INVESTIGATING BUS ROUTE WALKABILITY: COMPARATIVE CASE STUDY IN ORANGE COUNTY, CALIFORNIA

by

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Abstract

To improve bus route planning and understand walkability's role in bus network design, this study offers a method of evaluating the walkability of bus stops and provides a case study for stops along two bus routes in Orange County, California. Having better walkability for bus routes may both promote physical activity and encourage bus ridership. Previous studies on bus route planning focus mostly on the passengers' travels on the bus and minimal attention is given to the bus riders' experiences before reaching the bus, after departing the bus, and during transfers between bus lines. This study shows the relevance of considering the origin, destination, and walking paths for pedestrians when approaching bus network design problems. The walkability of the southbound bus stops along Route 47 and Route 89, operated by the Orange County Transportation Authority (OCTA), were evaluated by calculating and combining the scores of four variables within each bus stop buffer. The four variables evaluated were: population density, street connectivity, steepness, and tree canopy. Results show that Route 47 has higher overall walkability than Route 89, which is in accordance with the hypothesis that a route that runs through grid neighborhoods (Route 47) would be more walkable than a route that runs through cul-de-sac neighborhoods (Route 89). Sensitivity analyses demonstrated that walkability scores may change when a stop is repositioned to a hypothetical location further away from an arterial street and within a neighborhood.

Although walkability will never be the sole factor in designing bus routes, future modeling could weigh the importance of walkability as part of origin and destination modeling and use the scoring of walkability to guide adoption of the “flexible-route” bus lines. Future research should consider other methods of determining tree canopy scores and explore other methods of identifying pedestrian “catchment” area of the bus stops.

Chapter 1: Introduction

Generally, bus network design problems involve optimization to improve system performance requirements under given resource constraints (Fan and Machemehl 2006). Working within various constraints and specific optimization goals, most studies approach the bus network design problem only by considering the bus riders' travels on the bus. Such studies disregard the bus riders' travels before and after the bus ride, which are affected by factors such as length of waiting time, time spent walking, and bus route walkability. This study investigates one such factor, bus route walkability, and discusses its influence on the bus network design problems.

Walkability was first given attention in the post-modernist planning era starting in the 1970s, due to its emphasis on human-scale, urban, and unique forms (Hirt 2005). Post-modernist planners considered walkability as a crucial component of efficient, accessible, equitable, sustainable, and livable communities (Lo 2009). Although many studies tried to define "walkability", they struggled to directly explain, define, and measure the concept (Abley 2005). In addition, different technical disciplines, such as engineering, planning, and health, define walkability differently to be in alignment with their use and context (Abley 2005).

Even though there have been gaps and disagreements in defining walkability by the different professional disciplines, this study describes walkability as a measure of how easy it is to walk in a built environment (Abley 2005). A highly walkable environment provides residents with accessibility to the transport network in addition to encouraging community involvement and promoting healthy lifestyles.

As an initial exploration of the role of walkability in bus route planning, this project is a case study that examines two bus routes in Orange County, California, with a focus on residential neighborhoods as opposed to commercial and industrial areas. The study develops a method to evaluate the walkability of bus routes using Geographic Information System (GIS). As a case study on bus route walkability, two bus routes are chosen for comparison: 1) a bus route that runs through grid neighborhoods, and 2) a bus route that runs through cul-de-sac neighborhoods. The walkability of the bus routes is determined using four variables: population density, street connectivity, steepness, and tree canopy. In addition, several case studies on optimizing walkability by relocating bus stops are performed.

Bus routes are currently designed to optimize cost and time of travel based on ridership levels and traffic studies, among other factors (Chein, Dimitrijevic and Spasovic 2003). Redesigning the bus routes solely to optimize walkability to stops for the bus riders would not likely become the ideal solution in terms of the overall efficiency of the bus system; however, it is still a factor worthy of consideration (Ceder and Wilson 1986). Since bus routes are designed specifically for the local and immediate population, walkability of stops within or between bus routes varies depending upon a number of considerations; some examples might include local mode of transportation preferences, social and cultural norms, and specific geographic features, all of which make traveling by buses easier in some areas than others. But what is less clear is whether such variation is significant enough within existing routing parameters to make it effective and efficient to consider walkability when locating stops.

The objective of this study is to investigate how GIS and concepts of walkability contribute to bus network design using existing geospatial datasets in bus route planning. In addition, by performing a case study evaluating the walkability of two bus routes in Orange County, the project examines whether different levels of walkability can be seen at bus stopS for routes in areas that have undergone different historical patterns of urban development. Furthermore, this study also tries to understand whether walkability improvements can be measured and reported when stops are moved short distances from existing routes.

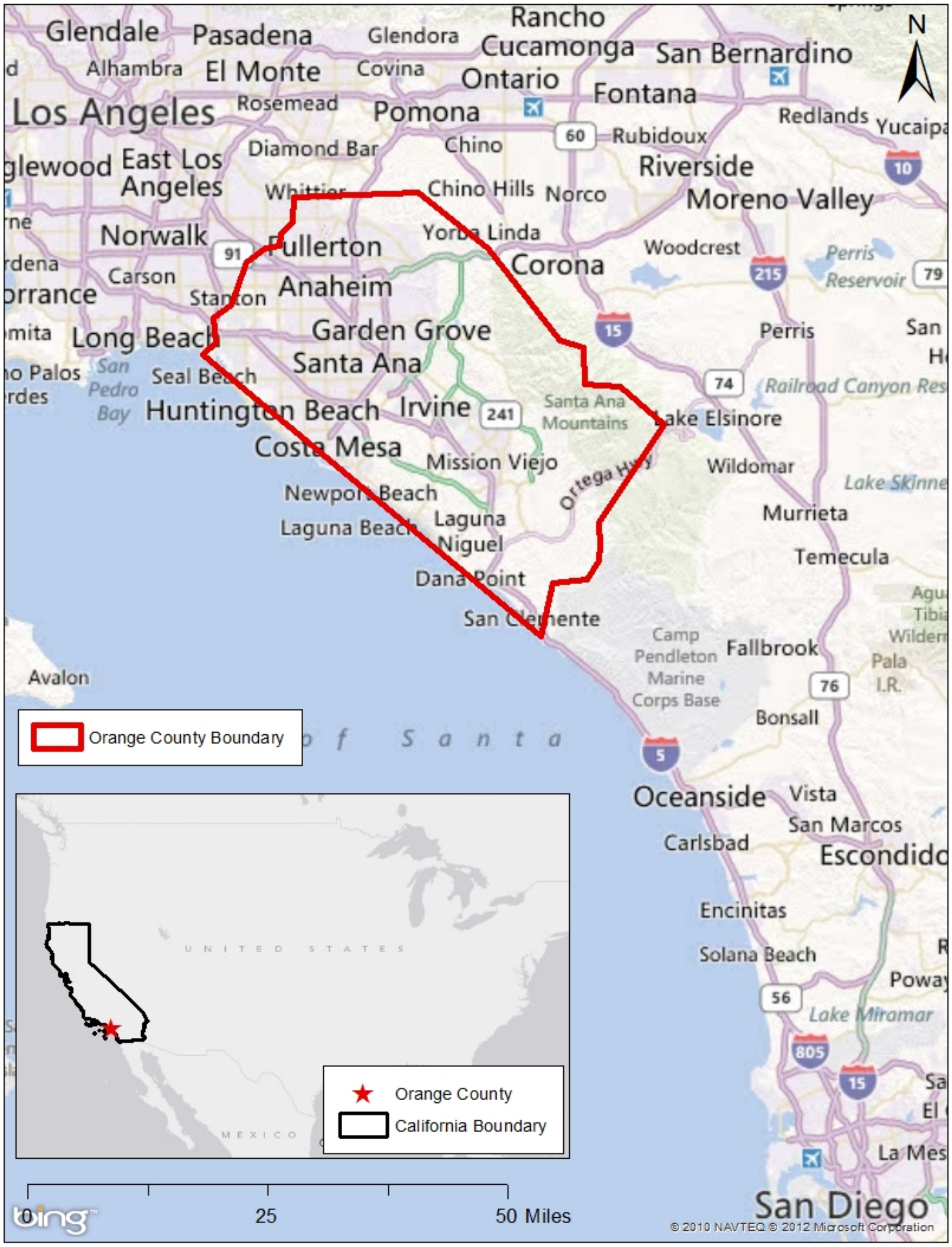
1.1 Motivation

California has long been known for its dense population growth and strained transportation infrastructure. Since its statehood in 1850, California has grown to approximately 37 million residents (United States Census Bureau 2012). The development of the California interstate highway system since the 1910s and the California State Routes since the 1930s has made Southern California, which was previously mostly rural, accessible to anyone owning an automobile and thereby invigorated the region's sprawling growth (Wolch, Pastor and Dreier 2004). In addition, from the 1950s until the 1990s, federal transportation funding explicitly favored the continuous expansion of federal and state highway system (Lee and Rivasplata 2001). The population growth and transportation development decisions in California resulted in an urban sprawl that encourages dependency on the private vehicle for transportation (Newman 1996).

As a case study focusing on bus route walkability in Orange County (Figure 1), it is pertinent to investigate and understand the growth and development of Orange County as a sprawling suburban community. There is no defined urban center in Orange County, which vastly differs from most population centers that identify and surround a major city, such as Greater Los Angeles or the San Francisco Bay Area (Halper and McKibben 2002). In the late 1800s and early 1900s, as an extension from the Greater Los Angeles urban center, Orange County was mostly comprised of agricultural land, both livestock and produce (Orange County Historical Society 2012). Aside from some traditionally urban areas at the center of the older cities, including Anaheim, Santa Ana, and Fullerton, Orange County remained mostly undeveloped in the early 1900s (Orange County Historical Society 2012).

With the introduction of citrus fruits and its subsequent economic boom, which continued until the 1950s and 60s, the region underwent substantial growth and older cities sought to keep up with the population increase by expanding these traditional urban areas (Orange County Historical Society 2012). These older city centers are based upon the gridiron plan that originated from traditional urban planning, in which city streets are laid out in an inter-connected grid running at 90-degree angles (Cozens and Hillier 2008). In addition, with the federal transportation funding that directly resulted in the expansive network of highway systems throughout Southern California starting in the 1910s, travel by way of automobiles became easier than before (Lee and Rivasplata 2001). With the increased use and popularity of cars, traffic engineers and urban planners sought to respond to consumer trends and abandoned the grid neighborhoods in favor of cul-de-sac neighborhoods when designing residential areas (Cozens and Hillier 2008). Cul-de-sacs are essentially the end of the road, resulting in a dead-end street with only one inlet or outlet; they are meant to reduce the amount of car traffic and crime rates (Cozens and Hillier 2008). In regards to the suburban development of Orange County, northern cities were established earlier with grid neighborhoods while southern cities in the county favor cul-de-sac neighborhoods.

Figure 1: Boundary of Orange County located in Southern California



Sources: Esri Bing Maps Road (2012), Esri World Light Gray Base Layer (2012), Esri USA Counties Layer (2012), Esri USA States Layer (2012)

In a discussion of the modern suburban community of Orange County, there lies a high reliance on automobiles which ties into severe traffic congestions, high rates of motor vehicle crashes, and urban air pollution of the overall region (Frumkin 2002). In addition, personal transportation by means of the automobile indicates a lack of physical activity as a means of transit, such as walking or bicycling (Frumkin 2002). This overall lack of physical activity among people increases the chances of obesity, diabetes, cardiovascular disease, and stroke, all of which lead to early mortality (Frumkin 2002). Therefore, in order to improve quality of life and to accommodate California's future population growth, authorities have been searching for different approaches to sustainable urban planning, design, and construction that would reduce air pollution, minimize automobile-related injuries and deaths, encourage physical activity, and promote mental health and a sense of community (The Strategic Growth Council 2012).

The importance of walkability of the built environment to physical health has been a leading topic or research and advocacy (Handy et al. 2002). In an effort to promote a healthy lifestyle, the Robert Wood Johnson Foundation created a national program called Active Living Research that aims, "to support and share research on environment and policy strategies that can promote daily physical activity for children and families in the United States" (Active Living Research 2012).

Active Living Research emphasizes increasing physical activity to prevent obesity and promote health in people (Active Living Research 2012). One of the ways for people to get regular physical activity from walking and bicycling is by investing in sidewalks, traffic-calming devices, greenways, trails, and public transit, which make it easier for people to walk and bike to places they need to go (Active Living Research 2012).

In conjunction with promoting a healthy lifestyle, smart growth is a set of planning practices and development principles that focuses on accessibility and aims for more efficient land use and transport patterns (Litman 2012). Smart growth consists of ten principles and two of these principles as articulated by the U.S. Environmental Protection Agency (EPA) are to create walkable neighborhoods and provide a variety of transportation choices (EPA 2012). Furthermore, Dan Burden, the Executive Director of the Walkable and Livable Communities Institute, comments on walkability as follows:

> Walkability is the cornerstone and key to an urban area's efficient ground transportation. Every trip begins and ends with walking. Walking remains the cheapest form of transport for all people, and the construction of a walkable community provides the most affordable transportation system any community can plan, design construct and maintain. Walkable communities put urban environments back on a scale for sustainability of resources (both natural and economic) and lead to more social interaction, physical fitness and diminished crime and other social problems. Walkable communities are more livable communities and lead to whole, happy, healthy lives for the people who live in them. (Mantri 2008)

In other words, by providing easily accessible transportation means, such as buses and trolleys, and promoting walking, people's reliance on automobiles could be decreased, improving people's health and the overall quality of life.

Seeing that walkability links the relationship between the average person, their choice of transportation, and the surrounding built environment, it is important to employ modern mapping techniques to visualize and conceptualize how bus route planning can be improved. This particular case study utilizes the mapping technologies of GIS with existing geospatial datasets. GIS became more popular in later 1980s and 1990s due to the growth of GIS use on personal computers and the Internet as people recognize GIS's ability to visualize spatial information in accurate and flexible ways (Johnson 1993). It is an integrated collection of computer software and data used to view and manage geographic information, analyze spatial relationships, and model spatial processes (Esri 2012). GIS emerged as an excellent field to address views on urban planning; however, being such a new technology, it is currently underutilized. This study therefore serves as an example of using GIS to investigate the importance of walkability in bus route planning.

In conclusion, most research literature on walkability has focused on investigating the general walkability of a study area. There are few studies that examine walkability of the walking paths of actual trips taken by pedestrians, which is the focus of this research. In addition, by evaluating the walkability to bus stops along the routes in Orange County, it can be determined whether the bus route locations, as planned by Orange County Transportation Authority (OCTA), are in favor of facilitating walking for bus riders. The result of the research can be a new source of valuable information for OCTA to re-examine their bus routes designs.

Walkability may in fact be added as one new factor among many used in route models that plan bus routes and placement of stops. Also, information on walkability can be used to consider abandoning fixed route stops in certain areas in favor of “flexible-route transit system.” This is a new bus transit concept introduced by Ouyang and Nourbakhsh (2012) that is particularly suitable for low-demand or less walkable areas.

Chapter 2: Background

To recognize how walkability fits into the big picture of bus route planning, it is important to understand the history of the development of Orange County in addition to the background research on bus route planning and walkability that has been done prior to this particular study. Section 2.1 analyzes and discusses how the development of Orange County since the 1900s until now has impacted urban planning in the region. Section 2.2 summarizes previous works in solving the bus network design problems. Lastly, Section 2.3 presents the different approaches and variables researchers use to evaluate walkability.

2.1 Orange County Development

Since its political division from Los Angeles County as a separate entity in 1889, Orange County’s population settlement remained a relatively organic process (Orange County Historical Society 2012). Northern regions of what is now Orange County tend to be older city centers that feature buildings constructed in the early 1900s, such as the Old Orange County Courthouse, built in 1901, and the Santa Ana Old City Hall constructed in 1935, both located in Downtown Santa Ana (Orange County Historical Society 2012).

With the opening of the Sana Ana Freeway in 1953, now the Interstate 5, an increased ease of travel by automobile from Los Angeles to the region invited significant residential development in Orange County (Orange County Historical Society 2012). Looking at urban planning, older city centers in Northern Orange County expanded and developed the pre-existing grid street pattern from hich these old city centers accommodated the quickly growing population (Cozens and Hillier 2008).

On the other hand, the land that occupies the South Orange County region was comprised of ranch lands that remained mostly agricultural until the introduction of master planned communities in the 1960s (Orange County Historical Society 2012). One such successful example is the development of the City of Irvine by the Irvine Company, which was designed by architect and urban planner, William Pereira (Irvine Company 2012). Having a master plan, communities are carefully designed and thoughtfully managed to minimize land use conflicts as well as optimize a variety of housing types, job centers, shopping centers, recreation centers, and open space to promote quality of life and economic growth (Irvine Company 2012). Specifically addressing residential developments, master planned communities integrate cul-de-sacs into their street designs because these types of streets appeal to consumers as ideal housing locations since they reduce vehicle traffic as well as lower noise, localized air pollution and the probability of accidents (Cozens and Hillier 2008).

In a general sense, modern Orange County urban planning maps exhibit grid street patterns in older cities to the Northern side, while the newer cities in South Orange County feature winding and twisting roads that incorporate cul-de-sacs into residential neighborhoods. The historical and socio-economical influences of each region's development partially contribute to the income gap observed between Northern and Southern Orange County. Furthermore, bus route planning is highly dependent on the specific geographic features and street network designs found in the region of interest for the proposed bus route, which is why it is pertinent to discuss the development of Orange County and how the Northern and Southern side differ. As a case study of bus routes in Orange County, this project examines two specific bus routes in which one is identified with the grid street pattern in the North side while the other bus routes run through cul-de-sac neighborhoods in the South side.

2.2 Previous Approaches to Bus Network Design Problems

Early work on bus network design problems can be generalized into two main groups: 1) optimization model approaches predicated on idealization of the network, and 2) heuristic approaches dealing with actual routes for more practical problems (Ceder and Wilson 1986). For the first group, bus network designs were formulated as analytical optimization models that are applied to determine route design parameters on simplified or regular shaped networks; parameters may include stop spacing, route spacing, route length, bus size, and/or frequency of service (Fan and Machemehl 2006). Examples of this type of bus route optimization model can be seen in the works of Newell (1979) and

Chang and Schonfeld (1991, 1993). These studies were based on the assumption of fixed demand, limited design parameters, and the objective of minimizing the sum of passenger and operator costs (Ceder and Wilson 1986). It has been shown that the analytical methods are effective in solving optimization-related problems for small networks with one or two decision variables but do not work well for bus network design problems with realistic sizes that have many parameters to be determined (Fan and Machemehl 2006). As a result, the optimization model approaches are more useful for screening or policy analyses where approximate designs are adequate and are not recommended for tasks that require route designs in real situations (Ceder and Wilson 1986).

For bus network design problems with larger network size and higher complexity, the heuristic approach is preferred (Tom and Mohan 2003). This approach adopts the rules by which the route network is built in a step-by-step procedure; therefore, it differs from case to case (Tom and Mohan 2003). Furthermore, it primarily deals with simultaneous design of the bus network and determination of its bus frequencies (Tom and Mohan 2003). Examples of heuristic methods are found in Lampkin and Saalmans (1967), Rea (1971), and Ceder and Wilson (1986). However, heuristic methods are tailor-made for different applications and therefore lack adaptability to other contexts, unlike the optimization model mentioned earlier (Tom and Mohan 2003).

Other studies that discuss solving bus network design problems include hybrid models, experience-based models, simulation models, and genetic algorithms (Tom and Mohan 2003). Hybrid models combine heuristic methods with accompanying methods (e.g., analytical optimization methods and linear programming) (Tom and Mohan 2003). Experience-based models are developed by capturing the experienced planners' knowledge that has been acquired over a number of years in the form of rules that can be used in the design (Tom and Mohan 2003). Simulation models are capable of incorporating numerous variables that affect bus transit operation thereby demonstrating different aspects of the bus systems (Tom and Mohan 2003).

All of the above methods are either only suitable for theoretical situations or are case-specific (Tom and Mohan 2003). Therefore, genetic algorithm, which is a general multipurpose optimization model for designing the bus transit network, emerged as an alternative to many conventional approaches (Tom and Mohan 2003).

Studies have used the genetic algorithm to approach bus network design problems. Tom and Mohan (2003) used genetic algorithms to select a solution route set and the associated frequencies to achieve the desired objective, subject to the operational constraint, which is the total system costs expressed as a function of bus operating cost and the cost of passenger total travel time.

In another application, Fan and Machemehl (2006) used a genetic algorithm to systematically examine the underlying characteristics of the optimal bus transit route network design given variable transit demand. It is different from the work of Tom and Mohan (2003) because it employs hybrid transit trip demand assignment models in the genetic algorithm.

The study done by Fan and Machemehl (2006) is one of the few studies that take the bus riders' walking into consideration for optimizing the bus network design problem. The objective of this project was to use a genetic algorithm to examine and understand the underlying characteristics of the optimal bus network design problem through the development of a multiobjective nonlinear mixed integer model (Fan and Machemehl 2006). To achieve the objective, the solution consists of three components: a route set generation procedure that generates all feasible routes, a network analysis procedure used to decide transit demand matrix, and a genetic algorithm procedure that combines these two parts to guide the candidate solution generation process and select an optimal set of routes (Fan and Machemehl 2006). The model's objective function minimizes the sum of user cost (walking cost, waiting time, transfer cost, and in-vehicle cost), operator cost (cost to operate the required buses), and the unsatisfied demand cost for the bus network (Fan and Machemehl 2006).

These three costs are determined based on planners' experience and expert judgment (Fan and Machemehl 2006). A such, it is important to note that these cost estimates come from institutional knowledge that are held by a group of people at the transit agency, which are difficult to be passed on and be considered for other studies.

As described previously, although Fan and Machemehl (2006) include the pedestrians' walking cost in its model, the walking cost is dependent on institutional knowledge instead of being derived from empirical (spatial) variables (Fan and Machemehl 2006). Therefore, to go beyond incorporating institutional knowledge, which can be subjective and inaccurate, this study empirically investigates the walking aspects of bus riding by analyzing spatial data through the use of GIS, taking advantage of its ability to present the results systematically and objectively.

To summarize, walkability has not played a major or regular role in bus network design problems in previous academic works and studies. From the literature on bus network design problems, it can be observed that researchers have been mostly focused on the passengers' travels on the bus, and minimal attention is given to the bus riders' travels before, after, and in between bus rides. However, it is apparent that people's travel behavior is greatly influenced by the built environment (Agrawal, Schlossberg and Irvin 2008).

There are various elements to the built environment that affect a person's decision in choosing to walk, bike, or drive to a desired destination. Thus, by investigating the walkability of bus routes through the use of GIS, this study suggests a new variable that can be optimized for the bus network design problems and also provides a new method to evaluate redesigning bus routes.

2.3 Summary of Studies on Walkability

It is important to understand "walkability" and its many contributing factors when developing a method for evaluating the walkability of the bus routes. There have been numerous studies on the subject in the past, and eight different works are reviewed and summarized in Table 1 to form the basis for identifying the measures of walkability used in this study. These nine variables are population density, dwelling density, retail floor ratio, street connectivity, safety, land use mix, access to facilities, steepness, and tree canopy. Out of these nine variables, this particular study focuses on population density, street connectivity, steepness, and tree canopy. Although not all of variables are considered in this study, they are all pertinent to the understanding of walkability and how it can be measured.

The first variable in Table 1 is population density; it is defined as the measurement of population per unit area in which higher population density means there are more people per unit area. This variable is a common measure in studies of the built environment and transportation-based physical activity in which higher population density correlates with higher walkability (Brownson et al. 2009). This variable was considered in the studies of Smith et al. (2008) and Marshall, Brauer, and Frank (2009). The main goal of the study of Smith et al. (2008) was to relate neighborhood walkability to residents' obesity. The authors emphasized that greater population density has been associated with fewer weight problems and that it may encourage walking destination development and discourage exclusive reliance on cars (Smith et al. 2008). Additionally, the paper written by Marshall, Brauer, and Frank (2009) considers population density as one of the four parameters that they used to estimate walkability in the study area, implying that higher population density results in higher walkability.

The second variable in Table 1 is dwelling density; it is the number of residential units per unit area (Frank et al. 2010). Dwelling density is similar to population density in which higher densities indicate more people living in the area; therefore, greater dwelling density also translates to higher walkability (Frank et al. 2010). This variable was considered in the studies of Frank et al. (2010), Mantri (2008), and Marshall, Brauer, and Frank (2009). In Frank et al. (2010)'s report of the Metro Vancouver Walkability Index developed at the University of British Columbia, which measures neighborhood urban form characteristics in Metro Vancouver, one of the five variables chosen was dwelling density. Also, Mantri (2008) uses a GIS based approach to measure walkability of a

Central West End, a neighborhood in St. Louis, Missouri in which dwelling density was also selected as one of the many measures used in formulating the GIS model (Mantri 2008). Marshall, Brauer, and Frank (2009) also consider dwelling density, in addition to population density described previously, as one of the four parameters that they used in their study on walkability.

Table 1: Measures for Determining Walkability Considered by the Authors

	Population Density	Dwelling Density	Retail Floor Area Ratio	Street Connectivity	Safety	Land Use Mix	Access to Facilities	Steep-ness	Tree Canopy
(Lo 2009)				✔	✔		✔	✔	
(Jaskiewicz 2000)				✔	✔				✔
(Smith, et al. 2008)	✔			✔		✔			
(Reynolds, et al. 2007)					✔		✔	✔	
(Frank, et al. 2010)		✔	✔	✔		✔			
(Marshall, Brauer and Frank 2009)	✔	✔	✔						
(Mantri 2008)		✔		✔	✔	✔	✔		
(Krambeck 2006)				✔	✔				✔

The third variable in Table 1 is retail floor ratio, which is defined as the proportion of the area designated for commercial use in the area of interest and a higher ratio reflects better walkability (Frank et al. 2010). This variable indicates the proximity between commercial destinations thereby showing the degree to which people can more easily travel between places in the region (Frank et al. 2010). Retail floor ratio was also considered in the studies of Frank et al. (2010) and Marshall, Brauer, and Frank (2009). To determining how walkable the study area is, Frank et al. (2010) calculate the retail floor ratio of Metro Vancouver as one of the variables in understanding the physical environment characteristics. Marshall, Brauer, and Frank (2009) also included retail floor ratio as one of the four parameters that they used for evaluating the built environment.

The fourth variable in Table 1 is street connectivity. This variable measures walkability in a given area by showing the directness of pedestrian routes; higher street connectivity correlates with high walkability (Brownson et al. 2009). It is often determined by the number of intersections per area, the percentage of 4-way intersections, or the number of intersections per length of street network (Brownson et al. 2009). This variable was considered in the studies of Lo (2009), Jaskiewicz (2000), Krambeck (2006), Smith et al. (2008), Frank et al. (2010), and Mantri (2008). Lo (2009) examined several walkability indices from different sources, such as the Pedestrian Potential Index, the Pedestrian Deficiency Index, and Kansas City pedestrian level of service matrices, in which street connectivity was a key determining factor. Jaskiewicz (2000) outlined a process where qualitative factors can be used to analyze pedestrian systems; the author emphasized that a complex path network guarantees a high degree of connectivity between activity centers and residential units that encourages pedestrians to walk as compared to places with poor path network in which people are bound to the same route all the time (Jaskiewicz 2000). Krambeck (2006) created the Global Walkability Index that ranks cities across the world and street connectivity is one of the variables used in the index (Krambeck 2006). Street connectivity was also deemed important in the study by Smith et al. (2008). The authors determined that pedestrian-friendly street connectivity is associated with fewer weight problems because people are more willing to walk. Frank et al. (2010) suggested that greater degrees of street connectivity enables more direct travel between places, which is why this measure is used in determining the walkability in Metro Vancouver. Lastly, Mantri (2008) also incorporated street connectivity in the GIS model built to evaluate walkability in a neighborhood in St. Louis, Missouri.

The fifth variable in Table 1 is the safety measure used to evaluate the level of safety of the walking path, which can be determined with a variety of factors, such as: crossing safety, traffic speed, traffic volume, road width, street lighting, sidewalk conditions, freedom from crime, and the walking path's separation from traffic (Krambeck 2006). This measure was included in the studies of Reynolds et al. (2007), Lo (2009), Jaskiewicz (2000), Mantri (2008), and Krambeck (2006). Reynolds et al.'s (2007) study identified the environmental correlates of urban trail use by evaluating urban trails in Chicago, Dallas, and Los Angeles using an instrument called Systematic Pedestrian and Cyclist Environmental Scan (SPACES) in which safety is a crucial factor in evaluating the trail. Safety is also considered among the various walkability indices examined by Lo (2009). In the work of Jaskiewicz (2000), the author points out that the pedestrian experience entails much more than simply a “commuting” function and that safety is one of many important measures that distinguish a good pedestrian environment from a poor one. Mantri (2008) also included the safety variable in the GIS model that was developed to evaluate walkability. Lastly, safety is an essential component that Krambeck (2006) used to develop the Global Walkability Index.

The sixth variable in Table 1 is the land use mix variable, which is often used to estimate the ease of walkability between residences and neighboring businesses for a given area (Brownson et al. 2009). This variable determines the evenness of square footage distribution across the different types of land use; a higher land use mix indicates a more even distribution of land between the land use type and higher walkability (Frank et al. 2010). The land use mix measure was also considered in the studies of Smith et al. (2008), Frank et al. (2010), and Mantri (2008). Smith et al (2010) suggested that a broad mix of land use with walkable destinations increases walkability. Similarly, Frank et al. (2010) stated that having a higher land use mix is associated with an increased likelihood of getting sufficient physical activity. Mantri (2008) also incorporated the land use mix measure into the GIS model as effective land use encourages residents to walk.

The seventh variable in Table 1 is the access to facilities measure. Shorter distances indicate greater walkability; therefore, by measuring access to facilities for residential areas using distances to schools, parks, transits, and shops, the ease of walkability for the area can be determined (Brownson et al. 2009). This measure was also included in the studies of Lo (2009), Reynolds et al. (2007), and Mantri (2008). The access to facilities variable was one of the influencing factors of walkability that was emphasized by the walkability indices examined by Lo (2009). Reynolds et al. (2007) suggested that having greater access to facilities results in increasing trail use. Lastly, Mantri (2008) also included the access to facilities variable into the GIS model to evaluate walkability.

The eighth variable in Table 1 is steepness. This variable considers the slope that pedestrians walk on; steep paths would be less desirable to walk on, as it requires more control to support the body and muscles (Lay, Hass and Gregor 2006). Therefore, steeper paths are associated with low walkability. The steepness variable is also included in the studies of Lo (2009) and Reynolds et al. (2007).

The ninth variable in Table 1 is the tree canopy variable. Having more tree canopy along a walking path results in shade, which protect pedestrians from the climate (Jaskiewicz 2000). In addition, tree canopy creates shade over surfaces such as asphalt, roofs, and concrete and prevents heating and storage of heat by these materials, which reduces in the urban heat island phenomenon (NASA 1996). Due to these various reasons, more tree canopy is associated with a cooler environment more pleasant for walking.

Tree canopy is measured in the studies of Jaskiewicz (2000) and Krambeck (2006). Jaskiewicz (2000) recognizes how the presence of tree coverage enhances pedestrians' experience; therefore, included tree canopy as an important factor in evaluating walkability. Krambeck (2006) also included the number of trees as one of the indicators in the Global Walkability Index.

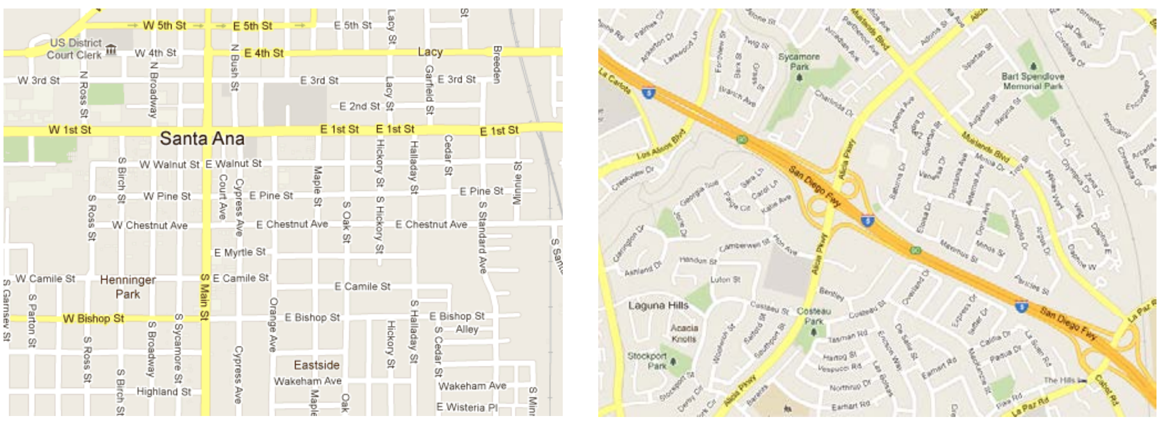
Out of these nine variables, population density, street connectivity, steepness, and tree canopy are chosen for this study. For the majority of the studies, walkability is evaluated for the entire study area in which all nine of these variables are applied. However, this project focuses on evaluating walkability for specific origination-destination nodes in a transit network; therefore, many of the variables are less applicable than others. For instance, retail floor ratio would make more sense when evaluated in larger study area and would be difficult to be meaningful in this particular study, in which only the walkability of short distances within a bus stop is examined. The same concept applies to the land use mix and access to facilities measure. Dwelling density is not incorporated into this study since it is very similar to population density and the results for the two variables may be too similar to be included in the same study. Furthermore, although safety is a crucial factor in walkability, it is a broad topic that is difficult to be evaluated for the scope of this project. Street connectivity, steepness, and tree canopy are variables that are directly related to the walking paths; therefore, they are chosen for evaluating the bus route walkability in this study.

Chapter 3: Methodology

This study is a case study of two bus routes in Orange County, California that aims to examine how GIS and ideas of walkability contribute to bus route planning using existing geospatial datasets. By evaluating two bus routes in Orange County, the project investigates whether different levels of walkability can be observed at bus stop for routes in areas that have undergone different historical patterns of urban development. In addition, sensitivity analyses are also performed to see whether moving stops short distances from existing routes would improve walkability.

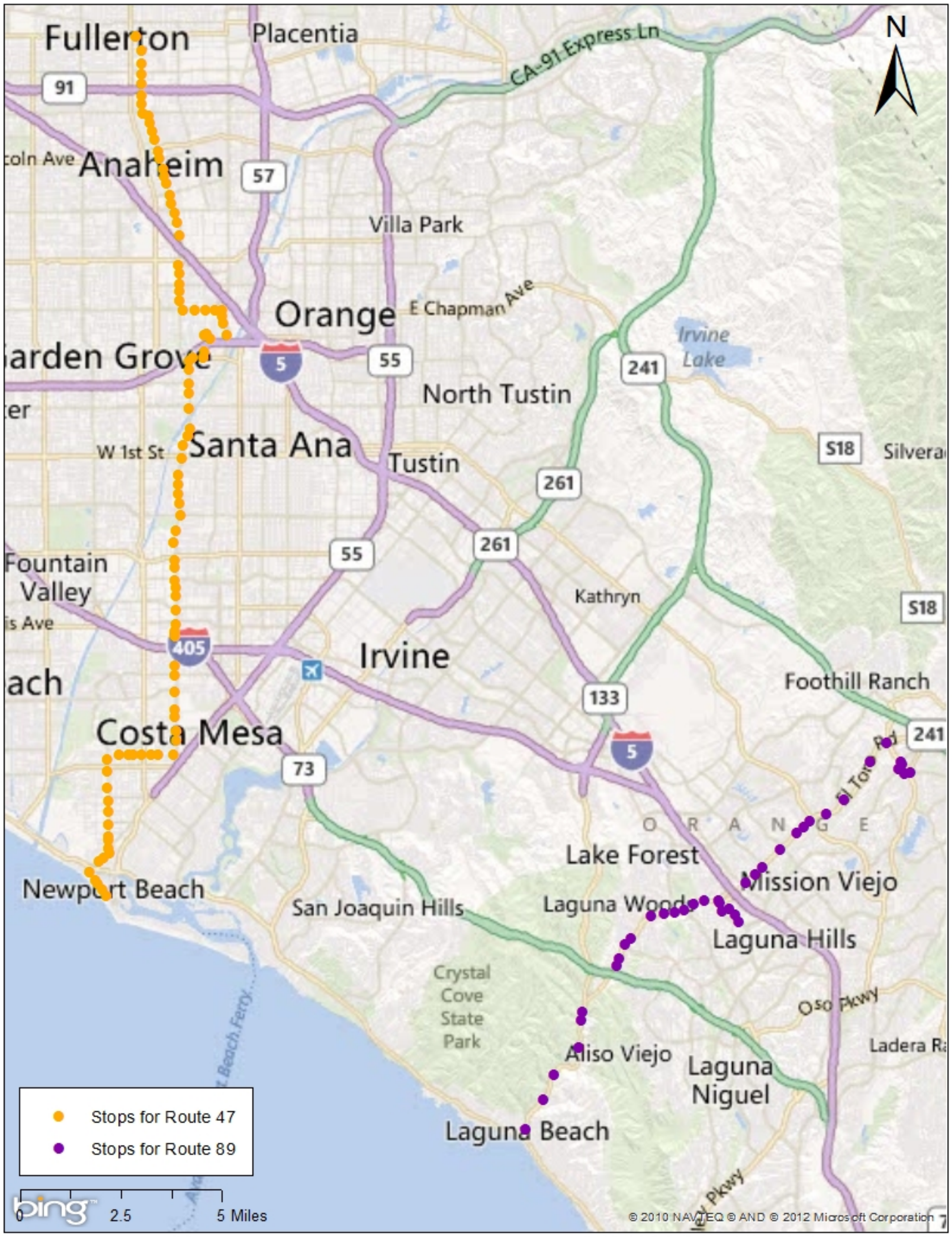
Two bus routes in Orange County are evaluated to develop and test a method for indexing walkability. This study selects Bus 47 that runs through grid neighborhoods and Bus 89 that runs through cul-de-sac neighborhoods to account for the two different types of developments that took place in Orange County. Figure 2 shows the difference of a grid and a cul-de-sac neighborhood and Figure 3 shows Route 47 and 89. The grid street pattern is a traditional urban form that can be observed in earlier developments (Cozens and Hillier 2008). It has highly connected linkages that incorporate commercial centers along arterials streets, residential subdivisions by way of secondary streets, and major transportation corridors and highways. This type of city planning encourages and promotes pedestrian activity due its frequent intersections with the choice and directness of route to desired destinations. In the latter part of the nineteenth century, city planners and developers turned to the cul-de-sac pattern design that has winding streets, irregular shapes, and dead-ends (Cozens and Hillier 2008). In a cul-de-sac neighborhood, the streets are not inter-connected, which results in fewer route choices and longer distances to travel, encouraging automobile dependency (Cozens and Hillier 2008). Since grid neighborhoods have better street connections compared to cul-de-sac neighborhoods, this study tests the effectiveness of the walkability scoring system by exploring the hypothesis that stops along Route 47 would have an overall higher walkability than Route 89. The bus stop locations in Orange County are maintained in an ArcGIS layer by OCTA personnel who provided the data for the purpose of this study.

Figure 2: Grid vs. Cul-De-Sac Neighborhood Examples from Orange County, California



Source: Google Maps (2012)

Figure 3: Southbound Bus Stop Locations of Route 47 and Route 89



Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

Table 2 presents the historic and demographic data of the cities Route 47 and 89 serves. It can be seen that the cities which Route 47 passes through are relatively older than those of Route 89, which is in alignment with the grid neighborhood type as characterized by a more traditional city planning and development. In addition, the cities that Route 47 runs through have a relatively lower average household income as compared to those of the cities for Route 89, which could be a result of the historical and socio-economical influences of the different developments in the Northern and Southern Orange County.

Table 2: Route 47 and Route 89 Comparison Table

	Route Length (miles)	**Number of Stops Southbound**	**City (Year Incorporated)**	**Mean Household Income** (U.S. Census Bureau 2012)
Route 47	~22	97	Fullerton (1904) Anaheim (1870) Garden Grove (1956) Orange (1888) Santa Ana (1886) Costa Mesa (1953) Newport Beach (1906)	$83,375 $70,436 $71,885 $90,125 $51,467 $80,480 $151,967 **Average: $85,676**
Route 89	~15	38	Lake Forest (1991) Mission Viejo (1988) Laguna Woods (1999) Laguna Hills (1991) Laguna Beach (1927)	$102,688 $109,510 $49,934 $123,968 $158,057 **Average: $108,831**

3.1 Three Types of Buffers

In this case study, a walkability score is given to each of the bus stops along the routes that are then used to understand the overall walkability of the two routes. Buffers, which identify pedestrians' potential origins and destinations, are created for each of the bus stops of the two routes; these buffers are where the variables are evaluated to determine the walkability score for the designated bus stop. There are three types of buffers with different logics of representing the pedestrians' origins with which the walkability scores are calculated and compared. The three types of buffers are: Half-Mile-Radii, Route-Adjacent, and Stop-and-Route-Adjacent. With the street network data acquired from Esri, the buffers are created using the Network Analyst tool in ArcGIS and setting the radius at the desired distance, which traces the distance outward from each of the bus stops along the streets and connects all the end points to form a polygon. The street network data used as the basis for creating the buffers is developed by Esri and acquired through ArcGIS Online.

According to the study by Agrawal, Scholossberg, and Irvin (2008), on average, people are willing to walk approximately half a mile to transit; and following this logic, the first buffer, the Half-Mile-Radii buffer, is created. Using ArcGIS's Network Analysis in which buffers of each of the bus stops are created by measuring half a mile along the accessible paths from the bus stops and connecting the ends of each of the paths.

To create the second buffer, a Route-Adjacent (RA) buffer, the distance is calculated from the subject bus stop to the closest transfer bus stop along a nearby route since there are other bus routes also running in the same direction within close proximity of Bus 47 and 89 several blocks away, as seen on the OCTA Bus System Map (OCTA 2012). If this distance is greater than half a mile, then the bus stop's buffer would be created with a half-mile radius as the maximum distance within this buffer. If this distance is less than half a mile, then the bus stop's buffer would be created with a radius of half of this distance since passengers would choose to walk to a closer route in favor of another bus route that was further away. The logic for not selecting more than half of this distance as the radius is to prevent the likelihood of including possible passengers who might be closer to the other bus stop.

When considering parameters for the third buffer, a Stop-and-Route-Adjacent (SARA) buffer, it can be assumed that bus riders are more likely to take the bus from the bus stop closest to their physical locations traveling in an appropriate route direction. Therefore, it is logical to say that bus riders who are less than halfway between the adjacent bus stops of the routes travelling in the same direction fall into the "catchment" area of the bus route. To create a Stop-and-Route-Adjacent (SARA) buffer, the distance is calculated between the bus stop of interest to the closest bus stop either on the same route or of an adjacent nearby route carrying passengers in the same direction.

If this distance is greater than half a mile, then the bus stop's buffer would be created with a half-mile radius as the maximum distance within this buffer. If this distance is less than half a mile, then the bus stop's buffer would be created with a radius of half of this distance. In this study, this distance is termed the "catchment" area for a given bus stop.

3.2 Variables, Data Sources and Calculations

Four variables from the nine main measures identified previously are chosen for this project: population density, street connectivity, steepness, and tree canopy. Unlike most of the other studies on walkability, this project evaluates walkability on an origination-destination approach (i.e. pedestrian path instead of bus routes); therefore, retail floor area ratio, land use mix, and access to facilities measures are not to be considered as they are more applicable for more general large study areas. Safety measures, which are also an important factor in determining walkability, are not measured as well due to the time constraint and the scale of this project. Table 3 includes the data sources for each of the four variables.

Table 3: Walkability Variables and Their Data Sources, Temporal Scales, and Spatial Scales

Variable	Data Source	Temporal Scale	Spatial Scale
Population Density	U.S. Census	2010	Block Group
Street Connectivity	U.S. Census	2010	Block
Steepness	USGS National Elevation Dataset	2012	30-meter resolution
Tree Canopy	USGS National Land Cover Dataset Tree Canopy Layer	2001	30-meter resolution

Higher population density is associated with more walking (Forsyth et al. 2007). Therefore, a buffer with a higher population density typically has a higher walkability score. The population density is measured as the number of people per square mile for each buffer. It is determined by creating an average for the overlapping block groups within each buffer in ArcGIS. The population density of each buffer is the total population divided by the total block group area and both the population data and the block group area layer are acquired from the U.S. Census 2010. The results are classified into 5 score levels using natural breaks (Jenks) classifications with 1 representing low population density and 5 representing high population density.

Street connectivity indicates the directness of pedestrian routes and the more direct the pedestrian routes the easier it is for people to walk (Brownson et al. 2009). Street connectivity is determined by dividing the number of blocks the buffer overlaps with by the buffer's area in square miles. The blocks layer used in the calculation is acquired from the U.S. Census 2010. Once the ratios of all the buffers along the bus route are calculated, they are classified into 5 scores using natural breaks (Jenks) classifications with 1 having the lowest ratios that correspond to low walkability and 5 having the highest ratios that correspond to high walkability.

Even though the influence of route steepness has not been investigated much in the walkability literature, aside from Reynolds' study on auditing trails, it is considered for this study since it is an important determining factor in evaluating the ease of walking to a given bus stop. The slope of each of the paths is determined from the digital elevation model at 10-meters resolution from USGS. Steep walking paths represent low walkability and vice versa. The equation for the degree of slope (ϴ) is:

$$\text{Eq. 1: } \Theta = \arctan\left(\frac{\text{rise}}{\text{run}}\right) \qquad (3.1)$$

In this formula, the range of the elevation in the buffer is the "rise" and the radius of the buffer is the "run." After the degree of slope is determined from the equation, they are classified into 5 scores using natural breaks (Jenks) classifications with 1 having the largest degrees of slope and 5 having the smallest degrees of slope.

Tree canopy provides pedestrians with protection from sunlight as well as blocks heat absorbing materials along the paths from the sun to reduce urban heat island effect (Jaskiewicz 2000; NASA 1996). The presence of tree coverage along a walking path is especially important in Southern California, which has a high percentage of sun exposure on any given day. The USGS National Land Cover Dataset (2001) Tree Canopy Layer at 30-meter resolution is used for determining tree canopy for the buffers. The tree canopy coverage in the raster layer was determined by extrapolating calibrated density prediction models derived with linear regression and regression tree techniques (Huang et al. 2001). The layer consists of three attributes: “Rowid”, “Value”, and “Count”. “Rowid” is the internal feature number, “Value” is the percent tree coverage, and “Count” is the total number of cells in a grid for each unique value (USGS 2010). Using ArcGIS, the layer is clipped against all the buffers in order to measure the coverage in each buffer. Then, for each buffer, all the values for “Value” are converted to their corresponding adjusted values according to Table 4. Afterwards, the adjusted values are multiplied by the “Count” for each “Value” and summed together and divided by the total number of cells that are within the buffer to become the new tree coverage value of the buffer. When the tree canopy values of all the buffers are determined, they are classified into 5 scores using natural breaks (Jenks) classifications with 1 having the lowest tree coverage and 5 having the most tree coverage.

Table 4: Tree Coverage "Value" and their Adjusted Values for Calculating Tree Coverage Value for Buffers

"Value" (Percentages)	Adjusted Value
0-20	1
21-40	2
41-60	3
61-80	4
81-100	5

As mentioned in the definition and classification of the four variables above, natural breaks (Jenks) classification is used to classify the walkability scores for each of the four variables. This optimization partitions data into classes using an algorithm that determines groupings of data values based on data distribution (Esri 2012). It is a classification method that aims to reduce variance within groups and maximize variance between groups (Esri 2012). By using natural break (Jenks) classification, the scores for each variable would be classified with maximized variance between groups, allowing the difference in the scores to be more obvious and distinguished among the stops.

3.3 Combined Score

All four variables are weighted equally and the calculated scores of each of the four variables are summed together for a combined score of the individual buffers. These combined scores represent the walkability of each of the bus stops and can be used to understand the overall walkability of stops along Route 47 and Route 89. The theoretical maximum combined score would be 20, where the highest score of 5 is obtained for each variable; while the theoretical minimum combined score would be 4 by scoring the lowest score of 1 for each variable.

3.4 Sensitivity Analysis

Sensitivity analyses on optimizing walkability by relocating bus stops are performed to determine whether walkability improvements can be measured and reported when stops are moved short distances from existing routes. In addition, by performing sensitivity analyses, the project tries to determine whether current geospatial datasets offer a potentially significant contribution for redesigning bus routes to increase walkability. Sensitivity analyses are done on select bus stops in each route with the highest, lowest, and average combined scores. For each of the stops, a hypothetical alternative bus stop is created by picking an area out of arterial streets and plotting a point on a street roughly half a mile away from the original stop. Then, the combined score for each of the hypothetical alternative bus stop locations are compared with the ones for the original bus stops.

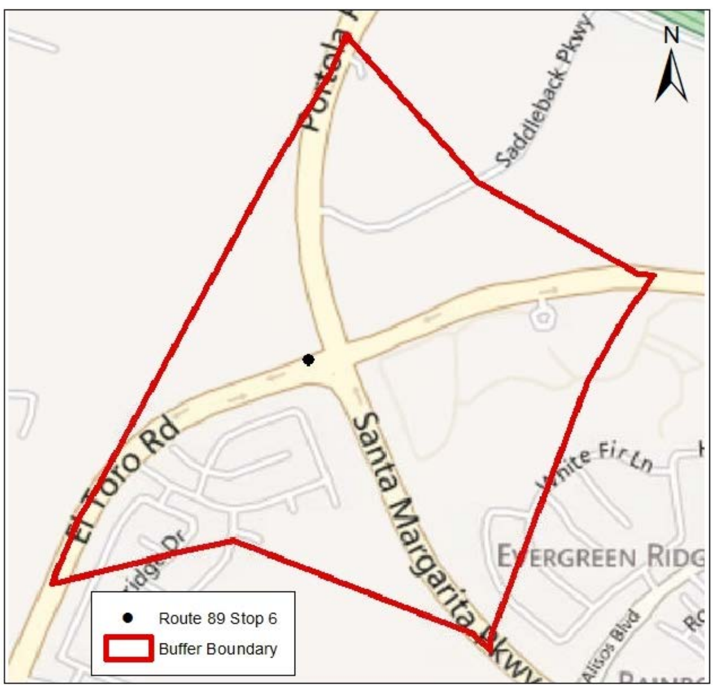
Chapter 4: Results

This chapter examines the results of the analysis. It covers the following topics: (1) results of Half-Mile-Radii buffers, (2) field observations, (3) combined score comparison for the three types of buffers, (4) combined score comparison for Route 47 and 89, and (5) sensitivity analysis results. First, some of the results of the walkability score calculations for Half-Mile-Radii buffers are shown and compared with observations from field works. Secondly, the results of the three types of buffers are compared to indicate whether changing the buffers from Half-Mile-Radii buffers to Route-Adjacent and Stop-and-Route-Adjacent buffers would make any difference. Then, the results of Route 47 and 89 are compared to see if the walkability scores for the two routes are different. Lastly, the sensitivity analysis results are presented to show whether relocating the hypothetical alternative bus stops makes any difference.

4.1 Scores for Half-Mile-Radii Buffers

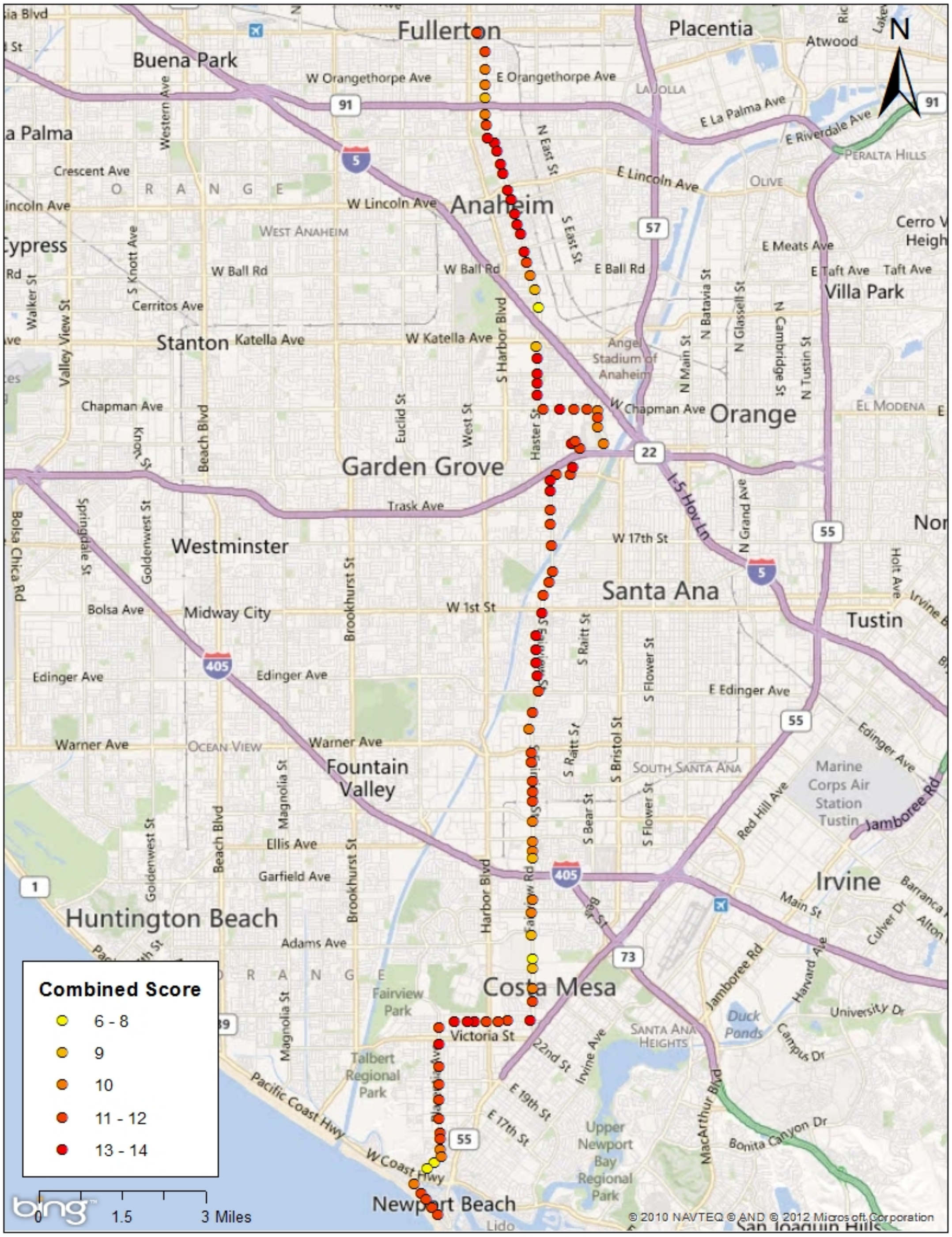
The four variables were evaluated for each of the Half-Mile-Radii buffers. Figure 4 illustrates the Half-Mile-Radii buffer. For the Half-Mile-Radii buffers, Route 47 has an overall higher combined bus stop score as compared to Route 89 (Figure 5 and 6). In other words, the general walkability for the route that goes through grid neighborhoods is better than that of the route which passes through cul-de-sac neighborhoods. The scores for individual variables and the overall scores for each stop of the Half-Mile-Radii buffers for both routes are listed in Table A.1 in the Appendix. The stops with the highest score (score = 14) along Route 47 are stops 10-17, 25-27, and 39. The stop with the lowest score (score = 6) is Route 89's stop 38, which is also the last stop of the route. The stops with the average score of 10 are Route 47's stop 3, 4, 6, 20, 32, 34, 35, 57, 63, 64, 67, 68, 89, 90, and 93 and Route 89's stop 2, 3, 8, 10-12, 19, 20, 29, and 31. For the majority of the stops of Route 47, the scores for population density and steepness are relatively high while the tree canopy scores are low throughout the route. Therefore, the street connectivity score is the variable that is driving the high scores and low scores as it varies for different stops along the route. By contrast, the scores for individual variables for Route 89 all vary along the route; hence, it is difficult to determine one specific variable that is driving the high scores and low scores.

Figure 4: Route 89 Stop 6 and its Half-Mile-Radii Buffer



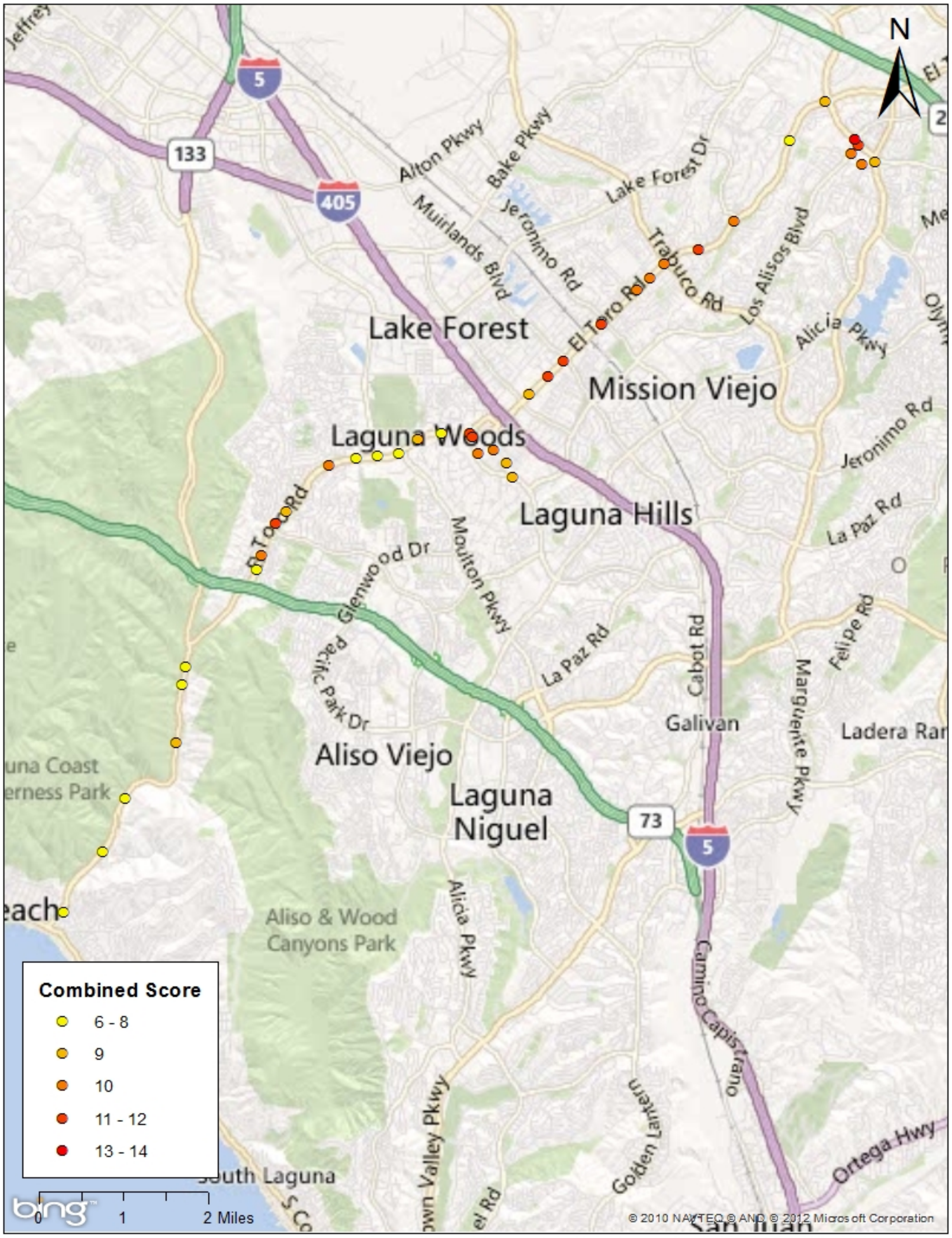
Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

Figure 5: Half-Mile-Radii Buffers Walkability Score Results for Route 47



Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

Figure 6: Half-Mile-Radii Buffers Walkability Score Results for Route 89



Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

4.2 Field Observations

The low scores for tree canopy for stops along Route 47 are confirmed from field observations. In general, most of the stops along Route 47 do not have bus shelters as shown in Figure 7 (a), (b), and (c) while (d) is one of the few stops that have shelters. In addition, out of the stops that do not have shelters, there are some of them that only have the bus stop sign and do not have any benches nearby. Even for the stops that have benches, often the benches are not located near trees or buildings to provide tree canopy for the passengers waiting for the bus (Figure 7 (a), (b), and (c)). On a sunny day, a passenger may choose to sit on the curb near the stop that is protected by tree canopy instead of the benches that are exposed completely to the sun as shown in Figure 7 (b). Furthermore, the majority of the stops on Route 47 are on busy arterial streets, and the greeneries are a lot of times more spread out and provide less shade for the pedestrians.

Comparing to Route 47, the majority of the stops along Route 89 have shelters as shown in Figure 8 (a), (b), (c), and (d). Not only do most of the stops provide shelters and benches, many of them also provide trashcans as shown in Figure 8 (a) and (d). The stops along Route 89 are more likely to be located in places with a lot of tree; yet many times the trees may be located too far away from the sidewalk to cast wide enough shadows to provide tree canopy for the pedestrians as shown in Figure 8 (a), (b), and (d).

Figure 7: Photos of Route 47 Bus Stops

Figure 8: Photos of Route 89 Bus Stops

4.3 Combined Score Comparison for the Three Types of Buffers (HMR, RA, and SARA)

Scores for the three different buffer types were calculated to allow for comparisons (see Table A.4 in the Appendix for the complete scores). Figure 9 shows the histograms of the score frequencies for the three types of buffers. From the histograms, it can be observed that Route 47 has higher walkability scores than Route 89 for all three cases. Also, Half-Mile-Radii buffers have overall higher combined scores compared to Route-Adjacent and Stop-and-Route-Adjacent buffers.

The three difference of means test results of the three types of buffers against each other indicate that the scores for Half-Mile-Radii buffers are significantly different from those for Route-Adjacent buffers and Stop-and-Route-Adjacent (Table 5). However, the scores for Route-Adjacent buffers and Stop-and-Route-Adjacent buffers are not significantly different from each other (Table 5). In other words, the walkability scores are significantly different for adjusted and non-adjusted buffers. However, it does not make a significant difference whether the buffers are adjusted with the Route-Adjacent or Stop-and-Route-Adjacent methods. Due to the proximity of the bus stops to each other, all of the buffers for Route 47 stops and the majority of the Route 89 stops are adjusted to a radius shorter than half a mile (Figure 10).

From the results, it can be observed that Half-Mile-Radii buffers consistently have better scores than those of Route-Adjacent and Stop-and-Route-Adjacent buffers. However, it is important to note this result should not be interpreted to mean that longer walks to bus stops are more walkable than shorter walks, since length of walk to bus stops was not measured as a variable. Instead, it appears that higher scores for the larger, HMR buffers may be a sort of "statistical artifact" where the size of the buffer drives up the scores on the four variables investigated in this study. The significance of having different types of buffers is to account for how people would choose to ride the buses, and in this particular study, it is assumed that people's choices depend on the distances to the bus stops relative to their locations to other routes and stops. Therefore, the different sizes in buffers and their varying results indicate that it is a difficult challenge to create buffers that are appropriate for potential bus stop locations in the bus route planning models.

Figure 9: Histograms of Combined Bus Stop Scores for the Three Types of Buffers (HMR, RA, and SARA)

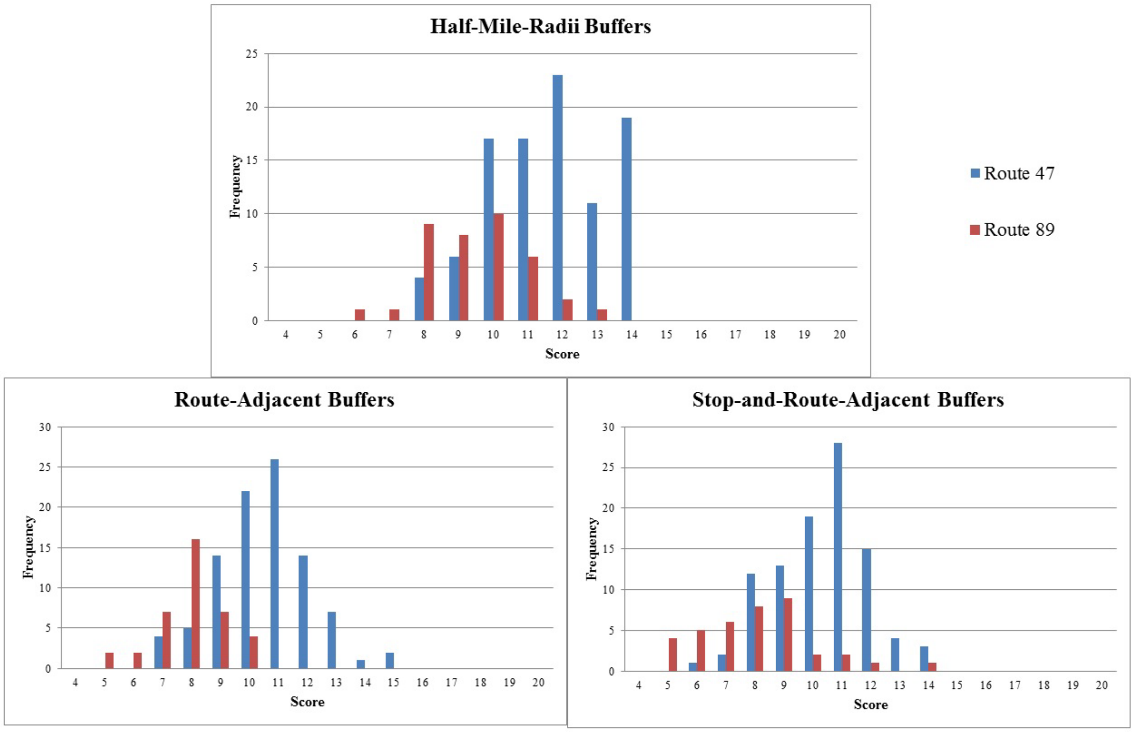
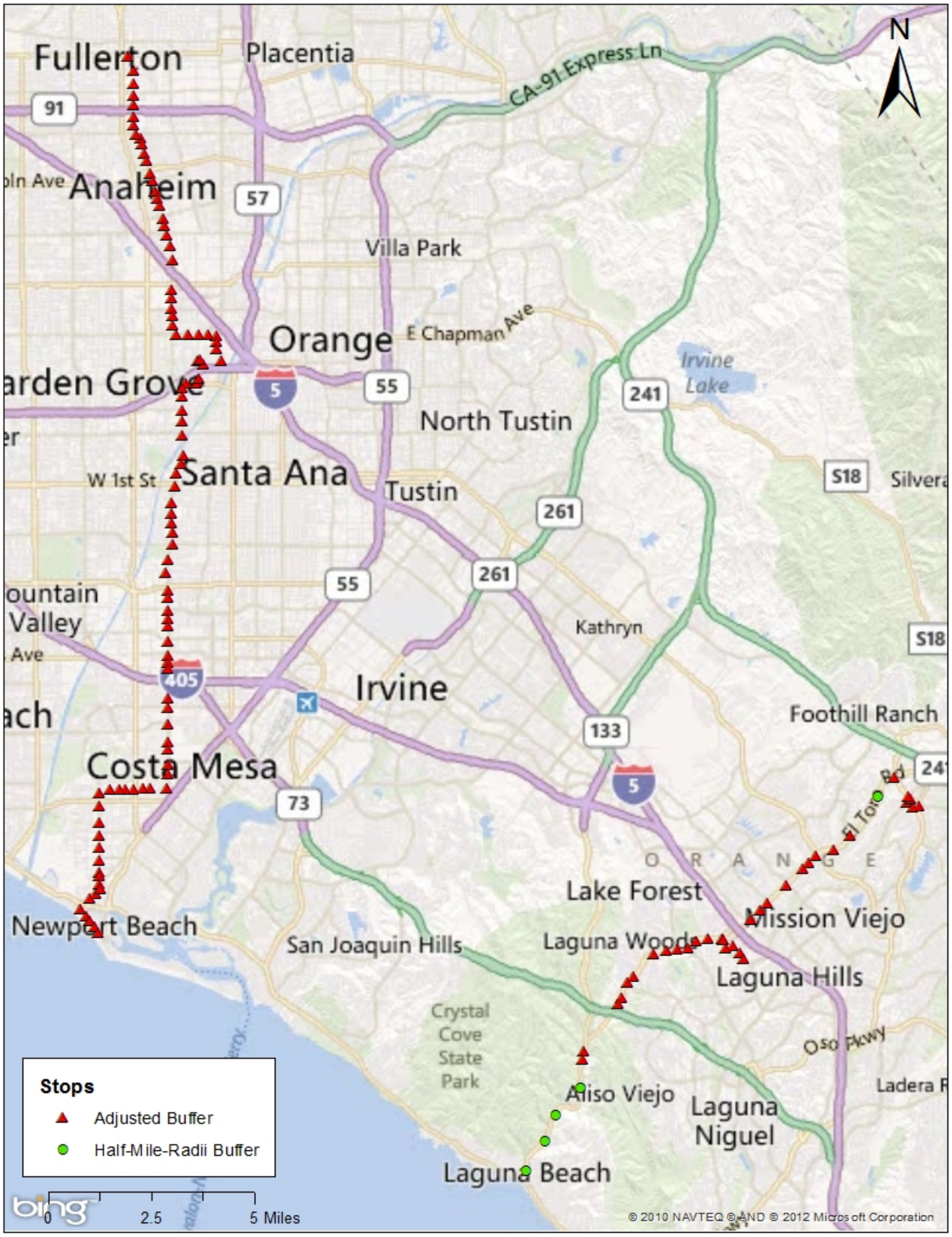


Table 5: Difference of Means Test Results for the Three Types of Buffers (HMR, RA, and SARA)

Buffer Types	Mean Scores	t Stat	P one-tail
HMR vs. RA	11.02 vs. 9.82	5.19	2.09E-07
HMR vs. SARA	11.02 vs. 9.70	5.51	4.29E-08
RA vs. SARA	9.82 vs. 9.70	0.46	0.32

Figure 10: Bus Stops with Adjusted and Non-Adjusted Buffers



Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

4.4 Combined Score Comparison for Route 47 and Route 89

The combined scores of Route 47 and 89 for the three types of buffers are listed in Table A.5 in the Appendix. Route 47 has higher "lowest score" and "highest score" than Route 89 for all three types of buffers except for the "highest score" for Stop-and-Route-Adjacent buffer, in which the "highest score" for both routes are the same (Table 6). The walkability score results support the hypothesis that stops along Route 47 are more walkable than stops along Route 89. The difference of means tests of Route 47 and 89 for each of the three types of buffers all indicate that the scores for Route 47 and 89 are 95% certain to be at least 1 value but not 2 values different from one another (Table 7). Overall, Route 47 has a higher walkability than Route 89 by approximately 1 score value difference.

Table 6: Descriptive Statistics of Route 47 and Route 89 for the Three Types of Buffers (HMR, RA, and SARA)

		Route 47	Route 89
Half-Mile-Radii	Lowest Score	8	6
	Highest Score	14	13
	Median	12	9, 10
	Mean	11.6	9.47
	Standard Deviation	1.70	1.48
	Range	6	7
Route-Adjacent	Lowest Score	7	5
	Highest Score	15	10
	Median	11	8
	Mean	10.5	7.95
	Standard Deviation	1.63	1.23
	Range	8	5
Stop-and-Route-Adjacent	Lowest Score	6	5
	Highest Score	14	14
	Median	11	8
	Mean	10.4	8.03
	Standard Deviation	1.63	2.01
	Range	8	9

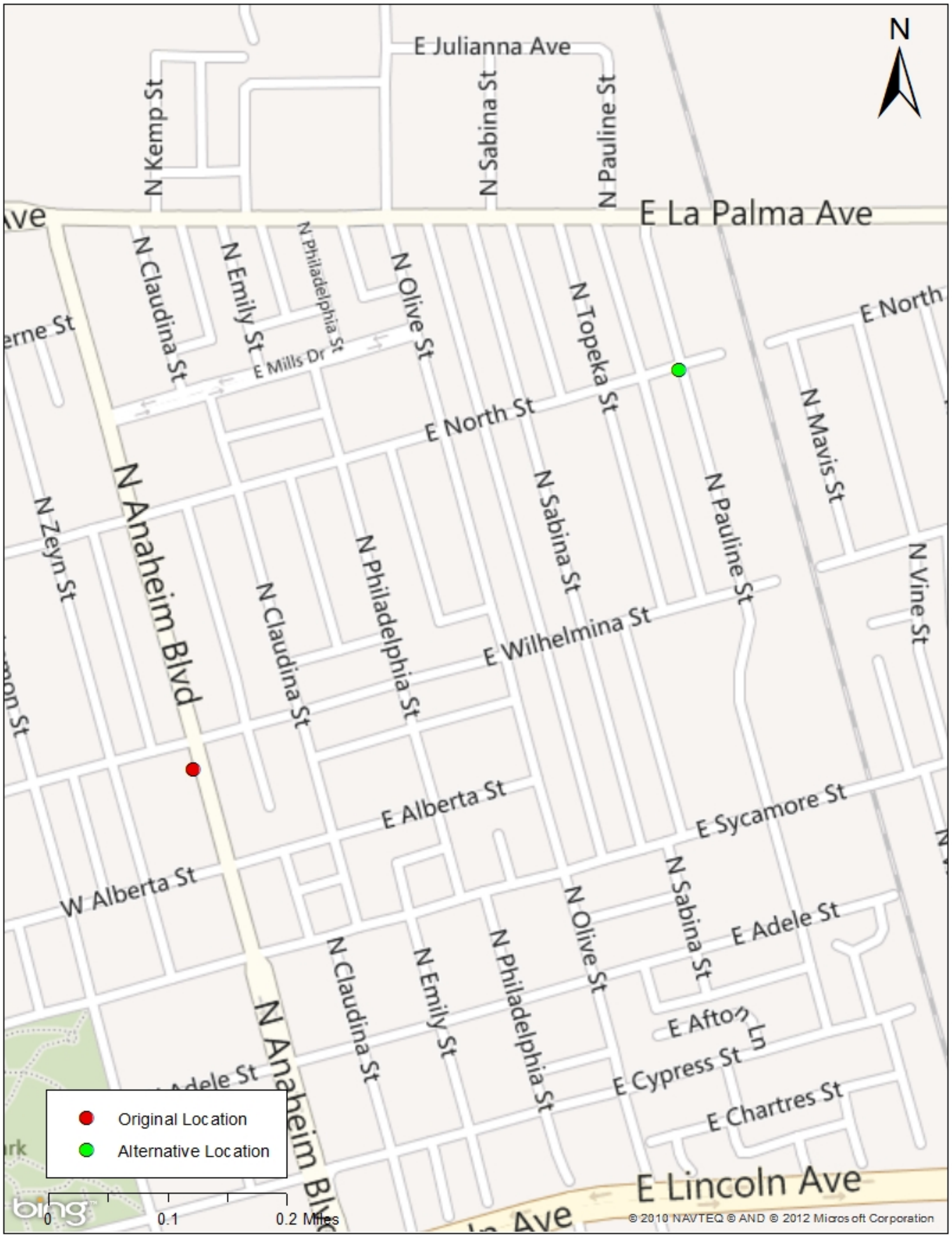
Table 7: Difference of Means Test Results for Route 47 and Route 89 for the Three Types of Buffers (HMR, RA, and SARA)

Buffer Type	Mean Scores 47 vs. 89	Hypothesized Mean Diff.	t Stat	P one-tail
HMR	11.6 vs. 9.47	0	7.30	1.22E-10
		1	3.90	0.0001
		2	0.52	0.301
RA	10.3 vs. 7.95	0	7.97	5.71E-13
		1	4.64	4.59E-06
		2	1.31	0.10
SARA	10.4 vs. 8.03	0	6.39	1.61E-08
		1	3.66	0.0003
		2	0.92	0.18

4.5 Sensitivity Analysis Results

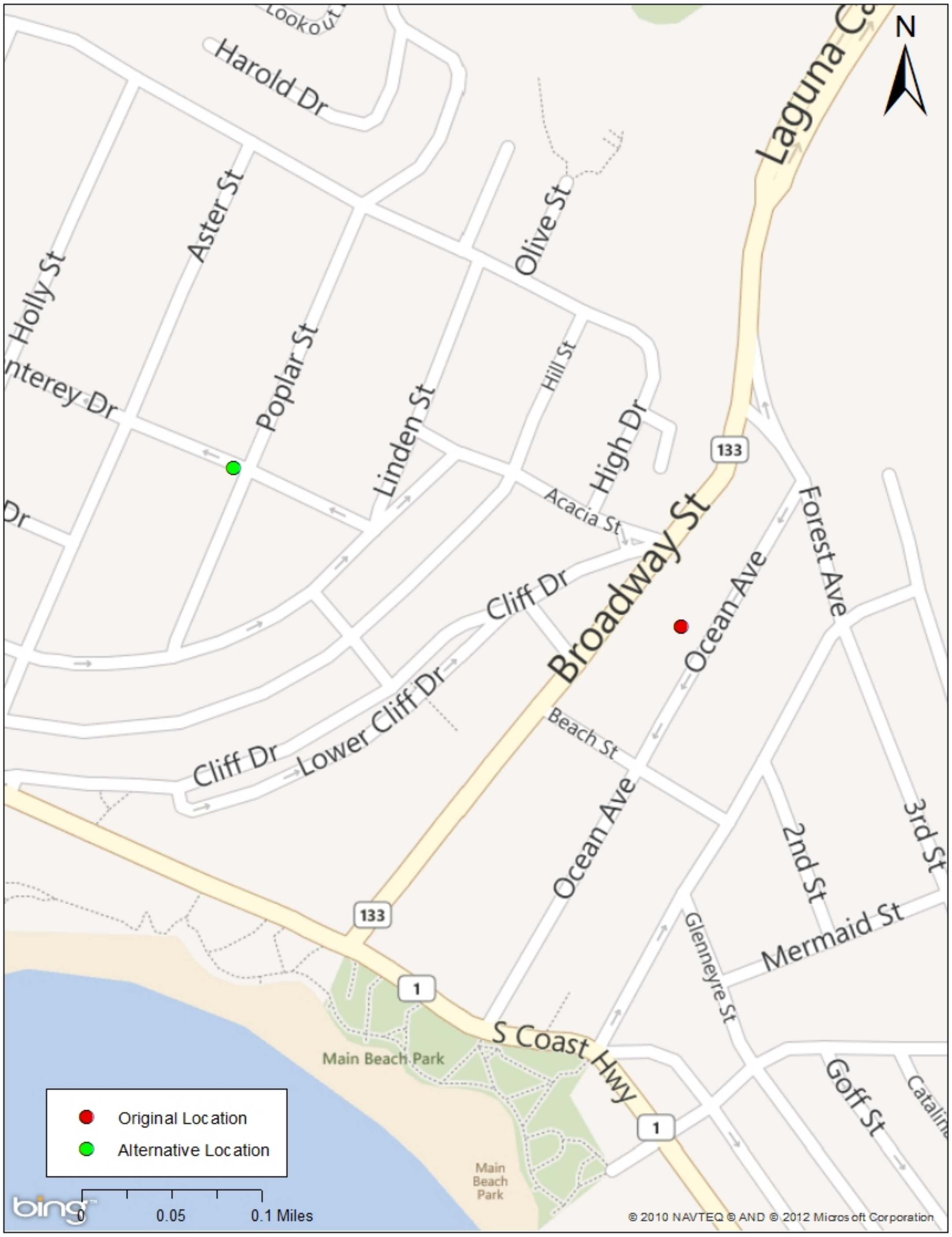
Case studies on relocating bus stops to optimize walkability are done to examine whether walkability improvements can be measured and reported when stops are moved short distances from existing routes. Stop 10 of Route 47, Stop 38 of Route 89, and Stop 3 of Route 47 were chosen for the sensitivity analysis because they represent the highest, lowest, and average combined scores respectively (Figure 11, Figure 12, and Figure 13). By adjusting the bus stop locations to a hypothetical alternative stop, the combined scores increased for stops with the average and the lowest scores (i.e., Stop 38 of Route 89 and Stop 3 of Route 7). However, for the stop with the highest score (i.e., Stop 10 of Route 47) the hypothetical alternative stop's combined score is lower than the original. From the score breakdown of the highest combined scores of the original and the alternative stop, it can be seen that lower street connectivity is the reason that this alternative stop has a lower walkability score than the original stop (Table 8). It is reasonable that the street connectivity score for the original stop is higher than that of the alternative stop since arterial streets have more intersections and crossroads than the smaller roads in neighborhoods. This might well be a common finding for high scoring stops along bus routes in grid–style neighborhoods where current route design often places the stops on arterial streets.

Figure 11: Original and Alternative Locations for Route 47 Stop 10



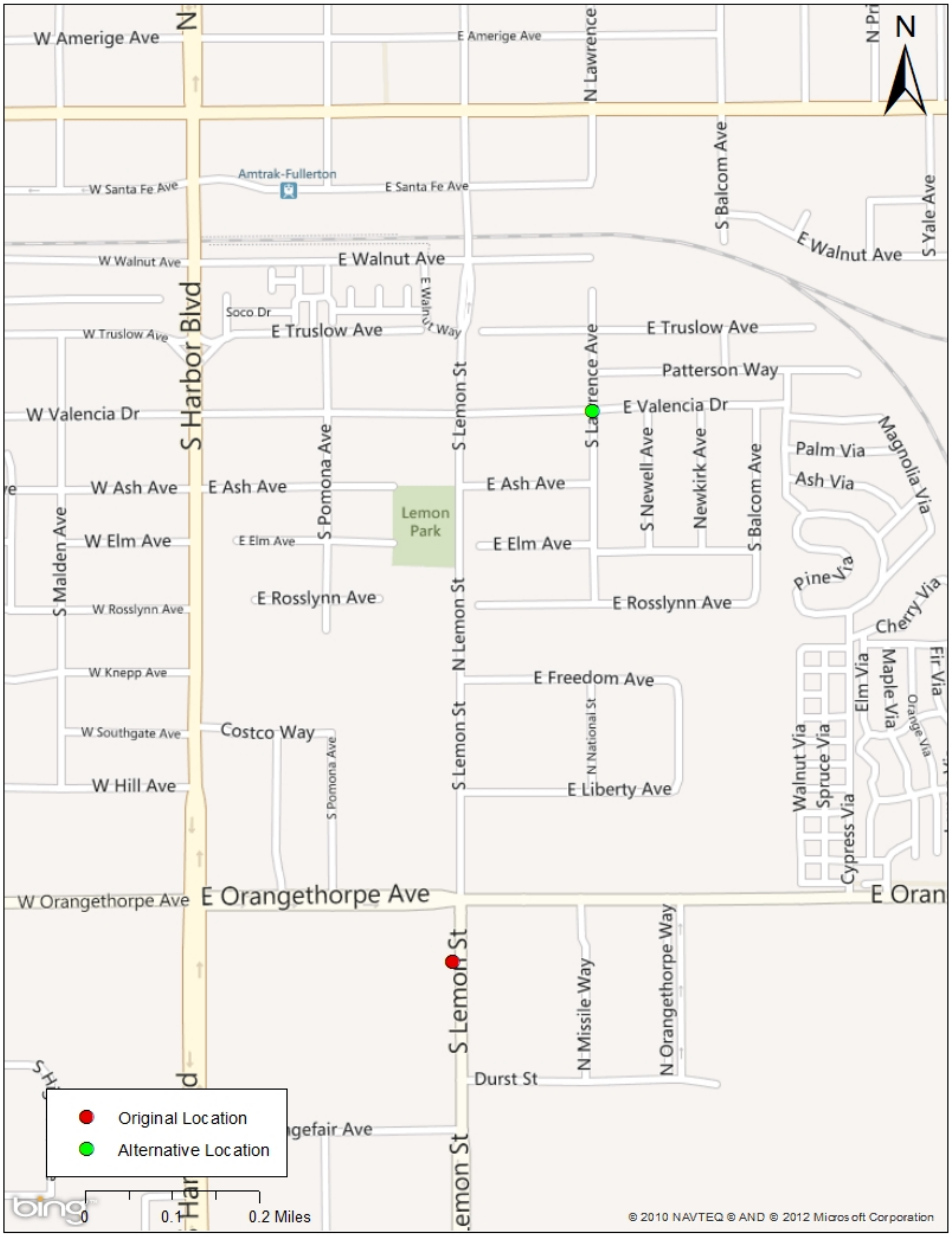
Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

Figure 12: Original and Alternative Locations for Route 89 Stop 38



Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

Figure 13: Original and Alternative Locations for Route 47 Stop 3



Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

Table 8: Comparison Table for Half-Mile-Radii Buffer Sensitivity Analysis Results

Route_Stop (Original/Alternative)	Population Density	Street Connectivity	Steepness	Tree Canopy	Combined Score
47_10 (Original)	4	4	5	1	14
47_10 (Alternative)	5	2	5	1	13
89_38 (Original)	1	2	1	2	6
89_38 (Alternative)	2	2	1	4	9
47_3 (Original)	2	2	5	1	10
47_3 (Alternative)	5	2	5	1	13

Chapter 5: Discussion and Conclusion

The results for the three types of buffers employed in this study all support the hypothesis that Route 47 has an overall higher walkability score than Route 89, which is drawn from the fact that grid neighborhoods have highly connected streets while cul-de-sac neighborhoods have less street linkages with lots of dead ends. Therefore, it is reasonable to conclude that, based on the present study, grid neighborhoods have higher walkability than cul-de-sac neighborhoods under normal circumstances. This research finding is cause for concern due to the fact that modern neighborhoods (cul-de-sac) are being built with less connectivity to public transportation systems compared to the traditional grid neighborhood design. The sensitivity analysis results indicate that moving a bus stop with an average or lower combined score to locations further from arterial streets and deeper into neighborhoods would increase the walkability of the bus stop. However, as stated by Ceder and Wilson (1984), there are real risks in redesigning the bus network that would result in poorer bus system performances. In the hypothetical examples developed here, each adjusted bus stop location would add approximately one mile to the original bus route.

Thus, if OCTA were to make numerous adjustments to the bus routes in each case where alternative bus stops' scores are higher than those of the original stops, then a lot of distances and time might be added to the already long bus rides. Therefore, although the walkability of each of the adjusted bus stops would be increased, the overall transportation efficiency, including time and fuel consumption, would be reduced. In other words, even though walkability is an important factor for people to utilize public transportation, rerouting to increase walkability may not be the optimal solution.

Although walkability may not be most significant factor in planning a bus route, the scoring system and geospatial datasets introduced here may help transit engineers and planners to weigh the significance of the walkability as part of origin and destination modeling. For example, Ouyang and Nourbakhsh (2010) introduced an entirely new transit concept called the "flexible-route transit system" that is suitable for low-demand areas. To summarize the concept, the flexible-route bus would move within a coverage area called a "bus tube" in which the bus moves back and forth picking up and dropping off passengers at their precise origins and destinations while passing transfer points along the way (Ouyang and Nourbakhsh 2010). The bus would only be dispatched when potential passengers request service through a website (e.g., mobile GIS technology) or phone calls (Ouyang and Nourbakhsh 2010). Passengers that want to travel beyond the "bus tube" would be dropped off at transfer points and be picked up by another bus (Ouyang and Nourbakhsh 2010). Since the bus would travel to the passengers' precise origins and destinations, passengers do not have to walk great distances to the nearest stop (Ouyang and Nourbakhsh 2010).

By knowing which stops along a route have the lower walkability scores using methods like the one demonstrated here, these places can be identified as the low-demand areas. “Bus tubes” for entire routes or portions of routes can be planned accordingly. By having the “flexible-route transit system” in which the buses would only be dispatched at the requests of the passengers in the “bus tubes”, the demand for bus resources would be reduced. Therefore, even if the result of this study indicates that redesigning bus routes to optimize walkability would decrease the bus system’s efficiency, information on walkability that is determined from this study can be used to consider abandoning fixed route stops in certain cases in favor of variable route bus service.

The theories of both the fields of Active Living Research as well as Smart Growth recognize the relationship between a walkable environment and public transportation. By designing the public transits to be more accessible and convenient, people would be more willing to travel with them regularly, thereby encourage walking and promote a healthy lifestyle. This study shows the significance of considering the origin, destination, and walking paths for pedestrians when approaching the bus network design problems. By having more walkable routes, not only would bus ridership be encouraged, people’s quality of life would be improved as well.

5.1 Limitations

As a specific case study done on understanding walkability's role in the bus network design problem, this project has several limitations. First of all, this study only investigated two bus routes, which is a very small sample size considering the numerous bus routes there are in Orange County, let alone the numerous bus systems worldwide. Secondly, walkability is only evaluated with four variables due to the scale of this study; yet there may be other crucial influencing factors that may contribute to walkability that were not taken into account in this particular case study.

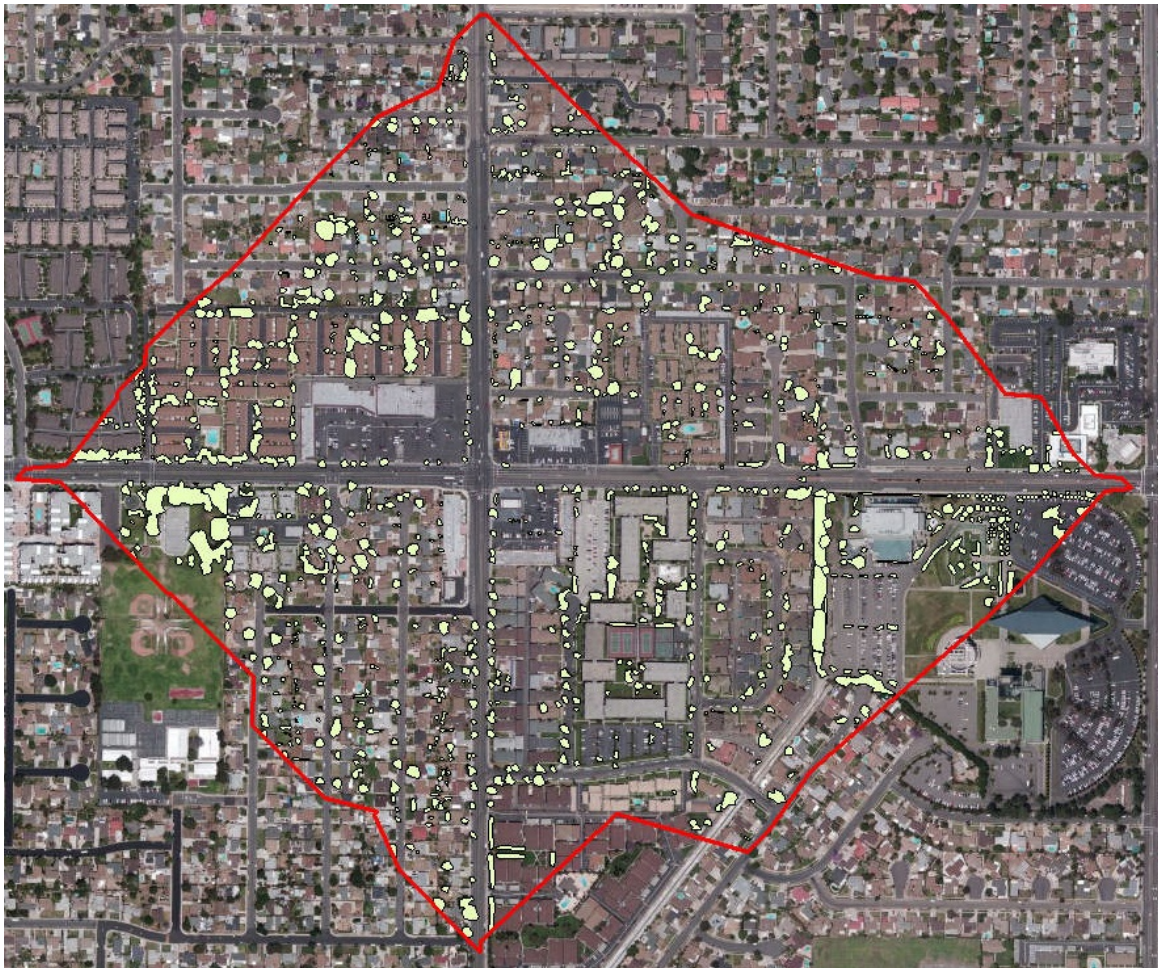
Furthermore, the USGS National Land Cover Dataset (2001) Tree Canopy Layer (USGS Tree Canopy Layer) that was used to determine the tree canopy score may not be the best representation of tree canopy for urbanized Orange County and resulted in inaccurate tree canopy score results. The USGS Tree Canopy Layer was developed for the USGS's National Water-Quality Assessment Program to assess land-use change and to allocate nutrient and pesticide loads to different land-use categories (USGS 2010). The layer was created with a specific intention for use by the USGS instead of for the general use of the public. In addition, the tree canopy coverage in the layer was determined by extrapolating calibrated density prediction models that were derived using both linear regression and regression tree techniques (Huang, et al. 2001).

Therefore, the data in the layer do not reflect the actual tree canopy locations but rather are an approximation. However, for the purpose of this project, it is important for the tree coverage data to be geographically accurate, which is why the USGS Tree Canopy Layer is identified as a limitation in this particular case study.

Another method to determine the tree coverage percentage for each buffer is by manually digitizing the trees. Figure 14 shows the manual digitization of the trees for Route 47 Stop 28's Half-Mile-Radii buffer. There is definitely the presence of trees within the buffer of Stop 28; however, according to the USGS Tree Canopy Layer, there are no trees within this region. The manual digitization method, although more accurate than using the USGS Tree Canopy Layer, requires a lot more time and manpower to develop. Furthermore, transit planning agencies will need to use ready-made GIS datasets to incorporate walkability into planning models which renders this method as ideal for understanding tree canopy's effect in bus route planning.

Even though the USGS Tree Canopy Layer was unable to yield tree canopy scores that reflect the actual tree coverage, it was used because other spatial data for the analysis were not found. After much research, it has been concluded that the USGS Tree Canopy Layer present in this study is the best option available for use in urbanized areas.

Figure 14: Manually Digitized Tree Coverage for Route 47 Stop 28's Half-Mile-Radii Buffer



Sources: Esri Bing Maps Road (2012)

5.2 Future Research

The Stop-and-Route-Adjacent buffers used in this study serve to identify pedestrian "catchment" areas of the bus stops. However, there may be more dynamic and sophisticated ways to calculate pedestrian "catchment" areas for transit stops based upon the utilization rates, speeds, or connectivity of particular routes in the overall transit network. Future research may consider building origin and destination demand models in which the walking to stops aspect would be taken into consideration. Besides only determining the "catchment" area by distance to the bus stops from pedestrians' origins, there are many other factors that contribute to people's decision in choosing to ride the bus from a certain stop than another. For instance, due to the variety of bus routes, people might be willing to walk to further to an initial transit stop if the entire journey can be made with fewer bus transfers. To consider the different possibilities, transit engineers should work with GIS specialists to feed data on walkability into their origin and destination demand models.

One topic that requires attention in future research is the problem that is introduced by relating low population density with low walkability. Bus stops located near concentrated nodes of shopping or industry may actually be quite convenient for people to walk to retail stores or work, yet because of the low population densities in these areas, they received lower walkability scores.

Therefore, the population density variable walkability results provide good representations for walkability in residential areas, but not so much for commercial or industrial areas. This limitation in the study needs refinement in future research that takes into account the type of land use variation in areas where bus stops are located.

Another issue that should be addressed in future research is the modifiable areal unit problem (MAUP) that may have affected the results of this study. In this study, three types of buffers are used to represent three logics of choosing the bus stops. Due to the way these buffers are determined, the Half-Mile-Radii buffers are generally much larger than that of Route-Adjacent and Stop-and-Route-Adjacent buffers (Figure 15). The walkability scores for the Half-Mile-Radii buffers are also higher than the other two buffers. Therefore, sizes of the buffers may or may not be the reason behind the differences in the scores. However, more data sampling and detailed field studies are needed in order to draw a conclusion.

Figure 15: Route 47 Stop 20 and its Three Types of Buffers (HMR, RA, and SARA)

Sources: Esri Bing Maps Road (2012), OCTA Bus Stop Layer (2012)

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Appendix

Table A.1 Combined Bus Stop Scores for Half Mile Radii Buffers

Stop	Population Density	Street Connectivity	Steepness	Tree Canopy	Combined Score
47_1	3	2	5	1	11
47_2	2	3	5	1	11
47_3	2	2	5	1	10
47_4	2	2	5	1	10
47_5	2	2	4	1	9
47_6	3	2	4	1	10
47_7	3	3	5	1	12
47_8	3	4	5	1	13
47_9	3	4	5	1	13
47_10	4	4	5	1	14
47_11	4	4	5	1	14
47_12	4	4	5	1	14
47_13	4	4	5	1	14
47_14	4	4	5	1	14
47_15	4	4	5	1	14
47_16	4	4	5	1	14
47_17	4	4	5	1	14
47_18	4	3	5	1	13
47_19	2	3	5	1	11
47_20	2	2	5	1	10
47_21	1	2	5	1	9
47_22	1	2	4	1	8
47_23	2	2	4	1	9
47_24	4	3	5	1	13
47_25	5	3	5	1	14
47_26	5	3	5	1	14
47_27	5	3	5	1	14
47_28	4	2	5	1	12
47_29	4	3	5	1	13

47_30	3	3	5	1	12
47_31	2	3	5	1	11
47_32	2	2	5	1	10
47_33	2	3	5	1	11
47_34	2	2	5	1	10
47_35	2	2	5	1	10
47_36	3	2	5	1	11
47_37	2	3	5	1	11
47_38	3	4	5	1	13
47_39	4	4	5	1	14
47_40	4	3	4	1	12
47_41	4	3	4	1	12
47_42	4	3	5	1	13
47_43	4	3	5	1	13
47_44	4	2	5	1	12
47_45	4	2	5	1	12
47_46	4	2	5	1	12
47_47	4	2	5	1	12
47_48	4	2	5	1	12
47_49	4	2	5	1	12
47_50	4	4	5	1	14
47_51	5	3	5	1	14
47_52	5	3	5	1	14
47_53	5	3	5	1	14
47_54	4	3	5	1	13
47_55	3	2	5	1	11
47_56	3	2	5	1	11
47_57	2	2	5	1	10
47_58	2	3	5	1	11
47_59	2	3	5	1	11
47_60	2	3	5	1	11
47_61	2	3	5	1	11
47_62	2	3	5	1	11
47_63	1	3	5	1	10

47_64	1	3	5	1	10
47_65	1	3	5	1	10
47_66	1	2	5	1	9
47_67	2	2	5	1	10
47_68	2	2	5	1	10
47_69	1	2	5	1	9
47_70	1	2	4	1	8
47_71	1	2	5	1	9
47_72	2	2	5	1	10
47_73	3	3	5	1	12
47_74	4	3	5	1	13
47_75	4	2	5	1	12
47_76	4	2	5	1	12
47_77	4	2	5	1	12
47_78	5	3	5	1	14
47_79	5	3	5	1	14
47_80	5	3	5	1	14
47_81	4	2	5	1	12
47_82	5	2	5	1	13
47_83	4	2	5	1	12
47_84	4	2	5	1	12
47_85	4	2	5	1	12
47_86	4	2	4	1	11
47_87	3	3	4	1	11
47_88	2	3	5	1	11
47_89	2	3	4	1	10
47_90	2	3	4	1	10
47_91	1	3	3	1	8
47_92	1	2	4	1	8
47_93	1	5	3	1	10
47_94	1	5	5	1	12
47_95	1	5	5	1	12
47_96	1	5	5	1	12
47_97	1	5	5	1	12

89_1	3	2	2	2	9
89_2	3	2	2	3	10
89_3	2	3	2	3	10
89_4	3	3	3	3	12
89_5	3	3	4	3	13
89_6	2	2	2	3	9
89_7	1	1	2	4	8
89_8	3	1	2	4	10
89_9	3	2	2	4	11
89_10	3	2	3	2	10
89_11	3	2	4	1	10
89_12	3	2	4	1	10
89_13	4	2	4	1	11
89_14	3	3	4	1	11
89_15	3	2	5	1	11
89_16	2	2	4	1	9
89_17	2	4	4	1	11
89_18	2	3	5	1	11
89_19	2	3	4	1	10
89_20	2	3	4	1	10
89_21	2	2	4	1	9
89_22	2	2	4	1	9
89_23	2	2	3	1	8
89_24	2	3	3	1	9
89_25	2	2	3	1	8
89_26	2	2	3	1	8
89_27	2	2	1	2	7
89_29	2	3	2	3	10
89_29	2	3	2	2	9
89_30	2	3	3	4	12
89_31	1	3	2	4	10
89_32	1	2	1	4	8
89_33	1	1	1	5	8
89_34	1	1	1	5	8

89_35	1	1	2	5	9
89_36	1	1	1	5	8
89_37	1	1	1	5	8
89_38	1	2	1	2	6

Table A.2 Combined Bus Stop Scores for Route-Adjacent Buffers

Stop	Population Density	Street Connectivity	Steepness	Tree Canopy	Combined Score
47_1	3	2	4	1	10
47_2	2	1	5	1	9
47_3	2	2	5	1	10
47_4	2	2	5	1	10
47_5	2	2	5	1	10
47_6	3	1	5	1	10
47_7	3	2	5	1	11
47_8	3	1	5	1	10
47_9	3	1	5	1	10
47_10	3	2	5	1	11
47_11	3	2	5	1	11
47_12	3	2	5	1	11
47_13	3	2	5	1	11
47_14	4	2	5	1	12
47_15	4	2	5	1	12
47_16	4	2	5	1	12
47_17	4	2	5	1	12
47_18	4	2	5	1	12
47_19	3	2	5	1	11
47_20	2	2	5	1	10
47_21	2	2	5	1	10
47_22	1	1	4	1	7
47_23	2	1	4	1	8
47_24	4	1	5	1	11
47_25	5	2	5	1	13

47_26	5	1	5	1	12
47_27	4	1	5	1	11
47_28	4	1	5	1	11
47_29	3	1	5	1	10
47_30	3	1	5	1	10
47_31	2	1	4	1	8
47_32	2	4	4	1	11
47_33	2	1	5	1	9
47_34	2	1	5	1	9
47_35	2	2	5	1	10
47_36	3	2	5	1	11
47_37	2	1	5	1	9
47_38	3	1	5	1	10
47_39	4	2	5	1	12
47_40	4	2	4	1	11
47_41	4	2	4	1	11
47_42	4	5	5	1	15
47_43	4	1	5	1	11
47_44	4	1	5	1	11
47_45	4	1	5	1	11
47_46	4	1	5	1	11
47_47	4	1	5	1	11
47_48	4	1	5	1	11
47_49	4	1	5	1	11
47_50	4	2	5	1	12
47_51	5	2	5	1	13
47_52	5	2	5	1	13
47_53	5	2	4	1	12
47_54	4	1	5	1	11
47_55	3	1	5	1	10
47_56	3	1	5	1	10
47_57	2	1	5	1	9
47_58	2	1	5	1	9
47_59	2	1	5	1	9

47_60	2	2	5	1	10
47_61	2	1	5	1	9
47_62	2	2	5	1	10
47_63	2	1	5	1	9
47_64	1	5	5	1	12
47_65	1	1	5	1	8
47_66	1	1	5	1	8
47_67	1	1	5	1	8
47_68	2	1	5	1	9
47_69	2	1	5	1	9
47_70	1	1	4	1	7
47_71	2	1	5	1	9
47_72	3	1	5	1	10
47_73	4	2	5	1	12
47_74	4	1	5	1	11
47_75	4	1	5	1	11
47_76	5	1	5	1	12
47_77	5	3	5	1	14
47_78	5	4	5	1	15
47_79	5	2	5	1	13
47_80	4	3	5	1	13
47_81	3	3	5	1	12
47_82	4	1	5	1	11
47_83	4	1	5	1	11
47_84	4	2	5	1	12
47_85	4	1	4	1	10
47_86	4	1	4	1	10
47_87	3	1	4	1	9
47_88	2	1	5	1	9
47_89	2	2	5	1	10
47_90	2	2	4	1	9
47_91	2	5	3	1	11
47_92	1	1	4	1	7
47_93	1	2	3	1	7

47_94	3	2	4	1	10
47_95	2	3	5	1	11
47_96	5	2	5	1	13
47_97	5	2	5	1	13
89_1	3	2	2	1	8
89_2	2	1	1	4	8
89_3	2	1	1	4	8
89_4	2	1	1	1	5
89_5	2	1	2	1	6
89_6	2	1	2	3	8
89_7	1	1	2	4	8
89_8	3	1	2	4	10
89_9	3	1	2	4	10
89_10	3	1	3	3	10
89_11	3	1	4	1	9
89_12	3	1	4	1	9
89_13	3	1	4	1	9
89_14	3	1	4	1	9
89_15	3	1	4	1	9
89_16	2	1	4	1	8
89_17	2	1	4	1	8
89_18	2	1	5	1	9
89_19	2	1	4	1	8
89_20	2	1	4	1	8
89_21	1	1	4	1	7
89_22	2	1	4	1	8
89_23	2	1	3	1	7
89_24	2	1	3	1	7
89_25	2	1	3	1	7
89_26	2	1	3	1	7
89_27	2	1	1	2	6
89_29	2	1	2	3	8
89_29	2	1	2	2	7
89_30	2	1	3	4	10

89_31	1	1	2	4	8
89_32	1	1	1	4	7
89_33	1	1	1	5	8
89_34	1	1	1	5	8
89_35	1	1	2	5	9
89_36	1	1	1	5	8
89_37	1	1	1	5	8
89_38	1	1	1	2	5

Table A.3 Combined Bus Stop Scores for Stop-and-Route-Adjacent Buffers

Stop	Population Density	Street Connectivity	Steepness	Tree Canopy	Combined Score
47_1	3	2	4	1	10
47_2	2	1	4	1	8
47_3	2	2	5	1	10
47_4	2	1	5	1	9
47_5	2	1	4	1	8
47_6	3	1	5	1	10
47_7	3	2	5	1	11
47_8	3	2	5	1	11
47_9	3	2	5	1	11
47_10	3	1	5	1	10
47_11	3	1	5	1	10
47_12	3	1	5	1	10
47_13	3	2	5	1	11
47_14	4	1	5	1	11
47_15	4	1	5	1	11
47_16	3	1	5	1	10
47_17	4	2	5	1	12
47_18	4	1	5	1	11
47_19	3	1	5	1	10
47_20	1	1	5	1	8
47_21	1	1	5	1	8
47_22	1	1	5	1	8
47_23	3	2	5	1	11
47_24	4	1	5	1	11
47_25	5	1	5	1	12

47_26	4	1	5	1	11
47_27	4	1	5	1	11
47_28	4	1	5	1	11
47_29	4	1	5	1	11
47_30	3	1	5	1	10
47_31	2	1	4	1	8
47_32	2	2	4	1	9
47_33	2	2	5	1	10
47_34	2	2	5	1	10
47_35	2	1	5	1	9
47_36	1	2	5	1	9
47_37	1	4	5	1	11
47_38	3	5	5	1	14
47_39	4	2	4	1	11
47_40	4	1	5	1	11
47_41	4	3	5	1	13
47_42	3	1	4	1	9
47_43	3	1	5	1	10
47_44	4	1	5	1	11
47_45	4	1	5	1	11
47_46	4	1	4	1	10
47_47	4	2	5	1	12
47_48	4	1	5	1	11
47_49	4	1	5	1	11
47_50	4	1	5	1	11
47_51	5	1	5	1	12
47_52	5	1	5	1	12
47_53	5	2	4	1	12
47_54	4	1	4	1	10
47_55	2	1	4	2	9
47_56	2	1	4	1	8
47_57	2	1	4	1	8
47_58	3	5	5	1	14
47_59	2	1	5	1	9
47_60	1	2	4	1	8
47_61	1	1	5	1	8
47_62	1	2	4	1	8
47_63	1	1	4	1	7

47_64	1	2	5	1	9
47_65	1	4	5	1	11
47_66	1	2	5	1	9
47_67	2	2	4	1	9
47_68	3	1	5	1	10
47_69	1	1	4	1	7
47_70	1	3	5	1	10
47_71	1	2	5	1	9
47_72	2	1	5	1	9
47_73	3	1	5	1	10
47_74	4	1	5	1	11
47_75	4	1	5	1	11
47_76	5	1	5	1	12
47_77	5	3	5	1	14
47_78	5	1	5	1	12
47_79	5	1	5	1	12
47_80	5	1	5	1	12
47_81	5	1	5	1	12
47_82	4	1	4	1	10
47_83	4	1	5	1	11
47_84	4	1	5	1	11
47_85	4	1	4	1	10
47_86	4	1	5	1	11
47_87	4	3	5	1	13
47_88	4	2	4	1	11
47_89	4	2	5	1	12
47_90	2	4	5	1	12
47_91	1	2	5	1	9
47_92	1	1	3	1	6
47_93	1	2	4	1	8
47_94	5	2	4	1	12
47_95	5	2	4	1	12
47_96	5	2	5	1	13
47_97	5	2	5	1	13
89_1	2	2	2	1	7
89_2	2	2	3	1	8
89_3	2	2	1	1	6
89_4	2	3	5	1	11

89_5	3	5	5	1	14
89_6	1	1	2	1	5
89_7	1	1	2	3	7
89_8	2	1	3	4	10
89_9	3	1	1	4	9
89_10	3	1	4	1	9
89_11	2	1	4	1	8
89_12	3	1	3	1	8
89_13	3	1	3	1	8
89_14	3	1	4	1	9
89_15	2	1	5	1	9
89_16	2	3	5	1	11
89_17	2	4	5	1	12
89_18	2	2	5	1	10
89_19	2	2	4	1	9
89_20	2	2	4	1	9
89_21	2	1	4	1	8
89_22	2	1	4	1	8
89_23	1	1	3	1	6
89_24	1	2	3	1	7
89_25	1	1	2	1	5
89_26	1	3	4	1	9
89_27	2	1	2	1	6
89_29	2	1	2	1	6
89_29	2	2	1	1	6
89_30	1	2	5	1	9
89_31	1	1	2	3	7
89_32	1	1	3	3	8
89_33	1	1	3	2	7
89_34	1	1	2	1	5
89_35	1	1	2	5	9
89_36	1	1	1	5	8
89_37	1	1	1	4	7
89_38	1	1	1	2	5

Table A.4 Combined Scores for the Three Types of Buffers

Stop	Half-Mile-Radii	Route-Adjacent	Stop-and-Route-Adjacent
47_1	11	10	10
47_2	11	9	8
47_3	10	10	10
47_4	10	10	9
47_5	9	10	8
47_6	10	10	10
47_7	12	11	11
47_8	13	10	11
47_9	13	10	11
47_10	14	11	10
47_11	14	11	10
47_12	14	11	10
47_13	14	11	11
47_14	14	12	11
47_15	14	12	11
47_16	14	12	10
47_17	14	12	12
47_18	13	12	11
47_19	11	11	10
47_20	10	10	8
47_21	9	10	8
47_22	8	7	8
47_23	9	8	11
47_24	13	11	11
47_25	14	13	12
47_26	14	12	11
47_27	14	11	11
47_28	12	11	11

47_29	13	10	11
47_30	12	10	10
47_31	11	8	8
47_32	10	11	9
47_33	11	9	10
47_34	10	9	10
47_35	10	10	9
47_36	11	11	9
47_37	11	9	11
47_38	13	10	14
47_39	14	12	11
47_40	12	11	11
47_41	12	11	13
47_42	13	15	9
47_43	13	11	10
47_44	12	11	11
47_45	12	11	11
47_46	12	11	10
47_47	12	11	12
47_48	12	11	11
47_49	12	11	11
47_50	14	12	11
47_51	14	13	12
47_52	14	13	12
47_53	14	12	12
47_54	13	11	10
47_55	11	10	9
47_56	11	10	8
47_57	10	9	8
47_58	11	9	14
47_59	11	9	9
47_60	11	10	8
47_61	11	9	8
47_62	11	10	8

47_63	10	9	7
47_64	10	12	9
47_65	10	8	11
47_66	9	8	9
47_67	10	8	9
47_68	10	9	10
47_69	9	9	7
47_70	8	7	10
47_71	9	9	9
47_72	10	10	9
47_73	12	12	10
47_74	13	11	11
47_75	12	11	11
47_76	12	12	12
47_77	12	14	14
47_78	14	15	12
47_79	14	13	12
47_80	14	13	12
47_81	12	12	12
47_82	13	11	10
47_83	12	11	11
47_84	12	12	11
47_85	12	10	10
47_86	11	10	11
47_87	11	9	13
47_88	11	9	11
47_89	10	10	12
47_90	10	9	12
47_91	8	11	9
47_92	8	7	6
47_93	10	7	8
47_94	12	10	12
47_95	12	11	12
47_96	12	13	13

47_97	12	13	13
89_1	9	8	7
89_2	10	8	8
89_3	10	8	6
89_4	12	5	11
89_5	13	6	14
89_6	9	8	5
89_7	8	8	7
89_8	10	10	10
89_9	11	10	9
89_10	10	10	9
89_11	10	9	8
89_12	10	9	8
89_13	11	9	8
89_14	11	9	9
89_15	11	9	9
89_16	9	8	11
89_17	11	8	12
89_18	11	9	10
89_19	10	8	9
89_20	10	8	9
89_21	9	7	8
89_22	9	8	8
89_23	8	7	6
89_24	9	7	7
89_25	8	7	5
89_26	8	7	9
89_27	7	6	6
89_29	10	8	6
89_29	9	7	6
89_30	12	10	9
89_31	10	8	7
89_32	8	7	8
89_33	8	8	7

89_34	8	8	5
89_35	9	9	9
89_36	8	8	8
89_37	8	8	7
89_38	6	5	5

Table A.5 Combined Score Comparison Table for Route 47 and 89

	Half-Mile-Radii		Route-Adjacent		Stop-and-Route-Adjacent	
Stop	**Route 47**	**Route 89**	**Route 47**	**Route 89**	**Route 47**	**Route 89**
1	11	9	10	8	10	7
2	11	10	9	8	8	8
3	10	10	10	8	10	6
4	10	12	10	5	9	11
5	9	13	10	6	8	14
6	10	9	10	8	10	5
7	12	8	11	8	11	7
8	13	10	10	10	11	10
9	13	11	10	10	11	9
10	14	10	11	10	10	9
11	14	10	11	9	10	8
12	14	10	11	9	10	8
13	14	11	11	9	11	8
14	14	11	12	9	11	9
15	14	11	12	9	11	9
16	14	9	12	8	10	11
17	14	11	12	8	12	12
18	13	11	12	9	11	10
19	11	10	11	8	10	9
20	10	10	10	8	8	9
21	9	9	10	7	8	8
22	8	9	7	8	8	8
23	9	8	8	7	11	6
24	13	9	11	7	11	7
25	14	8	13	7	12	5
26	14	8	12	7	11	9
27	14	7	11	6	11	6

28	12	10	11	8	11	6
29	13	9	10	7	11	6
30	12	12	10	10	10	9
31	11	10	8	8	8	7
32	10	8	11	7	9	8
33	11	8	9	8	10	7
34	10	8	9	8	10	5
35	10	9	10	9	9	9
36	11	8	11	8	9	8
37	11	8	9	8	11	7
38	13	6	10	5	14	5
39	14	N/A	12	N/A	11	N/A
40	12	N/A	11	N/A	11	N/A
41	12	N/A	11	N/A	13	N/A
42	13	N/A	15	N/A	9	N/A
43	13	N/A	11	N/A	10	N/A
44	12	N/A	11	N/A	11	N/A
45	12	N/A	11	N/A	11	N/A
46	12	N/A	11	N/A	10	N/A
47	12	N/A	11	N/A	12	N/A
48	12	N/A	11	N/A	11	N/A
49	12	N/A	11	N/A	11	N/A
50	14	N/A	12	N/A	11	N/A
51	14	N/A	13	N/A	12	N/A
52	14	N/A	13	N/A	12	N/A
53	14	N/A	12	N/A	12	N/A
54	13	N/A	11	N/A	10	N/A
55	11	N/A	10	N/A	9	N/A
56	11	N/A	10	N/A	8	N/A
57	10	N/A	9	N/A	8	N/A
58	11	N/A	9	N/A	14	N/A
59	11	N/A	9	N/A	9	N/A
60	11	N/A	10	N/A	8	N/A
61	11	N/A	9	N/A	8	N/A
62	11	N/A	10	N/A	8	N/A
63	10	N/A	0	N/A	7	N/A
64	10	N/A	12	N/A	9	N/A
65	10	N/A	8	N/A	11	N/A

66	9	N/A	8	N/A	9	N/A
67	10	N/A	8	N/A	9	N/A
68	10	N/A	9	N/A	10	N/A
69	9	N/A	9	N/A	7	N/A
70	8	N/A	7	N/A	10	N/A
71	9	N/A	9	N/A	9	N/A
72	10	N/A	10	N/A	9	N/A
73	12	N/A	12	N/A	10	N/A
74	13	N/A	0	N/A	11	N/A
75	12	N/A	11	N/A	11	N/A
76	12	N/A	12	N/A	12	N/A
77	12	N/A	14	N/A	14	N/A
78	14	N/A	15	N/A	12	N/A
79	14	N/A	13	N/A	12	N/A
80	14	N/A	13	N/A	12	N/A
81	12	N/A	12	N/A	12	N/A
82	13	N/A	11	N/A	10	N/A
83	12	N/A	11	N/A	11	N/A
84	12	N/A	12	N/A	11	N/A
85	12	N/A	10	N/A	10	N/A
86	11	N/A	10	N/A	11	N/A
87	11	N/A	9	N/A	13	N/A
88	11	N/A	9	N/A	11	N/A
89	10	N/A	10	N/A	12	N/A
90	10	N/A	9	N/A	12	N/A
91	8	N/A	11	N/A	9	N/A
92	8	N/A	7	N/A	6	N/A
93	10	N/A	7	N/A	8	N/A
94	12	N/A	10	N/A	12	N/A
95	12	N/A	11	N/A	12	N/A
96	12	N/A	13	N/A	13	N/A
97	12	N/A	13	N/A	13	N/A

Table A.6 Tree Canopy Score Comparison Table for Route 47 and 89

	Half-Mile-Radii		Route-Adjacent		Stop-and-Route-Adjacent	
Stop	**Route 47**	**Route 89**	**Route 47**	**Route 89**	**Route 47**	**Route 89**
1	1	2	1	1	1	1
2	1	3	1	4	1	1
3	1	3	1	4	1	1
4	1	3	1	1	1	1
5	1	3	1	1	1	1
6	1	3	1	3	1	1
7	1	4	1	4	1	3
8	1	4	1	4	1	4
9	1	4	1	4	1	4
10	1	2	1	3	1	1
11	1	1	1	1	1	1
12	1	1	1	1	1	1
13	1	1	1	1	1	1
14	1	1	1	1	1	1
15	1	1	1	1	1	1
16	1	1	1	1	1	1
17	1	1	1	1	1	1
18	1	1	1	1	1	1
19	1	1	1	1	1	1
20	1	1	1	1	1	1
21	1	1	1	1	1	1
22	1	1	1	1	1	1
23	1	1	1	1	1	1
24	1	1	1	1	1	1
25	1	1	1	1	1	1
26	1	1	1	1	1	1
27	1	2	1	2	1	1
28	1	3	1	3	1	1
29	1	2	1	2	1	1

30	1	4	1	4	1	1
31	1	4	1	4	1	3
32	1	4	1	4	1	3
33	1	5	1	5	1	2
34	1	5	1	5	1	1
35	1	5	1	5	1	5
36	1	5	1	5	1	5
37	1	5	1	5	1	4
38	1	2	1	2	1	2
39	1	N/A	1	N/A	1	N/A
40	1	N/A	1	N/A	1	N/A
41	1	N/A	1	N/A	1	N/A
42	1	N/A	1	N/A	1	N/A
43	1	N/A	1	N/A	1	N/A
44	1	N/A	1	N/A	1	N/A
45	1	N/A	1	N/A	1	N/A
46	1	N/A	1	N/A	1	N/A
47	1	N/A	1	N/A	1	N/A
48	1	N/A	1	N/A	1	N/A
49	1	N/A	1	N/A	1	N/A
50	1	N/A	1	N/A	1	N/A
51	1	N/A	1	N/A	1	N/A
52	1	N/A	1	N/A	1	N/A
53	1	N/A	1	N/A	1	N/A
54	1	N/A	1	N/A	1	N/A
55	1	N/A	1	N/A	2	N/A
56	1	N/A	1	N/A	1	N/A
57	1	N/A	1	N/A	1	N/A
58	1	N/A	1	N/A	1	N/A
59	1	N/A	1	N/A	1	N/A
60	1	N/A	1	N/A	1	N/A
61	1	N/A	1	N/A	1	N/A
62	1	N/A	1	N/A	1	N/A
63	1	N/A	1	N/A	1	N/A

64	1	N/A	1	N/A	1	N/A
65	1	N/A	1	N/A	1	N/A
66	1	N/A	1	N/A	1	N/A
67	1	N/A	1	N/A	1	N/A
68	1	N/A	1	N/A	1	N/A
69	1	N/A	1	N/A	1	N/A
70	1	N/A	1	N/A	1	N/A
71	1	N/A	1	N/A	1	N/A
72	1	N/A	1	N/A	1	N/A
73	1	N/A	1	N/A	1	N/A
74	1	N/A	1	N/A	1	N/A
75	1	N/A	1	N/A	1	N/A
76	1	N/A	1	N/A	1	N/A
77	1	N/A	1	N/A	1	N/A
78	1	N/A	1	N/A	1	N/A
79	1	N/A	1	N/A	1	N/A
80	1	N/A	1	N/A	1	N/A
81	1	N/A	1	N/A	1	N/A
82	1	N/A	1	N/A	1	N/A
83	1	N/A	1	N/A	1	N/A
84	1	N/A	1	N/A	1	N/A
85	1	N/A	1	N/A	1	N/A
86	1	N/A	1	N/A	1	N/A
87	1	N/A	1	N/A	1	N/A
88	1	N/A	1	N/A	1	N/A
89	1	N/A	1	N/A	1	N/A
90	1	N/A	1	N/A	1	N/A
91	1	N/A	1	N/A	1	N/A
92	1	N/A	1	N/A	1	N/A
93	1	N/A	1	N/A	1	N/A
94	1	N/A	1	N/A	1	N/A
95	1	N/A	1	N/A	1	N/A
96	1	N/A	1	N/A	1	N/A
97	1	N/A	1	N/A	1	N/A