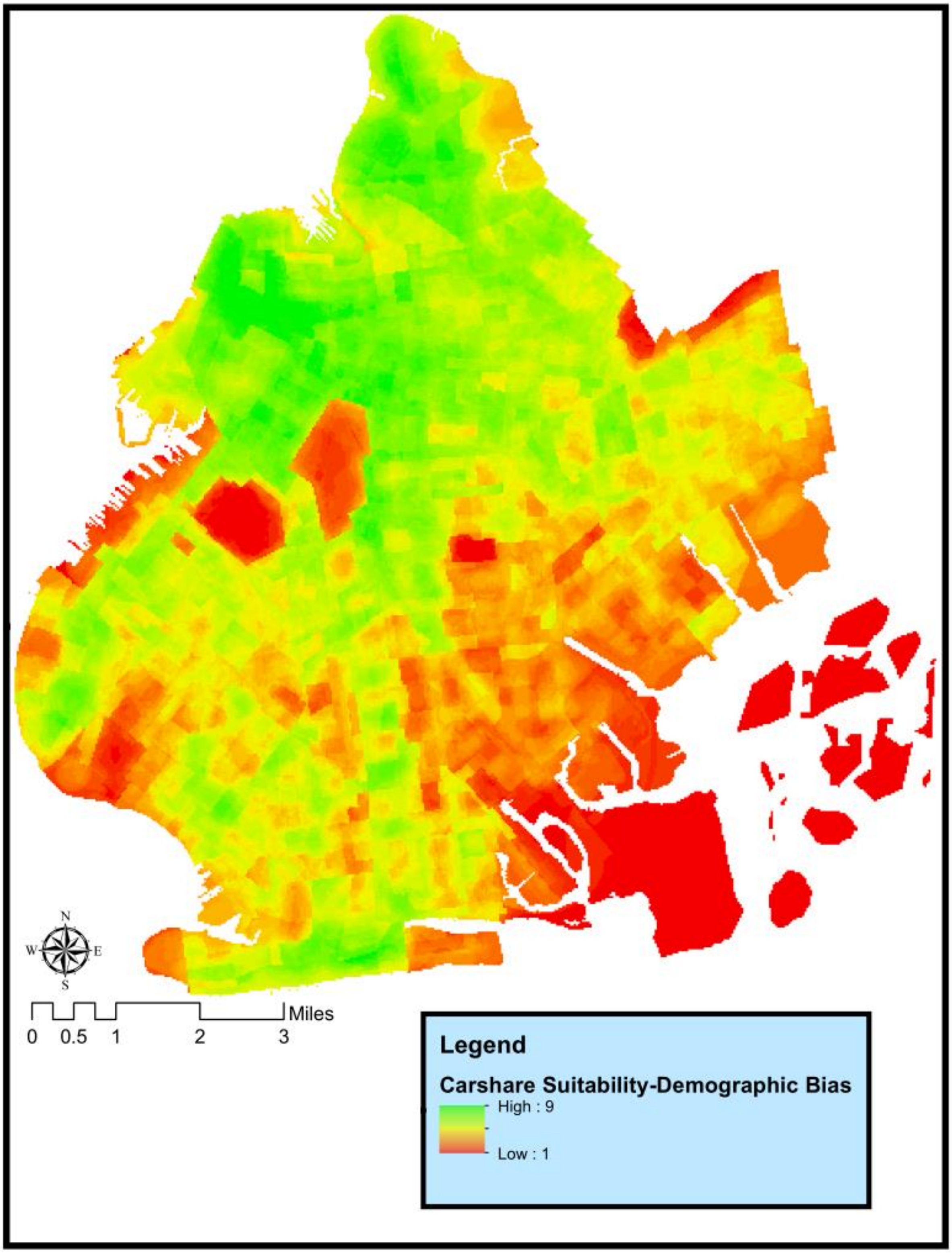

Figure 4-4. Demographic Bias Suitability Raster

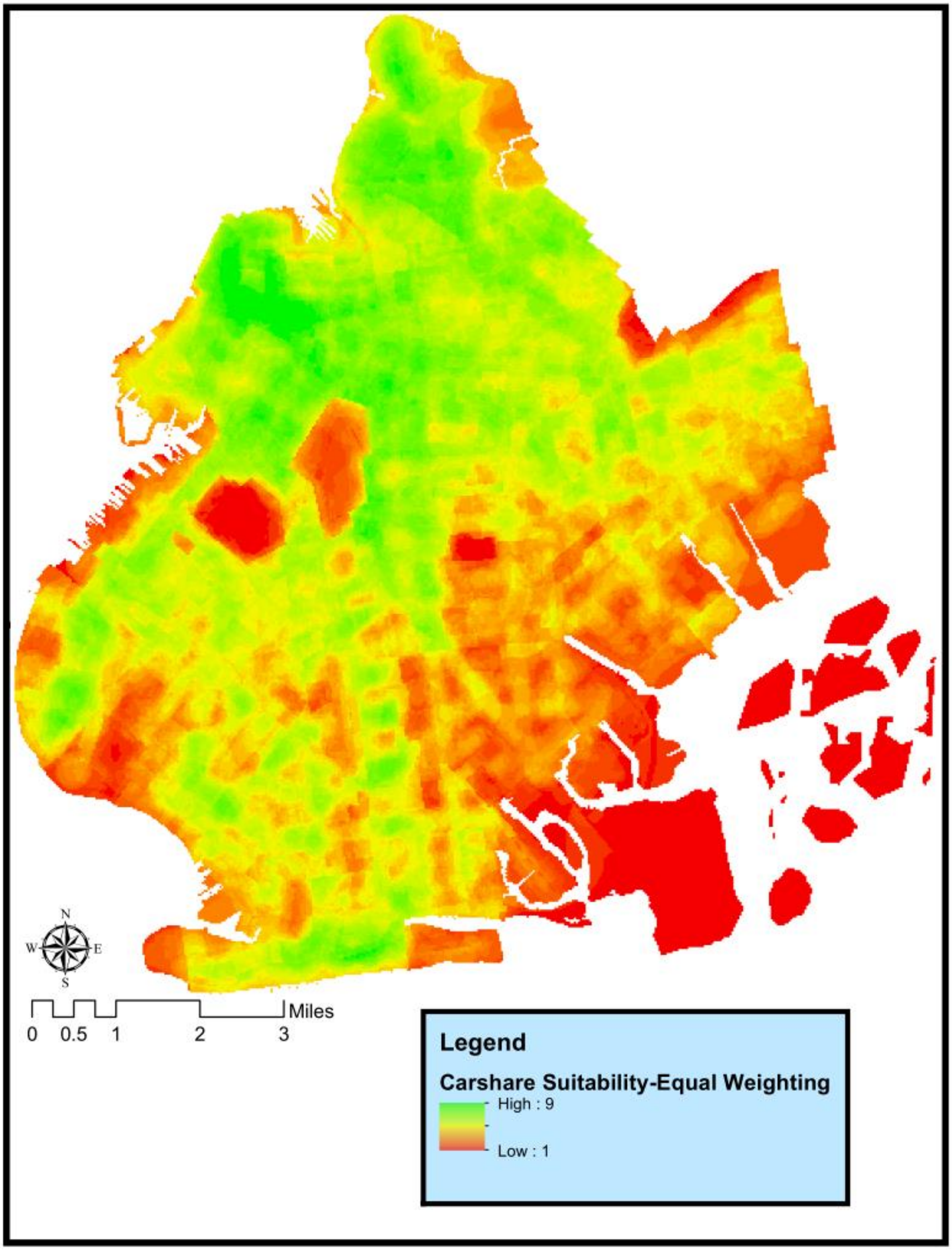

Figure 4-5. Equal Weighting Suitability Raster

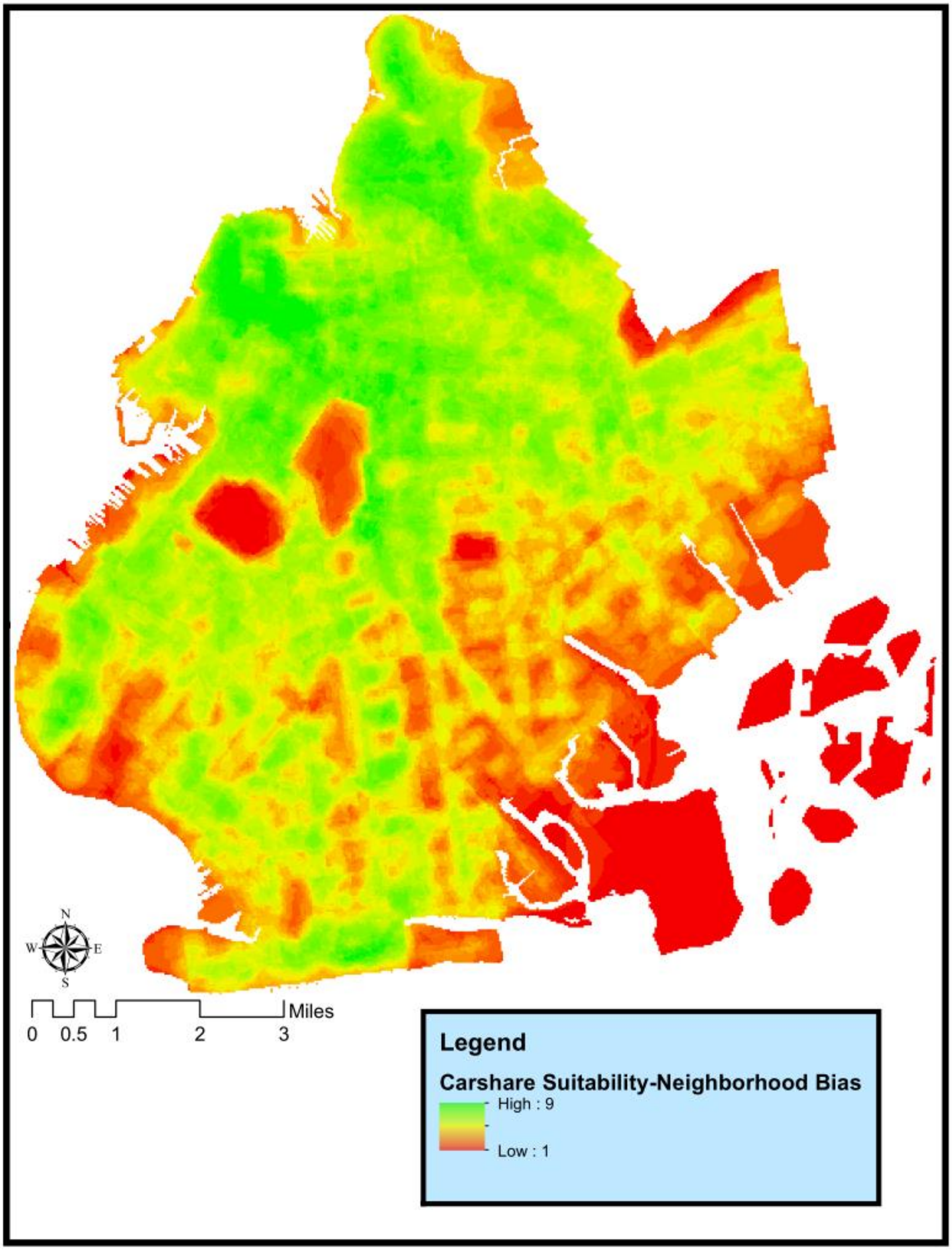

Figure 4-6. Neighborhood Bias Suitability Raster

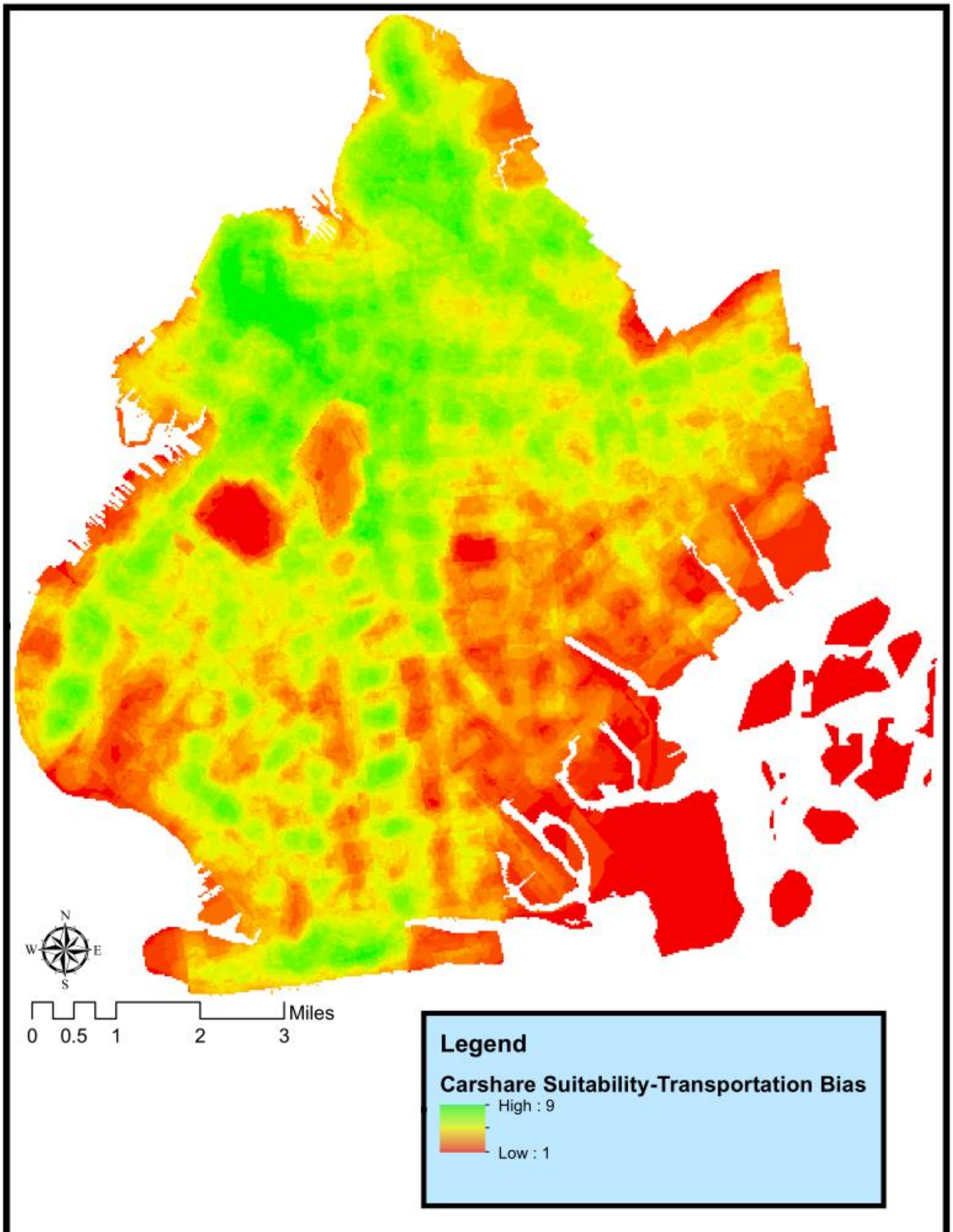

Figure 4-7. Transportation Bias Suitability Raster

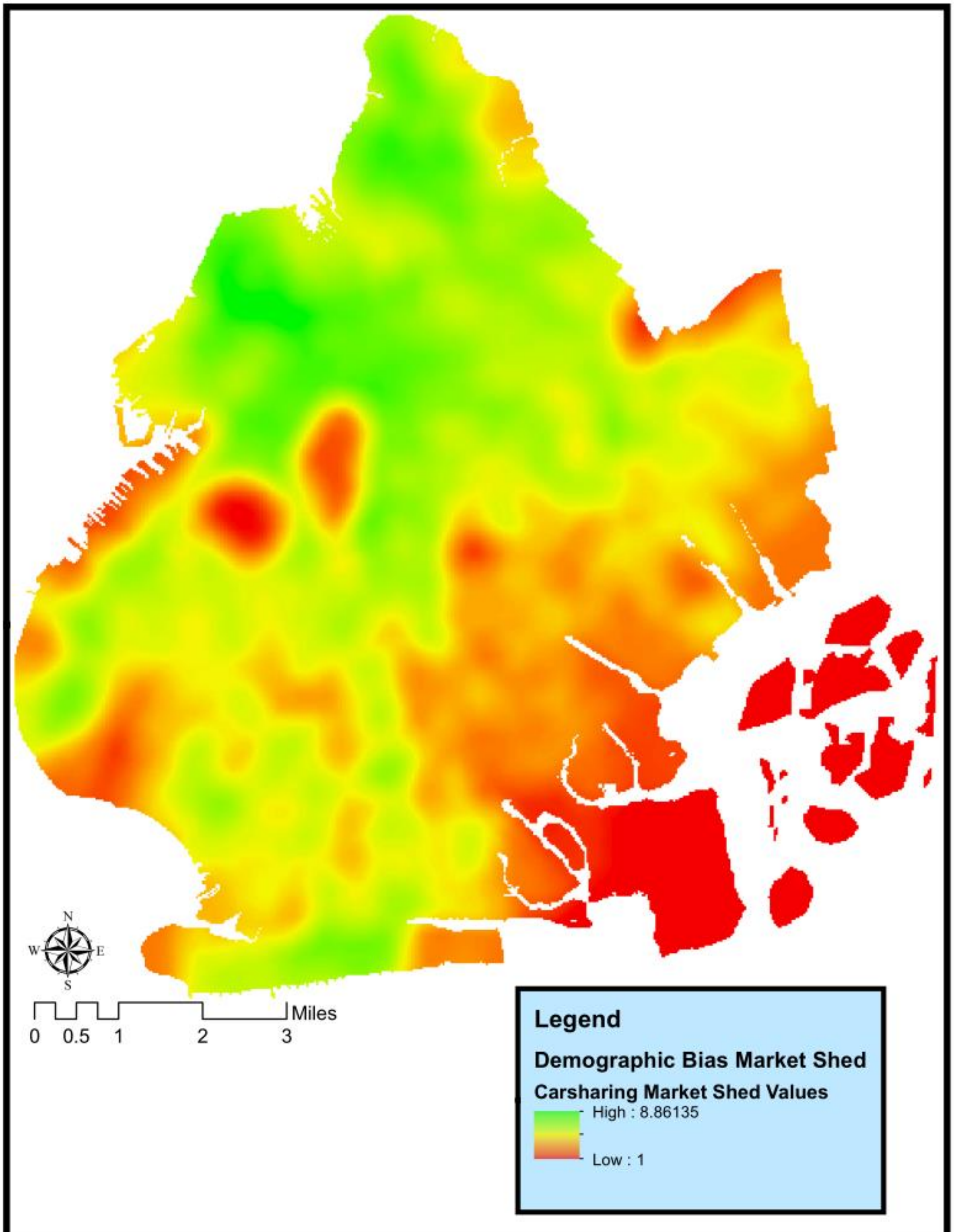

Figure 4-8. Demographic Bias Market Shed Raster

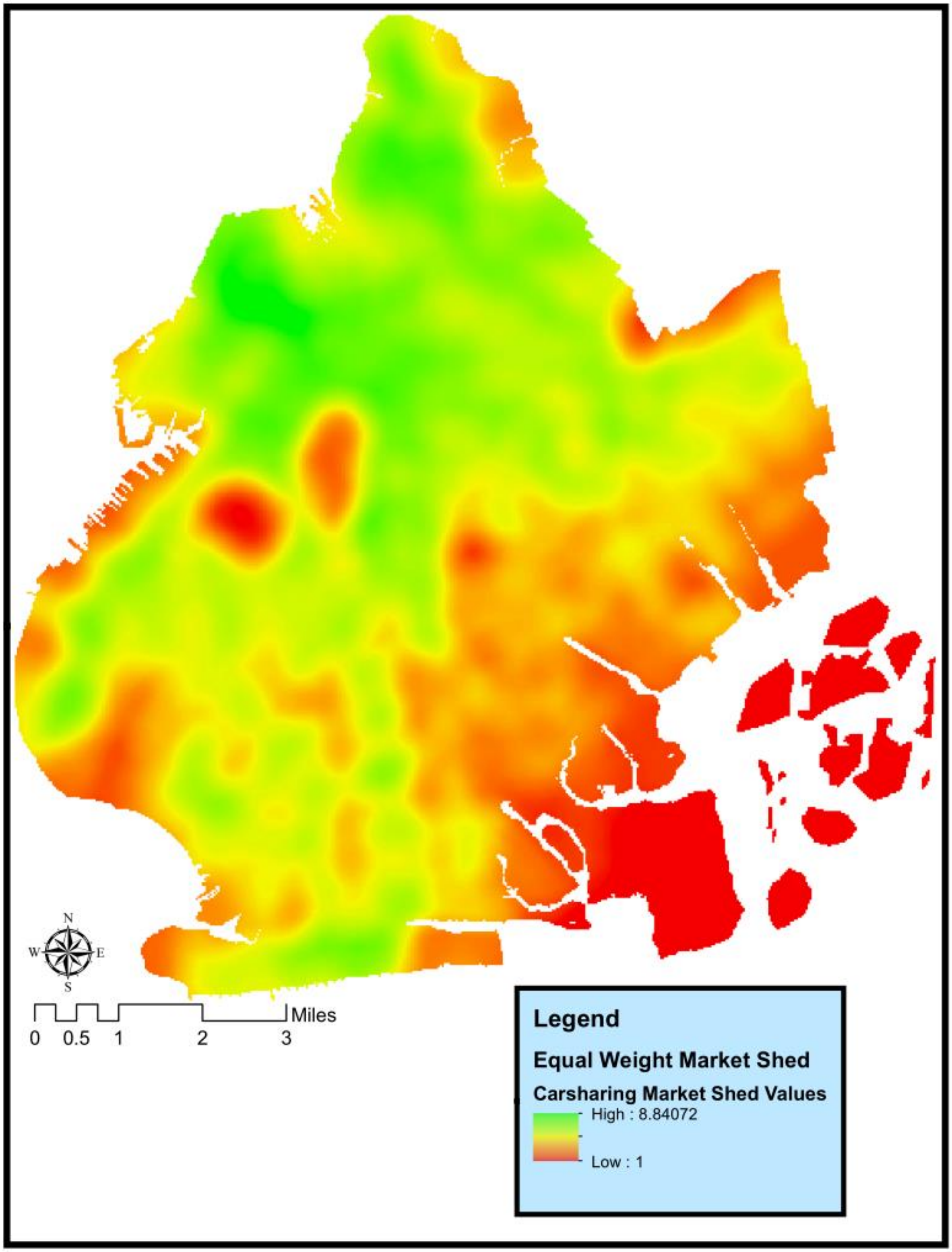

Figure 4-9. Equal Weight Market Shed Raster

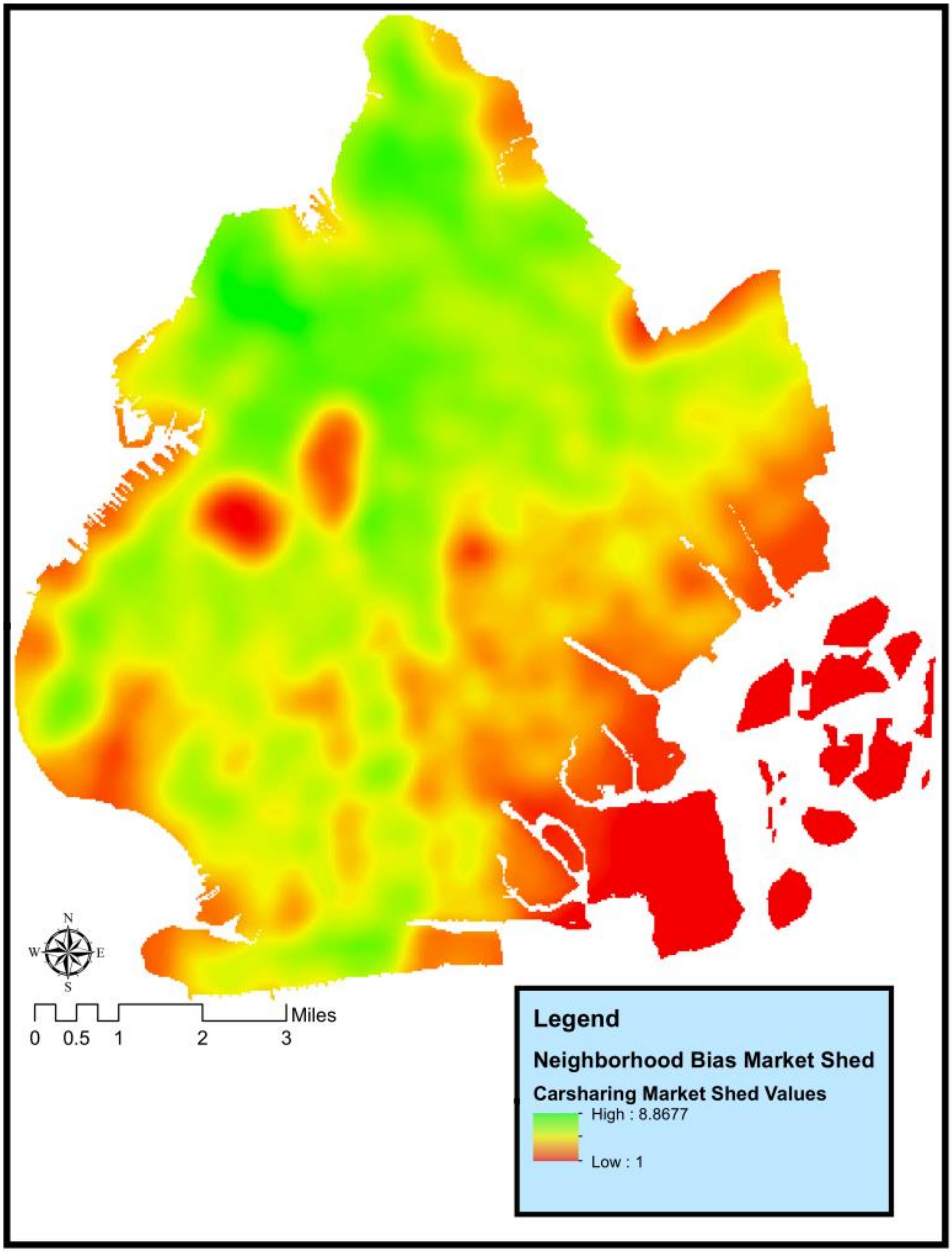

Figure 4-10. Neighborhood Bias Market Shed Raster

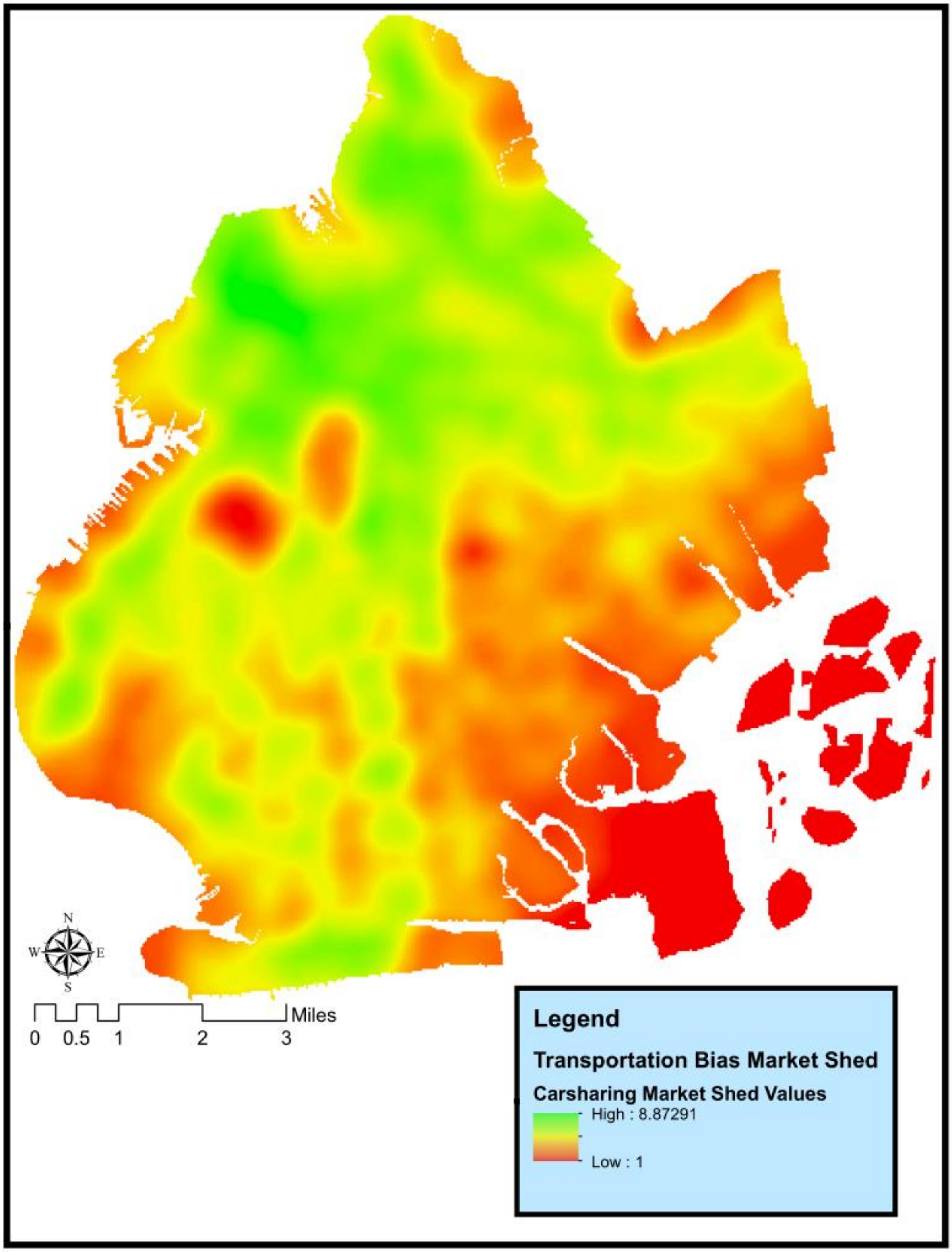

Figure 4-11. Transportation Bias Market Shed Raster

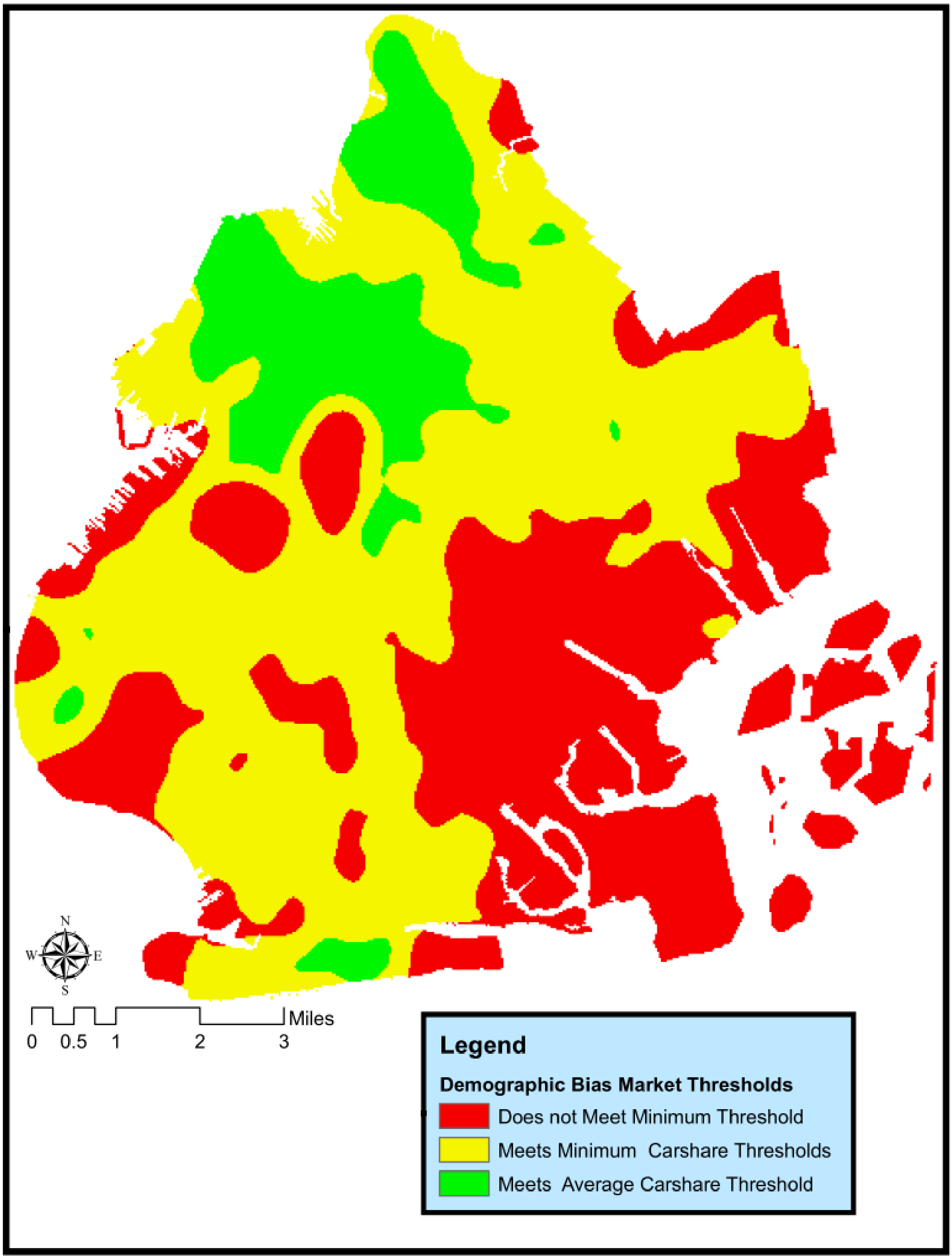

Figure 4-12. Demographic Bias Market Threshold Raster

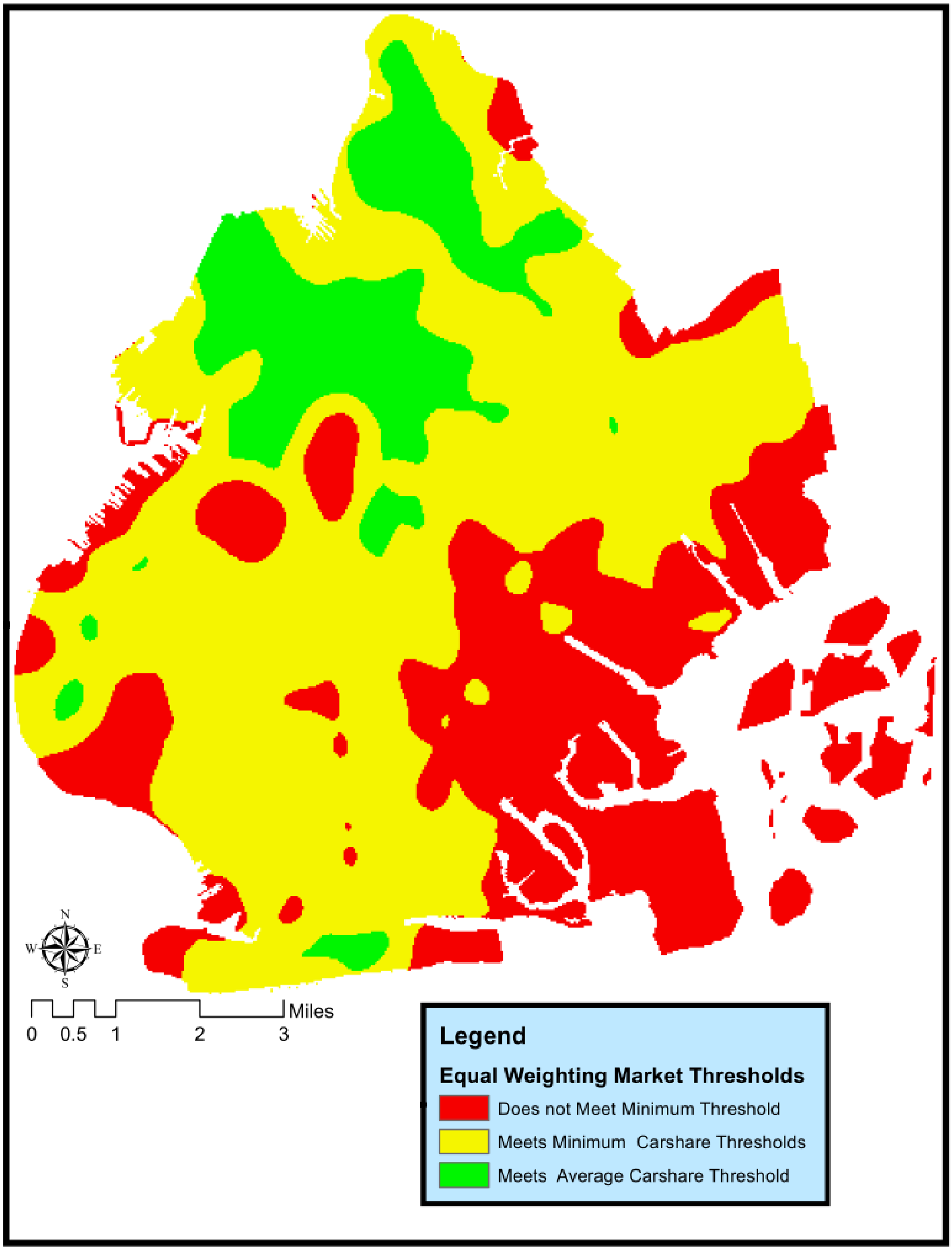

Figure 4-13. Equal Weighting Market Threshold Raster

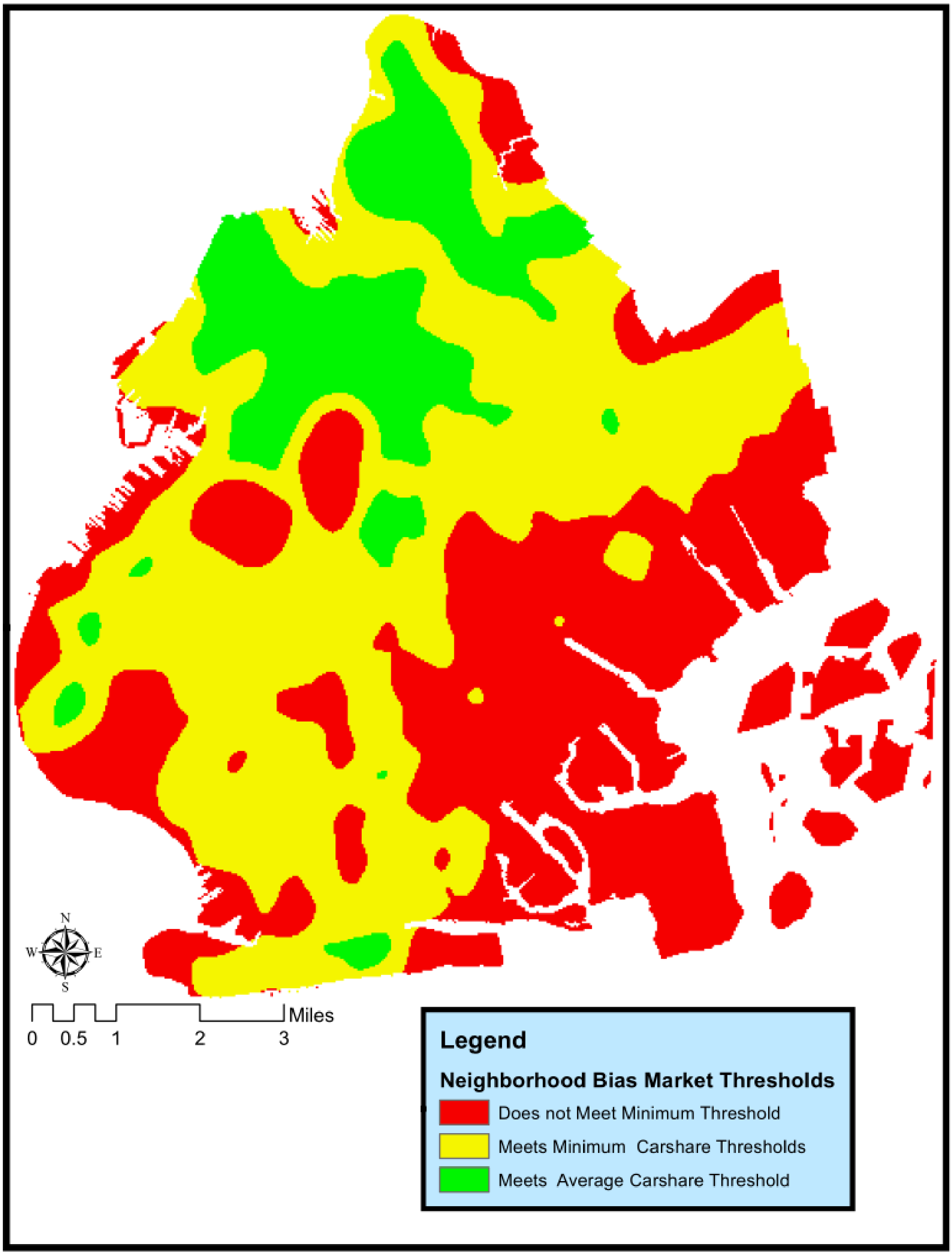

Figure 4-14. Neighborhood Bias Market Threshold Raster

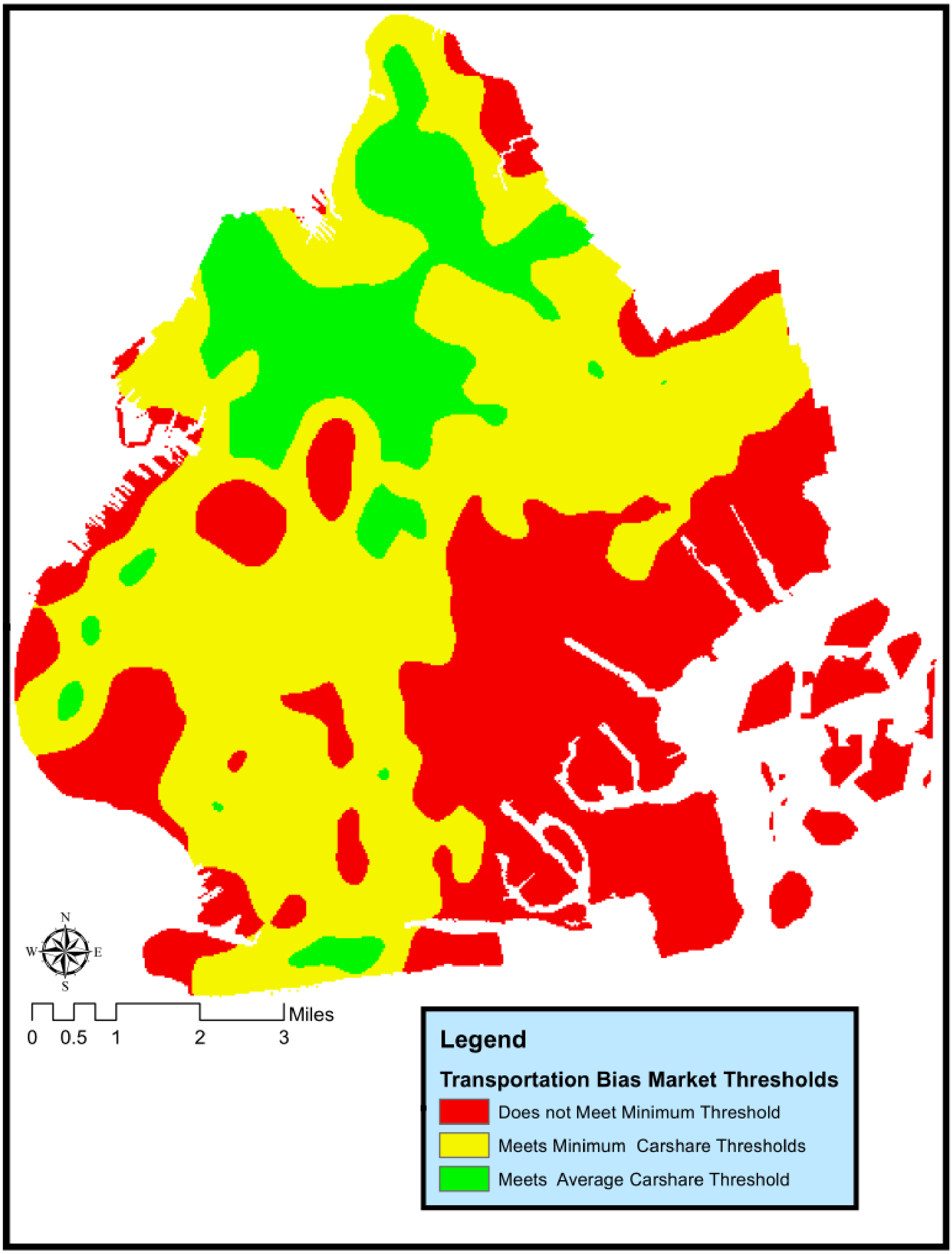

Figure 4-15 Transportation Bias Market Threshold Raster

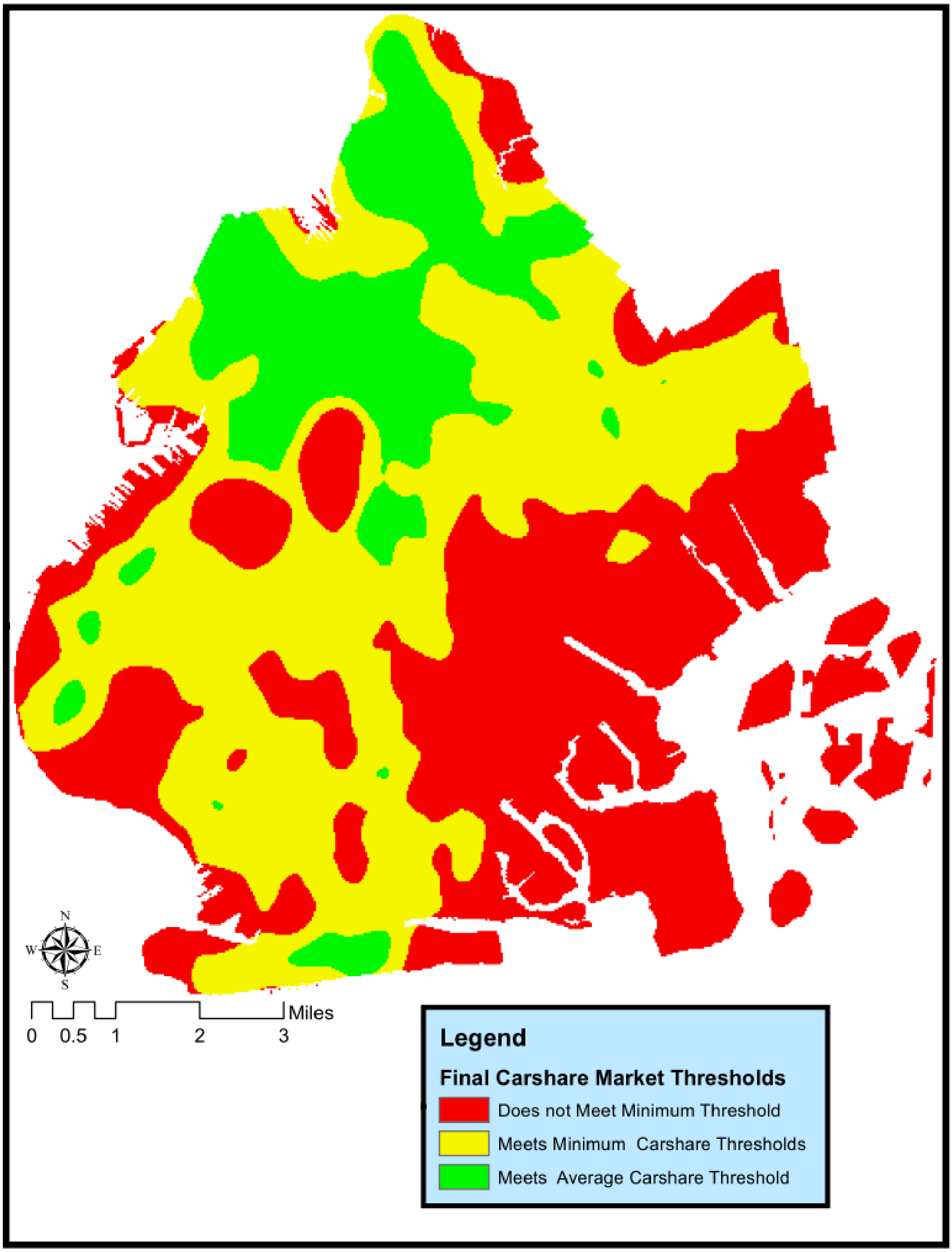

Figure 4-16. Final Market Threshold Raster

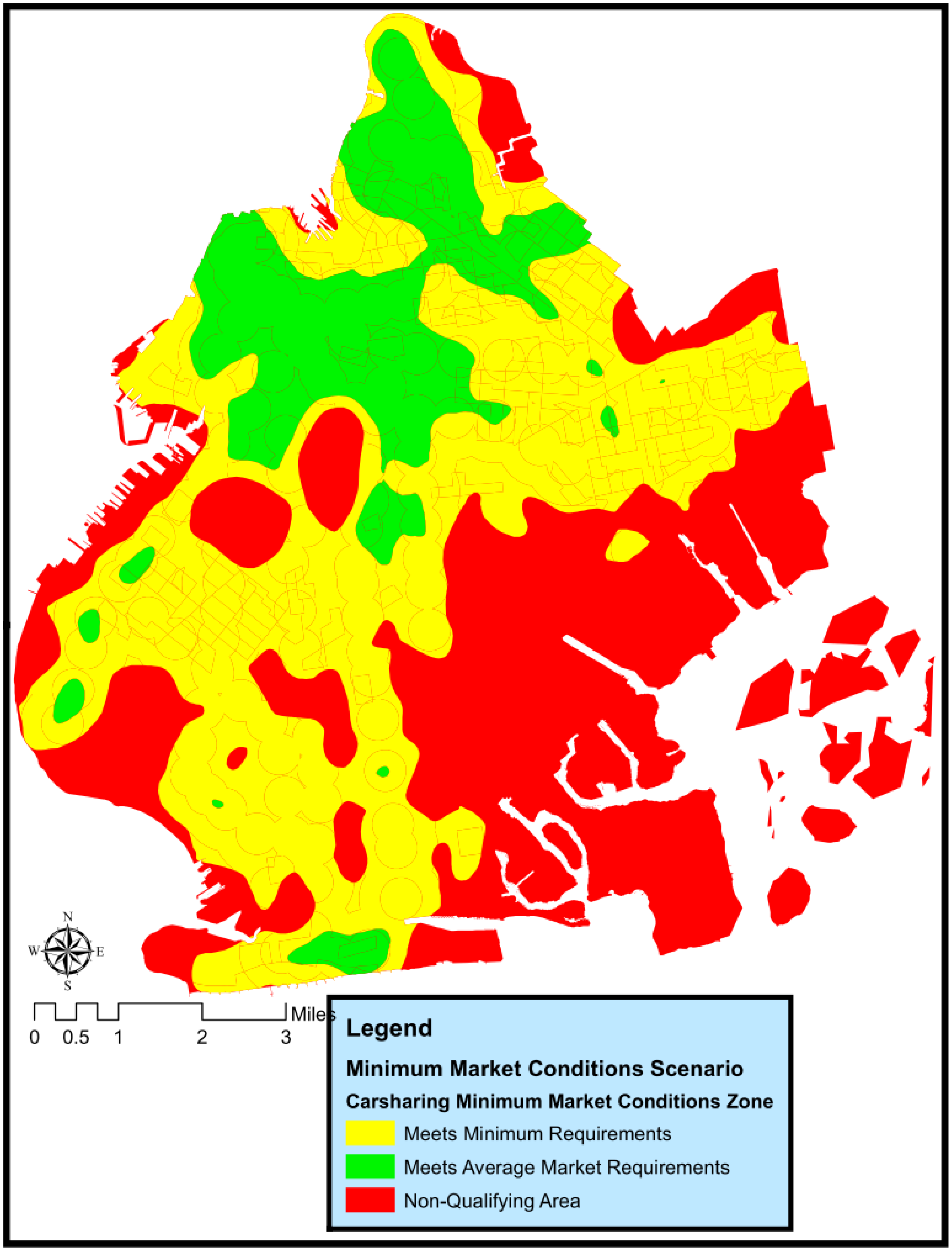

Figure 4-17. Minimum Market Conditions Scenario

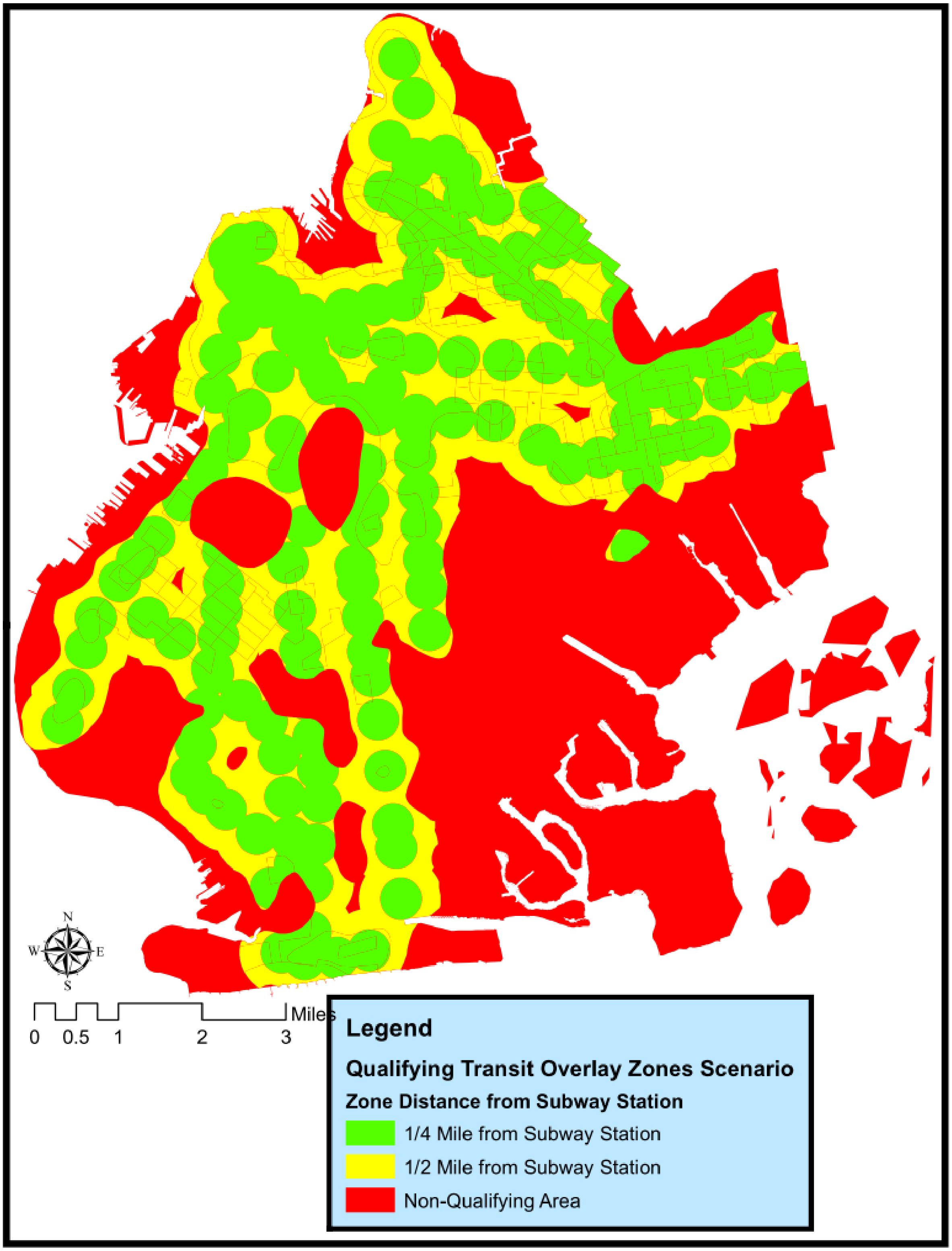

Figure 4-18. Qualifying Transit Overlay Zones Scenario

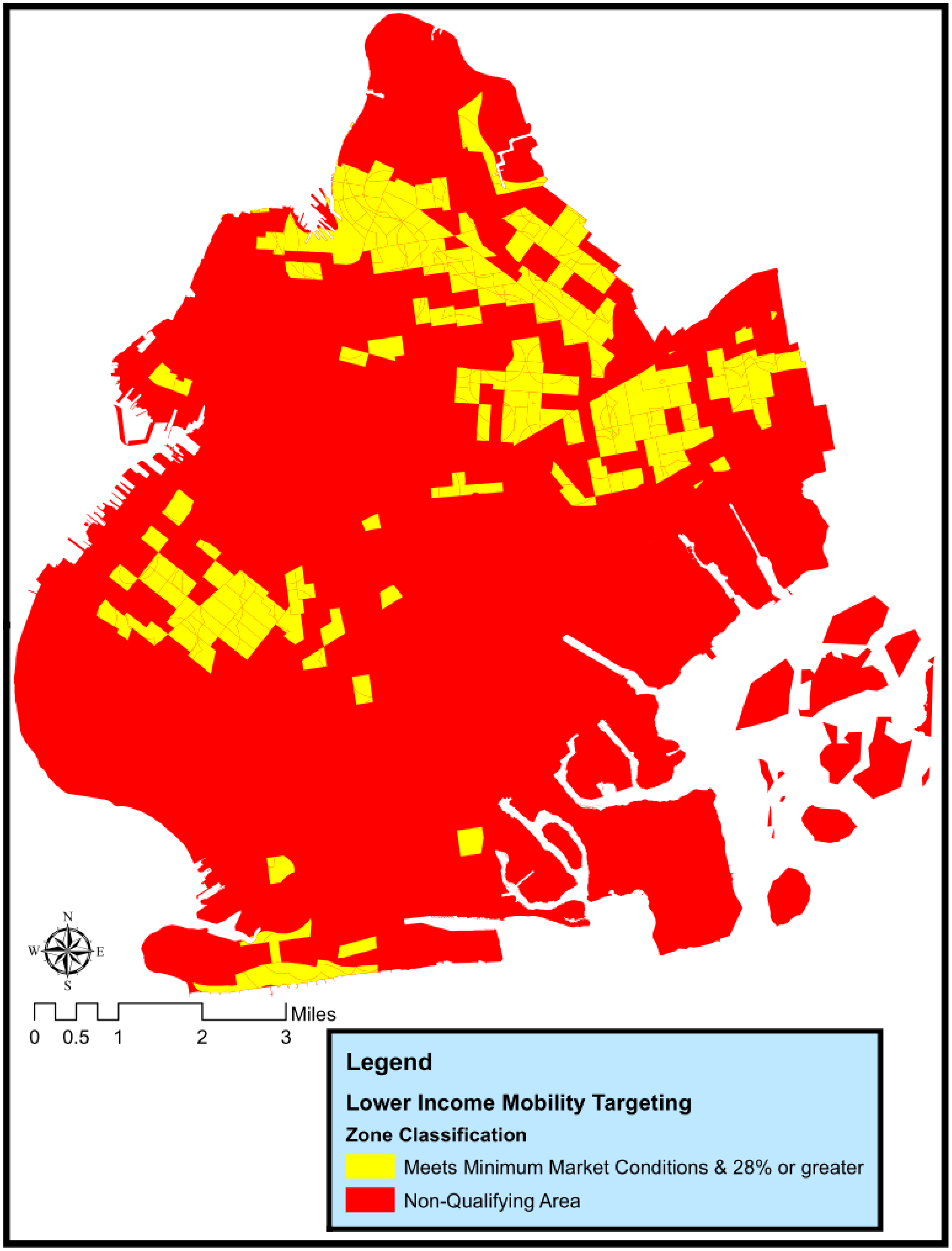

Figure 4-19. Low Income Mobility Targeting Scenario

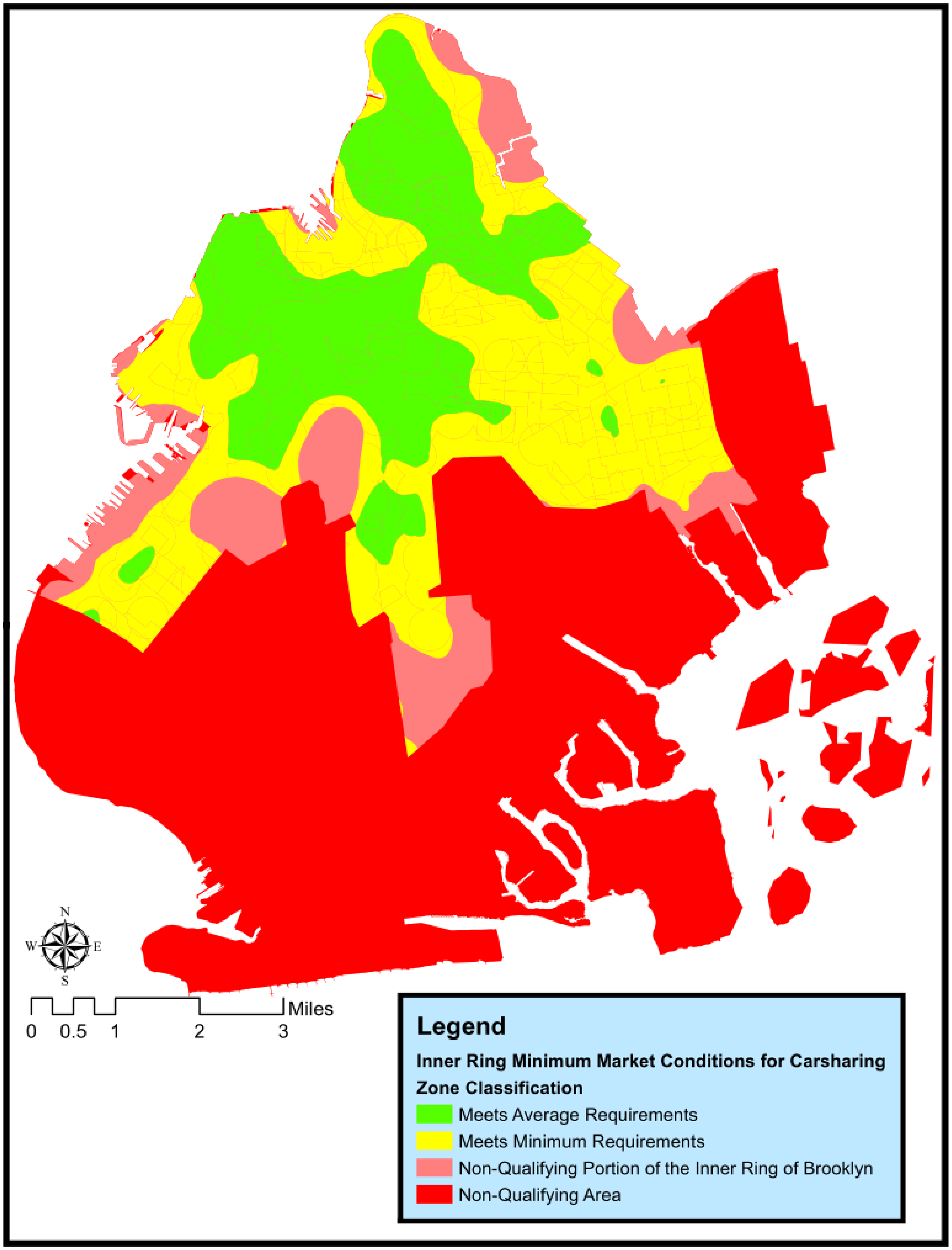

Figure 4-20. Inner Ring Minimum Market Conditions Scenario

CHAPTER 5
DISCUSSION AND RECOMMENDATIONS

The results were intended to be a rough gauge of market penetration potential and its purpose was to provide a guide on how to tailor carsharing policies to existing market conditions so that the incentives are limited to locations that have the basic existing conditions sufficient to support carsharing. The statistics and distributions of the statistics of market sheds of carsharing pods showed that most of the carsharing locations were clustered in higher-suitability locations. These results are intended to be used in conjunction with and in support of existing city policy and goals. For example, the existing carsharing amendment allows higher levels of substitution in higher-density residential locations; however, it is possible that high-density residential zoning districts might be suitable for parking requirement reductions if they are located in locations well served by transit and meet the minimum carsharing thresholds established in this analysis. While 82% of the Inner Ring of Brooklyn meets the minimum market requirements, when looking at high-density zoning (R6-R10) within the Inner Ring, the figure is close to 100%. This could mean that higher-density zoning might be amenable to some form of carsharing support, such as reduced parking requirements to developers or the provision of visible on-street parking to carsharing operators. If parking requirements were reduced in high-density zoned locations within the Inner Ring, the planning department could achieve two goals of improving transportation options within the Inner Ring and reducing parking requirements in areas where there is a high burden and cost associated with parking requirements. However, there is a degree of irreversibility to any changes to parking requirements because of the long time scales in which development occurs (TCRP, 2005; Engel & Passmore, 2010). In this way, on-street parking provision or parking substitution policies already offered by the NYC Car Sharing Zoning text amendment provide a degree of reversibility to the policy in that, if car sharing does not succeed in the area, the amount of available parking is unchanged (DCP, 2013). Regardless, geographic targeting of carsharing policy could help reduce the risk of potential abuse and misallocations of carsharing incentives so that their benefits can be realized with the city and experience minimal risk of creating unintentional parking shortages within city limits. However, there are limitations to the researcher's analysis that should be taken into consideration when examining its findings.

Limitations

There are several types of limitations to this type of analysis, and they are largely related to the nature of suitability analysis, the availability of data, and the types of processing options and metrics available to the researcher.

The first type of limitations includes those that are related to suitability analysis in general, in that there is a degree of subjectivity into the weightings used to evaluate carsharing market potential. For example, the variables and their weights are based on the researcher's interpretation of previous literature looking into the conditions required to support carsharing. The method used to limit the impact of subjectivity weighting between measures is a unique form of sensitivity analysis, in the sense that no one variable class weighting is considered more important than the other; all are integrated into the final product. However, this was only done for the 3 variable classes related to transportation, demographic, and neighborhood characteristics, but not for the weightings within each of the classes. Thus, there is still subjectivity in the researcher's interpretation of existing literature into what variables were considered, as well as what weighting they were assigned within each variable class.

Another limitation of this study is that, while it tries to encapsulate the general variables that carsharing needs to operate, it is oriented towards the traditional carsharing markets that operate in high-density multimodal environments (TCRP, 2005). The markets for carsharing are very diverse, but there are common characteristics between many of them that are captured in the analysis. For example, many carsharing-supportive environments tend to exist in fairly high-density areas where the ability to live without a car exists (TCRP, 2005). While there are some other markets (such as University) that might not have explicit recognition, there is reason to believe they would get some representation. For example, Universities tend to serve large concentrations of individuals at a central facility that should appear in the employment square footage and are often surrounded by high-density residential spaces; students also tend to have lower vehicle ownership, and these are locations that tend to be pretty well served by transit (Stasko et al., 2013; TCRP, 2005). Each of these traits would show up in the model, but the University- and student-related variables are not explicit. Another example is the case of the market for partnerships with transit operators, which aim to locate near transit stations—this would also be captured by the model, based on its explicit inclusion of bus lines and subway stations (TCRP, 2005). Thus, it is fair to say that this analysis is limited to traditional neighborhood carsharing, but the variables considered would be applicable in most urban environments in which the largest market share for carsharing exists (TCRP, 2005).

Another limitation is that this general analysis is limited to one point in time, and does not necessarily consider other types of carsharing, such as peer-to-peer carsharing or one-way carsharing, as well other types of markets (Shaheen et al., 2012). While peer-to-peer carsharing and one-way carsharing are different forms of carsharing, they still need similar environmental and demographic conditions in order to succeed in urban areas, such as the ability to live without a car (Shaheen et al., 2012). However, it is possible that their ranges may vary to a wider extent than traditional carsharing services offered by carsharing operators. Additionally, if changes in the technologies employed in carsharing occur, then the scope of carsharing markets in general could also be much wider, if these changes reduce risk and cost of vehicle sharing services or operation. However, the degree to which changing technologies or different forms of carsharing would cause the extent of carsharing-supportive conditions to vary is beyond the scope of this analysis.

Additionally, there were data limitations encountered during the study period that limited what type of analysis could be conducted. For example, the researcher attempted to contact Zipcar for GIS information related to where their vehicles were located and how many vehicles were at each POD. The request for information was considered, but ultimately denied. The researcher intended to use the number of vehicles found at POD as an indicator of carsharing level of service, similar to what was employed in previous studies (TCRP, 2005; Celsor & Millard-Ball, 2007). Ideally, this study would have attempted to get information on every carsharing operator and the number of vehicles at each POD, so that the averages could be weighted on a per-vehicle basis. What this means is that the analysis is centered on the suitability of each carsharing POD consisting of at least 1 carsharing vehicle, but if more than 1 carsharing vehicle is added, this analysis does not inform if the environment is suitable for more than at least 1 carsharing vehicle. Additionally, there were other pedestrian, parking, and transit metrics that the researcher would have preferred to employ, but data limitations further prevented their application.

One final type of limitation found in this analysis is that some of the data's organizational complexity limited the ability of the researcher to conduct the types of processing available. For example, in the case of pedestrian network metrics, the data available in the form of the center line data from the city did not lend itself to certain types of density metrics, nor did it provide information related to the overall pedestrian-friendliness of the street network. The use of state-level data did provide a source of such data that could be processed in a reasonable way, but it also had its own limitations. In addition, the complexity of the on-street parking regulation data, while ultimately able to be processed in an acceptable fashion, was also limited in the options available for query selection and creation.

Recommendations

Carsharing has a lot to offer in New York City. Based on the results from the Inner Ring Parking study, there is a high demand potential for carsharing in the Inner Ring, considering that the dominant use for vehicles within the Inner Ring is household errands and that, currently, only 4% of non-vehicle owning households who replied that they have used a car in the last month reported doing so by participating in a carsharing program (DCP, 2013). This, along with the fact that only 42% of vehicle owners surveyed in the Inner Ring Study said they use their vehicle for commuting, suggests that a large percentage of vehicle owners might shed a vehicle if they found carsharing to be both an accessible and convenient alternative. In addition, based on the suitability and threshold analysis conducted by the researcher, 82% of Inner Ring of Brooklyn was determined to have the minimally-suitable conditions to support carsharing. If the rest of the Inner Ring of New York City was to have roughly similar conditions to Brooklyn, it is possible that a large portion of the transit-oriented portions of New York City could be suggested to find carsharing to be a viable alternative to vehicle ownership in New York City. However, while other cities have taken fairly aggressive policy stances towards the support of carsharing, New York City has utilized a fairly conservative method of carsharing accommodation by allowing carsharing vehicles to substitute for parking spaces in public garages and accessory dwelling units (DCP, 2010). While allowing carsharing vehicles to be placed in parking spaces does provide some reversibility to carsharing-supportive policies, providing planning support to carsharing operators could go a long way toward improving transportation options in New York City's Inner Ring. In addition, whether support is provided in the form of parking reductions, subsidies, or the allocation of on-street parking, it could help to reduce the need for vehicle parking in the Inner Ring and provide a method of accommodating citizens' concerns when parking requirement reductions are considered for neighborhoods in the Inner Ring. Thus, the researcher recommends the following principles and potential policies for further consideration.

The provision of highly-visible on-street parking locations to carsharing operators in locations that meet the minimally-suitable environments for carsharing, in order to provide carsharing operators with test beds as avenues of expansion: This type of parking provision is very valuable, because it is both the provision of convenient parking for the carsharing service and the simultaneous provision of highly-visible marketing for carsharing operators. Additionally, these types of carshare parking provisions are reversible; if carsharing does not lead to desirable outcomes on residential streets, then the parking spaces can be reverted to vehicle parking once more. Potentially, this type of policy could be used to drive carsharing expansion by providing on-street parking in areas that seem to have minimally-suitable environments for carsharing, but are not currently within ¼ mile of carsharing vehicles (and are therefore not adequately served by them). An example of how such a policy could operate is that carsharing operators could be offered free on-street parking for the first year in a new service area; past that year, they would either pay for on-street parking or find off-street parking nearby. This type of pilot approach allows carsharing operators to determine for themselves if these new locations actually have traits that support carsharing and to test new markets at a reduced cost—at a lower risk to themselves and to the city. Also, the program is easy to pilot by simply reducing the number of total vehicles that carsharing vehicles could put on residential streets, in terms of both absolute number and of how many vehicles can be placed on an individual street block. One concern is that, in mixed-use commercial districts—where parking is already in high demand—this type of policy would be more controversial and would have to be weighed against lost revenue, cruising, and congestion concerns, if carsharing cannot mitigate them alone.

Conditional parking requirement reductions in areas served by high-quality transit within the Inner Ring for higher-density residential zoning classifications, if carsharing vehicles are provided to new developments: The city could consider the allowance of parking reductions near subway stations within the Inner Ring if carsharing vehicles were provided to residences. These reductions should follow best practices, such as connecting the parking reduction per carsharing vehicle to the size of the residential development, considering implementation factors, and considering the requirements in the context of existing parking requirements and market conditions (Engel & Passmore, 2013). Additionally, some consideration might be given to limiting the incentives to an area until a certain level of service (number of carsharing vehicles within ¼ mile of any location) has been reached and the area is therefore considered “saturated.” This type of policy would be kept to geographic regions that could support carsharing, but still has the risks associated with parking reductions being offered in lieu of carsharing vehicle provision. However, they would be offered in transit-oriented areas, so the impact would not be severely adverse if parking reductions are both warranted and considered for the Inner Ring, regardless. Ideally, this type of parking reduction could be approached through a much broader program that would provide reductions for other transportation demand management programs, such as cash out for employer-paid parking or transportation allowances.

Potential Integratation of Carsharing in transportation and transit planning activities and policy elements: This could include having carsharing operators as stakeholders during transportation planning studies and plans, and even having the MTA integrate carsharing into future station design, parking facilities, and ticketing and marketing strategies. There are other experiences in Seattle and other cities that can provide more information on how to integrate carsharing into transportation planning activities and operations, in order to improve the transportation options available to residents of neighborhoods in New York City.

Investigation of the feasibility of providing carsharing service to low-income areas by amending current affordable housing policies: Even though there are considerable barriers to low-income groups' uptake and potential use of carsharing, there is the possibility of improving low-income mobility if said barriers could be overcome. One way to approach this would be to invite carsharing operators to provide services in public housing developments where parking can be provided free of charge to carsharing operators, as was was done in the City of Vancouver, WA (TCRP, 2005). Other considerations could be amendments to Inclusionary Zoning policies, such as the provision of either further-reduced parking requirements or of increased FAR bonuses to developments that build affordable housing and arrange to provide carsharing vehicles to residents. In this way, it is possible to decrease the risks and costs associated with low-income household use of carsharing vehicles.

Offering other forms of carsharing support to locations that meet the minimally-suitable environments for car sharing: There are other forms of policy support that might be feasible with minimal expense or risk to support carsharing throughout New York City. Multiple policies should be considered in locations outside of the Inner Ring. While parking is one incentive for carsharing operators, others to consider include help with marketing efforts or potential integration of transit operators with carsharing organizations by forming partnerships in suitable regions.

Removal of barriers that may be inhibiting car sharing's growth and use: There may be existing policy barriers that inhibit car sharing's growth. One example is existing rental car taxes that put the effective tax rate of carsharing in New York City at 19.91%. Helping to relieve this taxation burden could help substantially towards supporting carsharing. While tax policy is just an example, there are other potential barriers that carsharing faces in the form of insurance acquisition and contracting between developers that could be considered as worthy of assistance.

CHAPTER 6
CONCLUSION

Parking policy in the United States has historically favored the oversupplying of parking in terms of absolute supply, but also in terms of convenience and certainty of accessing parking at the expense of other modes. While parking policy is changing either towards alternative parking requirements or towards transportation demand management strategies, parking policy for cities across the United States will continue to evolve. While the niche for carsharing is limited to multi-modal urban locations, it has been shown to complement existing parking and transportation demand management strategies by contributing toward the goals of reduced vehicle ownership and of reduced mode-adjusted VMT, while providing an affordable alternative to car ownership to members in urban areas. While policies supporting carsharing have been introduced in many cities, there remain the risks associated with providing incentives in locations that do not have environments with the appropriate conditions to support carsharing services in the long term. In order to reduce the risks associated with providing incentives for carsharing services to either developers or operators, this analysis maps the spatial extent of locations that have the minimally-suitable environments to support carsharing services in Brooklyn, NYC. The results from this analysis estimate that 57% of Brooklyn has minimally-suitable conditions to support carsharing services, and 82% of the Inner Ring of Brooklyn defined by the Department of City Planning Inner Ring Parking Study has the minimally-suitable conditions to support carsharing services. The estimates from this analysis imply that the New York City carsharing market has a lot of potential to expand to other locations if incentives were expanded for carsharing services and if barriers like parking costs could be reduced via appropriate parking and planning support mechanisms.

CHAPTER 7
FURTHER RESEARCH

Considerable research could be done to improve the results of the market shed model and inform the implementation of carsharing policy incentives in urban areas like New York City, including the changes to the model, the use of pilot projects directed at specific neighborhoods and specific populations who might benefit from carsharing, and the responses of various groups, such as developers and neighborhood residents, to carsharing incentives.

The market shed model could be improved with a more detailed suitability analysis with more complete data related to the number of carsharing vehicles that are available at each pod to establish potential carsharing level of service thresholds that could provide a more nuanced look at carsharing potential in the region.

The feasibility of combining car sharing with other policy programs, such as NYC Affordable Housing Policies or its welfare programs, could be explored to understand the potential for expanding the use of carsharing among low-income households who could potentially benefit from a new mobility option. Similarly, studies could be completed in specific neighborhoods in New York City that might be appropriate, viable candidates for carsharing incentives, such as the provision of visible on-street parking spots, FAR bonuses, reductions in minimum parking requirements, and other forms of support. Additionally, if carsharing incentives were to be considered in New York City, it would help to pursue research into developers' potential responses to carsharing incentives and gauge whether or not developers would respond favorably to incentives—and, if so, what types they would find most favorable. In addition to developers, it would help to pursue research into carsharing operators' response to carsharing incentives and gauge whether or not they will base expansion plans on new available parking. Also, some research could be conducted to understand the movement of vehicles between parking locations; for example, if carsharing vehicles did not need to be returned to specific pods, how often carsharing vehicles would be relocated from different locations and what conditions would contribute to their relocation. Finally, the model that was applied to Brooklyn could be extended to other parts of the New York City Region and to other regions that have data available for this analysis.

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BIOGRAPHICAL SKETCH

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