Understanding Transportation Related Infrastructure Access in 52 Major US Cities

PI: Junfeng Jiao, 2019

GRA: Chris Bischak

April 2019

A publication of the USDOT Tier 1 Center:
Cooperative Mobility for Competitive Megaregions
At The University of Texas at Austin

Technical Report Documentation Page

1. Report No. CM2-18	2. Government Accession No.	3. Recipient's Catalog No. ORCID: 0000-0002-7272-8805
4. Title and Subtitle Understanding Transportation Related Infrastructure Access in 52 Major US Cities		5. Report Date April 2019 6. Performing Organization Code
7. Author(s) Dr. Junfeng Jiao		8. Performing Organization Report No. CM2-18
9. Performing Organization Name and Address The University of Texas at Austin School of Architecture 310 Inner Campus Drive, B7500 Austin, TX 78712		10. Work Unit No. (TRAIS) 11. Contract or Grant No. USDOT 69A3551747135
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Transit Administration Office of the Assistant Secretary for Research and Technology, UTC Program 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered Technical Report conducted April 2018- April 2019 14. Sponsoring Agency Code
15. Supplementary Notes Project performed under a grant from the U.S. Department of Transportation's University Transportation Center's Program.		
16. Abstract Transit deserts are urban areas with poor transportation related infrastructure access. In these areas, transit demands usually exceed transit supplies. In this project we refined the concept of transit deserts further and introduce the new concept of transit oases and transit adequate areas. We then applied our methods to 52 US cities. We found that all cities have issues with transit deserts. Central Business Districts are almost all transit oases. The methods presented here can be applied to almost any city to quickly assess transportation supply and demand and determine which areas are potentially being underserved with regards to transportation.		
17. Key Words Transportation, Transit Desert, Infrastructure, GIS	18. Distribution Statement No restrictions.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 37 — 22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Acknowledgements

The authors are grateful to all those who supported this work. The authors wish to give special thanks to Mr. Jianwei Chen for his help with creating the website www.transitdeserts.org. They also wish to thank all those at CM2 at UT Austin especially Dr. Ming Zhang and Ms. Inessa Ach for their help.

Table of Contents

Contents

Executive Summary

Transit deserts are urban areas with poor transportation related infrastructure access. In these areas, transit demands usually exceed transit supplies. In this CM2 project we refined the concept of transit deserts further and introduce the new concept of transit oases and transit adequate areas. We then applied our methods to 52 US cities. We found that all cities have issues with transit deserts. Central Business Districts are almost all transit oases. The methods presented here can be applied to almost any city to quickly assess transportation supply and demand and determine which areas are potentially being underserved with regards to transportation.

Chapter 1. Introduction

Overview and Objectives

This report is the result of two years of work, assessing transportation infrastructure gaps in 52 cities in the United States. This work has resulted in the creation of the website www.transitdeserts.org and the submission of a paper to the Journal of the American Planning Association (JAPA). This work has also generated extensive press coverage including articles in the Chicago Tribune, Los Angeles Times, Smithsonian Magazine, and The Conversation. This report details the work, the methods used, the results, and the implications of our findings for urban planning and policy.

This chapter situates our research in the broader context of transportation planning. First, we discuss the importance of adequate transportation for well-being and health. Then we establish the validity of transit desert research methods and discuss current research into transit deserts. Finally, we provide a broad overview of the methods used.

Background

Transportation, at its core, is about empowering people to live their best lives. Without adequate transportation access people are worse off economically, are less healthy, are less socially connected, and have less fulfilling lives. For example, one study found that people with steady access to transportation have a higher degree of life satisfaction (Cutler, 1975). Another study found that those with less access to transportation are less healthy due to worse access to healthcare (Syed, Gerber, & Sharp, 2013). Other studies have demonstrated that transportation is key component of ensuring healthy food access and ensuring socially inclusive societies (Hendrickson, Smith, & Eikenberry, 2006; Lucas, 2006). Without good transportation people are far more limited in where they can travel and thus how they spend their time.

Despite the clear importance of good transportation access, adequate access is not guaranteed. Many areas in cities are underserved by transportation of all kinds. The Center for Neighborhood Technology found that 43% of households in Miami-Dade County, Florida were underserved by public transit ("A Brief Walkthrough of our Transit Gap Tool | AllTransit," n.d.). Additionally, prior transit desert studies have found significant areas of cities that are underserved by transportation networks (Jiao, 2017). Other studies have demonstrated that certain areas of cities have less access to bicycle networks (Tucker & Manaugh, 2018).

Given the fact that transportation access is critical for the health and wellbeing of citizens and the fact that certain areas of cities are underserved by transportation, providing adequate service to underserved areas should be a top priority for policy makers. This problem might seem difficult at first, but planners and policy makers have the tools at their disposal to begin to close the gaps. This might be done through a variety of policy measures including better transportation planning, more funding of transportation, and prioritizing transportation access as a matter of public policy. One study found that public transit usage is primarily determined by factors endogenous to the system like headways and reliability of service (Alam, Nixon, & Zhang, 2015). Another approach might be to shift some funding away from highways (which currently receive the majority of federal transportation funds) and shift them towards public transit (*The Benefits of Reliable Federal Funding for Public Transportation*, n.d.). These are two approaches among many that planners and policy makers could undertake to close these gaps. But, overall evidence suggests that policy makers and planners do have the tools at their disposal to begin to close these gaps.

Even though there are a number of potential approaches that might begin to close these transportation gaps, information about where these gaps occur is often lacking. Identifying areas where more transportation is needed can be time consuming and difficult especially if advanced modeling techniques are used. To help to solve this problem we refined a transportation gap detection method first developed by Jiao and Dillivan in 2013 (Jiao & Dillivan, 2013). This method provides a robust method to better identify areas in cities that are underserved by transportation infrastructure networks. It provides a framework for sketch planning that enables planners to quickly identify areas that might need better transportation infrastructure.

Transit Desert Literature Review

The transit desert concept is situated within a broader body literature that focuses on transportation gaps and transportation accessibility. A robust discussion of the literature on both transportation gaps and transportation accessibility is beyond the scope of this report. But the following paragraphs will provide a brief overview of the state-of-the-art in regard to both concepts.

Several studies have focused on assessing transportation gaps in various contexts. Mamun and Lowes looked at the gap between accessibility of public transit and the need for public transit in Meriden, Connecticut. They first assess the intensity of public transit in a given area and then assessed the need for public transit in area using the Census Transportation Planning Package 2000 Database (Mamun & Lownes, 2011). This study found consistently high unmet transit needs across the city (Mamun & Lownes, 2011). Another study looked Public Transit Accessibility (PTA) in Wasatch Front Region of Utah (Fayyaz, Liu, & Porter, 2017). Here the authors found that denser, urbanized areas, in this case core Salt Lake City, have good PTA while peripheral areas have worse PTA (Fayyaz et al., 2017). Bejleri et al. identified services gaps by identifying transportation disadvantaged areas and calculating transportation supply based on various accessibility metrics. They applied this method to Alachua County, Florida (where Gainesville and University of Florida are located). Their results are consistent with other studies in that they found downtown areas have high supply that meets demand and outer lying areas have low supply that does not meet demand (Bejleri, Noh, Gu, Steiner, & Winter, 2018).

A robust body literature exists with regards to transportation accessibility and providing an extensive review of all this literature is well beyond the scope of this project. Therefore this section will focus on literature reviews and meta-studies of transportation accessibility which provide good overviews of transportation accessibility scholarship.

Much of this literature focuses either on developing methods to measure accessibility or assessing what good accessibility looks like from a more philosophical perspective. Paez et al. looked at various implementations of the concept of accessibility. They found that accessibility is typically defined using some combination of "the cost of travel (determined by the spatial distribution of travelers and opportunities) and the quality/quantity of opportunities" (Páez, Scott, & Morency, 2012, p. 142). They found that using both positive and normative accesiblity measures provides the best overview of how accessible an area is (Páez et al., 2012). Another study conducted by Saif et al. provides a general overview of the literature on public transit accessibility to date. They found that accessibility measures are usually either place based or person based (Saif, Zefreh, & Torok, 2018, p. 5). Finally, another literature review focused on the efficiency of various accessibility measures and found that there is no single, best measure. Instead the best measure depends on the resources available and the specific context (Jones, 1981).

Specifically, transit deserts are a concept that evolved from earlier work on food deserts by Dr. Junfeng Jiao (Jiao & Dillivan, 2013). The idea is that, just as certain areas in cities do not have adequate access to food, some area do not have sufficient access to transportation. However, food access and transportation access not total analogues. Measuring food access, while complex, is not as complex as measuring transportation access. By accounting for both spatial and economic factors, food access can be measured reasonably well (Jiao, Moudon, Ulmer, Hurvitz, & Drewnowski, 2012). However, transportation access is more multi-faceted than food access. First, people move about cities through a wide variety of means. Some people may have their transportation needs met though sufficient access to roads, but others might require bike infrastructure for example. Second, adequate transportation access is a function of demand. Everyone has different transportation needs, as opposed to food where everyone as certain basic need for it. It might be tempting to say that areas that lack subways, for example have poor transportation access. But there is no need for a subway station is a rural area for example. Thus, measures of transportation access have to account for this varying demand. Finally, it is much harder to conceptualize what adequate transportation access looks like. Food access is easy to understand theoretically, but adequate transportation access is hard to imagine and thus more difficult to measure.

In order to fill this knowledge gap Dr. Junfeng Jiao first developed the concept of transit deserts in 2013. A transit desert is an area where transportation supply exceeds demand and thus a ‘gap’ exists between what the quantified demand for transportation is and what the transportation supply actually is. As mentioned, this method was initially developed by Junfeng Jiao in 2013, but since that time the method has evolved in several ways. First, Jiao further refined the method in 2017 to look at cities in Texas. This method incorporates more advanced methods to calculate the demand for transportation infrastructure. Jiao found that all major cities in Texas had transit deserts with San Antonio and Houston being the cities with the highest number of transit deserts.

Kim et al. took the transit desert concept further. In this study, instead of using the block group as the unit of analysis, Kim et al. used a series of buffers around transit stops as their unit of analysis (Kim, Hall, & Drive, 2019). They also gave different weights to different transportation modes. In this study Kim et al. that several high demand areas did not have good access to transportation service, creating transit deserts (Kim et al., 2019). A final study looked at transit deserts in Baltimore, Maryland in order to understand if the Baltimore Link helped to alleviate transit deserts. This study found that the Baltimore Link was generally ineffective in alleviating transit deserts (Franklin & Chavis, 2019).

All of these prior studies have the same general limitations, however. First all of the prior transit deserts did not account for all the of transportation modes in a given city. Prior studies have mostly used the primary public transportation network and not accounted for other, secondary public transportation services. Second, and maybe most importantly, all prior studies have been relatively small in terms of scope. For example, Jiao and Dillivan (2013) studied four cities and Kim et al. looked at a small area in Utah. Finally, all prior studies have simply classified areas as either transit deserts or non-desert areas. There has been no attempt to classify areas along a gradient.

To correct some these limitations, we applied a refined transit desert method to 52 US cities. We made three key innovations in this project. First, this is the largest study of transit deserts to date. This provides more information than ever before on the nature and distribution of transit deserts in the United States. Second, we accounted for more transportation modes than in previous studies We developed better methods to measure sidewalks which were previously underrepresented. We also accounted for more public transit services than prior studies. Finally, we refined the method for calculating demand, using better measures for the number of people ages 12-18 and the number of people in group quarters. In the next chapter we present the full study we conducted and our results.

Chapter 2. Transit Deserts USA: Lessons from 52 Cities

Junfeng Jiao and Chris Bischak

Please Note: This paper is being submitted for review to the Journal of XYZ.

Problem, Research Strategy, and Findings:

Transportation is one of the most critical services that cities provide. It allows people to access jobs, recreational opportunities, healthy food and more. Good urban planning is essential to creating a cohesive and efficient transportation network. However, traditional urban planners often lack appropriate tools to assess transportation service in their city independent of specialized transportation engineers. Moreover, regular transportation planning methods may not take a holistic look at existing networks. In this paper, we refine a method for quickly assessing transportation related infrastructure supply, demand, and gaps that can be adapted to a wide variety of circumstances. This method assesses transportation related infrastructure holistically rather than on a mode by mode basis. We apply this method to 52 major United States cities and then present our results. Our results indicate that providing sufficient transportation infrastructure access is an issue that all cities face, and areas with inadequate of transportation infrastructure are often of lower socioeconomic status. Full results, at the block group level, for all 52 cities can be found at www.transitdeserts.org.

Takeaway for Practice:

Enhancing urban mobility through tighter integration of multimodal transportation networks is a critical challenge for urban planners in the 21st Century. New tools such as the one presented here can be used to fill critical information gaps that currently exist. Using methods such as these as a starting point to assess transportation related infrastructure access can enable practitioners to better identify gaps in each city.

Keywords: Transit Deserts, Transit Dependent Population, Urban Mobility

About Authors: Junfeng Jiao (jjiao@austin.utexas.edu) is an assistant professor at the University of Texas at Austin and the director of the Urban Information Lab. Chris Bischak is a graduate research assistant in the Urban Information Lab.

Introduction

Transportation, in many ways, is the life blood of cities. It allows people to access jobs, recreational opportunities, healthy food, and much more. Good transportation networks make people's lives easier by allowing them efficiently to reach a variety of destinations with ease. But traditional transportation planning has often fallen short in at least three key respects. First, and most importantly is transportation planning often adopts a "unimodal perspective…as opposed to the often more fruitful intermodal approach" (Sussman, Sgouridis, & Ward, 2005). Additionally, transportation planning methods today have "achieved a sophistication unimaginable by those who laid their foundation in the 1950" (Verma & Ramanayya, 2014). However, this mean they are often expensive and time consuming to conduct as they rely on advanced statistical modeling. Additionally, traditional transportation planning methods often use land use patterns as a predictor of trip demand. However, this can be unreliable, as zoning and land use can rapidly change and may not truly reflect the demand for transportation in certain areas. This often leads to substantial inaccuracies in demand forecasting for both road and public transit systems (Flyvbjerg, Skamris Holm, & Buhl, 2005).

New tools are needed that allow urban planners to quickly assess what areas of a city may be underserved by existing transportation networks. These tools should account for the wide-range of transportation modes that urban residents might avail themselves of including driving, public transit, walking, and biking. This is especially important as there is an increasing recognition that transportation planning must be a comprehensive effort that integrates all forms of planning (Marshment, 1999). In this paper we present a refined, sketch planning method to assess transportation related infrastructure demand and supply at the block group in a given geographical area.

Our sketch planning tool relies on publicly available census data and GIS data to map out the relative transportation related infrastructure demand and supply in a city, then identify the gaps between the supply and demand. It identifies areas that have large gaps between demand for transportation and transportation related infrastructure which are termed 'transit deserts.' Additionally, in this paper, we further develop the concept and introduce a new a new term 'transit oases', to contrast with the concept to transit deserts. These areas have a potential oversupply of transportation related infrastructure as compared to demand.

We applied our planning method to 52 major United States cities. We found that every city had areas where transportation related infrastructure demand supply exceeded demand and where demand exceeded supply. The geographic distribution of the transit underservice was geographically uneven, whereas transit over service tended to cluster in the Central Business Districts of cities. Finally, we found that the populations living in transit deserts tend to be of lower socioeconomic status, younger, and less white than the populations living in areas with sufficient transportation related infrastructure supply.

Background

Transportation serves as a critical lifeline for nearly everyone that lives in a city. In theory a person could get by with almost no access to transportation except walking if everything they needed was in their neighborhood. But many US cities are not particularly walkable especially when compared to their European and Asian counterparts (Adams et al., 2014) . For example, in 2017 the United States Department of Health released its *Report Card on Walking and Walkable Communities* and found that “Only 32 percent of states (n = 16) meet the standard of ≥ 30 percent of residents living in a highly walkable neighborhood” (ODPHP, 2017). Additionally, the United States received an ‘F’ grade for walkable infrastructure and a ‘D’ grade for pedestrian safety. Transportation statistics reflect how little people walk in the US. As of 2013 US citizens traveled over 3 trillion vehicle miles per year in private vehicles, 57,17 million miles on all forms of public transit excluding airlines and spent 1.13 trillion dollars on transportation (Nguyen et al., 2016). Thus, given the rather dire situation when it comes to walking in the United States, most people in the US are probably dependent on transportation infrastructure like roads, public transit etc. to one degree or another; therefore transportation is an immensely important part of cities and society more broadly. Because of the immense importance of transportation much effort has been dedicated to the modeling of transportation systems. These methods have evolved from fairly simple ones to the exceedingly complex methods used today (Bandara & Wong, 2005; Chen & Kasikitwiwat, 2011; Karlaftis & Vlahogianni, 2011; Marshment, 1999; Xiao, Yang, & Ye, 2016; Yang, Bell, & Meng, 2000; Zhong & Young, 2010). The advantage of using such sophisticated models is that transportation modeling has become appreciably more accurate (Hartgen, 2013), but because their complexity, these traditional transportation planning models often consume significant time and resources.

The other issue that arises from the complexity of these methods is that other planning professionals, who might play a key role in transportation planning projects, may not be able to understand the results in a meaningful way or cannot conduct such modeling themselves if the need arises.

Increasingly urban planners are working both with engineers and the public to address transportation issues (Litman, 2013; Meyer, 2000). However, urban planners and the public cannot meaningful participate in the planning process if they do not have access to quality and easy to understand information (Zhong, Young, Lowry, & Rutherford, 2008). Such difficulties have led some to seek new planning tools and methods so that transportation supply can be optimally matched with transportation demand (Bertolini, Clercq, & Straatemeier, 2008).

Perhaps more important than the issues associated with complex transportation planning demands is the fact that these methods fail to account for all the various ways that residents can get around an urban area and transportation planning typically has a unimodal focus (Marshment, 1999). Litman further argued that "Conventional [transportation] decision-making is reductionist; each problem is assigned to a different person or agency…[this] approach tends to be ineffective at solving complex problems with interrelated and conflicting objectives" (Litman, 2003). One way to fill this gap and achieve this objective is to provide planners with tools that allow them to assess transportation networks holistically. The objective of this paper is to fill at least part of that gap by providing planners with a method to assess city's entire transportation infrastructure network that is both easy to use and understand.

To better measure and understand the transportation related infrastructure in 52 major US cities, we conducted a transit access analysis using a GIS based methods developed from earlier studies (Jiao, 2017; Jiao & Dillivan, 2013). This paper is organized as the following: We first explain the methods that we used to measure transit access in each city. We then test the relationship between transit access and socioeconomic status indicators. Finally, we discuss our findings from these 52 cities and their policy implications.

Research Methods

The methods presented here are developed from earlier methods (Jiao, 2017 and Jiao & Dillivan, 2013). The term transit desert describes an area where transportation infrastructure demand outstrips transportation related infrastructure supply. These are areas where transportation related infrastructure supply could potentially be improved or possibly need additional transportation infrastructure. The method presented here has been significantly improved from past transit desert studies. In the past transit deserts were simply considered to be areas with a 'gap' between transportation related infrastructure and demand (Jiao, 2017; Jiao & Dillivan, 2013). We refined the measurement of transit deserts and now can use our method to identify three different areas: transit deserts, adequately served areas, and transit oases areas.

W use the following three-step method to assess the transportation gaps in each city. First, we calculate the transportation related infrastructure supply using publicly available Geographic Information Systems (GIS) data and GTFS (General Transit Feed Specification) data at the block group level. Then we calculate the transportation related infrastructure supply for each block group using American Community Survey Data 5-year data from 2011-2015. Finally, we subtract the transportation related infrastructure supply index score from the transportation related infrastructure demand index score to get the transportation related infrastructure gap index score. Depending on the transportation related infrastructure index score areas are then classified as transit deserts areas, transportation related infrastructure adequate areas, or transit oasis (in contrast to transit deserts). All index scores are calculated at the block groups level.

We applied our methods to the 50 largest cities in the US. For some cities (e.g. Omaha) with inadequate or nonexistent GIS and/or GTFS data, we have to replace it with the next largest city. In most cities, we limited our study area to the city boundary. In some areas where they have overlapping transportation related infrastructure services and contiguous boundaries, to ensure a holistic measure of transportation related infrastructure service, we expanded the study areas to the overall region (e.g. Dallas Forth Worth, Phoenix area, Los Angeles etc). A full list of selected cites is presented in Appendix Table 1 A.

Transportation Related infrastructure Supply, Demand, and Gap

In this study, transportation related infrastructure Supply is calculated using publicly available GIS and GTFS data. The supply indicators varied slightly from city to city depending on the number of transportation related infrastructure services offered in the city. For each block group the following is a generic listing of the supply indicators used:

- Street Length

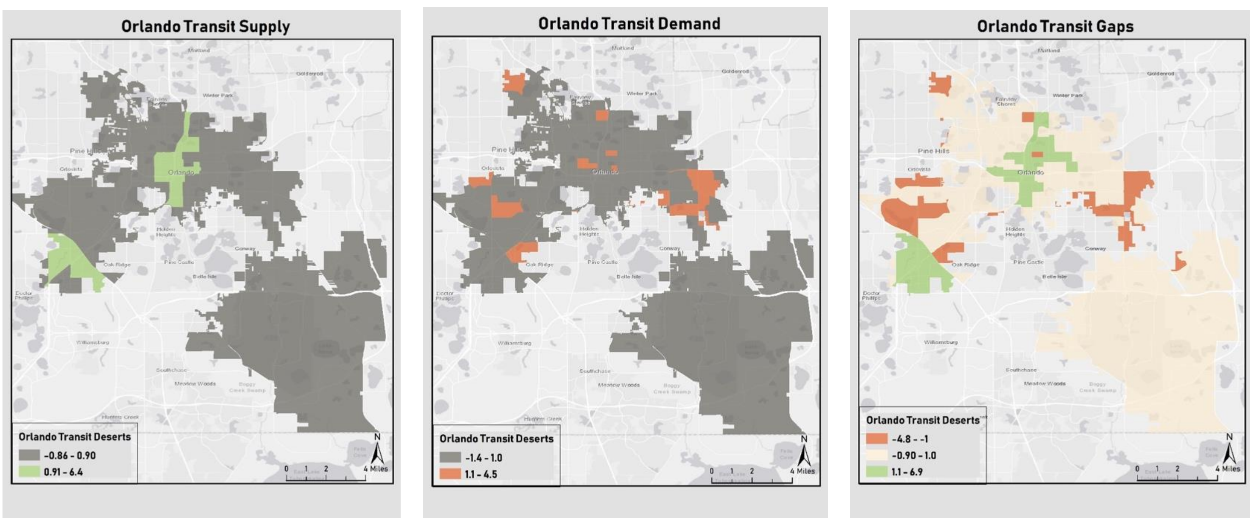
- Sidewalk Length
- Transit Route Length
- Number of Transit Stops
- Number of Street Intersections
- Bike Lane Length
- Total Trips Per Day Per Transit Stop
- Average Trips Per Hour Per Transit Stop
- Number of Transit Routes (Bus or Rail)

Most of the GIS data need for the calculations was obtained from the studied municipalities. OpenStreetMap Data was also used as a supplementary GIS data source.

Transportation related infrastructure demand is calculated from American Community Survey 5-year estimate data from the years 2011-2015. We used the number of transit dependent persons per block group as a proxy for transportation related infrastructure demand. The following is the three-step process used for calculation (Steiss, 2006; Jiao & Dillivan, 2013; Jiao, 2017):

1) Household drivers = (population age 16 and over) – (persons living in group quarters)
2) Transit-dependent household population = (household drivers) – (vehicles available) * national level carpooling ratio
3) Transit-dependent population = (transit-dependent household population) + (population ages 12–15) + (non-institutionalized population living in group quarters)

First, the number household drivers are calculated by subtracting the number of people 16 years and older from the number of people living in group quarters. Group quarters are places such as nursing homes, prisons, university dorms, and rehabilitation facilities. Second, the number of household drivers is subtracted from the number of vehicles available. This number is then multiplied by the nation carpooling ratio which is 9% (Mckenzie, 2015). This nets out the number of people who may not own a car but are not necessarily transit dependent. Finally, the number of 12 to 15 years old and the number of non-institutionalized persons in group quarters are added to the number of transit dependent people. The 12-15 year old are not legally able to drive, but are old enough to have transit needs and non-institutionalized people, those who live in college dormitories, military barracks, group home missions or shelters, are unlikely to be able to own cars and thus are transit dependent (US Census Bureau, 2018). This final number of transit dependent persons is then divided by the number of acres in the block group to get the number of transit dependent persons per acre. This number is then z-scored to get a final transit demand index score. We calculate the transportation related infrastructure gap by subtracting the supply index z-score from the demand index z-score. The block groups are then classified into either transit desert areas, transit adequate areas, and transit oasis areas. Transit deserts areas are areas that have a transportation related infrastructure gap index score at least one standard deviation below the norm for that city. Transit adequate areas are block groups with a transportation related infrastructure gap index score between -1 and 1 standard deviation of the norm for the city. Transit oasis areas are block groups with at a transit gap index score at least 1 standard deviation above the norm for that city. Figure 1 showing the transit demand, supply and gap in Orlando, FL.



1 Transit Supply, Demand, and Gap in the City of Orlando, FL

Findings from 52 Major US Cities

We then applied our methods to 52 major cities in the US. The complete set of maps has been published on the internet at www.transitdeserts.org. For the 42,778 block groups within these 52 cities, 9116 or 21% of them are either transit deserts (gap of -1 standard deviation or less) or transit oases (gap of 1 standard deviation or greater). This indicates that the clear majority of block groups have an adequate transit supply and are neither underserved or overserved.

On average 11% of block groups in each city were transit deserts and 6.6% of the population (4 million) of the city lives in these areas. Of all the cities San Francisco has highest percentage of population (13.5%) living in transit deserts. It was followed by Sacramento (12.8%) and Orlando

(12.2%). Denver had the least percentage of population (1.52%) who lived in transit deserts areas, followed by Cleveland (1.96%). The Bay Area, had on average, the highest percentage of people in transit deserts (Figure 1A and 2A).

Across all cities the spatial distribution of transit deserts did not show a clear pattern. The central business district for each city almost always is a transit oasis area. For example, the transit desert areas in Orlando have the Sunrail or I-Ride trolley service running through them. No other block groups have these transit services. Another example is in Seattle. Block groups that have ferry service are transit oases since no inland block groups have this type of extra transit service. This means that people living in transit oases have better access to more destinations via public transit than people living in merely transit adequate areas. Transit oases areas provide people with a wider variety of transit services to different areas in their cities.

Comparison between transit desert and non-transit areas

It is natural to ask the question of whether or not our methods actually identify areas with poorer transit infrastructure. It might be true that the methods developed here do not truly find areas that have poor transit infrastructure or that differences between transit deserts and non-transit deserts might be so small that they are insignificant. Thus, we used T-test to detect whether the identified transit desert areas in these 52 cities actually have worse transit infrastructure than non-transit deserts areas. The results of this analysis are displayed in Table 2.

Table 2: Comparison of Transportation related infrastructure in Transit Desert and Non-Transit Desert Neighborhoods

Variables	**TD**	**Non TD**	**Significance Level (0.05)**
Mean Number of Intersections	25.48	41.77	*
Mean Number of Transit Stops	3.46	5.43	*
Mean Transit Route Length (Miles)	7.72	10.75	*
Mean Street Length (Miles)	5.33	8.57	*
Mean Bike Route Length (Miles)	1.97	1.65	
Mean Sidewalk Length (Miles)	4.87	6.68	*
Mean Number of Transit Routes	2.85	4.07	*

Variables	**TD**	**Non TD**	**Significance Level (0.05)**
Mean Number of Transit Trips/Hour	6.76	11.10	*
Mean Number of Transit Trips/Day	147.65	239.78	*

The second question that naturally arises is whether people in transit desert areas have worse transportation outcomes. In order to measure this, we used American Community Survey data circa 2015 to assess commute times between transit desert and non-transit desert areas and then used t-tests to check if the mean commute times between these areas are statistically significantly different. For the purposes of our analysis we divided commute times into three basic categories short commutes which ranged from 0 minutes to 29 minutes, medium commutes which were between 30 minutes and 59 minutes and long commuter which were one hour or longer. The results of this analysis are displayed below in Table 3. We found that transit deserts neighborhoods on average have a significantly higher percentage of people who face medium length commutes. It makes sense that very long commutes are not statistically different as these are still relatively rare with only about 8% of workers having an hour plus commute (Copeland, 2013). The counterintuitive findings is that shorter commutes are not more common in non-transit desert areas. It might suggest that people in transit deserts are finding ways to cope with the lack of transportation infrastructure, which need further investigation to fully understand this finding (Table 3).

We also investigated if people in transit deserts are using different types of infrastructure to get around. We used ACS 2015 data to compare mode choice in transit deserts and non-transit deserts. The results showed that there was a statistically significant difference between all modes of transportation in transit desert areas vs. Non transit deserts areas. In transit deserts more people used public transit, carpooled, or used some other means of transportation. In Non transit deserts areas we found that people drove alone more, worked at home more and were more likely to commute by walking or biking (Table 3). Transit deserts had more people that used public transit or carpooled which indicates that they face a mobility disadvantage or are mode constrained. The working from home findings is also informative here. According to a 2011 report on the state of teleworking in the United States most people who teleworked “earn over $65,000 a year, putting them in the 80th percentile relative to the total workforce" and have at least a college degree (Lister & Tom, 2011). This would suggest that people in Non transit deserts areas, are somewhat more affluent than those in transit deserts areas. However, a note of caution must be exercised with this finding because a fair number of people who work from home are self-employed and do not follow the pattern of per se being more affluent (USBLS, 2009).

Table 3 Commuting Patterns and Modes in Transit Deserts and Non-Transit Deserts Neighborhoods

Variables	**Transit Desert**	**Non-Transit Desert**	**Significance level (0.05)**
Short Commute	53.4	53.64	
Medium Commute	32.54	31.22	*
Long Commute	10.35	10.63	
Public Transit	19.84	16.42	*
Active Mode (Bike or Walk)	5.45	7.82	*
Drive Alone	56.79	63.64	*
Carpooled	10.66	9.02	*
Worked at Home	3.72	4.51	*
All Other Modes	1.17	0.95	*

Socioeconomic factors varied significantly between transit desert areas and non-transit desert areas. We used T-test to compare a variety of socio-economic factors between transit desert areas and non-transit desert areas (Table 4). We found that in general transit desert areas were statistically significantly smaller, denser in terms of population, slightly younger, poorer, and had more minorities than non-transit desert areas. It shows that transit deserts disproportionately effect certain subsets of the population. Thus, transit access is a matter of social equity as well as a matter of planning.

Table 4 Socioeconomic Factor Comparison in Transit Deserts and Non-Transit Deserts Neighborhoods

Variables	Transit Deserts	Non-Transit Deserts	Significant (α = 0.05)
Acres	92.6	417.12	*
Population	1875	1377	*
Population Density (Per Sq. Mile)	42,526	15,707	*
Median Age	32.4	37.5	*
Percent White Population	51	56	*
Percent Non-White Population	49	43	*
Median Household Income in Dollar	$46,259	$58,232	*
Number of Super Commuters	23	18	*
Housing Units	684	570	*
Percent Owner Occupied Housing Units	33%	46%	*

Discussion

Our results show that all cities have areas where transportation related infrastructure service could be improved. Our analysis suggests that wealthier, less dense areas of most cities have better access to transportation. This makes intuitive sense for at least three reasons. First, wealthier people are more likely to own cars (Lescaroux, 2010) and in our model those with access to cars not counted as transit dependent population. Second, wealthier areas of cities may tend to have larger homes and thus be less dense in general. This would lead to a situation in which transportation related infrastructure demand is lower than in other areas of the cities. Finally, poorer areas may simply be underserved by transportation related infrastructure. However, previous studies do suggest that areas with lower income may have higher access to public transit (Welch, 2013).

Based on these findings transit deserts are physically different places than non-transit deserts. People living in transit deserts have less access to transportation services of all kinds, not just public transit. Residents in transit deserts have less access to all forms of transit infrastructure measured except for bike lanes. It is difficult to ascertain why this might be, but since transit deserts tend to be in denser areas of cities, bike infrastructure might be more common in these areas.

Overall, however, residents in transit deserts indeed lived in different built environment than that of non-transit deserts neighborhoods. People who live in transit deserts clearly have less overall access to transportation. This suggests that our method for finding areas with transportation gaps is a valid one.

A surprising aspect of our study is that cities with "good" public transit such as New York and San Francisco have a significant number of transit deserts. Transit deserts are not simply confined to cities that one might think of as having bad public transit. In many ways this make sense. It has been shown that transit supply also induces transit demand, that is if cities provide good transportation networks then people will both use these services more and be less auto dependent (Clark, Chatterje, Melia, 2016; Alam, Nixon, & Zhang, 2015). Our results seem to confirm this idea. Cities with better transportation networks create more demand for transportation.

Such a finding has important implications for planning. Currently, public transit ridership has been falling in nearly all cities across the US (Mallett, 2018). But our results confirm that the idea that policy makers have tools at their disposal to increase transit ridership as previous researchers have suggested (Alam et al., 2015). In our study cities with better public transit have, in general, have higher auto dependency rates and still have significant transit gaps. While this may appear to be a negative thing it also suggests that providing higher levels of service can significantly boost demand for public transit. Therefore, if transit planners wish to increase demand for their services they focus on providing high quality, reliable service that people want to use.

We recognize that improving public transit service may be easier said than done and correcting this problem of transportation mismatch is difficult. For example, one study found significant disparities in travel times to mammography clinics in those who used public transportation vs private vehicles. The average travel time on public transit was 56 minutes whereas the average travel time by private vehicle was 8 mins. This suggests that even if public transit headways were decreased service to these clinics by public transit would still be poor. Another study conducted in Tel Aviv, a city with a very dense bus network, found that even under these conditions there exists significant gaps in public transit network and many areas of the city are not accessible without a car (Benenson, Martens, & Rofé, 2010) . But small changes to service levels can help improve demand and planners need not seek perfection to begin making tweaks to their networks.

Moreover, the entire burden of fixing transportation gaps should not be placed on public transit planning officials. Thus, it is highly unlikely that cities can solve the transit desert problem through increased transit frequency alone, just like we cannot simply build out way of traffic. We suggest that cities approach the problem in a multi-faceted manner. First, there can be no doubt that better, more comprehensive planning and combine land use/transportation can help to alleviate some of the transit desert issues. Second, cities need to look to innovative means of providing people with transit access. A preliminary study conducted by the author suggests that shared mobility services like Uber, Lyft, bike-sharing services, and shared van pool services may help to alleviate some transit access issues. Third, cities need to utilize a wide array of tools like the one presented here to monitor transit access. As cities change over time there can be little doubt that transit need will shift as well. Through better detection and monitoring of transit issues cities can ensure better transit access.

Limitations and Future Work

Despite the great promise of this method it is also limited in some respects. First, it relies on publicly available GIS and GTFS data which is not always available. Better data sources could improve this method. Second, this method may show false positives in areas of extremely low population density and thus may have to be changed for usage outside of urban areas. Finally, this method cannot diagnose the exact causes of transit deserts. Further investigation is generally needed to understand the local issues associated with transit deserts.

The authors of this paper plan to continue this work in a variety of ways. First and foremost, the data generated from this study will be used to attempt to understand the planning and policy causes of transit deserts. Second, this transit desert method will be applied to a variety city in other countries to compare the results to those of US cities. The spatial distribution of transit deserts may vary by country and this poorly understood currently.

Finally, there is no single year age data or group quarters available at the block group level. Thus, this data is imputed from other ACS data sources. For example, ACS data only provides the total number of people living in group quarters at the block group level. To perform the calculations, the number of people living in institutionalized group quarters and non-institutionalized group quarters is also imputed from 2010 Census Data. This imputed data introduces some inaccuracy into the calculations performed. The authors suspect that our method somewhat overestimates the transit dependent populations in certain areas because of this. In future studies we intend to develop methods to better impute the needed data.

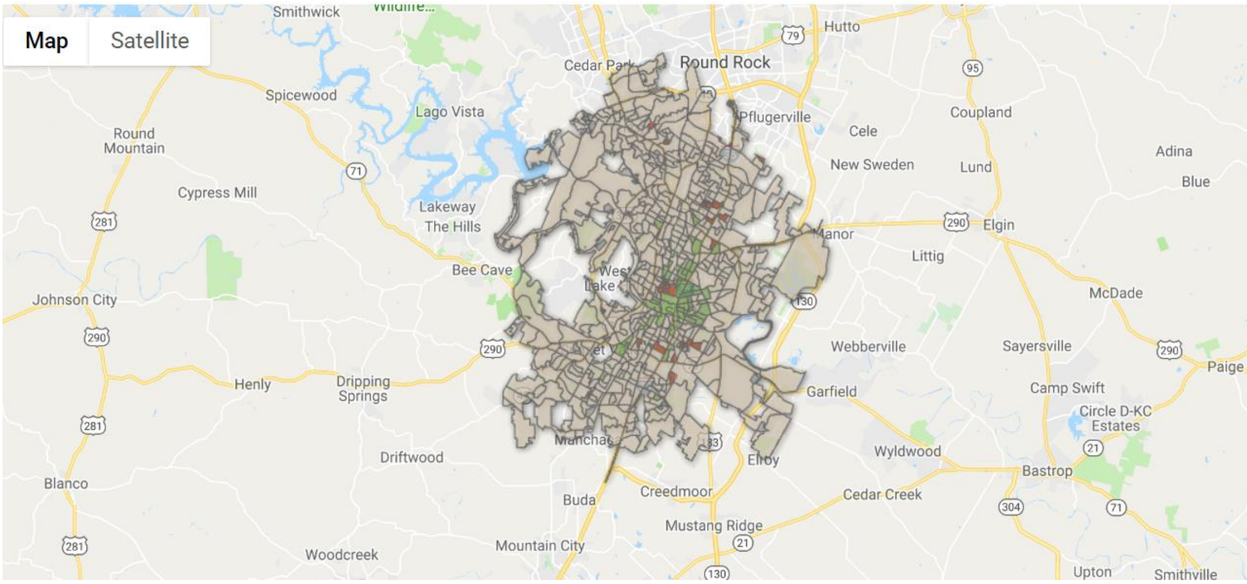
Chapter 3: Dissemination of Transit Desert Information

Website Creation

One issue with publishing material in academic journals is that these journals are very niche products with relatively low readership. Additionally, many of these articles are kept behind expensive pay walls that impair access for the general public. Thus, we opted to disseminate our findings through alternative channels are well.

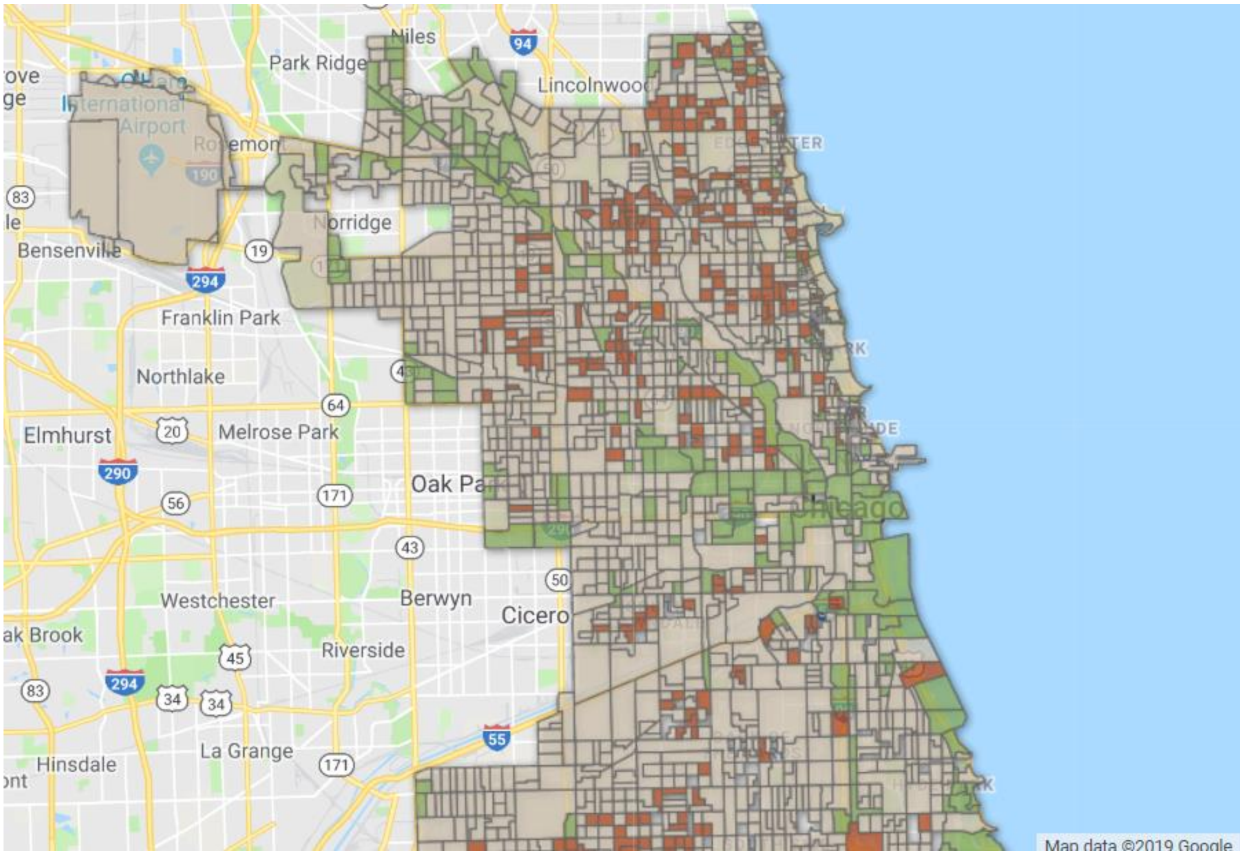
Primarily we did this through the creation of a website www.transitdeserts.org. This website was created by Mr. Jianwei Chen and Mr. Chris Bischak under the direction of Dr. Junfeng Jiao. It uses the Google Maps API and Google Fusion tables to display the location of transit deserts in all 52 cities. To date the website has been viewed more than 5000 times. Most of the audience for the website is located in the United States. But we have reached significant populations in China and Europe as well. Below in Figures 2 through 5 some screenshots of the website are displayed.

2. Screenshot of www.transitdeserts.org



3 Transit Deserts in Austin, TX

4 Transit Deserts in New York City



5 Transit Deserts in Chicago

This website has received significant attention from various publication outlets including Smithsonian Magazine, The Chicago Tribune, LA Times, and The Conversation. This website has allowed us to disseminate our findings beyond traditional academic journals and reach a much wider audience than would otherwise be possible.

Chapter 4: Implications for Megaregional Planning

This chapter will discussion the implications of this project for mega-regional planning and practice. We first outline the state of research with regards to megaregions and transportation accessibility. We then discuss how this research could be applied to megaregions.

Megaregions are a relatively new unit of analysis for planning practice and research. According to Hagler (2009) a megaregion is an area where "Interlocking economic systems, shared natural resources and ecosystems, and common transportation systems link" population centers together (Hagler, n.d., p. 1). There are about 11 megaregions in the United States although the exact boundaries of these regions is a subject of some debate (Hagler, n.d.; "Megaregions - America 2050," n.d.).

Megaregions represent an important new planning unit particularly for transportation. Transportation needs do not end at city, state, or even regional boundaries. People have travel demands that extend across urban centers and many of our transportation challenges "cannot be solved by actions taken solely at the city or metropolitan scale" ("Megaregions - America 2050," n.d.). For example many people in the northeast corridor routinely travel between the major city centers of Boston, New York, Philadelphia, and Washington D.C. ("The Future of the Northeast Corridor," n.d.). By recognizing these megaregions as important planning units we can begin to reshape transportation infrastructures to better align with people's real-life travel needs.

Despite the great promise of megaregions as planning units, research into transportation flows at the megaregional scale is relatively nascent. This is due to the fact that megaregions as a planning concept are still an emerging concept and also because of the difficulty of modeling transportation at the megaregional scale. However, some studies have been done that attempt to look at transportation accessibility at the megaregional scale. Again, a full literature review of megaregional transportation research is beyond the scope of this report. But a brief literature review will provided the needed background for our study.

Zhang et al. looked at how transportation can be better coordinated across the Texas Triangle megaregion. They found that megaregional planning has great potential to enhance mobility in Texas and move transportation infrastructure away from "environmentally sensitive areas" (Zhang, Steiner, & Butler, 2007, p. 32). However, the authors also found that megaregional transportation planning faces significant challenges (Zhang et al., 2007). Ross and Woo investigated megaregional mobility. They found that there is significant demand for better megaregional transportation networks. The authors suggest that the megaregion be adopted as the best planning unit for the management of transportation infrastructure (Ross & Woo, 2011). Another study by Ge and Jian measured transportation accessibility at the county level in China. They found that rail investment has greatly improved megaregional mobility in China. But the benefits have not been evenly distributed, the coastal megaregions (e.g. Western Taiwan Straits, Yangtze, and Pearl River megaregions) have benefited the most from this investment.

Within this context, this study specifically contributes to megaregional transportation research by providing a theoretical and methodological framework that can be used to assess transportation infrastructure demands. First and foremost, the methods developed in this study represent a significant step forward for transit desert research. Our refined methods have greatly improved the accuracy of transit desert detection, particularly because we now classify areas as either transit deserts, adequately served areas, and transit oases areas.

Second, these methods can be easily extended to megaregional areas and serve as a valuable tool for megaregional transportation planning. Kim et al. outlies how transit desert methods can be applied to areas outside of cities. This suggests that the concept of transit deserts, as a planning tool, is a valid one. By taking the methods developed here and extending them to megaregional areas transportation access can be better assessed at the megaregional scale. This is a significant a contribution because much of the research on megaregional transportation has focused on freight mobility or larger infrastructure planning (e.g. highspeed rail). Our method does not focus these types of transportation. Rather our methods are designed to analyze transportation access at a holistic level.

Finally, our methods clearly show that all cities across the United States have issue meeting travel demand. This implies that cities all have common problems that need to be solved. By working together at larger units these challenges can begin to be address not just in one city, but in many cities. This approach has already begun to show promise. For example, in the Northeast megaregion officials from various public transit agencies are working to make it possible to travel from DC to Philadelphia entirely by public transport (exclusive of Amtrak) ("What If You Could Get from Philly to D.C. on Public Transit?," 2015). This shows that a megaregional approach to transportation planning can benefit many cities across a larger area. New forms of thinking like this are needed to solve the complex issue of transit deserts.

Appendix

Table 1A Transit Deserts Calculation Results in the 52 Major US cities

City Name	**Average of Supply Zscore**	**Average Demand Zscore**	**Average Gap Zscore**
Albuquerque	-0.001	0.004	-0.005
Atlanta	0.000	0.003	-0.003
Austin	-0.001	0.003	-0.004
Baltimore	-0.002	0.004	-0.006
Bay Area	0.008	-0.026	0.034
Boston	0.005	0.002	0.002
Buffalo	0.016	0.004	0.012
Charlotte	0.003	0.000	0.003
Chicago	0.000	0.001	0.000
Cincinnati	0.011	0.003	0.008
Cleveland	0.001	0.001	0.000
Colorado Springs	0.007	0.000	0.006
Columbus	0.001	-0.004	0.006
Denver	0.003	0.004	-0.002
Detroit	0.000	-0.013	0.013
DFW-Arlington	-0.017	0.010	-0.027
El Paso	0.003	0.003	0.000
Fresno	0.010	0.015	-0.005
Honolulu	0.002	0.006	-0.003
Houston	0.002	0.000	0.001
Indianapolis	-0.003	-0.004	0.000
Kansas City	0.006	0.005	0.001

City Name	Average of Supply Zscore	Average Demand Zscore	Average Gap Zscore
Las Vegas-Paradise	-0.002	-0.005	0.003
Los Angeles County	0.001	0.001	0.000
Louisville	0.010	0.007	0.003
Miami	-0.003	0.013	-0.016
Milwaukee	-0.001	-0.002	0.001
Nashville	0.001	0.003	-0.002
New Orleans	0.003	0.005	-0.001
New York City	0.000	0.000	0.000
Oklahoma City	0.000	0.000	-0.001
Orlando	-0.025	-0.020	-0.005
Philadelphia	0.001	0.000	0.000
Phoenix-Tempe-Mesa	-0.001	-0.001	-0.001
Pittsburgh	0.000	0.000	0.000
Portland	0.001	-0.004	0.005
Raleigh-Durham	0.005	0.005	0.000
Sacramento	-0.030	0.001	-0.031
San Antonio	0.001	-0.001	0.002
San Diego	0.094	0.070	0.024
Seattle	0.002	0.000	0.002
St. Louis	0.009	0.003	0.006
Tucson	0.003	-0.008	0.011
Twin Cities	-0.001	0.000	-0.001
Washington DC	0.000	-0.001	0.001
Wichita	0.003	0.002	0.001

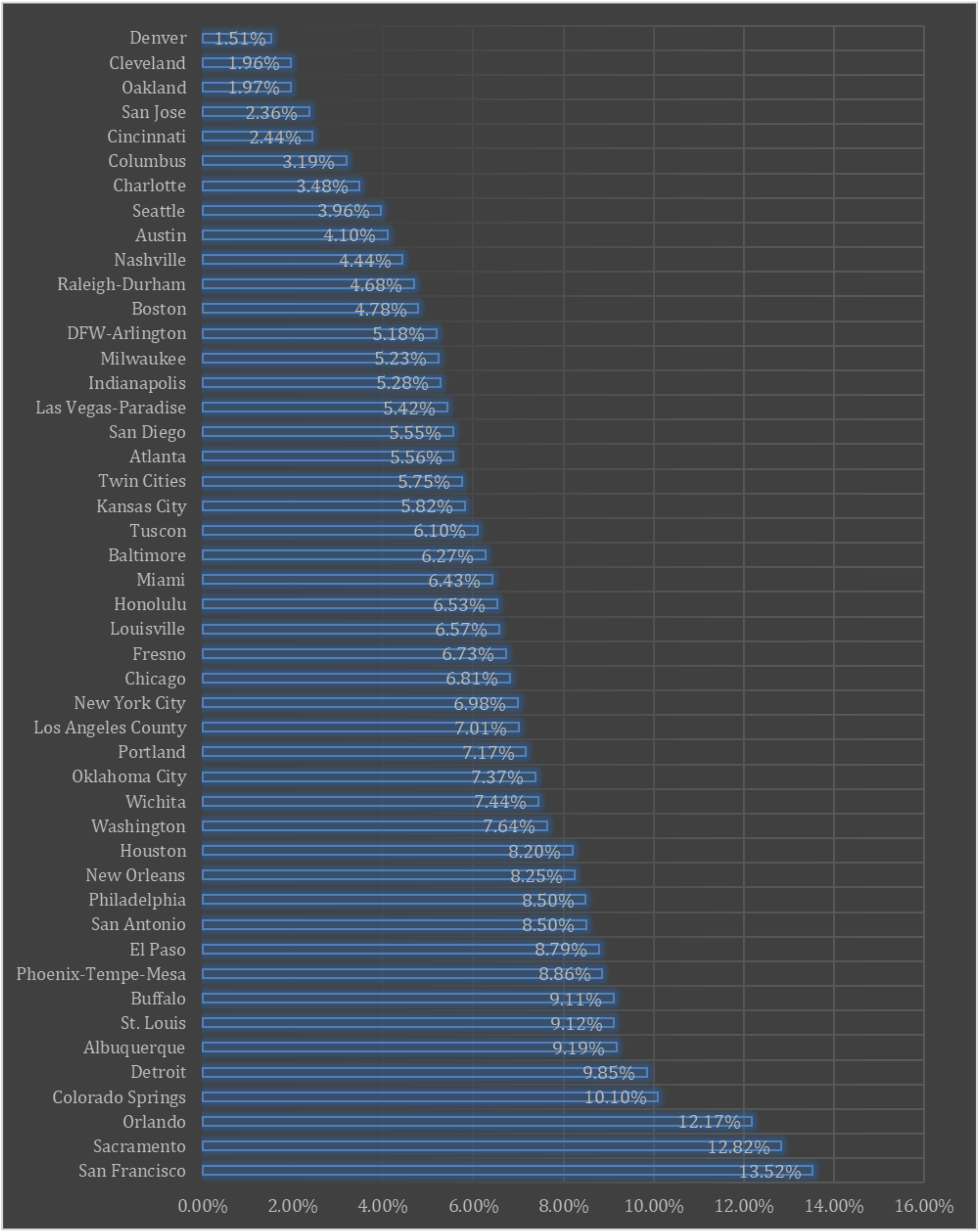


Figure 1A Percentage of Population Living in Transit Deserts in these 52 Major Cities

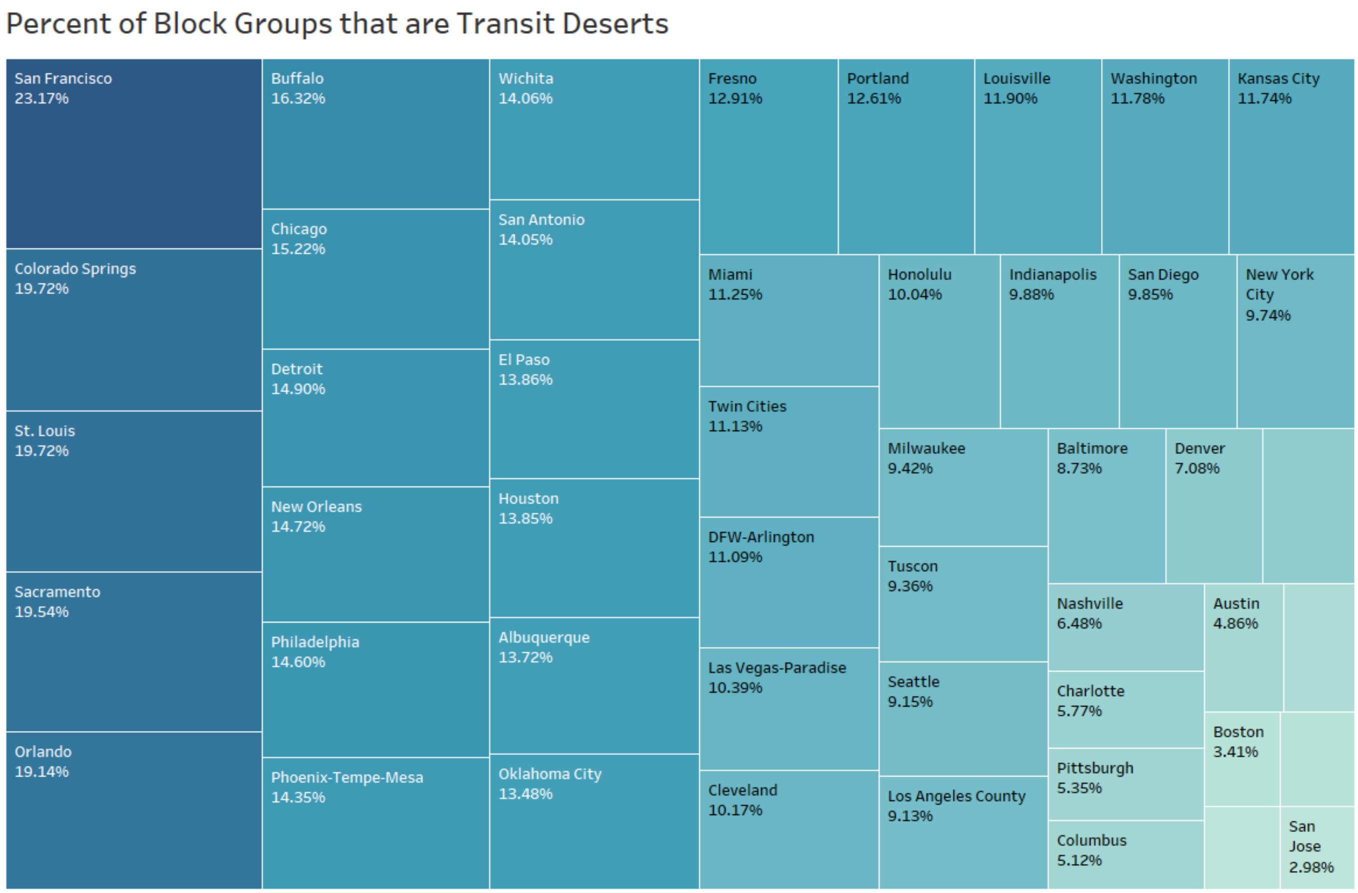


Figure 2A Percentage of Blocks Groups Identified as Transit Deserts in these 52 Major Cities

References

Adams, M. A., Frank, L. D., Schipperijn, J., Smith, G., Chapman, J., Christiansen, L. B., … Sallis, J. F. (2014). International variation in neighborhood walkability, transit, and recreation environments using geographic information systems: the IPEN adult study. *International Journal of Health Geographics*, *13*(1), 43. https://doi.org/10.1186/1476-072X-13-43

Alam, B., Nixon, H., & Zhang, Q. (2015). *Investigating the Determing Factors for Transit Travel Demand by Bus Mode in US Metropolitan Statistical Areas* (No. CA-MTI-14-1101; p. 69). San Jose, California: Mineta Transportation Institue.

America2050. (2016). Megaregions - America 2050. Retrieved April 7, 2019, from America 2050 website: http://www.america2050.org/megaregions.html

Bandara, J. M. S. J., & Wong, S. C. (2005). Special issue: Some recent advances in transportation modeling. *Journal of Advanced Transportation*, *39*(3), 241–245. https://doi.org/10.1002/atr.5670390302

Bejleri, I., Noh, S., Gu, Z., Steiner, R. L., & Winter, S. M. (2018). Analytical Method to Determine Transportation Service Gaps for Transportation Disadvantaged Populations. *Transportation Research Record: Journal of the Transportation Research Board*, 036119811879429. https://doi.org/10.1177/0361198118794290

Benenson, I., Martens, K., & Rofé, Y. (2010). Measuring the Gap between Car and Transit Accessibility: Estimating access using a High-Resolution Transit Network Geographic Information System. *Transportation Research Record*, *2144*(1), 28–35. https://doi.org/10.3141/2144-04

Benenson, I., Martens, K., Rofé, Y., & Kwartler, A. (2011). Public transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area. *The Annals of Regional Science*, *47*(3), 499–515. https://doi.org/10.1007/s00168-010-0392-6

Bertolini, L., Clercq, F. le, & Straatemeier, T. (2008). Urban transportation planning in transition. *Transport Policy*, *15*(2), 69–72. https://doi.org/10.1016/j.tranpol.2007.11.002

Blumenberg, E., & Manville, M. (2004). Beyond the Spatial Mismatch: Welfare Recipients and Transportation Policy. *Journal of Planning Literature*, *19*(2), 182–205. https://doi.org/10.1177/0885412204269103

Bohon, S. A., Stamps, K., & Atiles, J. H. (2008). Transportation and Migrant Adjustment in Georgia. *Population Research and Policy Review*, *27*(3), 273–291. Retrieved from JSTOR.

Center for Neighborhood Technology. (n.d.). A Brief Walkthrough of our Transit Gap Tool | AllTransit. Retrieved April 1, 2019, from https://alltransit.cnt.org/briefs/a-brief-walkthrough-of-our-transit-gap-tool.php

Chen, A., & Kasikitwiwat, P. (2011). Modeling capacity flexibility of transportation networks. *Transportation Research Part A: Policy and Practice*, *45*(2), 105–117.

Clark, B., Chatterjee, K., & Melia, S. (2016). Changes to commute mode: The role of life events, spatial context and environmental attitude. *Transportation Research Part A: Policy and Practice*, *89*, 89–105. https://doi.org/10.1016/j.tra.2016.05.005

Copeland, L. (2013, March 5). Americans' commutes aren't getting longer. Retrieved March 28, 2019, from USA TODAY website: https://www.usatoday.com/story/news/nation/2013/03/05/americans-commutes-not-getting-longer/1963409/

Cutler, S. J. (1975). Transportation and Changes in Life Satisfaction. *The Gerontologist*, *15*(2), 155–159. https://doi.org/10.1093/geront/15.2.155

Fayyaz, S. K., Liu, X. C., & Porter, R. J. (2017). Dynamic transit accessibility and transit gap causality analysis. *Journal of Transport Geography*, *59*, 27–39. https://doi.org/10.1016/j.jtrangeo.2017.01.006

Fink, J., Daigger, G. T., Brown, H., Ross, C. L., Woo, M., Bai, X., … Fink, J. (n.d.). *Infrastructure*.

Flyvbjerg, B., Holm, M. K. S., & Buhl, S. L. (2005). How (In)accurate Are Demand Forecasts in Public Works Projects?: The Case of Transportation. *Journal of the American Planning Association*, *71*(2), 131–146. https://doi.org/10.1080/01944360508976688

Franklin, K., & Chavis, C. (2019). *19-01808 Transit Deserts: Baltimore City, Maryland*. 15.

Hagler, Y. (n.d.). *Defining U.S. Megaregions*. 8.

Harrison, R. (n.d.). *Megaregion Freight Planning: A Synopsis*. 137.

Hartgen, D. T. (2013). Hubris or humility? Accuracy issues for the next 50 years of travel demand modeling. *Transportation*, *40*(6), 1133–1157. https://doi.org/10.1007/s11116-013-9497-y

Hendrickson, D., Smith, C., & Eikenberry, N. (2006). Fruit and vegetable access in four low-income food deserts communities in Minnesota. *Agriculture and Human Values*, *23*(3), 371–383. https://doi.org/10.1007/s10460-006-9002-8

Jiao, J. (2017). Identifying transit deserts in major Texas cities where the supplies missed the demands. *Journal of Transport and Land Use*, *10*(1). https://doi.org/10.5198/jtlu.2017.899

Jiao, J., & Dillivan, M. (2013). Transit Deserts: The Gap between Demand and Supply. *Journal of Public Transportation*, *16*(3), 23–39. https://doi.org/10.5038/2375-0901.16.3.2

Jiao, J., Moudon, A. V., Ulmer, J., Hurvitz, P. M., & Drewnowski, A. (2012). How to Identify Food Deserts: Measuring Physical and Economic Access to Supermarkets in King County, Washington. *American Journal of Public Health*, *102*(10), e32–e39. https://doi.org/10.2105/AJPH.2012.300675

Jones, S. R. (1981). ACCESSIBILITY MEASURES: A LITERATURE REVIEW. *Publication of: Transport and Road Research Laboratory*. Retrieved from https://trid.trb.org/view/168069

Karlaftis, M. G., & Vlahogianni, E. I. (2011). Statistical methods versus neural networks in transportation research: Differences, similarities and some insights. *Transportation Research Part C: Emerging Technologies*, *19*(3), 387–399. https://doi.org/10.1016/j.trc.2010.10.004

Kim, D., Hall, D. P., & Drive, D. (2019). *19-03552 IDENTIFYING TRANSIT DESERTS USING GEOSPATIAL ANALYSIS*. 17.

Kline, S. (2018). *The Benefits of Reliable Federal Funding for Public Transportation* (p. 36). Washington, D.C.: American Public Transportation Assocation.

Lescaroux, F. (2010). Car Ownership in Relation to Income Distribution and Consumers' Spending Decisions. *Journal of Transport Economics and Policy*, *44*(2), 207–230.

Lister, K., & Harnish, T. (2011). *The State of Telework in the US*. Retrieved from Telework Research Network website: https://www.shrm.org/ResourcesAndTools/hr-topics/technology/Documents/Telework-Trends-US.pdf

Litman, T. (2013). The New Transportation Planning Paradigm - ProQuest. *ITE Journal*, *83*(6), 20-24,26,28.

Lorbon, R. (2013). The Future of the Northeast Corridor. Retrieved April 7, 2019, from The Eno Center for Transportation website: https://www.enotrans.org/article/future-northeast-corridor-2/

Lubitow, A., Carathers, J., Kelly, M., & Abelson, M. (2017). Transmobilities: Mobility, Harassment, and Violence Experienced by Transgender and Gender Nonconforming Public Transit Riders. *Gender, Place & Culture*. Retrieved from https://pdxscholar.library.pdx.edu/soc_fac/65

Lucas, K. (2006). Providing transport for social inclusion within a framework for environmental justice in the UK. *Transportation Research Part A: Policy and Practice*, *40*(10), 801–809. https://doi.org/10.1016/j.tra.2005.12.005

Mallett, W. J. (2018). *Trends in Public Transportation Ridership: Implications for Federal Policy* (No. 7–5700; p. 19). Washington, D.C.: Congressional Research Service.

Mamun, S. A., & Lownes, N. E. (2011). Measuring Service Gaps: Accessibility-Based Transit Need Index. *Transportation Research Record*, *2217*(1), 153–161. https://doi.org/10.3141/2217-19

Marshment, R. (n.d.). *Transportation Planning Challenges and Opportunities*. 4.

McKenzie, B. (n.d.). *Who Drives to Work? Commuting by Automobile in the United States: 2013*. 28.

McLafferty, S. L., & Preston, V. (1992). Spatial mismatch and labor market segmentation for African-American and Latina women. *Economic Geography*, *68*(4), 406–431. https://doi.org/10.2307/144026

Meyer, M. D. (2000). Transport planning for urban areas: A retrospective look and future prospects. *Journal of Advanced Transportation*, *34*(1), 143–171. https://doi.org/10.1002/atr.5670340108

Nguyen, L., Riley, D., Zhang, J., Zhou, S., Beningo, S., Chambers, M., … Liu, M. (n.d.). *National Transportation Statistics 2017*. Retrieved from US Department of Transportation website: http://www.princeton.edu/~alaink/Orf467F17/NTS_Entire_2017Q2.pdf

ODPHP. (2017). *2017 United States Report Card on Walking and Walkable Communities*. Retrieved from Office of Disease Prevention and Health Promotion website: http://physicalactivityplan.org/projects/walking/Walking-report-card-FINAL.pdf

Páez, A., Scott, D. M., & Morency, C. (2012). Measuring accessibility: positive and normative implementations of various accessibility indicators. *Journal of Transport Geography*, *25*, 141–153. https://doi.org/10.1016/j.jtrangeo.2012.03.016

Ranković Plazinić, B., & Jović, J. (2014). Women and transportation demands in rural Serbia. *Journal of Rural Studies*, *36*, 207–218. https://doi.org/10.1016/j.jrurstud.2014.08.002

Retting, M. (2015, June 26). What If You Could Get from Philly to D.C. on Public Transit? Retrieved April 7, 2019, from Philadelphia Magazine website: https://www.phillymag.com/news/2015/06/26/public-transit-washington-philadelphia/

Rose, D., & Richards, R. (2004). Food store access and household fruit and vegetable use among participants in the US Food Stamp Program. *Public Health Nutrition*, *7*(8), 1081–1088. https://doi.org/10.1079/PHN2004648

Ross, C. L., & Woo, M. (2011). Megaregions and Mobility. *The Bridge*, *41*(1), 68.

Saif, M. A., Zefreh, M. M., & Torok, A. (2018). Public Transport Accessibility: A Literature Review. *Periodica Polytechnica Transportation Engineering*, *47*(1), 36–43. https://doi.org/10.3311/PPtr.12072

Sanchez, T. W., Stolz, R., & Ma, J. S. (2004). Inequitable Effects of Transportation Policies on Minorities. *Transportation Research Record*, (1885). Retrieved from https://trid.trb.org/view/746540

Song, G., & Yang, J. (2016). Measuring the spatiotemporal variation and evolution of transport network of China's megaregions. *Journal of Geographical Sciences*, *26*(10), 1497–1516. https://doi.org/10.1007/s11442-016-1340-x

Sussman, J. M., Sgouridis, S. P., & Ward, J. L. (2005). New Approach to Transportation Planning for the 21st Century: Regional Strategic Transportation Planning as a Complex Large-Scale Integrated Open System. *Transportation Research Record*, *1931*(1), 89–98. https://doi.org/10.1177/0361198105193100112

Syed, S. T., Gerber, B. S., & Sharp, L. K. (2013). Traveling Towards Disease: Transportation Barriers to Health Care Access. *Journal of Community Health*, *38*(5), 976–993. https://doi.org/10.1007/s10900-013-9681-1

Taylor, B. D., & Morris, E. A. (2015). Public Transportation Objectives and Rider Demographics: Are Transit's Priorities Poor Public Policy? *Transportation*, *42*(2). Retrieved from https://trid.trb.org/view/1345812

The Leadership Conference Education Fund. (2011). *Getting to Work: Transportation Policy and Access to Job Opportunities*. Retrieved from The Leadership Conference Education Fund website: http://civilrightsdocs.info/pdf/docs/transportation/getting-to-work-july20.pdf

Todd, A. S. (2006). *Calculating/Analyzing Transit Dependent Populations Using 2000 Census Data and GIS* (p. 10). Washington D.C: Federal Highway Works Administration.

Tucker, B., & Manaugh, K. (2018). Bicycle equity in Brazil: Access to safe cycling routes across neighborhoods in Rio de Janeiro and Curitiba. *International Journal of Sustainable Transportation*, *12*(1), 29–38. https://doi.org/10.1080/15568318.2017.1324585

US Census Bureau. (2018, March 20). Group Quarters/Residence Rules. Retrieved March 28, 2019, from https://www.census.gov/topics/income-poverty/poverty/guidance/group-quarters.html

Verma, A., & Ramanayya, T. V. (2014). *Public Transport Planning and Management in Developing Countries*. CRC Press.

Welch, T. F., & Mishra, S. (2013). A measure of equity for public transit connectivity. *Journal of Transport Geography*, *33*, 29–41. https://doi.org/10.1016/j.jtrangeo.2013.09.007

Xiao, F., Yang, H., & Ye, H. (2016). Physics of day-to-day network flow dynamics. *Transportation Research Part B: Methodological*, *86*(C), 86–103.

Yang, H., Bell, M. G. H., & Meng, Q. (2000). Modeling the capacity and level of service of urban transportation networks. *Transportation Research Part B: Methodological*, *34*(4), 255–275.

Zhang, M., Steiner, F., & Butler, K. (2007, April 4). *Connecting the Texas Triangle: Economic Integration and Transportation Coordination*. Presented at the The Healdsburg Research Seminar on Megaregions, Healdsburg, California. Retrieved from https://www.researchgate.net/profile/Ming_Zhang34/publication/228463644_Connecting_the_Texas_Triangle_Economic_Integration_and_Transportation_Coordination/links/56535f6408ae4988a7af89bc.pdf

Zhong, T., & Young, R. (2010). Multiple Choice Knapsack Problem: Example of planning choice in transportation. *Evaluation and Program Planning*, *33*(2), 128–137. https://doi.org/10.1016/j.evalprogplan.2009.06.007

Zhong, T., Young, R. K., Lowry, M., & Rutherford, G. S. (2008). A model for public involvement in transportation improvement programming using participatory Geographic Information Systems. *Computers, Environment and Urban Systems*, *32*(2), 123–133. https://doi.org/10.1016/j.compenvurbsys.2007.08.010