CTR D-STOP

Technical Report 116

Developing an Infrastructure-Informed Index for Pedestrians and Bicyclists

Mallory Necessary
Center for Transportation Research

January 2016

Project Title: *Infrastructure-Informed Travel Sheds*

Data-Supported Transportation Operations & Planning Center (D-STOP)

A Tier 1 USDOT University Transportation Center at The University of Texas at Austin

D-STOP is a collaborative initiative by researchers at the Center for Transportation Research and the Wireless Networking and Communications Group at The University of Texas at Austin.

Technical Report Documentation Page

1. Report No. D-STOP/2016/116	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Developing an Infrastructure-informed Index for Pedestrians and Bicyclists		5. Report Date January 2016 6. Performing Organization Code
7. Author(s) Mallory Necessary		8. Performing Organization Report No. Report 116
9. Performing Organization Name and Address Data-Supported Transportation Operations & Planning Center (D-STOP) The University of Texas at Austin 1616 Guadalupe Street, Suite 4.202 Austin, Texas 78701		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTRT13-G-UTC58
12. Sponsoring Agency Name and Address Data-Supported Transportation Operations & Planning Center (D-STOP) The University of Texas at Austin 1616 Guadalupe Street, Suite 4.202 Austin, Texas 78701		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes Supported by a grant from the U.S. Department of Transportation, University Transportation Centers Program. Project title: Infrastructure-Informed Travel Sheds		

16. Abstract

In this report, an infrastructure-informed index is developed for pedestrians and bicyclists to relate the natural and built environment with its impact on perceived travel distance and time. The objective is to develop an easy-to-use metric for use at all levels, allowing transportation planners to make better-informed decisions when planning or redeveloping a city or area. Building on similar research efforts, attributes are determined and weighted to capture the characteristics of a link, then summed to create the infrastructure-informed index for pedestrians and bicyclists, respectively. These indices are then visualized using ArcGIS mapping tools, creating a service area around specific origin or destination points to see the effective area a pedestrian or bicyclist can travel taking into account the effects of the infrastructure along the route.

17. Key Words Bicycle activity, pedestrian activity, ArcGIS, infrastructure	18. Distribution Statement No restrictions. This document is available to the public through NTIS (http://www.ntis.gov): National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161		
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 56	22. Price

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

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Acknowledgements

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers.

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1 Background

In recent years, the transportation planning sector has witnessed a steady growth in the design and implementation of policies and projects aimed at providing infrastructure not only for automobiles, but also for pedestrians and bicyclists. In the United States, multiple cities have implemented policies and design frameworks to encourage more pedestrian and bicyclist activity. Supporting non-motorized travel can help alleviate and reduce concerns related to environmental quality and public health, in addition to providing an outlet to mitigate congestion. As cities plan for new development or update existing infrastructure, more attention is being paid to developing “walk-friendly” or “bike-friendly” streets by focusing on both the natural and built environments as pleasant and enjoyable for pedestrians and bicyclists. Little data exists to quantify what is meant by “walk-friendly” or “bike-friendly” and this report hopes to fill the gap. While transportation engineers and planners may consult and determine how the concept presents itself in each respective neighborhood or local region, there is no uniform measure or definition to turn to. Incorporating non-motorized travel into planning measures is becoming a key investment and strategic tool at each level.

1.2 Motivation

This report is motivated by the fact that transportation and community planning are more and more frequently attempting to incorporate successful pedestrian and bicyclist facilities into neighborhoods and regions of all shapes and sizes without a tool or metric to fully capture the important characteristics relevant to active transportation. Various efforts have been made to categorize an area as “walk-friendly” or “bike-friendly” but current attempts all fall short of fully encapsulating the important factors from the perspective of pedestrians or bicyclists.

Walksheds are drawn to visualize how far a person can walk from a given origin and are often used to calculate how many amenities can be reached (e.g., number of grocery stores within a ten-minute walk). Walksheds can be created based on a buffer distance around a point or by using the street network to capture the effects of the network’s connectivity. In the same sense of using a walkshed drawn to visualize how far a person can comfortably walk from a given origin, a bikeshed can be created to visualize how far a person can bike from a given origin in any direction based on the infrastructure attributes along the route. Neither of these methods, however, captures the characteristics of the infrastructure aside from simple connectivity of origins to destinations.

The problem exists because of the limitations of the current tools or methodologies in place. A pedestrian or bicyclist needs not only to know how far a destination point may be, but also the attributes of the infrastructure along the route they take to travel to that point. Combining the network data of possible routes with the infrastructure attributes allows a more informed decision to be made.

1.3 Objectives

The overall goal of this report is to understand the impacts of the natural and built environment on the experience of an active commute to school or work or in running an errand, as perceived by a pedestrian or bicyclist. While recreational trips (e.g., walking the dog or exercising) are most comfortably taken in a well-planned infrastructure, the commuting or errand trips are generally made with more urgency, and thus less time for obstacles, barriers, or safety concerns. The data gathered through this report helped the author to understand the tradeoffs among environmental attributes (e.g., choosing a longer route with street trees that provide shading), and how these tradeoffs may differ by age, gender, and other demographic variables. Many studies have been conducted to analyze the relationships between various infrastructure attributes, generally determining the same recurring important variables from the pedestrian or bicyclists' point of view. These studies and attributes will be discussed in more detail in Chapter 2.

This report is the first to connect pedestrian and bicyclist perceptions about infrastructure quality and surrounding land uses to travel time and distance, and quantify the tradeoffs between all related attributes. Statistical models were developed for this purpose. The end results give the ability to assign an "impedance" value to each segment of roadway and each intersection. This impedance value accounts for all of the attributes of the segment (or intersection) and quantifies how easy or difficult it is walk or bike on.

These impedance values can be used by transportation, community, and urban planners to evaluate the "friendliness" of a given street or neighborhood for walking or biking and will help them to design and build better infrastructure to encourage and foster pedestrian and bicyclist activity in a given city or area. While this research was collected and analyzed in the Austin, Texas area, results from this analysis may be transferrable to other cities or regions similar to Austin. Further opportunities exist to modify the baseline to cities or regions dissimilar to Austin, Texas.

To this author's knowledge, this research is the first to attempt marrying factors from the natural and built environment of a given network to determine the impacts of infrastructure on travel time for pedestrians and bicyclists. Existing literature has greatly contributed to the background for determining the important infrastructure attributes, as perceived by the pedestrian and bicyclist community. The results of this research can potentially impact the transportation and community planning arenas with the availability of a new indexing tool. Additionally, this research may motivate further cultivation of the tool and improvements in the applications.

1.4 Organization

The research will be presented in this report by starting with a literature review of previous pedestrian and bicyclist studies and current practices of improvement in agencies and groups at the national, state, and local level in Chapter 2. Chapter 3 will follow with the discussion of methodology through assumptions and practices. Chapter 4 will present data collection, analysis, and results in detail. Finally, Chapter 5 will present conclusions, recommendations, impacts of this work, and opportunities for future work.

Chapter 2. Literature Review

2.1 Introduction

The focus of this research is to determine the impacts of the natural and built environment on the pedestrian and bicyclist active transportation experience. This section will review relevant literature in determining the data gathering and analysis of this research. Some previous work has been done to quantify the importance of various attributes on the pedestrian and bicyclist experience, but this research is the first to quantify the tradeoffs between these attributes and travel time (or distance). This section will be broken down into focusing on pedestrian measures of non-recreational activity, bicyclist measures of non-recreational activity, and current practices of infrastructure improvement.

2.2 Pedestrian Measures of Non-Recreational Activity

The San Francisco Department of Public Health developed the Pedestrian Environmental Quality Index (PEQI) (2008) as a tool to recognize and prioritize areas of infrastructure improvement in the planning process. An expert panel was convened to assign weights to each attribute (e.g., traffic speed, pavement quality) to reflect the level of importance each indicator has for pedestrians when evaluating street segments and intersections. The research in this report is similar to these efforts in that it will assign weights to various attributes to represent their impact on the walking experience, but the weights will be derived from a statistical model rather than via a Delphi process because it is more suited to the scope of the study and timeline assigned.

One popular effort to quantify walkability is the Walk Score developed by a company with the same name. Walk scores are developed “to promote walkable neighborhoods” by assigning points based on the distance to destinations in various categories, with destinations farther away being awarded lower point values. Walk scores are assigned based on proximity to a variety of amenities, but it does not take into account the quality of the infrastructure in traveling to or around the destination points. Walking routes to nearby amenities are included for calculating the walkability of the Walk Score, with points awarded based on network distances to amenities; street connectivity and route choice decisions are not directly incorporated, but are indirectly included through accessibility of walking routes.

Owen et al. (2007) reviewed eighteen relevant studies over the relationship of walking and environmental attributes. Here walking was broken into categories and analyzed separately by exercise and recreational walking, walking to get to and from places (such as commuting, running errands, or reaching an entertainment destination like a restaurant or friend’s home), and total walking. Aesthetics, conveniences of walking facilities, destination accessibility, and perceptions of traffic and roadway characteristics were associated with walking for particular purposes. Most highly correlated with walking to get to and from places (commuting) was the presence of sidewalks, perceptions of traffic safety, and stores within walking distance. The need was also identified to develop models for relating environmental influences and interactions with walking.

Oaks et al. (2007) identified the need for investigation into walking and “active transportation” in the environment. Here, the key factors of the built environment that impact walking are density, street pattern or connectivity, mixed land uses or the presence of destinations, and pedestrian infrastructure and design related to the issues of comfort, safety, and interest. From this research, a conclusion was made that higher densities encourage more people to walk by feeling safer upon seeing others walking, and as street network connectivity improves, so does the access for pedestrians to choose direct or alternative routes, thus increasing the efficiency of walking.

Goodwin (2005) studied pedestrian accessibility; the impact of land use on travel behavior was addressed through density and land-use mix. Here, socioeconomics, lifestyle, and attitudes toward the surrounding environment were identified as having a larger impact on travel behavior. Additionally, ratios and values were calculated to determine impedance values for segments based on potential path length, path deficiency, and roadway class. It was noted that an improved model could be developed to include sidewalk attributes, such as path width, curb distance, and presence of other infrastructure elements, connectivity, and crosswalks and signalization to measure the quality of pedestrian pathways.

Frank et al. (2006) researched the association between a single walkability index that incorporated measures of land use mix, street connectivity, net residential density, and retail floor area ratios with health related outcomes. The results of the walkability index noted the effects of the built environment measures on:

- The reduced opportunity for active transportation (reduced total physical activity, increased risk for chronic disease);
- Increased time spent in vehicles (reducing physical activity, increasing obesity, increasing risk for chronic disease);
- Increased vehicular travel (increasing per capita vehicle emissions, higher exposure to pollutants, and higher risk of respiratory and cardiovascular ailments).

A walkability index was used as a composite measure of the built environment, summing Z scores for net residential density, intersection density, land use mix, and retail floor area ratio. Results showed that people living in more walkable neighborhoods (mixed use, connected streets, high residential density, and pedestrian-oriented retail) did more walking and biking for transportation, had lower Body Mass Indices (BMIs), drove less, and produced less air pollution than people living in less walkable neighborhoods. The walkability index was significantly related to active transportation and BMI among adults (adjusted for socio-demographic factors).

Through Urban Form and Pedestrian Choices: Study of Austin Neighborhoods, Susan L. Handy (1996) studied how urban form interacts in pedestrian trip choice models. Handy hypothesized that pedestrian trips are made from a need or desire to participate in an activity located somewhere different than their location. Here, trips are also broken into strolling trips (simple walking for exercise or socializing) and walking to a destination (commuting). While urban form is an external factor in encouraging or discouraging trips to a destination, it is found here that trip distance and quality of the pedestrian environment at the destination are highly impactful on pedestrian trips.

While the research described in this section presents many useful insights into important factors impacting a pedestrian trip, this report differs by bringing the environmental characteristics and attributes into a direct relationship with a pedestrian's perceived travel time. Many aspects of the projects described above will provide invaluable information that this report uses foundationally and is able to build off of through the analysis conducted.

2.3 Bicyclist Measures of Non-Recreational Activity

Cyclists throughout the United States vary in skill levels, perceptions, and desires, which creates a difficult situation for determining what attributes factor most importantly in a ride. Prior studies have identified and/or evaluated various attributes, yet have not captured a relationship of relating multiple attributes to route choice decisions. After developing the PEQI, The San Francisco Department of Public Health (SFDPH) in San Francisco, California developed the Bicycle Environmental Quality Index, BEQI. Similar to the PEQI, the BEQI is an observational survey tool developed in 2007 by bicycle experts and members of the San Francisco bicycle community. Assessing the quality of a bicycle network, the BEQI scores and weighs the following characteristics for an overall index score:

- Intersection Safety: dashed intersection bicycle lane, no turn on red signs, bicycle pavement treatment and amenities;
- Vehicle Traffic: number of vehicle lanes, vehicle speed, traffic calming features, parallel parking adjacent to bicycle lane/route, traffic volume, percentage of heavy vehicles;
- Street Design: presence of a marked area for bicycle traffic, width of bicycle lane, trees, connectivity of marked bicycle network, pavement condition, driveway cuts, street grade;
- Safety/Other: presence of street lighting, presence of a bicycle lane or share roadway signs; and
- Land Use: line of site, bicycle parking, and retail use.

The criteria included in the BEQI are continuously reviewed and the SFDPH continues to update it based on applicable feedback. Additionally, the SFDPH work with other agencies, both in and outside of California, in applying the BEQI to other city bicycle networks.

Harkey et al. (1998) developed the Bicycle Compatibility Index, BCI, using video-based surveying and regression analysis as a tool for bicycle coordinators, transportation planners, traffic engineers, and others "to evaluate the capability of specific roadways to accommodate both motorists and bicyclists." The BCI model takes into account the presence of a bicycle lane or paved shoulder, bicycle lane width, curb lane width, curb lane volume, other lane(s) volume in the same direction, 85th percentile speed of traffic, presence of a parking line with more than 30% occupancy, and type of roadside development, with an adjustment factor for truck volumes, parking turnover, and right turn volumes.

Similar to Walk Score and developed by the same company, Bike Score Methodology assigns points to a location, based equally on bike lanes, hills, destinations and road connectivity, and bike community mode share in the surrounding area. The methodology behind calculating the Bike Score was assembled based on the Walk Score community input and expert opinions in the fields of public health as it relates to cycling and transportation. According to Bike Score Methodology, the Bike Scores are measured on a scale of 0 to 100, based on equivalent weights for the four categories listed previously.

After identifying the drastic shift away from bicycling and walking with the growth of the automobile in American households, McNeil (2010) addresses both "walkable" and "bikeable" concepts in the context of a twenty-minute neighborhood concept. Here, "walkable" is described as how far people will walk in relation to residential density, land-use mix, and street network connectivity. The concept of "Bikeability" is introduced as how far a bicyclist will go, under the assumption of a traveling speed of 10 miles per hour, in twenty minutes, a bicyclist will travel 3.3 miles. However, when applied to separate trip purposes, work commuting or non-work trips, a work commute might be farther at 2 to 4 miles and a non-work trip may be 0 to 2 miles from home. Bringing in the concept of environmental suitability for bicyclists, McNeil introduces the "bikeway quality index" (BQI) that addresses infrastructure and route characteristics through:

- Motor vehicle speeds and volumes,
- Number of travel lanes,
- Width of bicycle lanes,
- Dropped bicycle lanes and difficult transitions,
- Jogs in route,
- Quality of pavement,
- Quality of intersection crossings, and
- Number of stops.

By studying bicycle access and bikeability, in comparison to walkability, in the Portland, Oregon area through geocoding and mapping a multimodal network, McNeil determined a scoring methodology for destinations from a given origin. Criteria such as schools, parks, restaurants, and banks were awarded points based on the number of occurrences, with the sum of points equaling the Bikeability score.

Hood (2010) uses a mixed multinomial logit route choice model was also used to determine attribute relationships with San Francisco bicyclists. The results from the model developed indicate route length or travel time as an important factor in route selection, along with bicycle facility continuity, a preference for bicycle lanes, and a slight influence of overall route slope. Sener et al. (2009) found similar results where a mixed multinomial logit route choice was also used in analysis of bicycle route choice preference in Austin, Texas. Sener et al. addressed route-related attributes and bicyclist demographics through a web based stated preference (SP) survey of Texas bicyclists. The goal of the research was to develop a model evaluating the importance of six attribute categories influencing route choice preferences. The included categories are:

- Bicyclists' characteristics: age, gender, employment characteristics (commute distance, work schedule flexibility), bicycling experience, reason of bicycling;
- On-street parking: parking type (none, angled, parallel), parking turnover rate, length of parking area, parking occupancy rate;
- Bicycle facility type and amenities: bicycle lane (on-road, shared), wide-outside lane, facility continuity;
- Roadway physical characteristics: roadway grade, number of stop signs, red lights, and cross streets;
- Roadway functional characteristics: motorized traffic volume, speed limit; and
- Roadway operational characteristics: travel time.

The results of this research concluded that for commuting bicyclists, travel time and motorized traffic volume are the most important attributes in bicycle route choice. The number of stop signs, red lights, and cross-streets, speed limit, on-street parking characteristics, and bicycle facility continuity are also highly impactful on bicycle route choice. The results were modeled both with interaction effects and with time and money-based trade-offs.

Bicycle suitability evaluation criteria have been addressed in various studies over the past decade. Many attempts have been made to capture a unique bicycle level-of-service or suitability or safety index rating, and there are several commonalities between criteria and point assignments or rankings. Turner et al. (1997) identified recurring themes through many relevant studies:

- Stress levels as evaluated by curb lane vehicle speeds, curb lane vehicle volumes, and curb lane widths;
- Roadway condition as evaluated by traffic volumes, curb lane width, speed limit, pavement factors, and location factors;
- Capacity-based level-of-service generally volume-based but regarded as ill-suited for bicycle planning.

Landis et al. (2003) studied nearly 60 bicyclists in the Orlando, Florida area in specifically addressing the impact of intersections on bicyclist activity. The goal of the model developed was to identify which variables were relevant, test for the best configuration of each variable, and establish the coefficient for the variables for a best-fit regression model. Vehicle volume, width of the outside lane, and intersection crossing distance were found to be relevant for the model.

While the research described in this section presents many useful insights into important factors impacting a bicyclist's trip, this report differs by bringing the environmental characteristics and attributes into a direct relationship with a bicyclist's perceived travel time. Many aspects of the projects described above will provide invaluable information that this report uses foundationally and is able to build off of through the analysis conducted.

2.4 Pedestrian and Bicyclist Measures of Non-Recreational Activity

As described in the previous two subsections, various bicycle and pedestrian level-of-service measures have been developed, but were further studied in Linda B. Dixon's Bicycle and Pedestrian Level-of-Service Performance Measures and Standards for Congestion Management Systems. Here, the need for a bicycle and pedestrian level-of-service (LOS) is identified to better address the shift towards multimodal approaches of solving problems of air quality, congestion, infrastructure, and quality of life. The Gainesville, Florida bicycle and pedestrian LOS performance measures evaluate various criteria on a point system that translates to an A through F letter rating, with a LOS rating of E or F considered unacceptable, while C or D is considered acceptable and more realistic than an A or B. The criteria included in the bicycle LOS are:

- Bicycle Facility Provided: width of outside lane and off-street and parallel alternative parking facility;
- Conflicts: less than 22 driveways and side streets per 1 mile, barrier free, no on-street parking, medians present, unrestricted site distance, and intersection implementations;
- Speed Differential;
- Motor-Vehicle LOS;
- Maintenance; and
- Transportation Demand Management (TDM) and Multimodal Support.

The criteria of the Pedestrian LOS are:

- Pedestrian Facility Provided: dominant facility type, minimum 5 feet wide and barrier free, sidewalk width greater than 5 feet, and off-street parallel parking alternative facility;
- Conflicts: less than 22 driveways and side streets per 1 mile, pedestrian signal delay of 40 seconds or less, reduced turn-conflict implementation, crossing widths 60 feet or less, posted speed 35 miles per hour or less, and medians present;
- Amenities in Right-of-Way: buffer not less than 3.3 feet, benches or pedestrian scale lighting, shade trees;
- Maintenance; and
- TDM and Multimodal Support.

Using the bicycle and pedestrian LOS allows agencies and planning organizations to identify needed projects and gather inventories of deficiencies and improvements.

Timms and Tight (2010) explores how aesthetic "attractiveness of the built environment might be a significant factor in influencing walking and cycling." Social attitudes, functionality of the build environment, attractiveness and aesthetics, land-use patterns, political willingness to embrace change, transportation policy, technology, and operation-ability are the factors considered in visualizing and planning for increased walking and bicycling to achieve urban sustainability. Although highly subjective, the aesthetic attractiveness of a segment is considered a key factor in improving the pedestrian and bicyclist experience. Using computer-generated visualizations, while imperfect, an attempt can be made to improve bicyclist and pedestrian environments in planning.

Moudon and Lee (2003) assess existing walkability and bikeability tools. Three components are the underlying themes in guiding the model: the origin and destination of the walk or bike trip, the characteristics of the road traveled, and the characteristics of the areas surrounding the trip's origin and destination. Both recreational and transportation-related trips are included in the thirty-one instruments and almost 200 variables reviewed, however no single tool covers all constructs of the behavioral model of environments included.

Dill (2004) introduces measures of connectivity as indicators of "smart growth, New Urbanism, and neo-traditional development." In this school of thought, street connectivity increases walking and bicycling. Block length, block size, block density, intersection density, street density, connected node ratio, link-node ratio, grid pattern, pedestrian route directness (PRD), and effective walking area (EWA) are discussed as effective measures of connectivity for transportation and urban planners. An application was made with street network density (miles per square mile), connected node ratio, intersection density, and link-node ratio in the Portland, Oregon area network. While positive correlations were found, there was inconsistency in applying the level of connectivity at the census tract level.

Kasemsuppakorn and Karimi (2008) present a routing method for wheelchair users by taking sidewalk obstacles into account. Using fuzzy logic, impedance scores are calculated for each sidewalk segment, connecting a desired origin-destination pair in a sidewalk network by the optimal route. Slope, sidewalk width, steps, segment length, surface type, cracks, manhole covers, and uneven surfaces are the parameters included in calculating impedances.

2.5 Current Practices of Infrastructure Improvement

Currently, many practices are being implemented at the national, regional, and local level to improve pedestrian and bicyclist network activity. The following presents several of these measures relevant to the research conducted.

The U.S. Department of Transportation (USDOT) Federal Highway Administration (FHWA) defines Pedestrian Hybrid Beacons, also known as a High Intensity Activated Crosswalk (HAWK), as pedestrian-activated warning devices located on the roadside or on mast arms over midblock pedestrian crossings. To use, the pedestrian pushes a button to activate the beacon. Once activated, a red light stops drivers and allows pedestrians to cross, followed by a period of a flashing red for pedestrians to finish crossing. To date, the installation and use of the Pedestrian Hybrid Beacon has shown up to a sixty-nine percent reduction in pedestrian crashes and up to a twenty-nine percent reduction in total roadway crashes. Devices such as these can improve the walking experience, primarily at intersections, by increasing safety for pedestrians.

USDOT FHWA also defines Medians and Pedestrian Crossing Islands as another measure to improve safety for pedestrians in urban and suburban areas. Medians can either be raised or open areas between opposing lanes of traffic in the middle of the roadway. Pedestrian crossing islands are raised islands located either at an intersection or midblock crossing location. Both measures separate pedestrians from motor vehicles and help improve safety for both groups. Midblock crossings account for more than seventy percent of pedestrian fatalities, but when implemented correctly, medians and pedestrian crossing islands have been shown to:

- Reduce pedestrian crashes by forty-six percent and motor vehicle crashes up to thirty-nine percent;
- Decrease delays for motorists by over thirty percent;
- Enhance visibility for pedestrians;
- Reduce speed of approaching motor vehicles;
- Provide space for access management for vehicles; and
- Provide space for supplemental signage on multi-lane roadways.

Advanced Bike Detection (Dale 2013) is a specific example of a measure under consideration in Austin, Texas through the City of Austin, Austin Transportation Department Arterial Management Division. With many active bicyclists in Austin, issues have been identified associated with bicyclists not being detected at intersections. The proposed project would develop a smart phone application, which users would begin prior to making a trip. Location, velocity, and heading information would be provided at one-second intervals that would trigger a pedestrian actuation once the bicyclist entered a virtual detection zone prior to arrival at an intersection. While this effort is currently in pilot mode, it has the potential to greatly enhance safety and mobility for active bicyclists. Similar efforts are underway in the San Francisco Bay Area and Portland, Oregon metropolitan areas, among others. Efforts such as these are examples of how the infrastructure of an area can help improve the bicyclist experience along a route, rather than hinder it with risks and dangers of traveling through intersections.

Bike Share programs are very popular efforts appearing more frequently in cities around the world. In the United States, Bike Share programs have been in operation or planning stages since the early 2000s, with Washington, DC opening Smartbike DC in 2008 as the first major city to implement a modern bike share system (Toole Design Group 2013). Many programs promote bicycling around different city attraction points with memberships available on daily, weekly, monthly, or annual levels, often with initial use periods free, followed by interval pricing schemes. Some bicycles include in the programs go so far as to track not only mileage during use, but also calories burned and carbon emission offset. In this way, bike share programs are promoted as an active lifestyle choice, with the obvious health benefits, and as an environmental choice. Bike Share programs can encourage active transportation modes for travelers who may not have the access to bicycles. Additionally, the presence of more bikes in an area can improve the relationship between cyclists and motorists, with increased awareness and comfort for sharing the roadway. The following cities have implemented or planned programs ("Bicycle Sharing System" 2013):

- 2010: Denver, Des Moines, Iowa, Minneapolis, Minnesota, and Washington, D.C.;
- 2011: Boston, Miami, Boulder, Colorado, Madison, Wisconsin, and Chicago;
- 2012-2013: Charlotte, North Carolina, Chattanooga, Tennessee, Houston, Texas, Portland, Nashville, New York, Fort Worth, Texas, Columbus, Ohio, and San Francisco;
- Future Plans: Atlanta, Georgia and Austin, Texas, among others.

Complete or Green Streets are a growing measure of implementing policies on the regional or local level to ensure consistency in planning and design for multimodal uses-pedestrians, bicyclists, public transportation, and motor vehicles. Complete Streets aim to improve safety for all modes of transportation, regardless of user age or ability level. While there is no single design policy in place, Complete Streets are designed by transportation engineers or community planners to improve accessibility through such aspects as sidewalks, bike lanes, bus lanes, public transit stop shelters, designated crosswalks, median islands, pedestrian and/or bicyclist markings and signals, curb extensions, roundabouts, and more.

Roundabouts or traffic circles, while known for improving motor vehicle flow, can also incorporate bicycle and pedestrian activity in a safer manner. Pedestrians and bicyclists can be routed away from intersections through separate facilities, raised bridges, and signalized crossings. Motor vehicle traffic is calmed, with a lower speed limit, through the intersection, which facilities an improved level of safety for pedestrians and bicyclists.

The FHWA bicyclist and pedestrian planning site is a measure at the federal level to promote various programs to increase bicycle and pedestrian active transportation, safety, and accessibility. While each state possesses a Bicycle and Pedestrian Coordinator, the FHWA Bicycle and Pedestrian Program issues guidance and legislative requirements for each state and regional agency. Federal funding and sponsorships are available in various ways to implement and promote pedestrian and bicyclist programs, facilities, and educational outreach opportunities.

The research described in this section presents many useful insights into important factors currently trending, improving, or making an overall impact on trips made by both pedestrians and bicyclists. Many aspects of the projects improving the infrastructure for active, non-motorized transportation described above will provide invaluable information that this report uses foundationally and is able to build off of through the analysis conducted.

2.6 Summary

While many separate and combined pedestrian and bicyclist measures of active, non-recreational transportation exist, and infrastructure investments and improvements are being made at the federal, regional, and local levels, there are still gaps in encompassing the effects of the infrastructure on the trip of an active pedestrian or bicyclist. There is still the need for a tool to represent how the infrastructure impacts a pedestrian's or bicyclist's perceptions relative to the speed, distance, and time they have traveled. The following section presents the methodology of this research into creating an infrastructure-informed walkshed (IIW) and infrastructure-informed bikeshed (IIB). This report serves to make the initial efforts into developing the IIW and IIB to capture how the infrastructure along a route impacts the perceptions of an active, non-motorized traveler. The relationship between the natural and built environment and pedestrian and bicyclist perceptions is vast and complicated, yet based on prior research an insight into the most important infrastructure attributes is available. Using the combined knowledge gained from other research efforts, depicting an IIW and an IIB is possible.

Chapter 3. Methodology

3.1 Assumptions

One of the original goals of the research supporting this report was to develop one measure of activity to encompass both walking and cycling. After preliminary research and experimentation were conducted, however, it was discovered that based on the nature of the data involved and required, it was best to develop these measures separately. For the IIB, prior research was available to build off of, yet for the IIW, a new study was required to gather preliminary research. In both pedestrian and cyclist activity, there is a lot of information that is difficult to gather. The indices described in the following subsections require many points of data in order to operate effectively. Additionally, due to the nature of traffic patterns continuously changing based on the time of day, day of the week, season of the year, weather, holidays, etc., general assumptions were required in order to show the utility, rather than the precision, of the index.

For both the IIW and the IIB, information was gathered about the roadway segments and surrounding environment assuming no special conditions, such as inclement weather or holiday travels. Additionally, the time of day or day of the week is not considered as an impacting variable in this research, by using an average of traffic volume, where required. If the data were available, these could be considered impacting variables of study, but that is beyond the current scope. Several other assumptions are required in both indices, which are described in more detail in the subsections to follow.

3.2 Developing the Infrastructure-informed Walkshed

The hypothesis in developing the IIW is as follows: when the infrastructure is less desirable for walking, people are not willing to walk as far (or for as long). The goal of the IIW is to capture these effects. Instead of a ten-minute walkshed, for instance, the output would be a "ten-minute max" walkshed where the walkshed extends for ten minutes (using network distance) under ideal conditions, but it does not extend as far under conditions that are less than ideal.

To understand the creation of the IIW, different characteristics and attributes of the infrastructure of a given road segment, or link, must be understood. Listing each characteristic and assigning weight to the attribute levels of each can be used to determine an aggregate score of the attributes of a link, identified as the IIW.

Previous research has identified many factors that may influence the quality of a walk trip. The IIW used in this report draws primarily from San Francisco's Department of Public Health's Pedestrian Environmental Quality Index (PEQI), since this was the most comprehensive effort to date. The PEQI, which was developed in collaboration with experts including city planners, consultants, and pedestrian advocates, assigned weights to characteristics of street and sidewalk infrastructure. Many characteristics included in the PEQI are found in other literature (e.g., Dixon, Harkey et al, Kasemsuppakorn and Karimi) to be very important to pedestrian activities.

One goal of the current research is to characterize the infrastructure using data that is readily available, through online databases maintained by a federal, regional, or local government or agency, easily gathered through first-hand observations, or obtained through contacting an appropriate agency, if it is not posted publicly. Therefore metrics that are not ready available (e.g., the presence of foul odors) are left out. The variables that were chosen for the IIW are important factors in encouraging and enabling pedestrian activity. They serve as indicators that, when presented in the most adverse combinations, can hinder pedestrian activity. These variables were confirmed through surveys, experimentation, and expert opinions in the area of urban planning and development.

The resulting characteristics present in the IIW are:

- Number of lanes (Harkey, PEQI),
- Posted speed limit (Dixon, Harkey et al., Kasemsuppakorn and Karimi, PEQI, Sener at al.),
- Sidewalk width (Dixon, Kasemsuppakorn and Karimi, PEQI),
- Pavement type and condition (Dixon, Harkey et al., Kasemsuppakorn and Karimi),
- Traffic volume (Harkey et al, PEQI, Sener et al.),
- Street lights/shade trees (Dixon, PEQI), and
- Adjacent land use (Harkey et al., PEQI)

Weights were assigned to each of the above characteristics in the following way. For all characteristics except for pavement type and condition, the weights were taken directly from the PEQI. For pavement type and condition, weights were assigned based on the conclusions drawn from other research efforts (Harkey et al., Kasemsuppakorn and Karimi). A similar level of importance was found for pavement type and condition as traffic volume and sidewalk width on the impact of infrastructure on pedestrian activity. The weights for traffic volume and sidewalk width are equal in the PEQI and thus translated for the weights on pavement type and condition attributes. The final weights for the IIW can be found in Table A1 in the appendix.

For any given segment, the weights assigned to each of its attributes are summed to create its IIW. Based on the IIW weights in Table A1, the maximum and minimum walk indices a segment can have are 74 and -5, respectively. Using the assumptions of a pedestrian walking speed of 3 miles per hour and a maximum walking time of ten minutes (equivalent to one-half mile) creates a baseline under the best-case circumstances. In two minutes (equivalent to 0.1 miles or approximately the length of one block) in the worst-case circumstances, the worst case walking speed was assumed at 0.6 miles per hour, or one-fifth of the best-case scenario. (Note that we are not assuming that people walk slower under worse conditions; A lower walking speed is being used as a proxy to obtain a smaller walkshed; i.e., that people will only walk one block under the worst case circumstances.) Using these data points, a linear model was established to relate the speed (miles per hour, mph) that should be assigned to a link as a function of its IIW.

$$\text{Speed} = 0.031*(\text{IIW}) + 0.75 \qquad (1)$$

A similar method was used to relate the weight assigned for any given characteristic to a change in walk speed.

$$\Delta \text{Speed} = 0.031*(\Delta \text{IIW}) \quad (2)$$

An example of using equation 2 is as follows. If a segment has two lanes of vehicle traffic, the speed assigned to that link will decrease by 0.031*(12-6) = 0.186 mph. Twelve is the weight assigned to the best case scenario for number of lanes (a pedestrian and/or bicycle only street) and six is the weight assigned to the presence of two lanes of vehicle traffic. Therefore, the walk speed on a street segment that has ideal conditions in every other way except for having two lanes of traffic would be 3 - 0.186 = 2.184 mph and the maximum walking distance on a street with these characteristics would be 0.469 miles, which is less than the one-half mile walking distance under best-case conditions.

3.3 Developing the Infrastructure-informed Bikeshed

Sener et al. (2009) proposed various future research efforts to extend their results, including cost/benefit evaluations for bicycle route improvements and developing policy initiatives targeted at bicyclist groups, among others. This research, however, extends their results in a different manner. Utilizing the specific results for time-based trade-offs of route attributes for short-commute distances, this research overlays the minute values onto links in the Austin, Texas network. The route attributes included were determined by a stated preference survey administered to bicyclists of varying skill levels (please see reference 1 for more information). The route attributes and attribute levels included are:

- On-street Parking
    - Parking type: parallel or angle
    - Parking turnover rate: moderate or high
    - Length of parking area: moderate (2-4 city blocks) or long (5-7 city blocks)
    - Parking occupancy rate: moderate (26-75%) or high (76-100%)
- Bicycle Facility
    - Bikeway width/type: no bicycle lane and a 10.5 feet wide outside lane widths or no bicycle lane and a ≥14 feet wide outside lane widths
    - Continuous bicycle facility: continuous
- Roadway Physical Characteristics
    - Terrain grade: moderate hills or steep hills
    - Number of stop signs, red lights and cross streets: moderate (3-5) or high (more than 5)

- Roadway Functional Characteristics
    - Traffic volume: moderate or heavy
    - Speed limit: moderate (20-35 mph) or high (more than 35 mph)

For each of the attribute levels, a time value was calculated for a short-commute (less than or equal to 5 miles) or long-commute (greater than 5 miles). For this research, we will focus on the short-commute distance values. According to Dill (2009), in ideal conditions, a cyclist would travel an average of 3 miles in one direction at a 10 mile per hour speed. Similarly, Dixon (1996) cites an average bicycle speed of 15 miles per hour, although she also notes it is in the higher end of the range of average speeds for young adult and novice bicyclists. Each link possesses characteristics that are either perceived as positively or negatively impacting a bicyclist's ride along a route. Inventorying the links and cataloging the attributes allows a total time value to be assigned to each link. Relating the total time value to distance allows a speed to be derived, which represents the bicyclist's perceived speed along the link. Increasing or decreasing the speed from a baseline value provides a truer representation of how far a bicyclist can comfortably travel in any given direction from an origin point, visualized through the bikeshed buffer.

The time-based trade-offs of route attributes for commuting distances present positive values equivalent to how much additional travel time bicyclists would be willing to travel to avoid the corresponding attribute on a route; the negative values are equivalent to how much additional travel time bicyclists would be willing to travel to have the corresponding attribute on a route. The time value based trade-off (in minutes) as explained previously, is shown in Table 1 (Sener et al. 2009). Additional assumptions on several attribute levels are required, due to the size of the Austin, Texas network and the scope of this research. For this research, the assumption is made that the majority of non-recreational activity for cyclists will occur during the a.m. and p.m. peak time periods- commuters making trips to school or work, primarily.

Table 1. Time-Based Trade-Offs of Route Attributes For Short Commutes (Sener et al. 2009).

	Attribute	Attribute Level	Time Value (in min.) Short-commute distance (≤ 5 miles)
On-street Parking	Parking type	Parallel parking permitted	6.21
		Angle parking permitted	2.79
	Parking turnover rate	Moderate	3.88
		High	13.1
	Length of parking area	Moderate (2-4 city blocks)	8.29
		Long (5-7 city blocks)	9.28
	Parking occupancy rate	Moderate (26-75%)	4.26
		High (76-100%)	14.1
Bicycle Facility	Bikeway width/type	No bicycle lane and a 10.5 feet wide outside lane widths	-1.31
		No bicycle lane and a ≥ 14 feet wide outside lane widths	-1.43
	Continuous bicycle facility	Continuous	-12.63
Roadway Physical Characteristics	Terrain grade	Moderate hills	-3.32
		Steep hills	5.19
	# Stop signs, red lights and cross streets	Moderate (3-5)	7.54
		High (more than 5)	25.03
Roadway Functional Characteristics	Traffic volume	Moderate	10.68
		Heavy	31.29
	Speed limit	Moderate (20-35 mph)	10.91
		High (more than 35 mph)	22.93

Through the City of Austin GIS database (“Transportation: Meta Data” 2013), different inventories exist relevant to the route attributes included in the bikeshed calculation; however enough accuracy in details was not readily available at the time (and within the scope) of this project (i.e., using contour maps to determine changes in elevation along links to classify hills as moderate or steep). Thus, many route attribute levels were assumed based on the road class type, as defined in Table 2. These classifications were used to make reasonable assumptions of parking type, parking turnover rate, length of parking area, parking occupancy rate, bikeway width/type, number of stop signs, red lights and cross streets, and traffic volume. Additionally, moderate hills are assumed throughout the Austin network. Bicycle facility continuity was assessed through matching the street network to the bicycle route network, finding the voids, and assigning values based on the presence of a route on the links and the road class. Speed limit postings are embedded into characteristics of each link.

Table 2: Street Classification Based on Generalized US Census Bureau Standards (“Transportation: Meta Data” 2013)

Value	Definition
0	Category unknown
1	Interstate Highway, Expressway or Toll road
2	US or and State Highway
4	County Roads (RR, RM, FM, etc.) and Major Arterial
5	Minor Arterial
6	Local City/County street
8	City Collector
10	Ramps and Turn Arounds
12	Driveway
14	Unimproved Public Road
15	Private Road
16	Routing Driveway/Service Road

Utilizing the ArcGIS join tool, route attributes were cataloged for each link in the Austin, Texas regional network. This is done by first adding new fields created for each route attribute in the attribute table in GIS, into which either a ‘1’ or ‘0’ was recorded to indicate either the presence or absence of the attribute along each link. With values for each route attribute recorded for each link, an overall impedance score, or bikeshed, was calculated for each link by summing the given weights assigned to the presence of each route attribute. The bikeshed represents the perceived amount of time to be added or subtracted along the link for an average cyclist. Within the ArcGIS Network Analyst tools exists an analysis option to create a service area layer. In this case, the service area is equitable to the bikeshed. This option allowed the bikeshed of each link to be visualized. With the bikeshed in place, specific origin locations are pinpointed for a more detailed analysis.

Chapter 4. Analysis

4.1 Data Collection

In order to further investigate and verify the validity of both the IIW and IIB, example applications were made on both methods. In the subsections to follow, the details of the data collection, analysis, and results are given that apply the previously described methodology for both the IIW and the IIB. An additional extension of both the IIW and the IIB is provided as well, shown through an experiment with neighborhood connectivity.

All analysis, assumptions, methods, calculations, and results are presented in three separate cases. First, an introduction into a specific application of the IIB in the downtown Austin, Texas area through GIS will be presented, with background information explaining how the data was used to visualize the IIB. Next, a pilot study is detailed as an application of the IIW in the downtown Austin, Texas area. Last, a combined application of both the IIB and IIW is presented through an example of manipulating connectivity in the Austin, Texas area. Each separate application serves to better explore each area, presenting more details on the methods described in Chapter 3 previously.

4.2 Infrastructure-informed Bikeshed: GIS Application

For this report, visualizing the IIB was done through an application around three bike shops in downtown Austin, Texas, shown in Figure 1. These bike shops collectively offer services for maintenance, purchasing bikes and gear, training, and group rides. Utilizing the bikeshed values for each surrounding link, the bikeshed service area is visualized around these bike shops (the origins) to see the distance to which cyclists can travel away from the bike shop comfortably, in reality. The bikeshed service area depicts the true network of all accessible streets that lie within the impedance value of a cyclist traveling a perceived 10-minute short commute. In the map below, arrows point to the three bike shops studied.

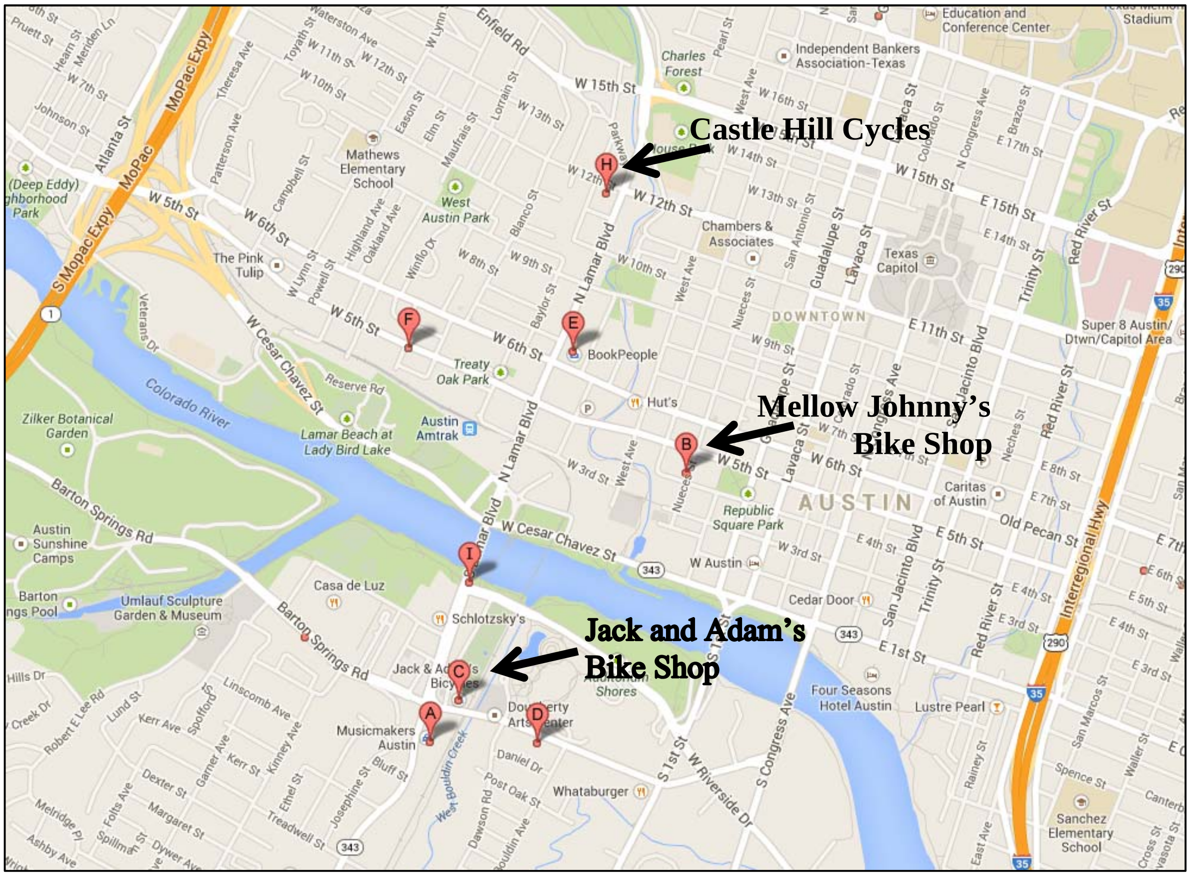

Figure 1: Map of Several Bike Shops in the Downtown Austin, Texas Area ("Austin, Texas" Google Maps 2013).

4.2.1 Analysis

To illustrate how the IIB differs from other similar efforts described in the literature review in Chapter 2, an application was made to directly compare Bike Scores to the IIB. Bike Scores were measured for these three locations, seen in Figure 1. Marker B represents Mellow Johnny's Bike Shop, which receives a Bike Score of 96, described as "Biker's Paradise: Flat as a pancake, excellent lanes" ("Bike Score™ Methodology" 2013). Marker C represents Jack & Adam's Bicycles, which receives a Bike Score of 93, described as "Biker's Paradise: Mostly flat, excellent lanes" ("Bike Score™ Methodology" 2013). Marker H represents Castle Hill Cycles, which receives a Bike Score of 86, described as "Very Bikeable: Some hills, excellent lanes" ("Bike Score™ Methodology" 2013). While the similarities described previously do exist between the Bike Score measurement and the Bikeshed, the goal of the Bikeshed is to present a better-informed and more thorough description of the service area of each bike shop analyzed, based on the inclusion of many more evaluation criterion points than are included in the Bike Score (such as taking into account parking characteristics).

From Sener et al (2009), a time value was calculated for a short-commute or long-commute (based on mixed multinomial logit analysis) for each of the attribute levels. For this research, we will focus on the short-commute distance values because it is the best set of values to visualize on a map. Additional assumptions are made to determine the ideal baseline of a 2-mile commute requiring 20 minutes at an average speed of 6 miles per hour. Additionally, assumptions will be made for the parking turnover rate and parking occupancy rate. Using the given time-based trade-offs of each route attribute, a new field will be added to the Austin, Texas network shape file via the ArcGIS Network Analysis tool. The new field will contain the weights of all attributes present on each link in the network to create buffers that will work as impedance values. Based on the total impedance value, the baseline time for traveling down the link will increase or decrease. As expected, no links reflected an improvement in the cyclist's experience as seen through the ability to travel farther than the average distance of 3 miles. Overall for each link, a positive time represents how the infrastructure hinders a cyclist's trip, effectively decreasing the distance to less than the average of 3 miles. Figure 2 shows the travel time on links without any impedance values.

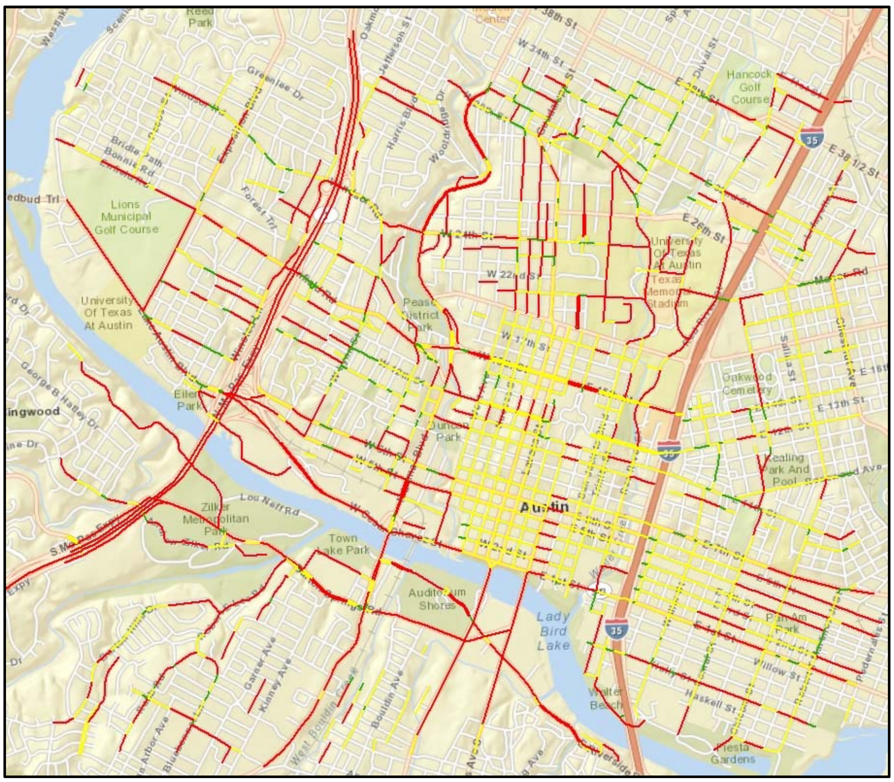

Figure 2: Visualization of Link Travel Times without Impact of Impedances.

As a comparison, the direct impact of infrastructure is shown in Figure 3 with red representing links perceived as an additional 30 seconds or more longer in time compared to the baseline, yellow representing links perceived as an additional 15 seconds to 30 seconds longer in time compared to the baseline, and green representing links perceived as an additional 2.1 seconds to 15 seconds longer in time compared to the baseline. Using the green, yellow, and red color scheme, green shows the least impacted links, yellow the moderately impacted links and red the most heavily impacted links when taking into account the impact on short-commute travel-time of the route attributes from Table 1.

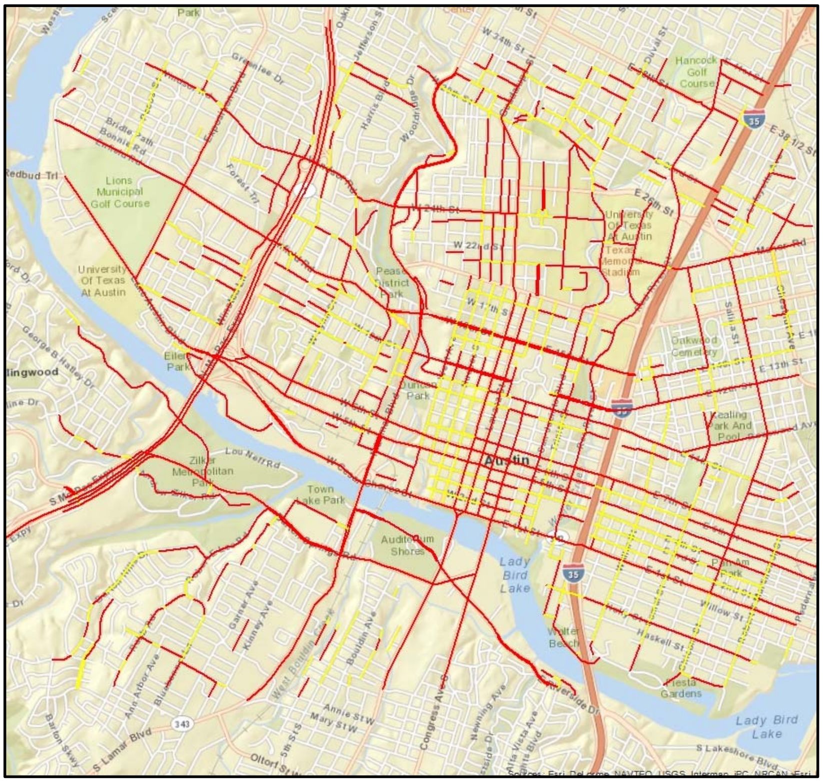

Figure 3: Visualization of Route Attributes Impacting Link Travel Time for Short Commutes.

After each route attribute was inventoried and the bikeshed impedance value was calculated for each link, the bikeshed service area was visualized using the ArcGIS Network Analyst tool. By using three bike shops as origin points, the bikeshed service area shows how the natural and built environment impacts a cyclist's trip, against the baseline of a 10-minute short-commute distance at a speed of 10 miles per hour.

4.2.2 Results

In comparison to the Bike Scores of each bike shop included in the analysis, the bikeshed service area is better for representing the true nature of the natural and built environment for the 10-minute radius area surrounding the bike shops. While Bike Score describes these areas as seemingly pleasant for cycling, the bikeshed service area shows that there is a stunted area compared to the service area based on travel time alone. Considering the previously discussed average short-commute distance of 3.0 miles and 30 minutes, traveling down almost any of the links surrounding these bike shops will immediately shorten the average cyclist's trip because of the perceived increase of time. As an extension, a cyclist could quickly glance at this depiction of the area surrounding the bike shops and determine the trip would pass through many links that will make the route traveled feel effectively longer in time. This analysis is in agreement with the idea that by including information about a higher number of route attributes, a more accurate reflection of cyclist perceptions is captured. These visualizations are captured in Figures 4, 5, and 6, with the 10-minute uninformed travel time service area shown in purple and the 10-minute IIB service area shown in turquoise blue. An interesting aspect of these visualizations occurs where the service area has “holes” in the midst of the overall area. These “holes” are attributed to areas where the time value associated with the link brings the total travel time to greater than 10 minutes.

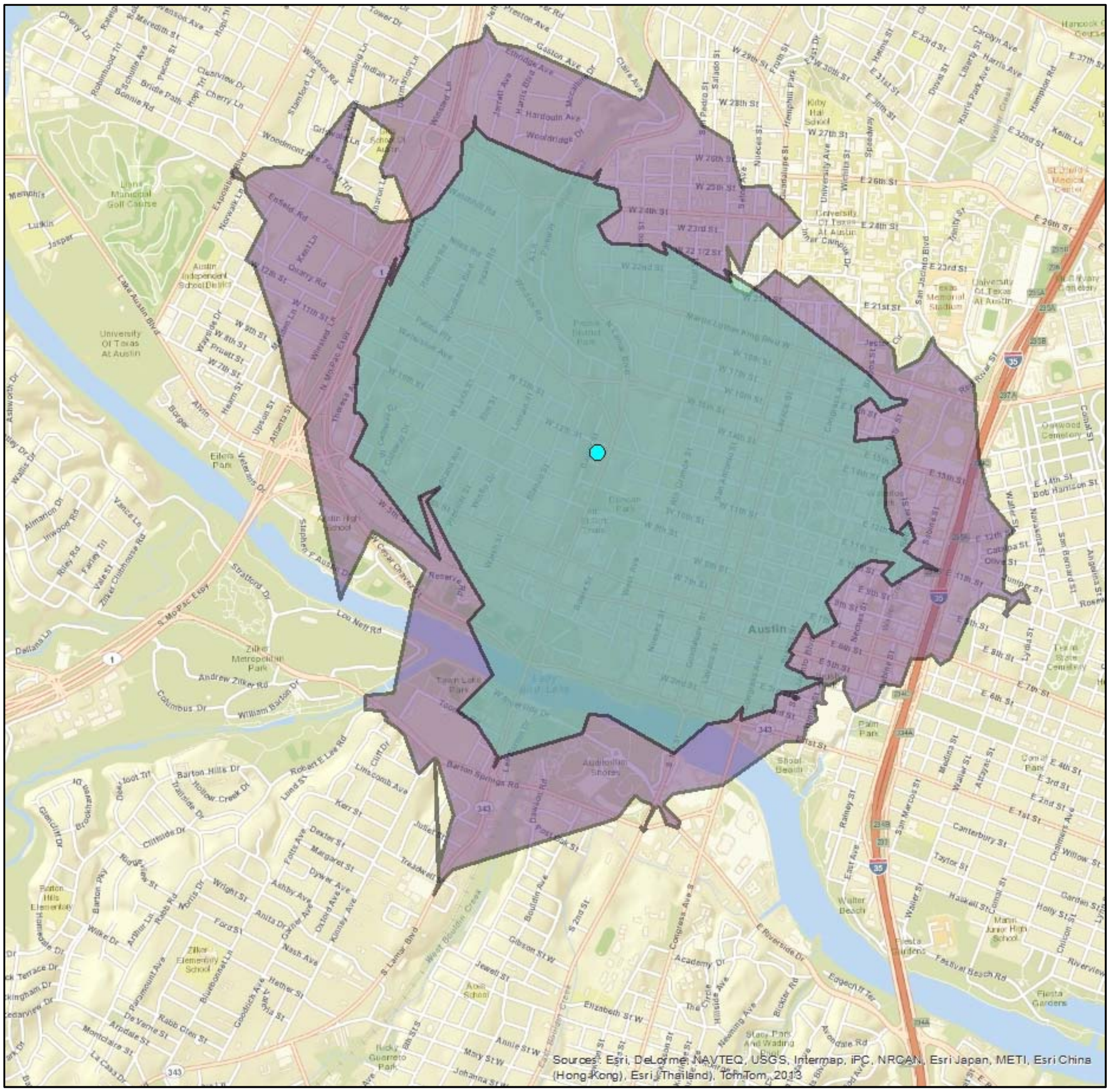

Figure 4: Uninformed Travel Time and IIB Service Area Visualization of Castle Hill Cycles.

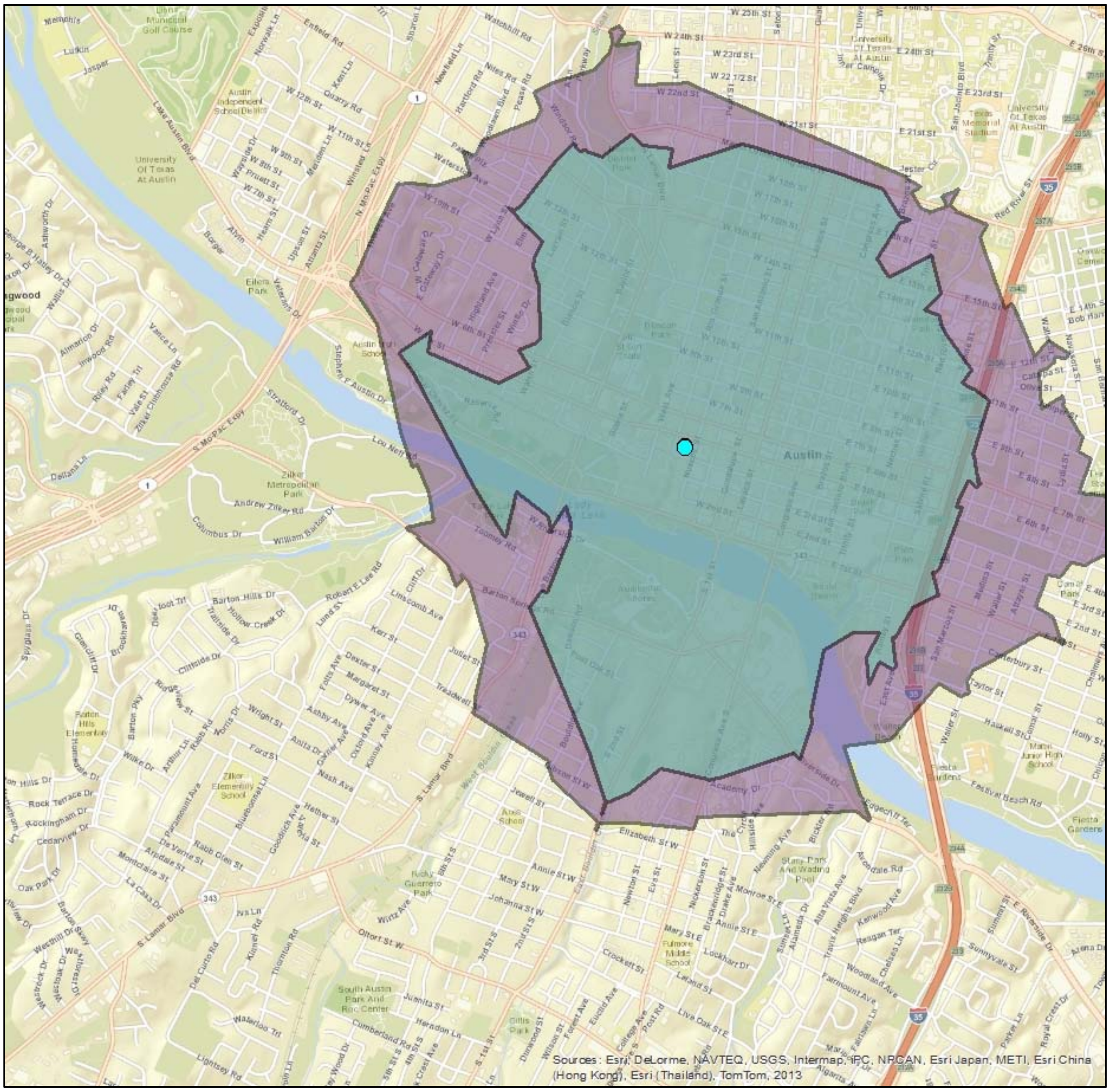

Figure 5: Uninformed Travel Time and IIB Service Area Visualization of Mellow Johnny's Bike Shop.

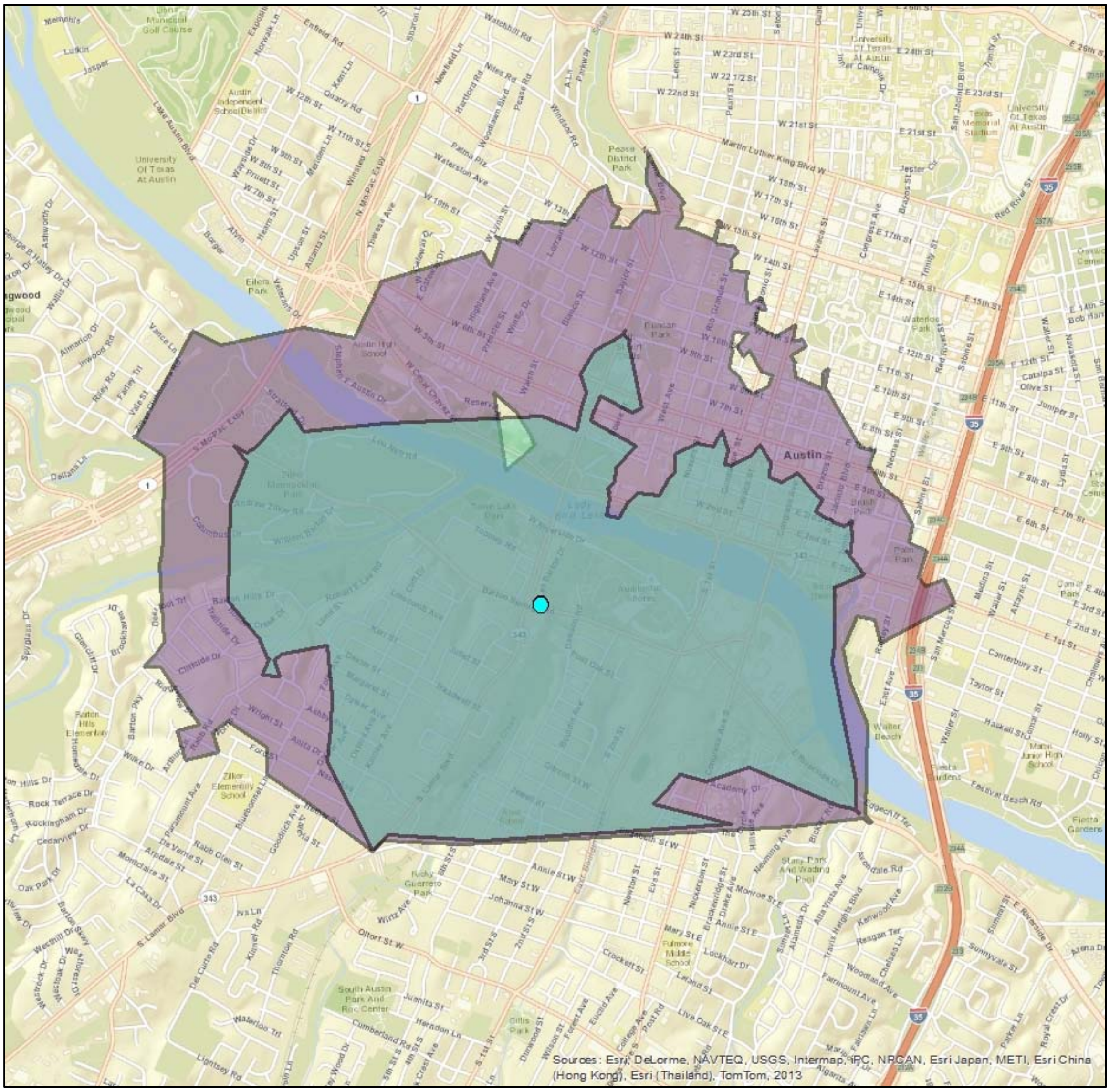

Figure 6: Uninformed Travel Time and IIB Service Area Visualization of Jack and Adam's Bicycles.

These service area layer visualizations are also useful in determining what the ratio of IIB area is to uninformed area, a metric the author has deemed the Active Transportation Index (ATI). In Table 3, the ATI for each location analyzed is calculated. The Uninformed Bikeshed Area and IIB Area were calculated for each location using a tool in ArcGIS that captures the area in square feet of a polygon. From these values, a conclusion can be drawn that the IIB is approximately 57% of the uninformed travel time service area.

Table 3: ATI Calculations for Each Analysis Location.

Location	Approximate Uninformed Bikeshed Area (square feet)	Approximate Infrastructure-informed Bikeshed Area (square feet)	ATI
Castle Hill Cycles	120800000	68030000	56.31%
Mellow Johnny's Bike Shop	124200000	73680000	59.32%
Jack and Adam's Bike Shop	115300000	65540000	56.81%

4.3 Infrastructure-informed Walkshed: Pilot Survey

Handy (1996) researched urban form and pedestrian choices and ultimately discovered that the distance from home to a destination is the most important factor in making the decision to walk. Additionally, the quality of the pedestrian environment at the destination is more important than that around the home. These factors encouraged a pilot survey, outlined previously, to be conducted in the downtown Austin, Texas area in order to determine how the quality of the pedestrian environment can impact perceived travel time and distance.

A pilot survey was developed to gather revealed data to inform the IIW calculations. The survey was implemented in Austin, Texas, which is important to note since there may be location-specific variation in any data collected (e.g., residents of hilly environments may view hills as less onerous than residents of flat environments). The basis of the pilot survey was completing a one-mile walk with each respondent, separately. Each walk followed the exact same route, stopping at each 0.25 mile to answer 3 questions aimed at gaining insight into the perceptions of pedestrians. The questions, listed below, were asked in the same order at each stopping point, and respondents were asked not to look at a clock at any time during the one-mile walk.

1. How far (distance in miles) do you think we have walked since the last segment?
2. How long (time in minutes: seconds) do you think we have walked since the last segment?
3. Do you have any comments about the segment you have been walking on since the last stop?

Before the walk, the only information provided was encouragement to walk at a comfortable pace along the highlighted route, shown in Figure 7. Throughout out each walk segment, casual conversation was upheld with the respondent for consistency between all walks. At the end of each walk, the purpose of the pilot survey was discussed with the respondent, with the option of learning more about the results once all data collection and analysis was complete.

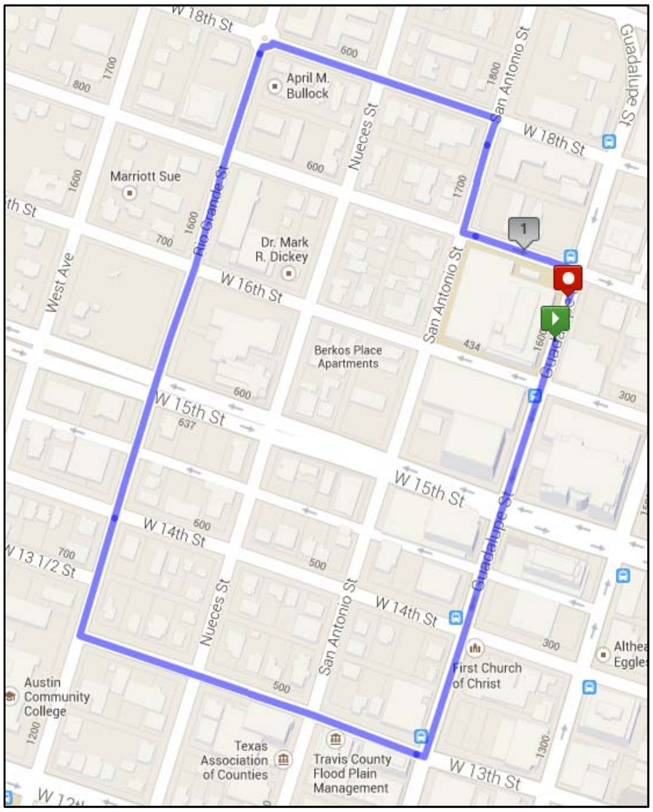

Figure 7: Map of Pilot Survey Walking Route.

The pilot survey was conducted over a seven-week period during the summer months (June, July, and August) in the downtown Austin, Texas area. Ten respondents were solicited through email and participated on a fully voluntary basis, with no incentives or rewards given. The initial recruiting email was sent to the University of Texas Undergraduate Summer Internship in Transportation (USIT) group. These USIT respondents were a mixed group of undergraduate students from throughout the country, including Austin, Texas, who were living in Austin for the summer. Given the high temperatures through these months, all data collection was scheduled for the morning hours, between 9:00 am – 10:30 am, to keep the temperature relatively consistent and as mild as possible.

4.3.1 Analysis

After all respondents had participated in the pilot survey, data from each walk was entered into a password-protected spreadsheet, keeping respondents' results private and anonymous in analysis. Initial analysis was done to determine an average response for time and distance of each segment, in comparison to the average actual time and distance for each segment. Overall, nine of the ten responses in distance were relatively close; however there was one outlier, due to a respondent who was not very familiar with the US measurement system. For the average distances guessed, the outlier is removed from the data set. In Table 4, all gathered data is shown, along with the averages calculated.

Table 4: Respondent Data Gathered from Pilot Survey.

Segment	Respondent	Times Guessed	Actual Times	Average Times Guessed	Average Actual Time	Distance Guessed	Actual Distance	Average Distance w/o Outlier
1	1	7:00	4:43	5:15	4:28	0.33	0.25	0.3144
	2	4:30	4:46			0.2	0.25	
	3	5:00	4:27			0.25	0.25	
	4	6:00	4:22			0.75	0.25	
	5	5:00	4:30			0.062	0.25	
	6	5:00	4:59			0.15	0.25	
	7	4:00	4:14			0.14	0.25	
	8	6:00	4:17			0.43	0.25	
	9	6:00	3:52			0.33	0.25	
	10	4:00	4:32			0.25	0.25	
2	1	7:00	4:53	6:18	4:46	0.33	0.25	0.3378
	2	6:00	4:40			0.25	0.25	
	3	7:00	4:45			0.25	0.25	
	4	7:00	4:50			0.75	0.25	
	5	8:00	4:30			0.093	0.25	
	6	7:00	5:26			0.15	0.25	
	7	5:00	4:39			0.19	0.25	
	8	5:00	5:05			0.37	0.25	
	9	6:00	4:22			0.4	0.25	
	10	5:00	4:37			0.35	0.25	
3	1	6:00	4:57	5:36	4:52	0.28	0.25	0.3478
	2	5:30	4:44			0.2	0.25	
	3	8:00	4:20			0.4	0.25	
	4	5:00	4:59			0.75	0.25	
	5	5:00	5:08			0.062	0.25	
	6	8:00	5:39			0.2	0.25	
	7	5:00	4:51			0.2	0.25	
	8	7:00	5:02			0.75	0.25	
	9	4:00	4:24			0.15	0.25	
	10	2:30	4:40			0.2	0.25	
4	1	4:00	4:30	4:38	4:39	0.15	0.25	0.2589
	2	4:30	5:05			0.17	0.25	
	3	5:00	4:25			0.25	0.25	
	4	6:00	4:36			0.75	0.25	
	5	4:00	4:29			0.043	0.25	
	6	7:00	5:18			0.15	0.25	
	7	4:00	4:40			0.15	0.25	
	8	5:25	4:36			0.31	0.25	
	9	3:00	4:15			0.1	0.25	
	10	3:30	4:42			0.3	0.25	

4.3.2 Results

Based on these initial results, it was seen that segment 4 contained the most accurate responses in both time, only one second off, and distance, only 0.0089 miles over 0.25 miles. Segment 2 had the biggest difference in average time guessed compared to actual time, with an average of 6 minutes and 18 seconds guessed, compared to the average actual time of 4 minutes and 46 seconds. Segment 3 had the biggest difference in average distance guessed (removing the outlier distance) at 0.3478 miles, almost a full tenth of a mile over the actual distance of 0.25 miles. Additionally, the range, median, and mode for the average times guessed over each segment are captured in Table 5. An interesting note is that while segment 4 had the closest average guessed time to average actual time, the range is 4 minutes.

Table 5: Range, Median, and Mode Times Guessed Over Each Segment.

	Segment 1	Segment 2	Segment 3	Segment 4
Range	3:00	3:00	5:30	4:00
Median	5:00	6:30	5:15	4:15
Mode	5:00	7:00	5:00	4:00

For the third pilot survey question asked to each respondent, comments ranged across the board, however there were some commonalities between respondents along the same segments. Over segment 1, common responses included: flat route, loud because of heavier traffic volume, wide sidewalks in relatively good condition, pleasant buildings and landscaping appearance, ample crossing time across a well-marked intersection. Over segment 2, common responses included: more shade than on segment 1 (which is preferable), less traffic and less noise along quieter side/residential streets, overgrown tree limbs/brush obstructed path, sidewalks had many cracks/gaps/uneven spots, but were set back from the road (unlike segment 1). Segment 3 common responses included: more of an inclined segment than the previous two segments, sidewalks in a little better maintained condition, signage was adequate for crossing a large intersection, not as shaded as segment 2 but more shaded than segment 1. Segment 4, which was guessed most accurately in average time and distance, included the following common comments: route was downhill, which was enjoyable, sidewalk needed some minor repairs, segment contained more turns than other segments, less shade than other segments, crossings had no striping at intersections, and a little more traffic than previous 2 segments. Many of these comments were directly related to the characteristics included in the walkshed index, and thus gathered to develop the IIW for each segment.

The calculations for the IIW of each link, based on equations 1 and 2 described previously, are shown in Table 6. Based on these calculations, the experiences of the pilot survey are aligned with the expectations for each segment. The calculations predict that the infrastructure impacts each segment of the pilot survey route by decreasing the perceived speed. These results, in Table 6, show that the biggest discrepancy is on segment one, followed by segment two, and then followed equivalently by segments three and four. On any given segment, under ideal conditions, the total IIW weight is 74 and the speed is approximately 3.0 miles per hour (mph). With the data collected, perceptions of the respondents indicate walking farther and longer than the actual distance and time. By studying the results of the data collected from the pilot survey, it is evident that the impact of the infrastructure of each segment resulted in respondents perceiving they had walked both further in distance and time. The characteristics included in the IIW calculations were reinforced through the comments provided along each segment by each respondent. This confirms that the IIW calculations are an accurate reflection of reality. The only conflicting results are for segment 3: the IIW calculations show that this segment would be closest to ideal conditions, when in reality, segment 4 was closest. This could be accounted for by the presence of an incline of 43.86 feet on segment 3 and a decline of 21.86 feet on segment 4. While the presence of hills is not included in the IIW calculations, hilly terrain was frequently included in respondents' comments on the pilot survey. This attribute characteristic could certainly be explored as an option for inclusion in future work with the IIW.

Table 6: IIW Calculations on Pilot Survey Segments.

	Segment 1	**Segment 2**	**Segment 3**	**Segment 4**
Total Weight	34	43	48	43
Speed (mph)	1.804	2.083	2.238	2.083
Δ weight (from ideal)	-40	-31	-26	-31
Δ speed (from ideal)	-0.49	-0.211	-0.056	-0.211

Additional analysis over the pilot survey data was done through creating an ArcGIS Network Service Area Layer, similar to the visualizations created for the IIB. The pilot survey service area layer was created in the same way, by building network datasets for both the uninformed travel time and the IIW down the pilot study links. An assumed walking speed of 3.5 feet per second was used along with the length of the segments included in the pilot survey to determine an uninformed travel time. The IIW travel time was determined based on the observed data from the pilot survey, presented previously. Due to the small extent of the pilot area studied, the service area was created in a 5 minute radius area, starting from the same location as the pilot survey. Not every street segment included in the pilot survey area was traveled as part of the pilot survey, so assumptions were made for these streets, assigning values from streets with data to the similar streets without data. Figure 8 shows the visualization of the uninformed walkshed area in light blue, overlaid with the IIW area in light purple.

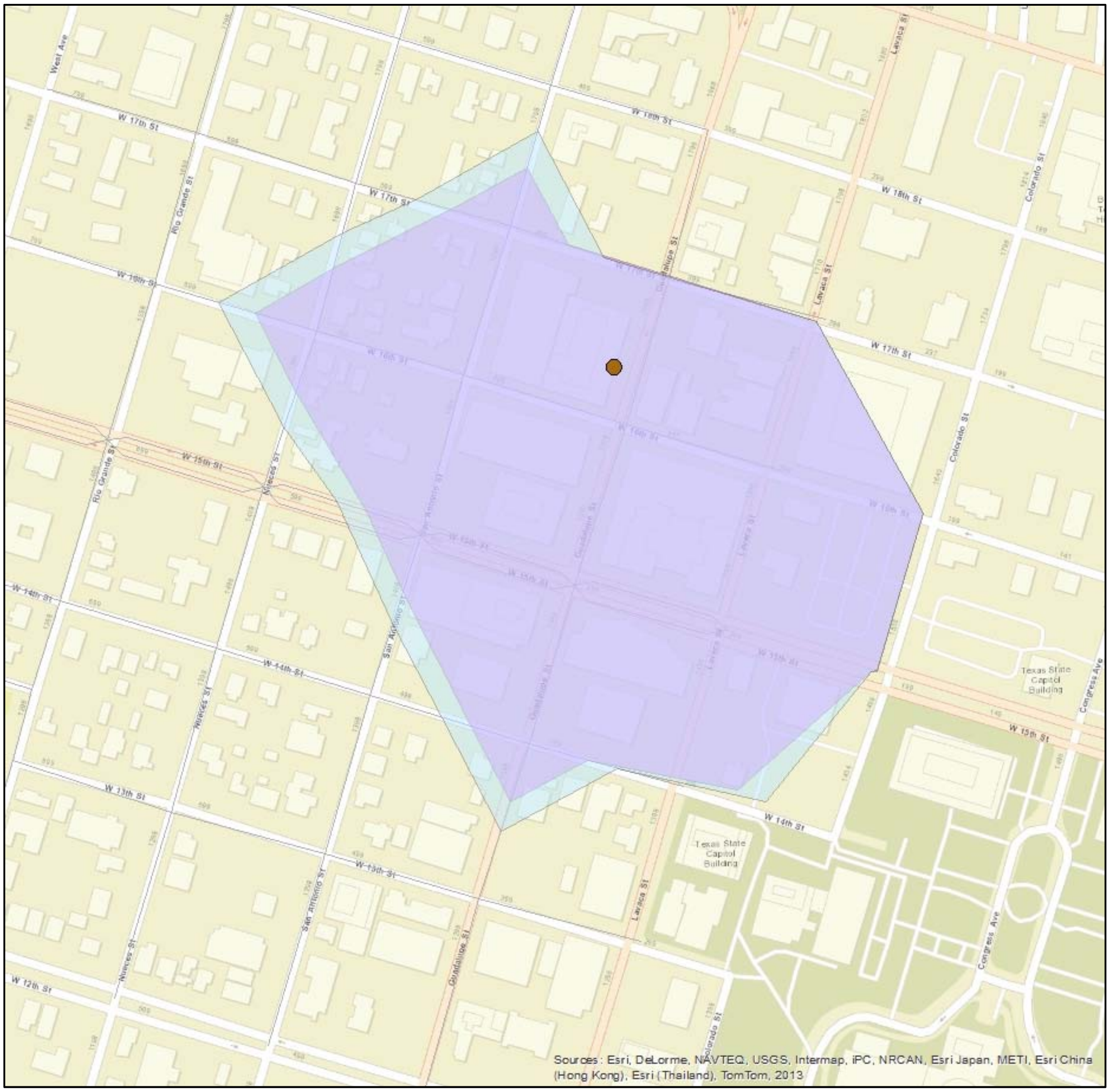

Figure 8: Service Area Layer Visualization for the Pilot Survey Segments.

Additionally, similar to the IIB, the ATI metric shown in Table 7 was calculated to compare the area of the uninformed walkshed area to the IIW area, based from the starting location in the pilot survey. From this very small pilot survey, the ATI shows that approximately 89% of the uninformed walkshed layer area is accounted for in the IIW service layer area.

Table 7: ATI Calculation for Pilot Survey Data.

Walkshed Pilot	Approximate Uninformed Walkshed Area (square feet)	Approximate Infrastructure-informed Walkshed Area (square feet)	ATI
From Pilot Survey Start	1401000	1252000	89.36%

4.4 Application Example: Neighborhood Connectivity

In conjunction with making improvements to pedestrian and bicyclist networks, providing increased connectivity presents a new complexity in the relationship between pedestrian or bicyclist modes and motor vehicles. Interactions between these groups are a major factor in comfort levels during short and long commute trips. Analyzing this relationship can be done by linking changes in vehicular network connectivity to suitability for pedestrians and bicyclists.

An early application of assessing the impact of motor vehicle connectivity on pedestrian and bicycle infrastructure was done through the development of the ATI. Starting with a study area in the Austin, Texas Traffic Analysis Zone (TAZ) network, a poorly connected motor vehicle network, and adjustments were made to the centroid connectors used to load trips onto the network, to improve the study area into a well-connected motor vehicle network, shown below in Figures 9 and 10.

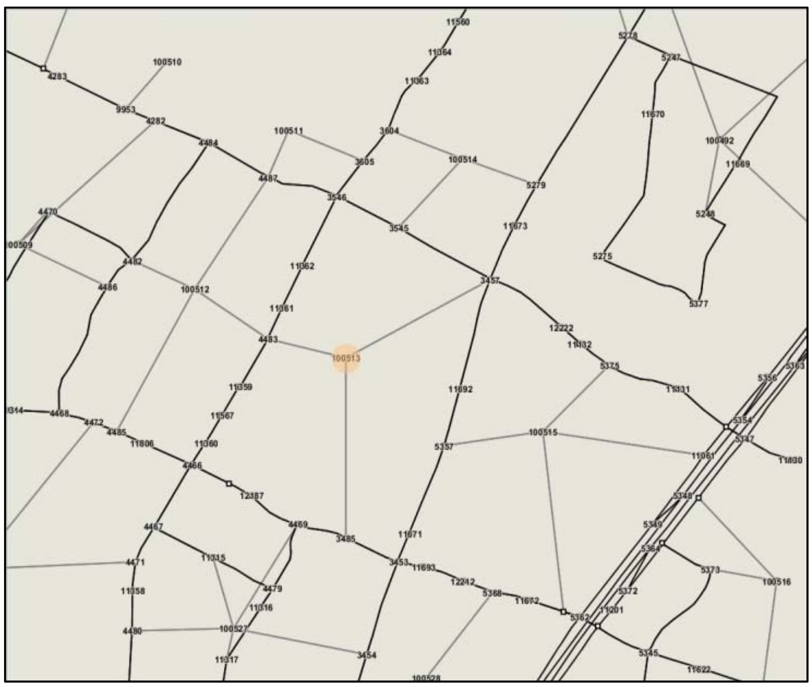

Figure 9: Well Connected Network

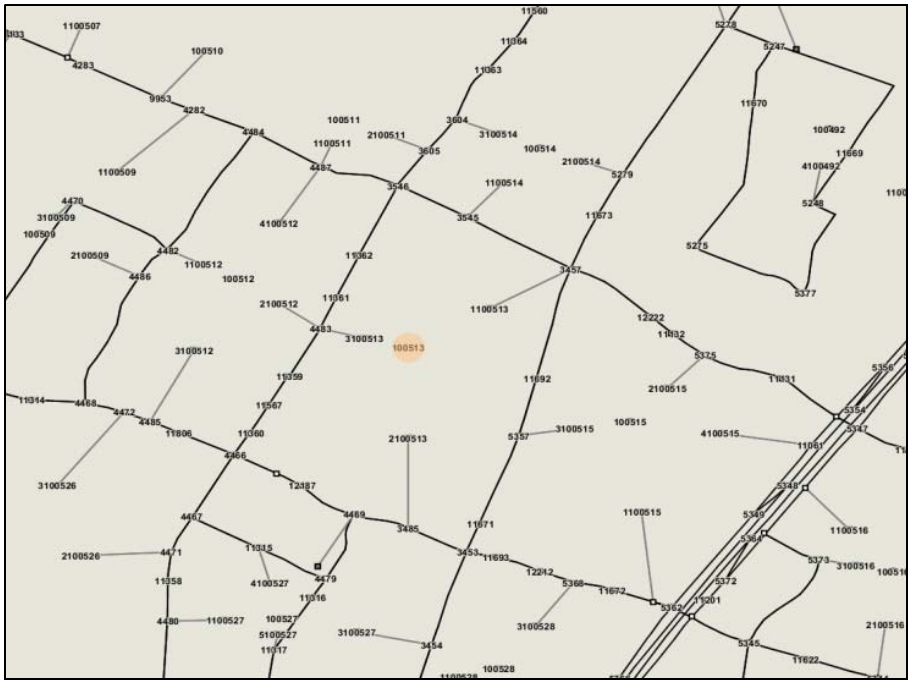

Figure 10: Poorly Connected Network

By addressing the motor vehicle network, connectivity issues were identified based on link-node ratios and path directness between origin-destination pairs. In the original network, vehicle movement is constrained by cul-de-sacs, subdivisions, and other obstacles inhibiting directness of path. Dynamic traffic assignment (DTA) was used to predict roadway volumes and route choice in this connectivity problem. In DTA, travel times and congestion levels are predicted iteratively for consistent network equilibrium, under the assumption that drivers choose the route that minimizes their travel time.

The ATI connects pedestrian and bicyclist perceptions about infrastructure quality and surrounding land uses to travel time and distance, and quantifies the tradeoffs between all related attributes. The attributes included measuring the ATI for pedestrians and bicyclists were determined based on the recurring attributes throughout prior research studies and analysis. Although the ATI is not all encompassing, the authors believe it adequately represents the attributes of highest importance for pedestrians and bicyclists when making transportation trips related to commuting or errands.

4.4.1 Methodology

With the attributes determined for each street segment and intersection, weights were assigned to each characteristic. The weights were assigned based on prior work and expert opinions gathered from various studies (Kasemsuppakorn and Karimi 2009, Stinson and Bhat 2003, Sener, Eluru and Bhat 2009). The Pedestrian Environmental Quality Index (PEQI) and Bicycle Environmental Quality Index (BEQI) from the San Francisco Department of Public Health were very valuable tools in determining appropriate weights for each attribute. From the PEQI and BEQI, many attribute weights were translated directly, however, not every attribute considered for the ATI is included in either the PEQI or BEQI ("Bicycle Environmental Quality Index (BEQI)" 2009, "The Pedestrian Environmental Quality Index (PEQI)" 2008). For the differences or gaps in attribute weights, the authors relied on comparative ranking of comparable attributes, assigning similar weight ranges to attributes of similar importance. These attributes, and the characteristics related to each attribute, along with the corresponding weight are shown in Table 8.

Table 8: ATI Street Segment Attributes and Characteristics with Assigned Weights

Attribute	Characteristic	Weight
Number of Lanes	Pedestrian/Bicycle Only Street	12
	1 Lane	9
	2 Lanes	6
	3 Lanes	3
	4+ Lanes	0
Posted Speed Limit	Under 25 mph	10
	25 mph or None Posted	5
	Over 25 mph	0
Bicycle Lanes/Sharrows	Two Directions	10
	One Direction	5
	None	0
Width of Bike Lane	> 6 ft.	15
	5 - 6 ft.	10
	< 5 ft.	5
Width of Sidewalk	Greater Than 8 Feet	15
	4.5 - 8 Feet	10
	Less Than 4.5 Feet	5
	No sidewalk	0
Pavement Type/Condition	Smooth Surface	15
	Mild Obstructions (cracks)	10
	Medium Obstructions (raised cracks, raised parallel pavement)	5
	Large Obstructions (pot holes, bumps)	0
Bicycle/Pedestrian	3+ countermeasures	11
Signs/Postings/Markings	2 countermeasures	7
	1 countermeasure	4
	None	0
Traffic Volume	Less than 1,000 vehicles/day (vpd)	15
	1,000-6,000 vpd	11
	6,001-12,000 vpd	4
	More than 12,000 vpd	0
Street Lights/Shade Trees	Yes	5
	No	0
Adjacent Land Use	Residential	3
	Commercial/Retail	2
	Business/Industrial	1
	Construction	-2
	Abandoned/Empty	-5

For this study, the ATI is broken into ranges that represent the "friendliness" of a given link based on the sum of all weights for that link. The values for each range, shown in Table 9, were defined based on the author's research in prior studies, examining different threshold values for each attribute. Using experiential background and descriptions of various road segments with different attribute combinations, five ranges were defined as excellent, very good, good, poor, and very poor. These range levels present a reasonable scale to characterize the perceived usability of a given segment based on its infrastructure.

Table 9: Ranges of ATI Scores for Street Segments.

	Street Segment ATI
Max Possible Points	111
Min Possible Points	-5
Excellent	≥95
Very Good	80-94
Good	66-79
Poor	46-65
Very Poor	≤45

4.4.2 Analysis

For the purposes of this example the ATI on four links at one intersection and the change in travel volume on all of the links in the network were the only points of analysis. The goal of this example is to examine how changing the network connectivity impacts the ATI. The node was identified as the intersection of Brodie Lane and Slaughter Lane and the links were identified as street segments traveling south on Brodie Lane, traveling west on Slaughter Lane, traveling north on Brodie Lane, and traveling east on Slaughter Lane. The node was chosen because it is located in a typical area that would draw pedestrians and bicyclists for many transportation trips related to work or errands, including a pharmacy, a church, a school, several restaurants and other shops. Each link ATI was calculated in the 0.5-mile direction away from the intersection, rather than crossing through the intersection. The half-mile distance was chosen as a typically accepted walking distance. Additionally, this was the extent to which the area was captured in Google Earth, which was used to gather certain segment characteristics, including presence of bicycle lanes and sidewalks, signs, postings and markings, and adjacent land use, among others.

Assigning a weight value respective to each link characteristic for the four links studied resulted in the ATI values shown in Table 10. When the connectivity was improved for vehicular traffic, the same data points were analyzed for each link. All link infrastructure characteristics remained the exact same in the before and after networks, except for link volumes. Interestingly, the volumes on two links were reduced, while the volumes on the other two links increased, shown in Table 11. Based on this information, the only differences in the ATI for the before and after networks was reflected in the change of volume. However, because of the range of volume characteristics being large, no changes were made in the ranges of ATI scoring, even with the volume of traveling north on Brodie Lane being about one-third on the well-connected network compared to the poorly connected network. This change is also shown in the ATI scores for each link in Table 10. This is a simple scenario, and in a true network change, infrastructure changes would be expected, whether in posted speed limit, presence or width of bike lanes or sidewalks, or other infrastructure attributes.

Table 10: ATI Scores for Each Link before and after Network Connectivity Improvements.

Street Segment	ATI Before	ATI After
South on Brodie Lane	40	40
West on Slaughter Lane	41	41
North on Brodie Lane	58	47
East on Slaughter Lane	46	46

Table 11: Daily Vehicle Volume on Each Link before and after Network Connectivity Improvements.

Street Segment	Volume Before	Volume After
South on Brodie Lane	6600	6020
West on Slaughter Lane	10160	10270
North on Brodie Lane	5360	17200
East on Slaughter Lane	8740	8490

4.4.3 Results

Street segments for traveling south on Brodie Lane and west on Slaughter Lane were categorized as very poor (from Table 9), both in the poorly connected and the well-connected networks. The street segment for traveling east on Slaughter was poor in both the poorly connected and well-connected networks. Similarly, the street segment for traveling north on Brodie Lane was at the low end of the poor range in the poorly connected network, but with the effect of the volume on the ATI score in the well-connected network, it moved up to the top of the poor range.

Throughout many of the earlier studies conducted, the impact of traffic volume is seen as highly important for both pedestrians and bicyclists, shown through this shift in the ATI range of friendliness on the street segment for traveling north on Brodie Lane. In this case, improving the network for vehicular traffic has an adverse effect on the numerical ATI range, although not in the category. Translating this result into experience would mean more perceived danger or risk by pedestrians or bicyclists, with potentially fewer using this link to travel for transportation purposes of work commuting or running errands in the well-connected network than in the poorly connected network to improve vehicular connectivity.

The entire example network has 2440 links. Running analysis on the volume on each link, we know if the ATI improved or worsened by subtracting the volume on the well-connected network from the link volume on the poorly connected network. Although this does not allow us to see to what degree the ATI changes for each individual link, whether it moves from very poor to excellent or excellent to very poor, or even stays within the same range for small changes, we can get a sense of the overall impact on this network. Of the 2440 links in this network, 1462 saw a decrease in traffic volume and thus, an improved ATI. For 911 links, the traffic volume increased, worsening the ATI, and sixty-seven links remained unchanged. Overall, there is a 60% decrease in the traffic volume for this network, supporting the hypothesis that improving the vehicular network connectivity also improves the network for pedestrian and bicyclist activity. While these overall network results are somewhat contradictory to the specific intersection of Brodie Lane and Slaughter Lane, we did see slight improvements in traveling south on Brodie Lane and east on Slaughter Lane, although they did not improve enough to move ranges.

The DTA software produced volume data for the peak three-hour period in units of vehicles per hour. Using the assumption of the 5:00 to 6:00 PM peak hour carrying one-tenth of the traffic per day, the change in volume per day was calculated to address the impact on the ATIs. As shown in Figure 11, the distribution of traffic volume differences is skewed right of zero, which corresponds to the 60% of links seeing an improvement in traffic volume on the well-connected network relative to the poorly connected network. The statistics of this distribution state zero as the mode. The link with the greatest ATI improvement had a decrease in traffic volume of 13,690 vehicles per day in the well-connected network. The link with the worst ATI decline had an increase in traffic volume of 42120 vehicles per day in the well-connected network.

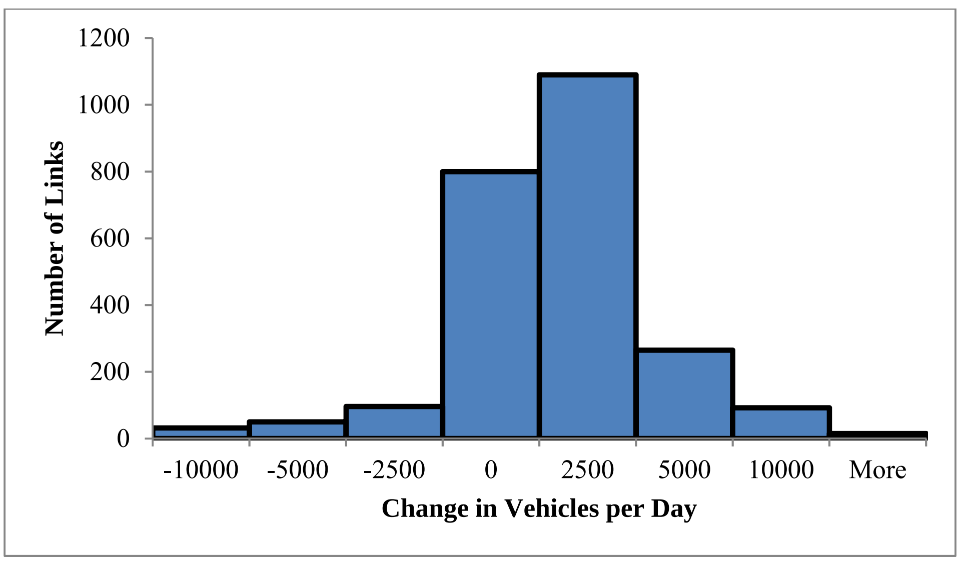

Figure 11: Distribution of Daily Vehicular Traffic Volume Changes in Moving from Well Connected to Poorly Connected Network Connectivity during the Evening Peak Hour.

4.4.4 Conclusions and Future Work

The initial hypothesis was that improving vehicular network connectivity would also improve pedestrian and bicyclist activity, as measured by the ATI. The results show that this hypothesis does not apply universally: in applying the ATI to one specific intersection area of four links, results were mixed. In analyzing the impact of volume change, two of the links saw slight improvements, one saw a slight decline, and one saw a more drastic decline, none of the changes were enough to shift any segment into a new category ranking. For traveling north on Brodie Lane, the well-connected vehicular network was decreased to nearly one-third in traffic volume, which caused the numerical ATI range to improve, though not the category, and had a positive impact and favorable effect on pedestrian and bicyclist activity.

However, the hypothesis was better supported when considering volume changes on the network as a whole. Looking at the poorly connected network compared to the well-connected, improved vehicular network, sixty percent of links included in the overall network saw a decrease in traffic volume when the vehicular network connectivity was improved, and thus an improved ATI for pedestrian and bicyclist activity. Note that this study was specifically designed to isolate the impact of connectivity alone: no other attributes of the network were adjusted (number of lanes, presence of sidewalks or bicycle paths, etc.). All other attributes being equal, comparing the traffic volume for the poorly connected network to the well-connected network shows specifically how the improvements in vehicular network connectivity impact pedestrian and bicyclist activity through the ATI. This measure could be further developed to understand for how many links the improvements in traffic volume caused a positive change in the ATI range category and to what degree, rather than just looking at overall improvements.

Several insights were obtained from this analysis. First, if no new links are created or no changes are made to the physical infrastructure of the existing lengths (adding lanes, changing direction of traffic, adding or removing sidewalks or bicycle lanes, etc.), the only difference to be captured is the change in automobile traffic volume along the segment. Knowing this, assessments using the ATI to measure impacts from changing a network can be done very easily with quick results. Secondly, this research spotlights the need for planning network connectivity, both from the beginning and for making changes or improvements, in a multimodal reference frame, rather than focusing on one mode. The mindset of including and planning for multimodal travel is growing and receiving more attention in the planning and policy arenas and the ATI can be leveraged as a tool to better understand these relationships and tradeoffs. Similarly, the ATI can be used to help plan for better pedestrian and bicycle facilities, operating congruently with regular automobile traffic. The attributes included and characteristics measured are common to any region or city, thus allowing the use of the ATI to be transferrable and relevant in areas outside of the study region of Austin, Texas.

Further work should be done to include assessing more segments and intersections for impacts from improving vehicular network connectivity on pedestrian and bicyclist activity. While the segments used in this research are considered good “typical” segments of attractions and destination points for pedestrians and bicyclists, gathering more data points would garner further support in stating that improving vehicular network connectivity has a positive or negative impact on pedestrian and bicyclist activity. The method of applying the ATI onto street segments and intersections will result in a more universal interpretation of impacts by relating the attributes of the physical and built environment to a perceived distance length, either positive or negative, onto the actual length of each segment. Additional future work aims to improve the utility of the ATI by replacing the range of weights and categories of Excellent, Very Good, Good, Poor and Very Poor with better informed ranges calculated through data analysis directly associating infrastructure attributes to travel time.

Chapter 5. Conclusions

5.1 Implications of Work

The study provides an understanding of impedances in the natural and built pedestrian environment, and thus enables better structured growth and maintenance of street segments and intersections to best provide for pedestrians and bicyclists. Engineers and planners can use the metrics developed and tools utilized to analyze the IIB and the IIW, either directly as they stand or indirectly as a piece of a bigger picture. The IIB and the IIW are unlike other methods to analyze bicyclist and pedestrian activity in a given area in the way each indexes aspects of both the natural and the built environment against a user's perceived travel time.

5.2 Future Work

This information helps us learn more about the relationships between characteristics of the walking or biking environment and how they impact a pedestrian or bicyclist, with potential future use for urban planners and developers. Results from this study may be transferrable to other cities and regions similar to Austin: the weights assigned to attributes and characteristics in both the IIB and the IIW; the visualization of the IIB and the IIW through ArcGIS, which provides the polygonal area to calculate the ATI; and the ability to relate environmental attributes to perceptions of travel time.

The importance of bicycles as a valid form of transportation in non-recreational activities is growing and gaining acceptance and popularity all over the world. As a result, transportation planners need a better tool to truly measure how the natural and built environment influences a cyclist's route and overall trip. Visualizing and creating the bikeshed in the Austin, Texas regional network, is one method that allows a better grasp to be gained of the impact of route attributes on cyclist perceptions. The bikeshed is created based on relating route attributes with positive or negative time-based trade-offs over a link, forming a bikeshed service area to visualize how far in any direction (along a link) a bicyclist can comfortably travel. Initial assumptions are made to determine the baseline, with an average short-commute distance of 3-miles and average speed of 10 miles per hour, thus equating to an average short-commute trip length of 30 minutes (*8*). In the example given applying the bikeshed buffer to a bike shop in downtown Austin, Texas, a cyclist (or proprietor) can see a more accurate distance and time an average biker would be able to travel, based on accepted speeds and distances of comfort.

Using the data gathered on the time based trade-offs for route attributes on a short-commute distance (Sener et al. 2009), bikeshed impedance scores were calculated for each link in the Austin, Texas network. The bikeshed impedance score was translated and visualized as a bikeshed service layer, and established for three bike shops (origin points) in the network. While the application of the bikeshed service layer onto a bike shop in downtown Austin, Texas is only one example of depicting an origin point and the extent to which customers can easily access the shop, there is potential to extend this methodology for other origin and destination points. The required inputs can be difficult to obtain, requiring various assumptions to be made. However, with the desire, this method could be used for and applied to any given network. For best results, a direct application would be for regions similar to Austin, Texas, stemming from the background research conducted by Sener et al. (2009) for the time-based trade-offs of route attributes for short commutes. Similar efforts could be conducted at any level to capture the relationships between these route attributes in a different geographical location, and applied through the same ArcGIS Network Analyst Service Area Layer tool.

Opportunities exist to continuously improve the accuracy of the bikeshed by incorporating more detailed information about the impacting route attributes of each link. In this research, many assumptions were made about route attributes based on the road class of each link in the network studied. Obtaining specific data relative to route attributes, such as parking characteristics along the link, could result in a change in the bikeshed impedance value. As the research stands, there are no links in the network that are characterized with an infrastructure than enhances the cyclist's travel time along the link, however these links may truly exist. Again, by obtaining more specific data for each route attribute, and removing the points of uncertainty stemming from assumptions, the validity of the bikeshed will only continue to grow.

Improvements can be made to the IIW by adapting the existing metric to be more representative of the data gathered through the pilot survey. While most of the feedback from the pilot survey was already incorporated into the weights of the IIW, including an attribute for terrain, with characteristics of very hilly (weight 0), moderately hilly (weight 5), and flat (weight 10), would be better representative of the infrastructure impacting pedestrian perception. By including the terrain attribute, the IIW total weight maximum would increase to 84 and the minimum would remain -5. Further expansion on the pilot study would also allow more educated recommendations to be made for adjusting the existing street characteristic, presence, and weight.

Although the pilot survey data collected only has nine relevant data points, there are some early recommendations that can be made on a hypothesis level. These updates and changes to the existing IIW are included in Table A2 of the Appendix. Through these early recommendations for changing the existing IIW, the new maximum total weight would be 77 and the new minimum weight would be -2. The reason for a small change to both the maximum and minimum weight values is due to changing the weights in the existing categories to be more aligned to the pilot study results and feedback. For example, in the current IIW, the maximum weight for the number of lanes is 12 on a pedestrian/bicyclist only street. In the new IIW, however, this weight changes to 10. Changes were made to each street characteristic presence or weight except traffic volume and street lights/shade trees.

While this report makes headway into relating infrastructure to speed through distance and time, the relationship can be enhanced further. Adding a way to measure connectivity of bicyclist or pedestrian routes traveled by directness of route, in addition to the infrastructure along the route, would even better reflect the impact of the natural and built environment on pedestrian and bicyclist activity. Going further with the existing research to gather more data points, make fewer assumptions, and enable more fine-tuned analysis would only continue to improve the contributions of this report from its current state.

Appendix

Table A1: Infrastructure-informed Walkshed Characteristics and Weights.

Street Characteristics	Presence	Weight
Number of Lanes	Pedestrian/Bicycle Only Street	12
	1 Lane	9
	2 Lanes	6
	3 Lanes	3
	4+ Lanes	0
Posted Speed Limit	Under 25 mph	10
	25 mph or None Posted	5
	Over 25 mph	0
Width of Sidewalk	Greater Than 8 Feet	15
	4.5 - 8 Feet	10
	Less Than 4.5 Feet	5
	No sidewalk	0
Pavement Type/Condition	Smooth Surface	15
	Mild Obstructions (cracks)	10
	Medium Obstructions (raised cracks, raised parallel pavement)	5
	Large Obstructions (pot holes, bumps)	0
Traffic Volume	Fewer than 1,000 V/D	15
	1,000-6,000 V/D	11
	6,001-12,000 V/D	4
	More than 12,000 V/D	0
Street Lights/Shade Trees	Yes	5
	No	0
Adjacent Land Use	Residential	2
	Business/Industrial	1
	Commercial/Retail	1
	Construction	-2
	Abandoned/Empty	-5

Table A2: Adjusted Infrastructure-informed Walkshed Characteristics and Weights.

Street Characteristics	Presence	Weight
Number of Lanes	Pedestrian/Bicycle Only Street	10
	1 Lane	9
	2 Lanes	5
	3 Lanes	2
	4+ Lanes	0
Posted Speed Limit	Under 35 mph	10
	35 mph or None Posted	5
	Over 35 mph	0
Width of Sidewalk	Greater Than 8 Feet	12
	4.5 - 8 Feet	10
	Less Than 4.5 Feet	5
	No sidewalk	0
Pavement Type/Condition	Smooth Surface	10
	Mild Obstructions (cracks)	7
	Medium Obstructions (raised cracks, raised parallel pavement)	5
	Large Obstructions (pot holes, bumps)	0
Traffic Volume	Fewer than 1,000 V/D	15
	1,000-6,000 V/D	11
	6,001-12,000 V/D	4
	More than 12,000 V/D	0
Street Lights/Shade Trees	Yes	5
	No	0
Adjacent Land Use	Residential	5
	Business/Industrial	2
	Commercial/Retail	2
	Construction	0
	Abandoned/Empty	-2
Terrain	Flat	10
	Moderately Hilly	5
	Very Hilly	0

References

"Austin, Texas." Google Maps, 2013. <http://maps.google.com>. Accessed 16 July 2013.

"Bicycle & Pedestrian." Office of Planning, Environment, and Realty (HEP). U.S. Department of Transportation Federal Highway Administration, 24 Oct. 2012. Web. 20 June 2013. <http://www.fhwa.dot.gov/environment/ bicycle_pedestrian/>.

"Bicycle Sharing System." Wikipedia. Wikimedia Foundation, 10 July 2013. Web. 20 June 2013. <http://en.wikipedia.org/wiki/Bicycle_sharing_system>.

"Bike Score™ Methodology." Bike Score Methodology. Walk Score, 2013. Web. 01 July 2013. <http://www.walkscore.com/bike-score-methodology.shtml>.

Dale, Jim. "Advanced Bike Detection." 17 April 2013. E-mail.

Dill Jennifer, Measuring Network Connectivity for Bicycling and Walking, Proceedings of the 83rd Annual Meeting of Transportation Research Board, Washington D.C., USA, January 11-15, 2004.

Dill, Jennifer. "Bicycling for Transportation and Health: The Role of Infrastructure." Journal of Public Health Policy 0197-5897 30.S1 (2009): 95-110. Journal of Public Health Policy. Palgrave Macmillan. Web. 28 June 2013. <http://www.palgrave-journals.com/jphp/journal/v30/nS1/full/jphp200856a.html>.

Dixon, Linda B. "Bicycle and Pedestrian Level-of-Service Performance Measures and Standards for Congestion Management Systems." Transportation Research Record 1538: 1-9. 1996.

Duthie, Jennifer, Stephen Boyles, Mallory Necessary and Rohan Shah. "The Impacts of Network Connectivity on Multimodal Travel Metrics." American Society of Civil Engineers Green Streets Conference Journal (2013).

Frank, Lawrence D., Engelke P.O., Schmid T.L., Health and Community Design: The Impacts of the Built Environment on Physical Activity, Island Press, Washington D.C., 2003

Frank, Lawrence D., James F. Sallis, Terry L. Conway, James E. Chapman, Brian E. Saelens, and William Bachman. "Many Pathways from Land Use to Health: Associations between Neighborhood Walkability and Active Transportation, Body Mass Index, and Air Quality." Journal of the American Planning Association 72.1 (2006): 75-87. Web. 20 May 2013. <http://dx.doi.org/10.1080/01944360608976725>.

Goodwin, Justin M. "Where the Sidewalk Begins: Pedestrian Accessibility Analysis in Suburban Cincinnati." Thesis. Ohio University, 2005. Print.

Handy, Susan L. "Urban Form and Pedestrian Choices: Study of Austin Neighborhoods." Transportation Research Record: Journal of the Transportation Research Board1552.1 (1996): 135-44. Transportation Research Record. Web. 20 May 2013. <http://trb.metapress.com/content/4157588723Q73473>.

Harkey, David L., Donald W. Reinfurt, and Matthew Knuiman. "Development of the Bicycle Compatibility Index." Transportation Research Record 1636, Paper Number 98-1073: 13-20.

Hood, Jeffrey N. "A GPS-based Bicycle Route Choice Model for San Francisco, California." Thesis. University of California, Berkley, 2010. Print.

Kasemsuppakorn, Piyawan, and Hassan A. Karimi. "Personalised Routing for Wheelchair Navigation." Journal of Location Based Services 3.1 (2009): 24-54.

Landis, Bruce W., Venkat R. Vattikuti, Russell M. Ottenberg, Theodore A. Petritsch, Martin Guttenplan, and Linda B. Crider. "Intersection Level of Service for the Bicycle through Movement." Transportation Research Record: Journal of the Transportation Research Board 1828.1 (2003): 101-06. Transportation Research Record. Web. 20 May 2013. <http://trb.metapress.com/content/R6T63R2G723 661U8>.

"List of Bicycle Sharing Systems." Wikipedia. Wikimedia Foundation, 20 June 2013. Web. 20 June 2013. <http://en.wikipedia.org/wiki/List_of_bicycle_ sharing_systems>.

McNeil, Nathan. "Bikeability and the Twenty-Minute Neighborhood: How Infrastructure and Destinations Influence Bicycle Accessibility." Portland State University, 2010. Print.

"Medians and Pedestrian Crossing Islands in Urban and Suburban Areas." Proven Safety Countermeasures. U.S. Department of Transportation Federal Highway Administration, n.d. Web. 20 June 2013. <http://safety.fhwa.dot.gov/ provencountermeasures/fhwa_sa_12_011.htm>.

Moudon, Anne Vernez, and Chanam Lee. "Walking and Bicycling: An Evaluation of Environmental Audit Instruments." The Science of Health Promotion 18.1 (2003): 21-36. Web.

"National Complete Streets Coalition." National Complete Streets Coalition. Smart Growth America, n.d. Web. 20 June 2013. <http://www.smartgrowthamerica.org/complete-streets>.

Oaks, J. Michael, Ann Forsyth, and Kathryn H. Schmitz. "The Effects of Neighborhood Density and Street Connectivity on Walking Behavior: the Twin Cities Walking Study." Epidemiologic Perspectives and Innovation 4.16 (2007). Web. 20 May 2013. <http://www.epi-perspectives.com/content/4/1/16>.

Owen, Neville, PhD, Nancy Humpel, PhD, Eva Leslie, PhD, Adrian Bauman, PhD, and James F. Sallis, PhD. "Understanding Environmental Influences on Walking: Review and Research Agenda." American Journal of Preventative Medicine 27.1 (2007): 67-76. Print.

"Pedestrian Hybrid Beacon." Proven Safety Countermeasures. U.S. Department of Transportation Federal Highway Administration, n.d. Web. 20 June 2013. <http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_012.htm>.

"Roundabout." Https://en.wikipedia.org/wiki/Roundabout. Wikimedia Foundation, 19 June 2013. Web. 20 June 2013. <https://en.wikipedia.org/wiki/Roundabout>.

Program on Health, Equity and Sustainability, The Bicycle Environmental Quality Index (BEQI), Environmental Health Section, San Francisco Department of Public Health, 2009, <http://www.sfphes.org/elements/24-elements/tools/102-bicycle-environmental-quality-index>.

Program on Health, Equity and Sustainability, The Pedestrian Environmental Quality Index (PEQI): An assessment of the physical conditions of streets and intersections, Environmental Health Section, San Francisco Department of Public Health, 2008, <http://www.sfphes.org/elements/24-elements/tools/106-pedestrian-environmental-quality-index>.

Sener, Ipek N., Naveen Eluru and Chandra R. Bhat. "An Analysis of Bicycle Route Choice Preferences in Texas, U.S." In: Proceedings of the 89th Transportation Research Board Annual Meeting, Washington, D.C., 2009.

Stinson, Monique A. and Bhat, Chandra R., "An Analysis of Commuter Bicyclist Route Choice Using a Stated Preference Survey." In: Proceedings of the 83rd Transportation Research Board Annual Meeting, Washington, D. C., 2003.

Timms, Paul, and Miles Tight. "Aesthetic Aspects of Walking and Cycling." Built Environment 36.4 (2010): 487-503. Alexandrine Press. Web. 20 May 2013.

Toole Design Group. “Bike Sharing in the United States: State of the Practice and Guide to Implementation.” U.S. Department of Transportation Federal Highway Administration, September 2012. Web. 7 October 2013. <http://5728452006d458e3e74c-2f6bef8b2d7e04086879310a43d837d9.r29.cf1.rackcdn.com/Guide_BikeSharingUS_Sept2012_1.pdf>.

Turner, Shawn M., PE, C. Scott Shafer, and William P. Stewart. Bicycle Suitability Criteria: Literature Review and State-of-the-Practice Survey. Rep. no. 3988-1. College Station: Texas Transportation Institute, 1997. Print.

“Transportation: Meta Data.” City of Austin GIS Data, 8 July 2013. <ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/transportation/str_address.htm>. Accessed 22 July 2013.

Walk Score, Walk Score Methodology, www.walkscore.com/methodology.shtml.