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FINAL REPORT

Automated Sidewalk Quality and Safety Assessment System

(Regional University Transportation Center Subproject)

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Sidewalks are often unsafe, exposing pedestrians, wheelchairs users, travelers with strollers, and persons carrying heavy loads to unnecessary risk. However, prioritizing sidewalk repairs and improvements requires knowledge about the current system state. The Automated Sidewalk Quality and Safety Assessment System developed in this project can help communities evaluate the condition of sidewalks and pathways based on sidewalk existence, condition, and conformance with Americans with Disabilities Act (ADA) standards. In consultation with local transportation planners and public interest groups, the team calibrated the system to assess sidewalk characteristics and developed an initial sidewalk quality index (SQI). The team then developed a weighted ranking system to prioritize pedestrian projects by coupling app-derived ADA compliance data with pedestrian safety indicators (crash rates), land use, and demographic data (pedestrian activity). The researchers collected and analyzed sidewalk data for 1,352 miles of sidewalks within the City of Atlanta and used the system to derive block-level pedestrian potential and deficiency indicators to prioritize planning investments within a subarea of Midtown, Atlanta, Georgia. The results of the rank-order prioritization analyses indicate that blocks near rail stations and high-density land uses should be prioritized for investment. The system developed in this project can help communities evaluate sidewalk condition, ADA compatibility, and help agencies use the data in prioritizing pedestrian infrastructure repairs and improvements. Further refinements will extend the application of the methods to larger geographic scales and to incorporate repair costs into the prioritization framework.

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Final Project Report

Automated Sidewalk Quality and Safety Assessment System

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Executive Summary

Transportation planners, engineers, and decision-makers generally recognize that non-motorized transportation provides environmental, economic, and public health benefits. However, many sidewalks in Atlanta and across the country do not adequately provide for pedestrian needs and fail to help make communities safe and livable. Sidewalks that do not meet Americans with Disabilities Act (ADA) design criteria are often unsafe, exposing pedestrians, wheelchairs users, travelers with strollers, and persons carrying heavy loads to unnecessary risk. Best practices for pedestrian planning suggest that jurisdictions prioritize pedestrian projects based on a variety of concerns, such as high pedestrian activity, pedestrian safety, accessibility to transit, and mobility for persons with disabilities, children and older adults. Most regions lack a spatial sidewalk inventory and could benefit greatly from the development of a systematic approach to evaluating sidewalk quality and ADA compliance. The Automated Sidewalk Quality and Safety Assessment System developed in this project helps communities evaluate sidewalk condition and ADA compatibility. Results will help agencies to prioritize sidewalk improvements and improve pedestrian infrastructure.

The first step in achieving improvements to pedestrian infrastructure and increased walkability is assessing current infrastructure quality. Prioritizing improvements requires knowledge about current system state. The Georgia Institute of Technology (Georgia Tech) research team successfully deployed a new sidewalk quality assessment Android application (app) to collect global positioning system (GPS) tagged video of the sidewalks and record Android tablet gyro and accelerometer data for use in evaluating sidewalk quality. By adapting video processing tools previously developed by Georgia Tech researchers for vehicle tracking, the researchers were able to post-process the video to estimate sidewalk width, identify cracks and potholes in need of maintenance, and record the localized presence of walkway obstructions. Although the research team could not completely automate the video data processing, the final semi-automated system significantly reduces labor required to assess sidewalk quality and the video facilitates for consistency reviews and state-of-system asset management archives.

In consultation with local transportation planners and public interest groups, the team calibrated the system to assess sidewalk characteristics and developed an initial sidewalk quality index (SQI). The team developed a weighted ranking system that can be used to prioritize pedestrian projects. The system couples app-derived ADA compliance data with pedestrian safety indicators (crash rates), and land use and demographic data (pedestrian activity). Researchers collected and analyzed sidewalk data for 1,352 miles of sidewalks within the City of Atlanta. The team used the system to derive block-level pedestrian potential and deficiency indicators to prioritize planning investments within a subarea of Midtown, Atlanta, Georgia. The results of the rank-order prioritization analyses indicate that blocks near rail stations, the Georgia Tech, and Technology Square (based upon both existing condition and pedestrian activity) should be prioritized for investments. Further refinements are still needed to extend the application of the methods to larger geographic scales and to incorporate repair costs into the prioritization framework. The final outreach and education project involved development of an ADA transition plan for the downtown Hotel District by a class of Georgia Tech undergraduate honors students.

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List of Acronyms

AASHTO	American Association of State Highway Transportation Officials
ABM	Activity based model (a type of travel demand model)
ACS	American Community Survey
ADA	The Americans with Disabilities Act
ADAAG	Americans with Disabilities Act Accessibility Guidelines
ARC	Atlanta Region Commission
CT-RAMP	Coordinated Travel - Regional Activity Based Modeling Platform
DOT	Department of Transportation
DPW	Department of Public Works
FHWA	Federal Highway Administration, USDOT
Georgia Tech	Georgia Institute of Technology
GDOT	Georgia Department of Transportation
GIS	Geographic Information System
GPS	Global Positioning System
GRA	Graduate research assistant
GRTA	Georgia Regional Transportation Authority
HCM	Highway Capacity Manual
HD	High definition
HDV	Heavy-duty vehicle
HPMS	Highway Performance Monitoring System
HSV	Hue-Saturation-Value
IB	International Baccalaureate program
ITE	Institute of Transportation Engineers
L-K	Lucas-Kanade (video tracking algorithm)
MARTA	Metropolitan Atlanta Rapid Transit Authority
NA	Not applicable
NaviGAtor	The intelligent transportation system operated by GDOT
NPU	Neighborhood Planning Unit
PDA	Personal digital assistant
PCI	Pedestrian composite index
PDI	Pedestrian deficiency index
PPI	Pedestrian potential index
PEDS	Pedestrians Educating Drivers on Safety
PROWAG	Proposed accessible right-of-way guidelines
PTZ	Pan, tilt, zoom (cameras)
PVW	Percentage of valid width measurements
ROI	Region of interest
RMS	Root mean square
SPI	Special public interest (zoning overlay)
SQI	Sidewalk quality index
SRTA	Georgia State Road and Tollway Authority
STRIDE	Southeastern Transportation, Research, Innovation, Development, and Education
TRB	Transportation Research Board
USDOT	United States Department of Transportation
URA	Undergraduate research assistant
USAB	United States Access Board
USB	Universal Serial Bus
USDOJ	United States Department of Justice
USDOT	United States Department of Transportation
USGAO	United States Government Accountability Office
WTS	Women’s Transportation Seminar

1 Introduction

State, regional, and local transportation plans usually focus design and engineering improvements on critical elements levels of our transportation infrastructure. In most of these transportation plans, increasing the walkability of existing transportation systems is also a planning objective. Hence, assessing current pedestrian infrastructure condition and service quality is an important first step in prioritizing infrastructure repairs and improvements and in developing long range plans to meet future transportation needs. When it comes to pedestrian accessibility and mobility, sidewalks and pathways (including ramps, crosswalks, and transitions) are the critical infrastructure elements that must be evaluated.

The Georgia Institute of Technology (Georgia Tech) research described in this report sought to calibrate and field-deploy a new Android application, commonly known as an “app,” to automatically assess sidewalk condition, and explore potential mechanisms for prioritizing sidewalk repair and expansion projects. The Sidewalk Sentry™ system collects rolling video of a sidewalk for post-processing, and records location-tagged gyroscope and accelerometer data for use in evaluating sidewalk quality. The researchers developed mechanisms to post-process the video to estimate sidewalk width, identify cracks and potholes in need of maintenance, and record the local presence of walkway obstructions. Researchers originally planned to develop a completely automated system using visual recognition techniques to estimate sidewalk widths using rolling video collected with Sidewalk Sentry™. However, the fully-automated processes did not yield sufficiently accurate and precise measurements and requires further research and development. The team developed, tested, and employed an alternative semi-automated method for width estimation and identification of sidewalk defects under the Americans with Disabilities Act (ADA) design standards.

The research project called for video system modifications, system calibration under various operating conditions, coordination with planners and interest groups on sidewalk quality index (SQI) development, followed by widespread Atlanta deployments for data collection. Ongoing analysis of the field data and feedback from deployment were used to update system calibration, modify the system design, and enhance operations guidelines to technology transfer and education. In consultation with local transportation planners and local public interest groups, the team has implemented the system to assess sidewalk characteristics under ADA requirements and developed a flexible SQI approach that can be used to prioritize sidewalk repairs and improvements.

The next chapter of this report (Chapter 2) provides background insight into the importance of sidewalks and ADA requirements for sidewalk design and quality. Sidewalk quality parameters and methods for assessing sidewalk quality are outlined in Chapter 3. An overview of the automated and semi-automated methods is provided in Sidewalk Sentry™ Chapter 4. Field data collection for Atlanta is summarized in Chapter 5. An overview of sidewalk quality prioritization goals and objectives can be found in Chapter 6, and Chapter 7 presents a case study employing these data for prioritization of Midtown Atlanta sidewalk repairs. Chapter 8 describes the project’s public outreach efforts. Conclusions and recommendations are then provided in Chapter 9.

2 Sidewalks and the Americans with Disabilities Act (ADA)

In 1961, Jane Jacobs implored city planners across the United States to work towards the retention, rehabilitation, and creation of "lively, diverse, intense" cities, where children play in the street, all neighborhoods have sidewalks and parks, and land use is both dense and mixed-use. Jacobs singled out sidewalks as being necessary tools to increase safety and personal contact, to bring up children with a sense of community, and to mitigate social problems at the highest level, especially with respect to segregation, racial discrimination and all of the social and economic disadvantages associated with slums. Sidewalks bring people together on the streets, and encourage them to play, shop, and travel with direct interaction in vibrant, shared space.

2.1 Sidewalk Quality and Walkability in the Literature

Even before the widespread use of the term walkability existed, Jacobs (1961) lauded walkable space, describing sidewalks as "uniquely vital and irreplaceable organs of city safety, public life, and child rearing." Researchers today delve into not only the definition of walkability, but also the individual performance measures associated with walkability. Good sidewalks certainly do not define a walkable community, but they are one vital piece of the puzzle. In her study "What is Walkability? The Nine Faces of a Common Concept," Ann Forsyth (2013) identifies sidewalks as one of the nine faces of walkability. However, the scope of Forsyth's study, and most other studies, do not include or assess methods for evaluating sidewalks with respect to their role in a walkable environment.

In his book *Walkable City*, author Jeff Speck (2013) argues that walkable communities are an imperative if our society is to address such problems as "economic competitiveness, public welfare, and environmental sustainability." Speck discusses the need for walking, and thus pedestrian infrastructure, to be useful, safe, comfortable, and interesting, to increase walkability. Designing an equitable walking environment also calls for addressing accessibility and mobility needs, and focusing on sidewalk design and networks. Table 1 identifies various sidewalk factors that contribute to the social and transportation needs of a community. Each of the factors in the Table 1 helps bring communities together in a safe, inclusive, and healthy way. Increased socialization, personal contact, and community-building are secondary advantages to getting more people to choose to walk in their environments, and providing the appropriate sidewalks and pedestrian infrastructure is an essential element to reach this goal.

Table 1. Factors Associated with Desirable Sidewalks

Sidewalk Factors	Description
Safety	Sidewalks provide pedestrians with an exclusive right of way, reducing the potential for collisions between vehicles and pedestrians. Sidewalks are typically disrupted by curbcuts for driveways that can increase pedestrian risk. Hence, minimizing or concentrating curb cuts can minimize pedestrian-vehicle interactions. Sidewalks are especially important along streets where vehicles travel at high speeds because the risk of pedestrian fatalities increases nonlinearly with speed. Sidewalks can provide safer pedestrian routes and create a safer environment for all roadway users.
Accessibility	Under the ADA, persons at all levels of physical and mental ability are entitled to the same access to public (and most private) programs. Transportation infrastructure, including sidewalks, must be fully accessible to allow all members of the community equal access to the street and the buildings, parks, etc. This includes accessibility for the young, elderly, visually impaired, wheelchair users, persons with limited mobility, etc.
Mobility and Utility	Sidewalks can help people get from point A to point B, making sidewalks a viable option to meet travel demand. Proper sidewalks help maximize the utility of the streetscape and public space for all users. Sidewalks in commercial areas and public gathering areas provide significantly greater public benefit than cost. Encouraging walking can produce other "useful" community benefits by, 1) reducing vehicle emissions for air quality; 2) reducing congestion; and 3) providing access to transit.
Comfort	Creating comfortable public space and walkways draw people to a community and makes people want to stay. Elements such as street trees for shade, street furniture, or other pedestrian amenities along the sidewalk can increase user comfort.
Interest	People go for walks and sit in parks, plazas, patios, and other public and private spaces to "people watch." Pedestrian friendly environments that include seating, store fronts, and cafés support walking and people watching as activities (in and of themselves). Maintaining person scale streetscapes with interesting facades, public art, and plenty of activity keeps a community vibrant and can encourage walking.
Community	Encouraging people to walk, sit, and play on the street, instead of just driving along it, increases personal interaction within a community, bringing community members closer together. Increased familiarity can in turn also increase safety when neighbors look out for each other.

The push to increase non-motorized transportation over the past three decades has led to an increased need for research and data relating to walking and walkability. Walkability can promote healthier, safer, more livable communities and provide better access for persons with limited mobility and those who use walking and transit as their primary modes of transportation. While walkability is recognized as an important element to vibrant communities, no standard definition based upon systematic data collection and analysis has been developed to measure walkability. Popular websites such as http://www.walkscore.com (Walk Score, 2013) define walkability by land use density and mix but do not evaluate the physical pedestrian infrastructure and accessibility of individual pathways. While parcel-level land use data are often available, data on the presence and condition of sidewalks, which are a critical part of a walkable environment, are rarely available. As part of this project, the research team conducted a sidewalk quality survey with pedestrian transportation experts to try to identify sidewalk condition variables that best describe sidewalk quality (see Chapter 3). Survey results were intended be used in conjunction with the objective data collected with Sidewalk Sentry™ to weight the variables appropriately to assign quality ratings to each individual sidewalk segment. Due to potential biases in the results associated with the visual nature of the survey instrument, the survey reported in Chapter 3 served an "exploratory role" in the research, and as a learning experience for future survey iterations.

2.1.1 Sidewalk Quality

Studies show that elements typically associated with sidewalk quality play a key role in the public perception of sidewalk safety (Mendoza, 2013), and some may actually affect pedestrian safety. However, municipalities are struggling with developing appropriate and efficient sidewalk evaluation methods. Previous methods of sidewalk evaluation involve agencies sending personnel out into the field to subjectively evaluate sidewalks by visually examining the pavement and/or taking measurements (Mendoza, 2013; City of Portland, 2013). While visual assessment method can provide useful data and may be accurate, they are neither time-efficient nor cost-effective. Qualified technical experts generally conduct these surveys and physical inspections are time-consuming. In many cities in the US, including Atlanta, community members have the ability to report sidewalk problems to local governments (Mendoza, 2013). However, attendance of public forums in Atlanta relating to city sidewalk maintenance revealed that citizens are often disillusioned and dissatisfied with the results of simply reporting problems. Current field methodologies also suffer from a major disadvantage in that it is difficult to conduct equitable assessments across large urban areas. Sending inspectors out to specific sites in response to problems called in by neighborhoods will only alert officials to the needs of communities that are engaged in the public process. Repairing sidewalks in one area where deficiency data are available, and not in another area because deficiency data are not available, is an equity dilemma. For optimal sidewalk assessment, and equitable policy implementation, it can be argued that data should be collected over an entire jurisdiction (i.e., for the complete sidewalk network) and assessed using standardized criteria to describe sidewalk quality before sidewalk repair and rehabilitation decisions are made.

The prioritization process is further complicated by the lack of consensus on which types of sidewalk and ramp infrastructure deficiencies are of the greatest concern. In the field of transportation, surveys are more often distributed to users of the transportation network, than to experts in the field of transportation, to obtain information about user satisfaction with the system. One such study in Korea sought to tie emotional satisfaction to sidewalk environments by showing sidewalk users images of sidewalk segments and asking them to rate the sidewalk s on a numerical scale. Researchers then looked at variables such as width, surface condition, and presence of trees and shrubs in conjunction with peoples' satisfaction (Wang, et al., 2012). While high satisfaction may correlate with high quality sidewalks, designing a quality rating was not the aim of the Korean study. Another study examined the relationship between the physical environment and walking for elderly adults in Brussels, Belgium. The study included an interview about the built environment while walking from an origin to a destination. Questions pertained to land use, pedestrian facilities, traffic, safety, familiarity, social contacts, aesthetics, and weather. Results showed that pedestrian facilities, among other factors, were important to older adults in a walking environment (Cauwenberg, et al., 2012). Expert evaluations designed to develop consensus on the importance of various sidewalk elements, and conduct of sidewalk quality rating surveys (see Chapter 3), are not widely used. A great deal of research is still needed in this area to assess user-preferences with respect to sidewalk quality indicators.

2.2 The Americans with Disabilities Act

In 1990, Congress adopted the ADA; signed into law by President George H.W. Bush. The ADA prohibits discrimination against persons with disabilities in the workplace, schools, public spaces, and in the provision of public programs and services. The ADA evolved from social policy that began in the early 1960s, a time when discrimination in employment and services based on demographic characteristics (such as gender, race, and physical abilities) was fairly commonplace. Social discrimination, and lack of accommodation for persons with physical and mental disabilities, was also quite prevalent in public transportation system. The U.S. Civil Rights Commission concluded that persons with disabilities were being treated as second class citizens, and that our failure to fully integrate persons with disabilities into society constitutes significant wasted potential in human productivity.

Title I of the ADA covers employment and requires businesses to provide reasonable accommodations in all aspects of employment for persons with disabilities. Possible accommodations or changes relating to transportation and sidewalks to meet Title I include changing the layout of work locations and providing appropriate access to the facility, or parts of the facility. Title II of ADA ensured reasonable accommodation to all government services and programs, and subsequent regulation have clarified that the scope includes all activities of state and local governments. Title II therefore requires that all buildings, structures, and programs operated by government agencies (or any entity with over 50 employees) comply with the ADA. Transportation infrastructure, such as transit services, streets, and sidewalks, fall under the category of 'programs' and therefore are covered by the provisions of Title II of the ADA. Hence, transportation infrastructure used in day-to-day life must be made accessible for persons with disabilities.

Under Title II of the ADA, all new infrastructure (such as buildings and transportation systems), and major alterations to the infrastructure, must be designed and constructed to meet ADA accessibility design guidelines, and older buildings and systems must be updated or retrofit whenever practicable (28 CFR §35.151 New construction and alterations). Although the regulations did not require the retrofit of pre-1992 facilities in the absence of major alterations, jurisdictions were required to develop an ADA transition plan and self-evaluation by January 26, 1992. These ADA transition plans describe how existing facilities will be updated to achieve program accessibility for persons with disabilities (28 CFR 35.151(d)). The transition plan must also include a schedule for providing curb ramps or other sloped areas where pedestrian walks cross curbs, giving priority to walkways serving entities covered by the Act, including State and local government offices and facilities, transportation, places of public accommodation, and employers, followed by walkways serving other areas. In developing the ADA transition plan, the agency must have provided an opportunity to interested persons, including individuals with disabilities or organizations representing individuals with disabilities, to participate by submitting comments. More than 20 years has passed since these ADA transition plans were required; yet, sidewalks and ramps in many cities across the country still do not meet ADA design criteria.

Federal, state, and local municipalities recognize that inaccessible and unsafe pedestrian facilities are a problem across the country. However, most (the vast majority) transportation planning agencies have not developed a sidewalk inventory in their asset management systems, nor do many of these agencies have infrastructure condition data for their sidewalk facilities, irrespective of whether a formal asset management system has been implemented. In 2007, the United States Government Accountability Office (USGAO) transmitted a report to the House of Representatives recommending that the USDOT and state departments of transportation improve data and guidance for ADA compatibility (USGAO, 2007). In 2010, the Highway Capacity Manual (HCM) included a chapter on pedestrian transportation for the first time. The 2008 report entitled "ADA Compliance at Transportation Agencies: A Review of Practices" (Quiroga and Turner, 2008), contracted by the American Association of State Highway and Transportation Officials (AASHTO), states that agencies must adhere to ADA guidelines, and must develop a system for assessing pedestrian facilities to assure compliance. ADA design and implementation requirements affecting sidewalks essentially evolved over time via an iterative process of legislation, regulatory development, and policy response to court decisions related to ADA compliance.

Sidewalks in Atlanta, and in many urban areas across the county, often do not adequately provide for the needs of pedestrians. Sidewalks should help make communities safe and livable, but often fail to do so. Sidewalks that do not meet ADA criteria are often unsafe, exposing pedestrians, wheelchairs users, families using strollers, and persons carrying heavy loads to unnecessary risk. As noted above, most regions lack a spatial sidewalk inventory and will benefit greatly from the project from an infrastructure planning perspective. The Automated Sidewalk Quality and Safety Assessment System project has yielded a system to effectively and easily evaluate sidewalks and pedestrian pathways based on their existence, condition, and ADA compatibility. Results from the research reported herein will help agencies to prioritize sidewalk improvements and improve the pedestrian infrastructure.

2.3 ADA Background

Roadways served pedestrians long before they served automobiles, street cars, bicycles, or horse-drawn carriages. Roman cities provided raised sidewalks on both sides of the street, with stepping stones to cross animal cart pathways (Grava, 2003). However, it was probably not until the middle of the 18th century (1700's) that major European cities began to embrace sidewalks (Grava, 2003). Even in the 19th century, concern for pedestrian safety was indicated by the adoption of red flag laws and low speed limits for steam-powered carriages. As the utility and popularity of motor vehicles continued to increase, separation of right-of-way became more and more prevalent. Vehicle speeds have increased so significantly over time that the measures needed to ensure safety of pedestrians have changed, with a focus on grade separation across modes of disparate speeds.

In the mid-twentieth century, during the highway-construction era, the debate over the impact of current transportation policies on the accessibility of persons with limited mobility and limited economic means led to significant changes in public policy. The Rehabilitation Act of 1973 sought to eliminate discrimination in federal programs. The Act was designed to ensure that programs as a whole were accessible; but, the Rehabilitation Act did *not* require that every element of every program be accessible, leaving gaps in accessibility equity in public programs. Subsequent to the passage of the Rehabilitation Act, the United States Department of Transportation implemented regulations addressing accessibility accommodation in urban transportation systems. Regulations required the addition of wheelchair lifts, installation of elevators in rail stations, and modifying rail cars and buses to make them more accessible.

The ADA was introduced in the United States Congress in 1988, and signed into law on July 26, 1990. The purpose of the law was to create a more accessible society, improving social equity for individuals with physical disabilities. The law extends to individuals with disabilities the same protections enjoyed by other citizens in the areas of employment, public accommodations and services, transportation, communications, and services provided by state and local governments. Contrary to popular belief, the ADA goals are not oriented toward provision of equality in service (e.g., making sure that individuals with disabilities can get from point A to point B via a transit option). Rather, the ADA goals are oriented around social inclusion and making sure that individuals with disabilities are able to participate in the same activities as the non-disabled community (e.g., riding on the same bus and interacting with other passengers). Hence, not only must all individuals be accommodated, but all users need to be integrated into the same system as much as practicably possible. The ADA of 1990 changed the way that new facilities are designed and constructed and required modifications to existing facilities and transportation services to increase accessibility to those with disabilities.

2.4 ADA Sidewalk and Ramp Design Standards

Since 1990, federal, state, and local agencies have developed a variety of design guidelines for ADA accessibility. In 2002, the U.S. Access Board (USAB) published the first definitive ADA Accessibility Guidelines (ADAAG) addressing accessibility in pedestrian infrastructure design (USAB, 2002). These design guidelines were amended by the USAB in 2004, 2006, and 2010. The various iterations of the ADAAG design standards are incorporated by reference into Title 28 of the Code of Federal Regulations (28 CFR 305.104 and 28 CFR 35.151(c)), which are the federal regulations that implement the Americans with Disabilities Act. Hence, the ADAAG constitute regulatory design standards that must be met. The specific ADAAG standards that apply to each project alteration depends upon the date the alteration is made (28 CFR 35.151(c)). The ADAAG standards must be met for public accommodations and apply to pedestrian travel paths, defined as continuous, unobstructed pedestrian pathways for approach, entry, and exit to facilities, including sidewalks, streets, and parking areas (28 CFR 35.151(b)(4)(ii)).

One of the most important contributions of the pedestrian infrastructure design elements was the establishment of an appropriate sidewalk width. The ADAAG design guidelines require a minimum "continuous clear width" that provides sufficient space for persons with disabilities (especially wheelchairs) to travel. Minimum sidewalk design standards are set to 36 inches, with 60-inch x 60-inch passing zones every 200 feet. ADAAG guidelines require that the maximum running slope of pedestrian access routes shall not exceed 5%, unless the slope of the adjacent roadway exceeds 5% in which case the pathway slope may equal that of the adjacent roadway. The ADAAG identifies cross-slopes greater than 2% as a barrier to accessibility because higher cross-slopes tend to pull wheelchairs away from their linear path. Appropriate cross-slope is an issue that applies continuously along the sidewalk surface, applying also to ramps and sidewalk curbcuts (driveway crossings). Curbcuts with non-compliant cross-slopes can often be found in older neighborhoods. Sidewalk pavement must be free of obstructions and must be "stable, firm, and slip-resistant," but these terms are not specifically defined by the regulation. ADAAG design guidelines specify criteria for abrupt changes in surface level, to ensure that vertical disjoints in the pavement surface do not create trip hazards or problems for wheelchair users and the visually impaired (white canes can catch on disjoints and in gaps). Vertical displacements of up to 1/4 inch are allowed without treatment. However, vertical displacements from 1/4 to 1/2 inch must be beveled to a slope no greater than 1:2. Any vertical change greater than 1/2 inch requires the installation of a ramp treatment, which is not to exceed a maximum ramp slope of 8.33%. Ramps cannot extend more than 30 feet without a landing area for wheelchair rest. The USAB's proposed accessible right-of-way guidelines (PROWAG) will reaffirm and further strengthen these design standards (USAB, 2011a and 2011b).

Table 2 summarizes the ADAAG-required criteria for widths, surface condition, grade, and cross-slope for "accessible routes," applying therefore to sidewalks (USAB, 2002; Quiroga and Turner, 2008). These federal guidelines for accessible design under the ADA apply to all federal, state, and local activities under the ADA. However, as with almost every major federal initiative, the federal design standards serve as minimum requirements. State and local agencies are free to adopt design guidelines that provide greater accessibility. For example, the City of Atlanta requires 60 inch sidewalks and the Florida DOT requires minimum sidewalk widths of 48 inches, plus 12 inches for buffer strips.

The ADAAG also specifies standards for curb ramps, which connect sidewalks with street crossings. The sidewalk standards in Table 2 also apply to ramps (e.g., cross-slope, smooth surface, and vertical displacement limits), except that maximum ramp slopes are allowed to be greater than sidewalk slope (8.33% vs. 5%). Additional standards apply to ramp features (e.g., flare slopes and the landing zone). Figure 1 illustrates standard ramp features: ramp surface, landing, gutter, and flare. A detectable warning surface must also be present to warn visually impaired pedestrians that they are approaching the vehicle right-of-way (Figure 2). The design standards that must be met for each ramp element are outlined in Table 3 below. Some of these ADA design standards remain a bit vague. For example, sidewalk and ramp surfaces must be stable, firm, and slip-resistant; however, no specific standards or test methods are defined.

Table 2. Standards for Sidewalk Design Features

Sidewalk Design Feature	**Federal Standards (ADAAG/PROWAG)**
Clear Sidewalk Width	• 36 inches minimum • If the width is less than 60 inch width, a 60-inch by 60-inch passing space must be provided every 200 feet
Running Slope	• 5% maximum slope or equal to roadway slope
Cross-Slope	• 2% maximum cross-slope
Obstructions	• No obstructions may be present within the pedestrian access route
Pavement Material	• Surface must be “firm,” “stable,” and “slip-resistant”
Changes in Level	• Vertical displacements up to 1/4 inch are allowed • Vertical displacements from 1/4 to 1/2 inch must be beveled to a slope no greater than 1:2 • Vertical changes greater than 1/2 inch must be smoothed so as not to exceed a ramp slope of 8.33%
Vertical Clearance	• 80 inches minimum vertical clearance

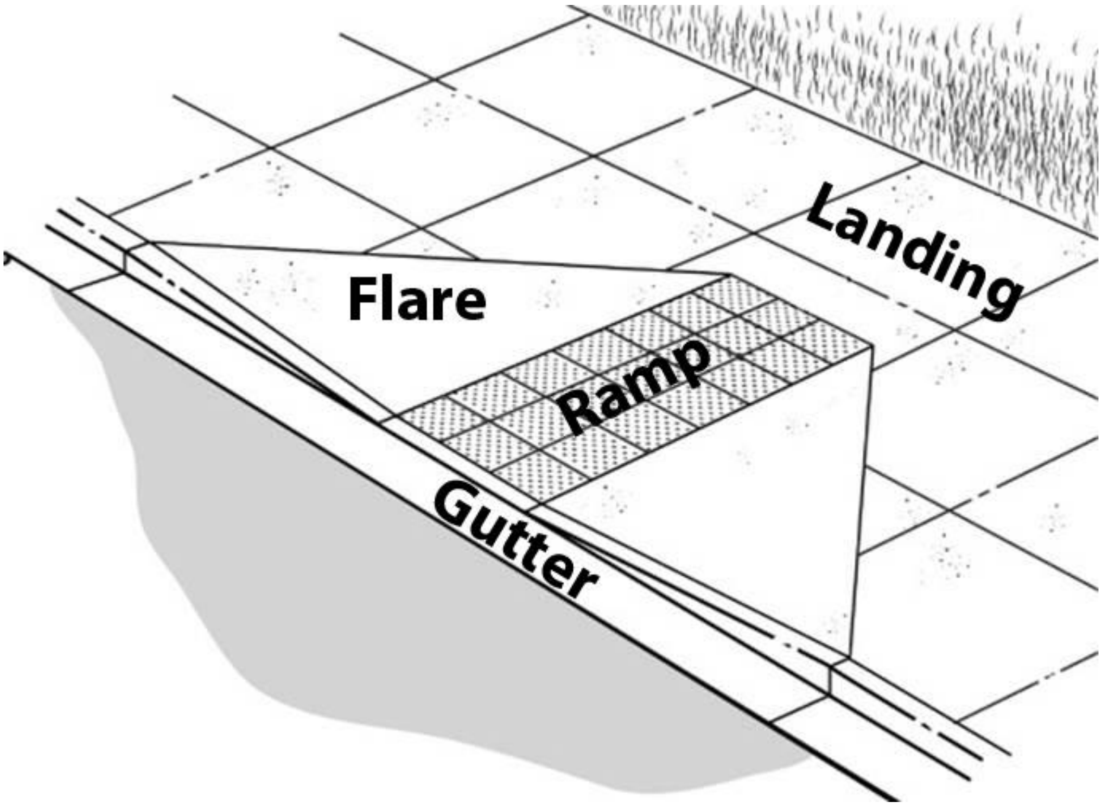

Figure 1. Ramp Design Features

Figure 2. Detectable Warning Surface

Table 3. Standards for Ramp Design Features

Sidewalk Design Feature	Federal Standards (ADAAG/PROWAG)
Clear Ramp Width	• 36 inches minimum (same as the value for sidewalks)
Passing Area on the Ramp Landing	• 36 inches behind ramp
Ramp Running Slope	• 8.33% maximum slope
Ramp Cross-Slope	• 2% maximum cross-slope (same as the value for sidewalks)
Gutter Slope	• 5% maximum slope from the bottom of the ramp up into the street (in the direction of wheelchair travel)
Ramp Obstructions	• No obstructions may be present within the pedestrian access route
Ramp Pavement Material	• Surface must be "firm," "stable," and "slip-resistant"
Changes in Level on Ramp and at Ramp Transitions: Street to Gutter Gutter to Ramp Ramp to Sidewalk	• Vertical displacements up to 1/4 inch are allowed • Vertical displacements from 1/4 to 1/2 inch must be beveled to a slope no greater than 1:2 • Vertical changes greater than 1/2 inch must be smoothed so as not to exceed a 5% slope
Vertical Clearance	• 80 inches minimum vertical clearance
Detectable Warning Surface	• Detectable warning surface must be present

Some of the updates to the ADAAG design guidelines in 2004, 2006, and 2010 apply to specific design features for accessible public facilities and programs. For example, Appendix A: ADAAG Transit and Parking Discussion provides a brief discussion on transit accessibility and parking requirements. Taken together, the federal regulations and ADAAG design guidelines provide a framework for assessing pedestrian infrastructure conditions.

2.5 Maintaining ADA-compliant Sidewalks

Pedestrian infrastructure is considered part of the "public right of way" under Title II of ADA (public services) and local governments can be held liable for physical injury resulting from negligent maintenance of infrastructure (Prystowsky, 2010). Case law has established that sidewalks are subject to ADA requirements and that municipalities are responsible for removing barriers to reasonable accessibility (Barden v. Sacramento, 2002). The same case (Barden v. Sacramento, 2002) established that roadway maintenance projects, such as resurfacing of roadway pavement, are covered under the definition of roadway "alterations," and therefore trigger evaluation and upgrade of the right-of-way under ADA design guidelines. The issue of sidewalk maintenance was also affirmed in a more recent case in which plaintiffs sought injunctive relief under Title II of ADA (public services) and argued that pedestrian facilities are considered a public service or program administered by governments (Lautt, 2011). Municipalities are responsible for addressing sidewalk and ramp compliance as they perform adjacent roadway alterations, including street resurfacing.

2.6 Examples of Sidewalk and Ramp Defects under ADA Standards

Many common design and maintenance problems found in sidewalks and at curb ramp transitions are specifically covered by the ADA and PROWAG guidance. The type and severity of various problems can be used in prioritizing repair activities. For example, an uplift of 1/4 inch in a sidewalk paver might not be as important to repair as a 3" vertical rise caused by a tree root. However, failure to meet any of the design specifications for sidewalks and ramps will create a barrier to a person who uses mobility aids, such as a wheelchairs, walkers, or canes. Even problems perceived by City officials as 'minor' may render an entire route or block inaccessible to individuals with disabilities. Table 4 illustrates typical problems that can be found on sidewalks and Table 5 contains similar examples of problems that can be found for ramps (midblock and corner locations). Allowing any single problem, such as a damaged detectable warning surface, to persist creates safety hazards for all pedestrians, especially those who depend on the damaged feature for warnings. Limiting access at a crosswalk can create a barrier that causes a pedestrian to take unnecessary crossing risks or retrace an entire block to find an alternative route.

Table 4. Example Sidewalk Defects under AADAG Standards

Photo of Typical Sidewalk Problem	**Non-conformance with Federal Criteria (ADAAG/PROWAG)**
	Sidewalk width is less than 36 inches
	Sidewalk running-slope is greater than 5%

	Sidewalk cross-slope is greater than 2%
	Sidewalk obstruction is present

	Pavement material is not "firm, stable, and slip-resistant"
	Vertical displacement is greater than 1/2 inch and a proper ramp (8.33%) is absent Example 1

	Vertical displacement is greater than 1/2 inch and a proper ramp (8.33%) is absent Example 2
	Vertical displacement is between 1/4 inch and 1/2 inch and surface is not beveled 1:2 (requires milling or patching)

	Vertical clearance is less than 80 inches

Table 5. Example Ramp Defects under AADAG Standards

Photo of Typical Sidewalk Problem	Non-conformance with Federal Criteria (ADAAG/PROWAG)
	Ramp width is less than 36 inches

	Ramp running slope is greater than 8.33%
	Ramp cross-slope is greater than 2%

	Passing area behind the ramp is less than 36 inches deep (36 inches ramp width by 36 inches deep)
	Ramp obstruction is present

	Ramp pavement material is not “firm, stable, and slip-resistant”
	Gutter slope (from road to ramp) is greater than 5%

	Road to gutter transition is not flush Vertical displacement is greater than 1/2 inch without a sloped ramp, or is between 1/4 inch and 1/2 inch without a 1:2 bevel
	Gutter to ramp transition is not flush Vertical displacement is greater than 1/2 inch without a sloped ramp, or is between 1/4 inch and 1/2 inch without a 1:2 bevel

	Ramp to sidewalk transition is not flush Vertical displacement is greater than 1/2 inch without a sloped ramp, or is between 1/4 inch and 1/2 inch without a 1:2 bevel
	Vertical clearance is less than 80 inches

	Detectable warning surface (texture pad) is missing
	Detectable warning surface (texture pad) is damaged

With respect to evaluating “sidewalk quality,” the development of innovative and automated methods to assess compliance of sidewalks with ADA design standards was the initial focus of this research effort. Traditional sidewalk data collection methods require significant time and resources for public works departments and could be significantly improved via technology. New methods have been emerging to streamline the sidewalk assessment process and aid municipalities in transportation planning efforts and in developing ADA transition plans for sidewalks and pedestrian pathways. Advanced data collection systems, volunteer efforts, and Geographic Information System (GIS) technologies have been utilized by state and local agencies to streamline pedestrian and ADA data collection processes (Quiroga and Turner, 2008).

However, “sidewalk quality” likely encompasses more than just ADA compliance. Chapter 3 of this report documents the efforts of the research team to identify additional elements and data sources that might be considered in the assessment of sidewalk quality through surveys of technical experts.

3 Sidewalk Quality

The goal of the research effort was to develop a system to generate spatial sidewalk inventories, automatically assess sidewalk quality, and ultimately prioritize sidewalk repairs. However, to identify where improvements and repairs need to be made, a definition of high quality, acceptable quality, and unacceptable quality sidewalks must be developed. Certainly, compliance with ADA design standards (e.g., the width a sidewalks must be to be considered accessible) must be considered in any assessment of sidewalk quality. However, additional goals of mobility, pedestrian safety, liability, sense of community, and other aspects of walkability are also important in transportation planning. Hence, an objective of this research effort is to develop a sidewalk quality ranking system that employs objectively-collected sidewalk measurement data (see Chapter 4 on the Sidewalk Sentry™ Android tablet application), in conjunction with other potential variables identified through a Sidewalk Quality Assessment Expert Survey. Taken together, objective and subjective data might be efficiently employed.

In conjunction with field data collection efforts to gather objective data for sidewalks in Atlanta (Chapter 5), the researchers developed and deployed an expert survey that employed detailed data collected from 40 sample sidewalk segments. The survey asked invited pedestrian transportation professionals to evaluate and rate four randomly-selected sidewalk segments from the database of 40 segments (experts could repeat the survey multiple times, obtaining different sidewalk segments per trial). The survey solicited the experts to assign an individual sidewalk rating (from “very poor” to “excellent”), asked what factors were important in the expert’s ratings, and asked respondents to comparatively rank each sidewalk against the other three sidewalks for the sample of four. The main objective of the survey was to inform sidewalk quality research with opinions of experts in pedestrian transportation and infrastructure.

A classification tree analysis identified three important variables in the expert rankings: presence of cracks and potholes, gaps and vertical disjoints in pavement, and the presence of planting strips with trees as a pedestrian amenity. After analyzing the data, however, the research team concluded that a potential survey bias was suggested by the results. All three critical variables in rating decisions of experts were gauged visually from video and image data, while other potentially-important variables to wheelchair users were not identified by the experts as being important. Sidewalk width, grade, and cross-slope were either not important to the experts, or were not readily identified by the experts as “problems” in reviewing the video images, although numerical values were provided adjacent to the images.

Based on the survey results, the research team concluded that any future system for prioritizing repairs and maintenance would need to incorporate a mechanism to allow decision-makers to independently weight sidewalk quality variables to set priorities based on their own goals and objects. A flexible/adaptable prioritization system would allow local agencies to focus on elements that are most important to the local community. This Chapter focuses uses the results of the expert panel survey to identify various factors useful for developing a sidewalk repair prioritization system.

3.1 Sidewalk Quality Survey Data

The research team scoped 60 sidewalk segments in the City of Atlanta and selected 40 for inclusion in the online survey. This scoping process identified a range of what were expected to be rated as poor quality to high quality sidewalk segments across a variety of parameters such as width, surface roughness, etc. Locations were based on previously outlined pedestrian infrastructure needs, recently completed sidewalk/streetscape projects, and an analysis of high-crash intersections within the City of Atlanta.

Graduate student members of the research team visited all 40 survey segment locations and collected video and sidewalk measurement data for each segment. The survey segment data collection consisted of the following elements:

- Field collection of rolling video using Sidewalk Sentry™ (see Chapter 4)
- Field collection of sidewalk widths at the beginning and end of each segment
- Field collection of slope and cross-slope at the beginning and end of each segment
- Total distance of each segment, estimated via Google Maps distance measurement
- Surrounding land-use and transit options observed in the field and via online scoping

The research team collected video data for 40 of the sidewalk segments for approximately one block length (later trimmed to 0.1 to 0.2 miles) for use in the survey. Data were collected using the Sidewalk Sentry™ Android application and by hand measurement to procure video, width, grade, cross-grade, amenity, and surrounding land use information.

The Sidewalk Quality Survey was designed as a web-based, user-friendly survey targeting pedestrian and transportation planning and engineering professionals. The survey was developed at the Georgia Institute of Technology (Georgia Tech) using a custom-developed web survey platform that allowed flexibility in the design and functionality of the survey. The system was designed to support the use of large linked files, such as multiple videos, images, and maps. The web-based survey tool uses PHP linkages to a MySQL database so that researchers can create a variety of different types of surveys using standardized pre-established question and answer formats. The surveys and responses are hosted within secure servers at the Georgia Institute of Technology to provide greater privacy protection than commercial survey tools. A relational database stores the questions, answers, and the survey layout, along with the order and dependence of questions and answers. The survey tool supports standard question types such as single answer, multiple answers, comments, scale questions, and rank order questions. The survey tool also supports unique question types, such as questions that pull randomly from choice sets and options that allow users to review videos and photos (used in this research). Because the survey tool was constructed from the ground-up, Georgia Tech researchers can customize question types and surveys to suit various research needs.

The survey respondents were asked to rate the quality of each of the four sidewalk segments they received in the survey on a 1 to 5 scale. Then, users were asked to comparatively ranking the four sidewalk segments given (resolving any ties). Respondents were asked to indicate what variables play a positive or role in the rating, and were provided space to write comments. The nine variables included are sidewalk grade, cross-slope, width, cracks and maintenance, vertical clearance, presence of obstructions, buffers and pedestrian amenities, gaps and level changes, and curb ramps. The nine variables were chosen based on elements associated with ADA compatibility and are qualities often cited in sidewalk assessment studies. Sidewalk grade, cross-slope, and width were all provided in numeric form as percent or inches, based upon ADA criteria (Maghelal and Capp, 2011; Marshall and Garrick, 2010). All variables were included in a question that asked which parameters were important in the expert's ranking decision (i.e., whether each variable relates to the overall quality rating). The survey also includes an "other" option that may be elaborated upon by the user in a comments text entry section.

3.2 Survey Design

The Sidewalk Quality Expert Survey was developed using an online survey building system developed in-house. The survey included the data described in the last section, as well as screen shots from the video and context maps of the location of the segment in the city. The online system contained a SQL table with information for all 40 segments, from which four segments were randomly selected for each survey iteration. Users were allowed to take the survey up to 12 times, each time with different randomly-selected segments. Figure 3 shows the progression of the survey in flow chart form with boxes representing the survey pages and black text representing actions taken by the user.

The survey begins with a survey overview page, which leads survey takers to a page with four randomly selected sidewalk segments from the database of 40 possible segments. Respondents choose one segment to start and are brought back to the 2X2 grid of the given segments for their survey iteration after rating each individual sidewalk segment. Figure 4 shows this first survey page with the four random segments to rate. The photos show a street view of the sidewalk location. When the user clicks on the photo, a segment evaluation page "pops up" for completion by the user.

Each segment is selected by the user one at a time. For each segment, the survey respondents watch the linked sidewalk video, access still images, access context maps, and see measurement data. The user then rates each segment on a five-point scale. The 1 to 5 ratings are shown as: 1) Non-existent or very poor; 2) Poor to below average; 3) Average; 4) Above average to good; and 5) Very good. These categories give an even spread of 'very bad' to 'very good' for researchers to examine as related to different variables' effects on the ratings. Figure 5 shows a screenshot of the page for a sidewalk segment where users see basic measurement information, click on links to view video and images of the sidewalk segment including a context map, and then rate the segment. Methods and initial results were presented in TRB summary paper for the survey effort (Grossman, et al., 2014).

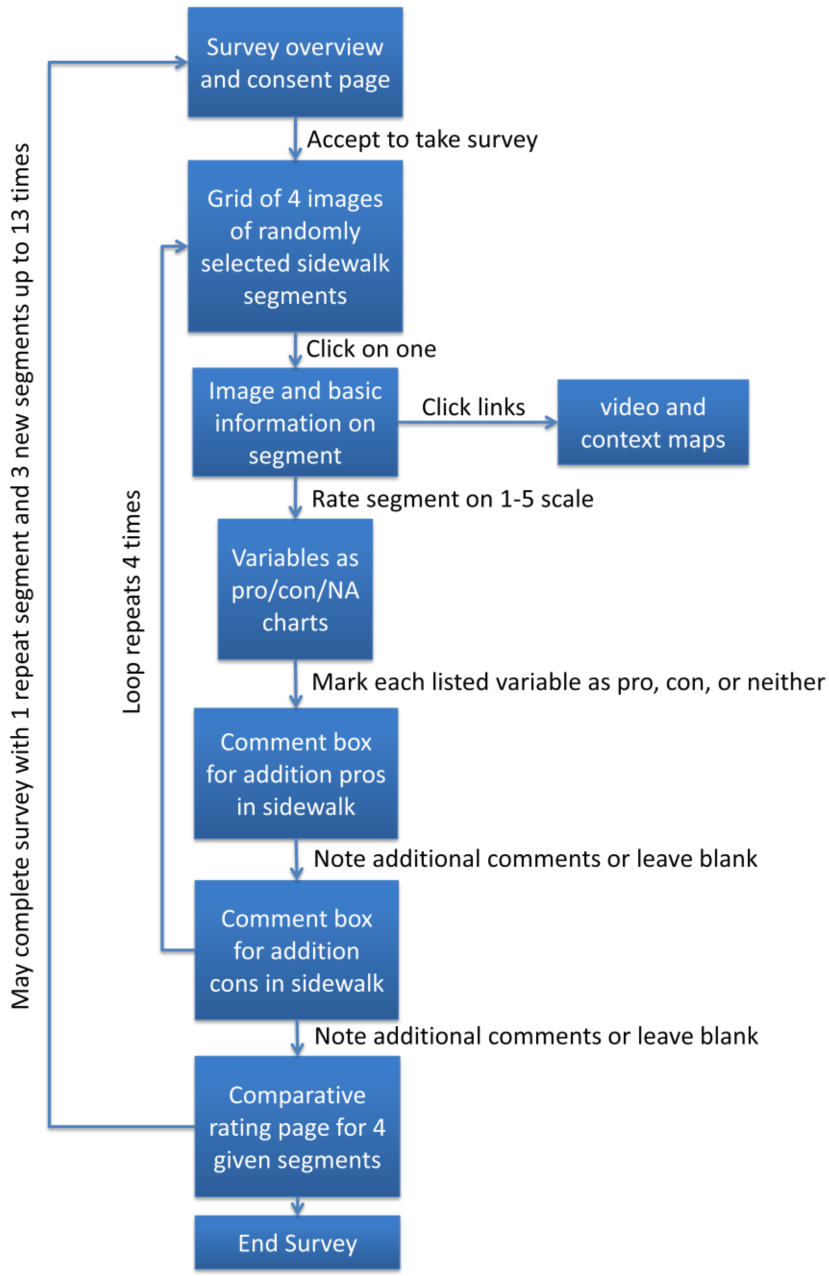

Figure 3. Flow Chart of Survey Progression

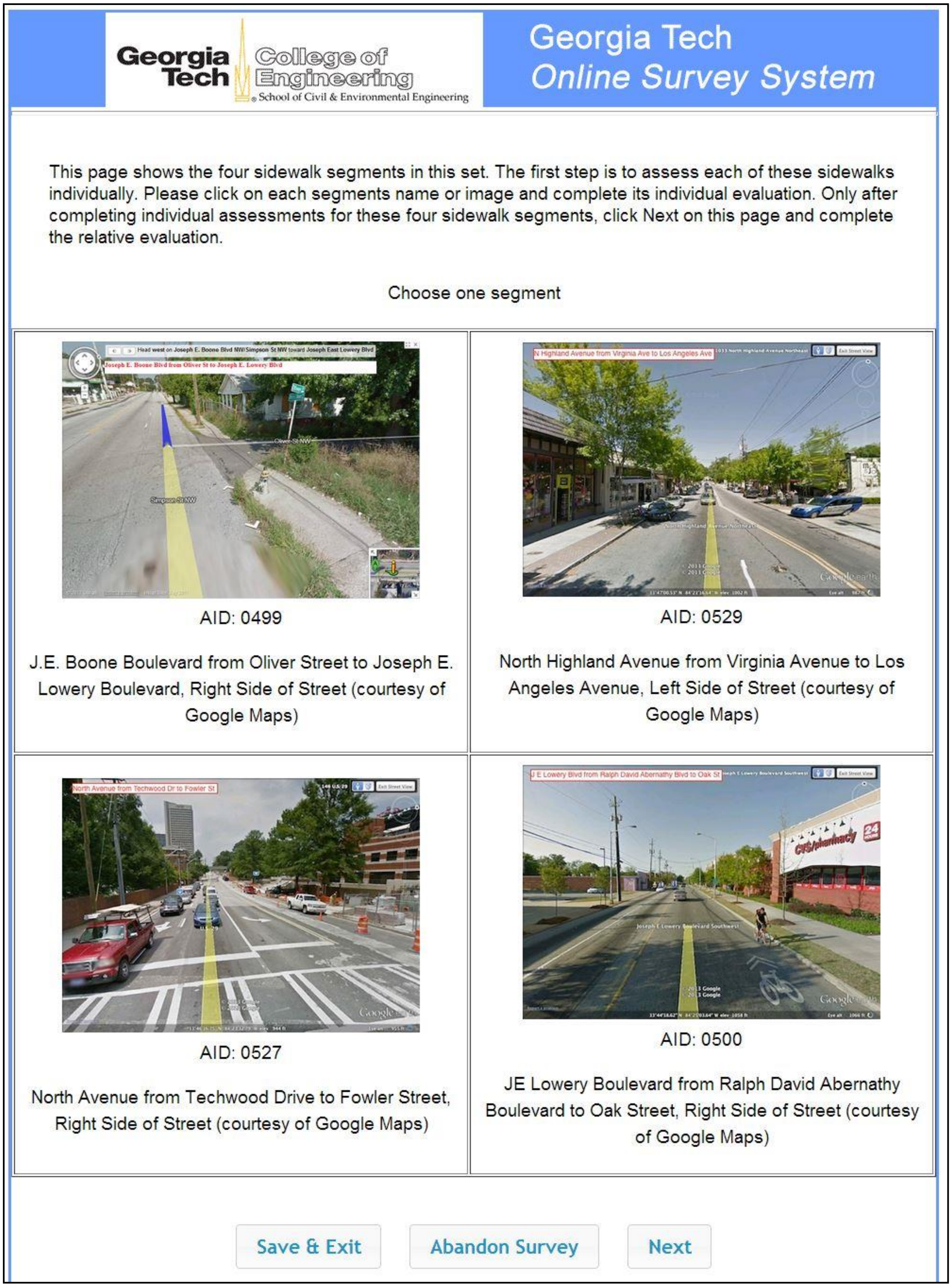

Figure 4. Screenshot from Start of Sidewalk Assessment Survey

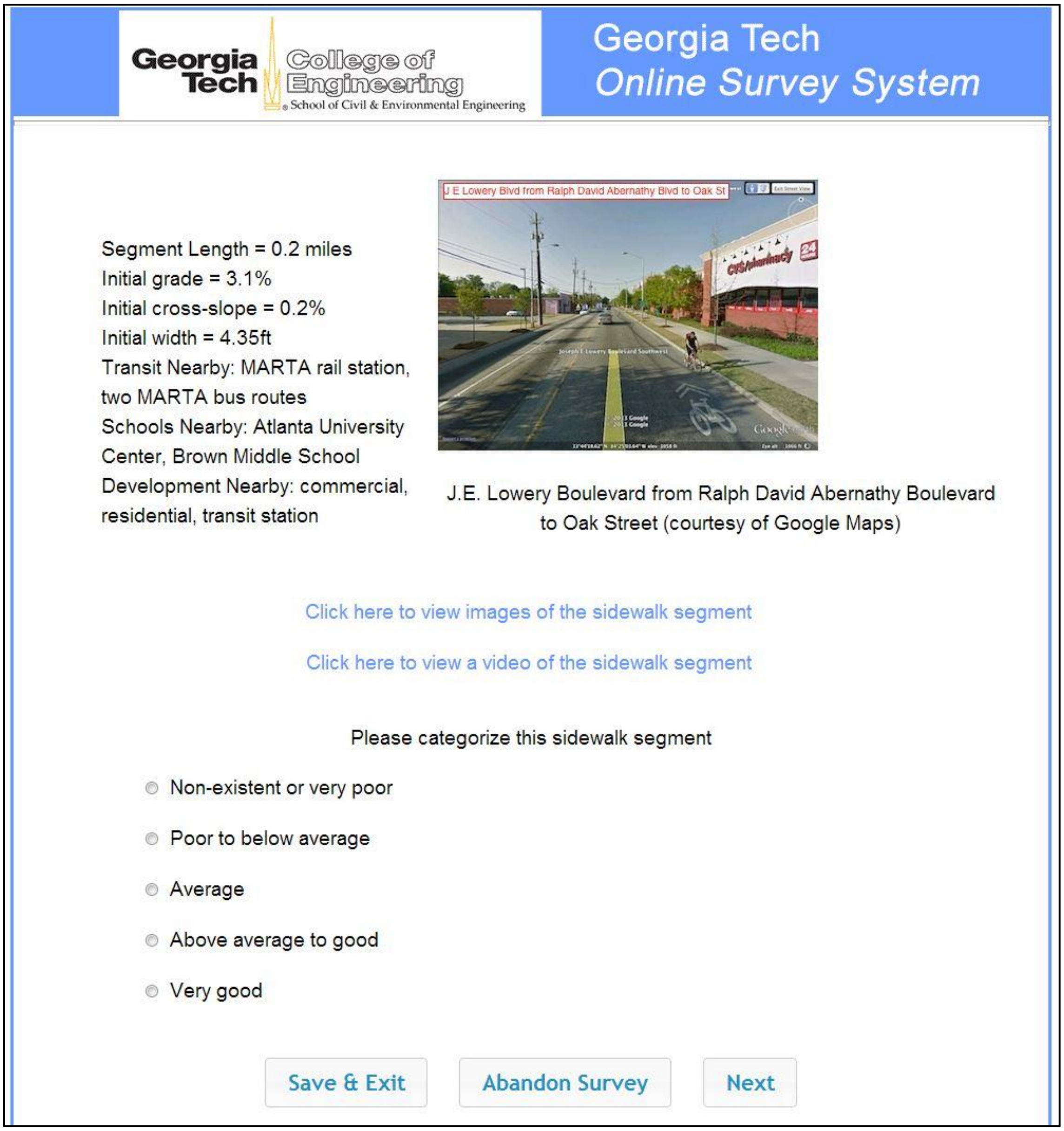

Figure 5. Screenshot from Rating Page of Sidewalk Assessment Survey

After rating each sidewalk, users were asked to indicate which of the nine variables had a positive (pro), negative (con), or not-applicable (NA) effect on their overall rating of the sidewalk segment. There is also an optional field to add extra comments on pros or cons identified in the segment. Once the respondent rated all four sidewalk segments given to them for each survey, they finish the survey by asking the user to rank order the four segments by quality (1, 2, 3, and 4). Upon completion, a respondent may repeat the survey for four segments up to twelve times. Each time the user is provided new segments from the database of 40, with the possibility of one repeat segment (for control). The initial survey was pre-tested by graduate students and by members of the Atlanta pedestrian advocacy organization, Pedestrians Educating Drivers on Safety (PEDS), in April 2013. Pre-testers provided input to refine individual questions and survey instrument flow.

3.3 Survey Deployment

On April 28, 2013, The Sidewalk Quality Assessment survey "went live" and was published as a web-based survey. Survey access was provided to invited professionals via an email link to the site. Professionals in the field of pedestrian transportation, non-motorized transportation, and transportation in Atlanta were invited to participate. State DOT Bicycle and Pedestrian coordinators, members of the Transportation Research Board (TRB) Pedestrian and Bicycle Data Subcommittee, members of the Association for Bicycle and Pedestrian Professionals and America Walks email mailing lists, members of the TRB Accessible Transportation and Mobility committee, Professionals at the Atlanta Region Commission (ARC) and other local Atlanta public, transportation, and community groups were also included on the list of stakeholders to which the survey was deployed. The link distributed by email was redistributed further by some of these professionals to coworkers and acquaintances in the field. Researchers also sent out multiple reminder emails to participants. Participants received notification of the survey closing one month after distribution. Researchers obtained 113 survey responses from transportation experts.

3.4 Sidewalk Quality Survey Results

Of the 113 instances of a survey being taken, 87 surveys were complete (73 unique user logins) and 297 cases of individually rated sidewalk segments were collected. As the survey was intended for a convenience sample, not a probability sample, the desired sample size was simply to reach as many experts in the field as possible. An unknown number (minimum 200) of experts were contacted to participate, suggesting a maximum response rate of 36% which is encouragingly-high, compared to the standard 10% expected response rate for surveys. The 297 cases to analyze also provide what is generally considered in the literature as a sufficient volume for statistical analysis (Dillman, 2000). Unusable responses did not contain complete data, due to users logging in and then deciding to not continue the survey either on a first or repeat iteration. The survey data set contains at least two responses with ratings, variable influences, and comments for every one of the 40 segments. Eight of the 40 segments received seven responses. Figure 6 shows the cross of survey responses and segments.

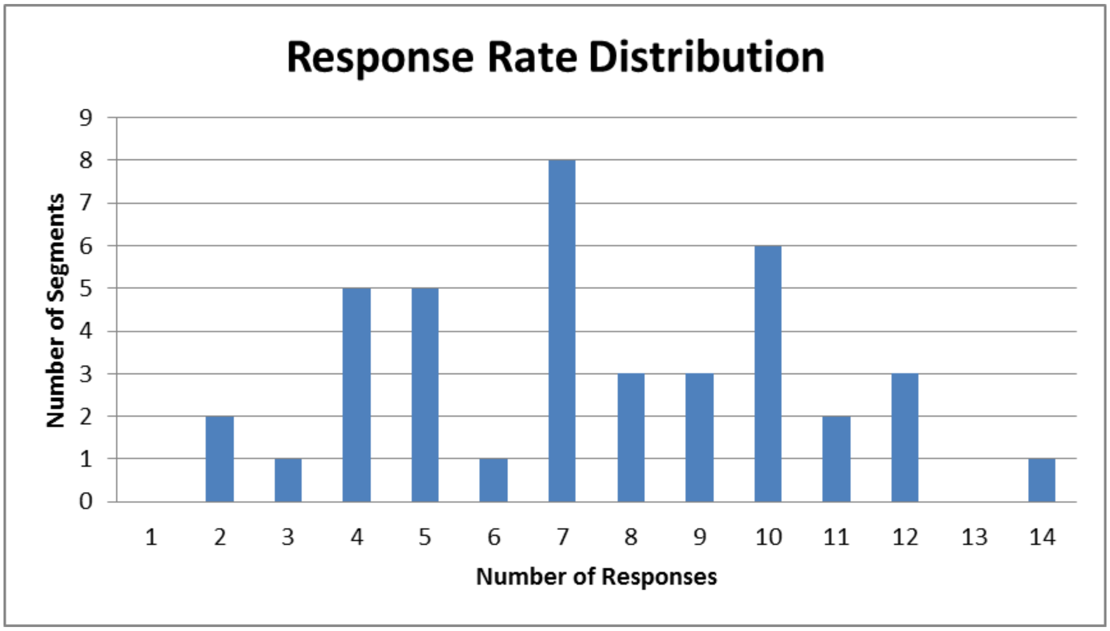

Figure 6. Survey Segment Response Rate Distribution

This uneven distribution in responses is due to the nature of the random selection of four segments for each survey. Some incomplete segment responses were also removed during data cleaning. In assessing each segment, it is important that enough survey responses are recorded for results to be reliable. Segments with two and three responses have low response rate values, and conclusions will be caveated accordingly. For the purpose of conciseness, the five possible sidewalk ratings of 'non-existent to very poor,' 'poor to below average,' 'average,' 'above average to good,' and 'very good' will correspond to numbers 1 through 5 (1 being nonexistent to very poor and 5 being very good) for the remainder of this Chapter.

The two segments with only two responses were the segments at Martin Luther King Drive and HE Holmes Drive and the segment at South Ponce de Leon Avenue and Springdale Road. Both segments were rated as a 2 by one respondent and a 3 as the other. The sidewalk segment at JE Boone Boulevard and Oliver only received three responses, with ratings of 2, 2, and 3. These numbers indicate that each segment with a low response rate still received comparable response ratings. The consistency in overall ratings allows us to use all 297 cases to analyze all 40 sidewalk segments; even segments with a lower response rate.

Figure 7 below shows the distribution of the ratings across the 297 cases showing a clear tendency of survey respondents to rate the given sidewalks as below average (2), average (3), or above average (4), with fewer ratings on either extreme as non-existent to poor (1) or as very good (5).

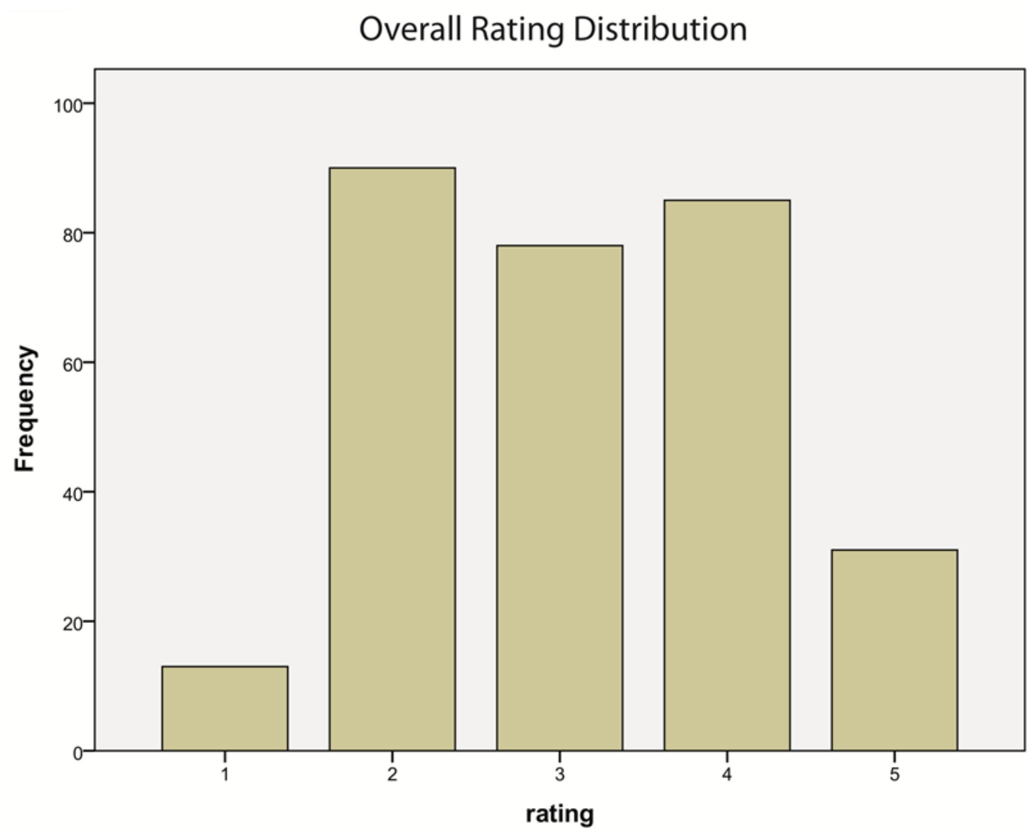

Figure 7. Overall Rating Distribution

3.4.1 Sidewalk Quality Rating Distributions

The overall distribution of ratings gives an idea of how survey takers tended to rate the sidewalk sections. Table 6 shows the distribution of ratings over each individual segment in a simple cross-tabulation, where each line represents one of the 40 segments and each column shows the percentage of survey takers who gave the segment that number rating. The challenge in working with the discrete rating system is choosing which overall rating to give each sidewalk in the end. Each box in Table 6 is shaded to an intensity level proportional the percent of people who gave the segment that ranking. The ratings are not uniformly distributed. For each segment, variability in response is noted. Segment 1 only received four responses, and one deviated significantly from the other three. However, the responses for each segment do trend toward either a lower or a higher rating value. Interestingly, Segment 23 received a 100% response ranking value of 2 for all seven responses.

Table 6. Rating Distribution by Sidewalk Segment

Sidewalk Segment Number	Rating					Number of Responses for Segment (n)
	1	2	3	4	5	
1	25%			75%		4
2		42%	50%	8%		12
3	25%	75%				12
4	14%	14%	43%	14%	14%	7
5	14%	43%	29%	14%		7
6			14%	57%	29%	7
7	10%	70%	20%			10
8		25%	58%	17%		12
9		67%	33%			3
10			11%	78%	11%	9
11		50%	50%			4
12			20%	60%	20%	5
13				60%	40%	5
14		29%	29%	43%		7
15		60%	20%	20%		5
16		9%	45%	36%	9%	11
17		17%	67%	17%		6
18			38%	50%	13%	8
19		7%	7%	57%	29%	14
20		11%	22%	67%		9
21		43%	14%	43%		7
22		50%	50%			2
23		100%				7
24			20%	60%	20%	10
25	75%	25%				4
26				71%	29%	7
27		40%	60%			10
28		50%	50%			2
29		60%	40%			5
30		10%	10%	60%	20%	10
31		50%	38%	13%		8
32	20%	60%	20%			5
33		50%	38%		13%	8
34			50%	50%		4
35			29%	43%	29%	7
36		18%	18%	27%	36%	11
37				25%	75%	4
38		80%	20%			10
39			44%	33%	22%	9
40	20%	70%	10%			10

The segments with one darkly shaded box in Table 6 shows, white or weakly shaded boxes in the rest of the row, infer consensus among survey takers and a clearer dominant overall rating number. In other cases, less consensus is evident and the chart shows a larger spread of ratings among survey respondents. Segment numbers 36 and 37 are good examples of two distinct cases, where segment 37 has a clear consensus of a 5 rating and segment 36 is more difficult to classify. Segment 37 received 75% of the responses rating the segment as a 5 and 25% rating it as a 4. This suggests a clear dominant rating of 5 for the segment and agreement among the experts. However, segment 36 has responses spread at 18% as a 2, 18% as a 3, 27% as a 4, and 36% as a 5 leaving ambiguity as to where the segment stands on a quality rating scale.

3.4.2 Individual Variable Effects on Overall Ratings

Each sidewalk quality analysis variable identified in the survey was examined individually to assess trends in experts listing the variable as a pro (Pro), a con (Con), or not applicable (NA) in their overall rating decision. Figure 8 shows the counts for how many times each variable was indicated to be a Pro, Con, or NA for each ranking of 1, 2, 3, 4, or 5.

Although strong patterns are not easily identifiable across all the graphs in Figure 8, a few trends are discernable. Most variables having high levels of non-applicability appear in ratings of 2, 3, and 4, with the exception of width and cracks/maintenance. There is a tendency for higher rated sidewalk to have cracks and maintenance, obstructions, buffers and amenities, and gaps and level changes listed as a pro and lower rated sidewalks to have these variables listed as a con. However, there are some anomalies to this pattern with a few sidewalks rated as a 5 but having at least one of the variables listed as a con. Additionally, there are instances of sidewalks rated as a 1 with at least one of these variables listed as a pro.

To assess the impact each variable has in comparison to one another, they must be analyzed together with respect to sidewalk segments ratings. Researchers performed a classification tree analysis including all relevant variables to assess the relative importance of each individual variable in determining an overall sidewalk quality rating.

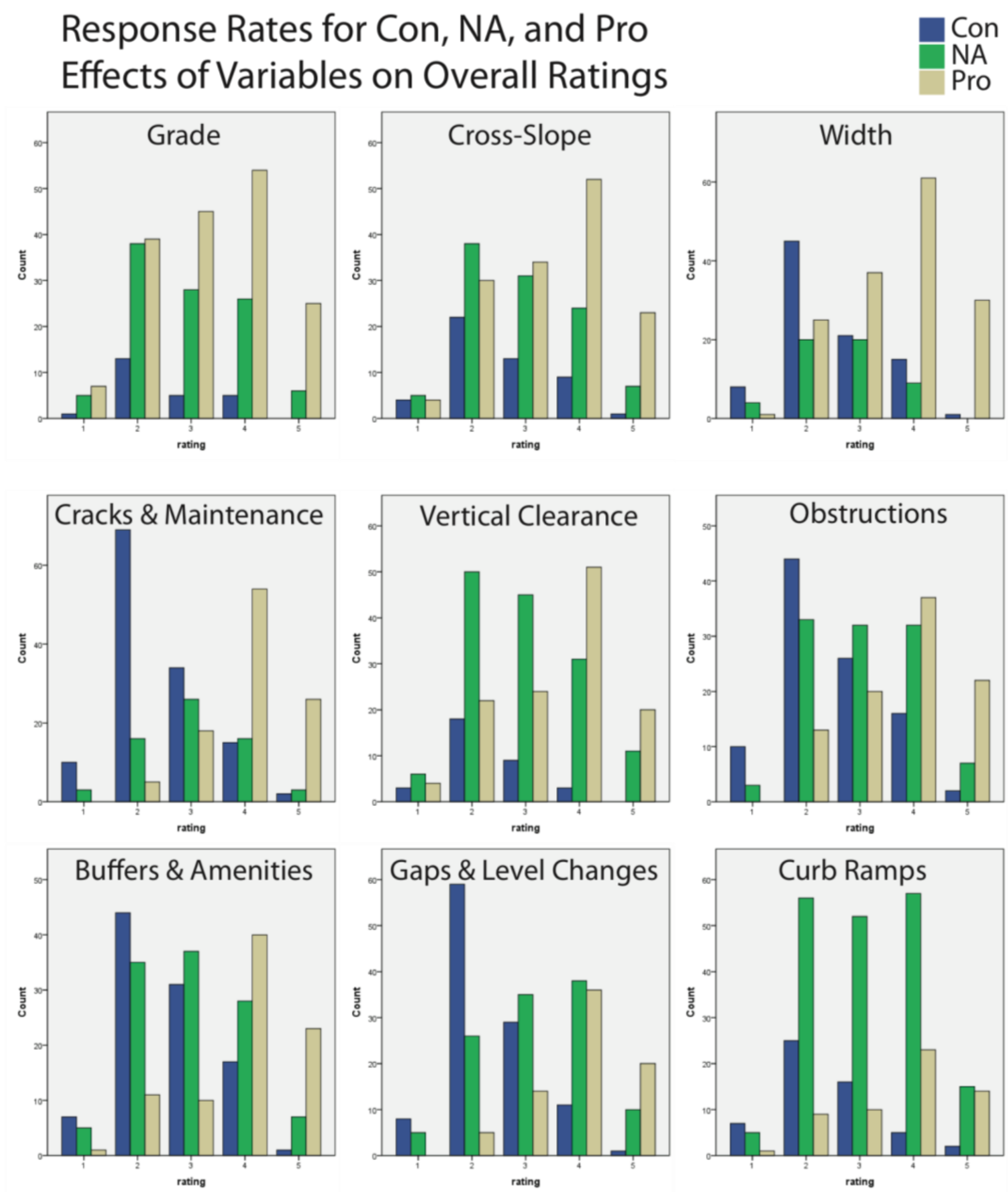

Figure 8. Response Rates for Con, NA, and Pro Effects of Variables on Overall Ratings

3.4.3 Classification Tree Analysis

Classification trees are used to assess the potential influence of variables on an observed outcome. When working with discrete data, such as numerical rankings and categorical variables, a classification tree can be a very straightforward and powerful assessment tool (Shalizi, 2013). The basic approach of classification tree analysis is to test all independent variables across all discrete values (or the range of a continuous value), using the variable and variable value to split the large sample into two data subsets; one subset containing all sample data where the value of the specific variable falls below the variable value cutpoint, and the other subset containing all sample where the value of the specific variable is above the variable value cutpoint. An iterative testing process ensues until the program finds the variable and cutpoint value that obtains the largest reduction in total variance of the dependent variable after the large group is subdivided into the two subsets (sum of squared errors for the dependent variable around the mean response value for the large data set vs. the total of the sum of squared errors around the means in each of the data subsets). After the sample is split into two subsets, the process is repeated for each remaining data subset. The bifurcation process continues for each of the newly created subsets, until a prescribed analytical limit is reached, typically a minimum reduction in variance for the split and /or a rule that ensures that some minimum number of observations remain in each of the final data subsets. In summary, the classification tree process partitions the data into subsets based upon the hierarchy variables that reduce sample variance.

A classification tree analysis of the survey response data indicates how sidewalk quality variables affect sample response variance. The tree identifies the mode rating for each given classification on the 1 to 5 scale (1 being ‘non-existent to poor’ and 5 being ‘very good’). All ten variables (including “other”) that users were asked to identify as having a positive, negative, or negligible impact on their overall rating of the sidewalk were employed in the analysis. The first variable used to split the sample typically has the greatest influence on the experts’ overall rating of a sidewalk segment. Figure 9 shows a tree diagram of the classification tree for this data. The top number in each oval or box is the mode of the rating for segments with the given characteristics. The five numbers separated by dashes below the mode rating show the distributions of ratings (1/2/3/4/5) within the category. The classification tree was pruned to a minimum final bucket size of 15 data point for each data subset to eliminate frivolous leaves and nodes.

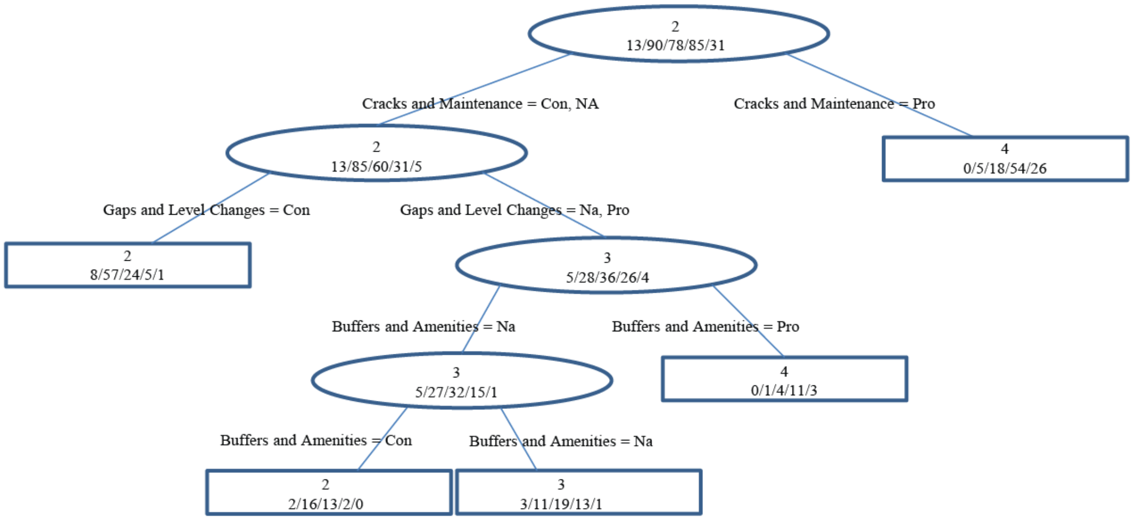

Figure 9. Sidewalk Quality Variables to Describe Overall Ratings Classification Tree

The analysis identifies the variables that likely play the largest role in the overall rating of the sidewalk, indicating also whether the variable is influential as a pro or a con in the evaluation. The first level of the tree shows a mode of 2 for sidewalk quality rating for the entire database of 40 sidewalk segments included in the survey. The first split of the tree is on the variable 'cracks and maintenance.' Once the sample is divided into two groups, one where reviewers identified 'cracks and maintenance' as a positive variable in their decision, the mode of sidewalk quality rating was 4 for the positive effect and 2 for the negative effect. None of the sidewalk segments rated as 1 (very poor), and only 5 of the 90 segments rated as 2 (poor), by survey respondents were identified as having a positive influence associated with the cracks and maintenance variable. Only 5 of the 31 sidewalk segments rated as 5 (very good) by survey respondents were identified as having a negative influence associated with the cracks and maintenance variable. Hence, the presence of cracking or surface maintenance issues appears to have largest impact on the sidewalk segment quality ratings. Interestingly, no other variable was identified by the model for the highest quality segments, meaning that either no additional variable was influential, or that other potentially important factors were simply highly correlated with the noted smooth sidewalk surface. On the poor quality sidewalk side of the model, sidewalks with gaps and level changes as Con are grouped together and those with gaps and level changes as Pro and NA are grouped together. The final variable involved in splitting the samples was the presence of buffers and sidewalk amenities. The sample splits into Con and NA vs. Pro, and then splits again on Con vs. NA. Hence, the presence of buffers and amenities appears to be important to the survey participants, breaking the sample into median sidewalk quality ratings of 2 vs. 3 vs. 4 for the subsamples that remained after accounting for cracks and pavement surface disjoints.

The three top variables appearing in the classification tree are all visually-perceived variables (i.e., cracks, gaps, and presence of planting strips) and are relatively easy to identify during video review. These top three variables were not numerically-measured variables. Going back to the screenshot of the survey and video interface (presented earlier in Figure 5), the measurements for width, grade, and cross-slope were provided as text on the screen and may have been more difficult for respondents to evaluate while viewing the videos than the presence of cracks and pavement disjoints. Hence, it is possible that the difference in perception of displayed information may have influenced the survey results, perhaps as a function of potential individual response bias to the visual and numerical data cues. The fact that width, grade, and cross-slope do not appear in the classification tree could mean that experts do not generally identify them as important variables, or these variables could be highly correlated with variables that were selected (cracking and pavement disjoints) and are therefore already accounted for (not likely), or it could simply indicate a survey response bias because the display of information did not readily allow the user to identify width and cross-slope problems in the videos. Nevertheless, presence of buffers between sidewalks and traffic and other sidewalk amenities are clearly perceived by the expert community as important in assessing sidewalk quality.

3.5 Expert Survey Results vs. ADA Requirements

Under the federal ADA design guidelines and previous court decisions, mobility of individuals with disabilities must remain a focus of sidewalk planning, maintenance, repairs, and rehabilitation. Yet, the expert panel survey results presented in this Chapter do not necessarily correlate well with ADA compliance parameters (other than pavement surface disjoints and roughness). Cross slope, for example, is a significant issue for wheelchair users but was not identified as a critical factor despite the fact that a significant number of curbcuts in the sample had cross-slopes in excess of ADA requirements. Assuming that the survey responses are not biased due to the way that information was presented, this might suggest that expert planners and engineers in the field do not deem ADA design criteria compliance as important as other factors with respect to sidewalk quality. Cities focusing time and money on aesthetic aspects of the pedestrian environment such as benches and street trees, rather than on ADA compliance, could end up on the wrong side of a legal challenge and pay penalties for inaccessible sidewalks. In Atlanta sidewalk repairs are necessary at a minimum to stem the hemorrhage of public works dollars currently flowing into lawsuit settlements and to ensure that the City avoids future ADA compliance penalties.

3.6 Follow-up Survey of the Disability Community

In the summer of 2014, the research team adapted the Sidewalk Quality Survey for the disability community, seeking survey participants with physical disabilities. Given the results of the survey of experts, the follow-up survey was designed to identify whether persons with physical disabilities identify different sidewalk quality variables than the transportation experts. The team re-deployed the same survey to the disability community to see: 1) which variables the members of the disability community identify as important in sidewalk quality, given that they are most affected by lack of ADA compliance; and 2) to compare the responses of member of the professional expert community and members of the disability community to see how they line up and/or differ. Two questions were added at the end of the survey asking what (if any) mobility aids the respondent currently use, and what (if any) mobility aids the respondents formerly used. The survey was deployed using similar methods to the previous survey of professionals. Researchers sent a nearly identical cover letter to leaders and members of groups associated with the disability community and these contacts were asked to share with their groups and contacts. Robust efforts were used in distributing the survey to the disability community, but fewer than 30 responses were received. Although the low response rate may have resulted from reaching a smaller population as compared to pedestrian transportation professionals, the research team believes that the survey was likely to reach a comparable number of people. Hence, the research team suspects a significant difference in response rates. Due to the small number of responses in the disability community (under 30 responses), a comparison of response sets from the two deployments is not presented in this report to avoid any perception that the follow-up results are reliable. That said, the experts and small group of participants in the disability community identified different variables as being important, inferring that additional research in this area may be warranted.

3.7 Sidewalk Quality Survey Conclusions

The original research plan included using expert survey results to weight data collected with Sidewalk Sentry™ to develop the overall sidewalk quality rating. In this way, variables deemed by experts as being more important to sidewalk quality could receive a greater weighting in a sidewalk quality index value than variables that deemed by experts as less important. However, as described earlier in this Chapter, the survey responses from experts showed a preference towards pedestrian accommodations associated with pleasant walking environment, such as smooth surfaces and benches and street trees, and less focus on the variables related to measurable ADA standards for making sidewalks accessible, such as grade and cross-slope. The research team suspects that the survey responses may have been biased toward the readily perceived visual cues in the video (such as cracks and gaps and presence of trees), and that important accessibility parameters may not have perceived as readily. Hence, the research team decided to not use the survey results to establish any sidewalk quality weighting factors as the results could potentially bias the weighting against ADA-required accessibility elements.

Based on the expected disparities between the priorities of sidewalk users and professionals, which may not be statistically significant, the research team concluded that it would be important to develop a system that would allow decision-makers to weight various sidewalk quality variables and indicators to take into account the needs of the local community and balance the wants and needs of users and planners. A city focusing on improving pedestrian safety might want to focus improvements in areas where pedestrian-vehicle incidents have occurred, or are likely to occur. Areas with high vehicle volumes combined with high pedestrian volumes could receive additional attention if the rating system includes such safety/exposure variables. Furthermore, given that the probability that a pedestrian will survive a vehicle impact at 30 mph is about one-third the probability of surviving a 20 mph impact (UK Department of Transportation, 1987; Limpert, 1984), sidewalk repair and new construction prioritization could employ prevailing vehicle speeds as a factor in a safety index. A combined safety variable might be derived as a function of safety-related factors such as pedestrian crash rates, signal walk times, presence of walk signals, traffic volumes, traffic speeds, etc. And these safety parameters could be internally weighted by users as a function of local priority to derive a composite safety index.

3.8 Sidewalk Quality Evaluation

A sidewalk quality rating system could employ sets of variables representing different pedestrian and sidewalk goals, such as safety, mobility, and ADA compliance. For example, a city or metro area might decide that reducing pedestrian incidents and liability (safety), is more important than ensuring ADA compliance, which may in turn be more important locally than enhancing pedestrian mobility. Figure 10 shows an example of a composite weighting scheme wherein the composite index is calculated with a heavier weighting for safety considerations, then ADA compliance, and then by mobility.

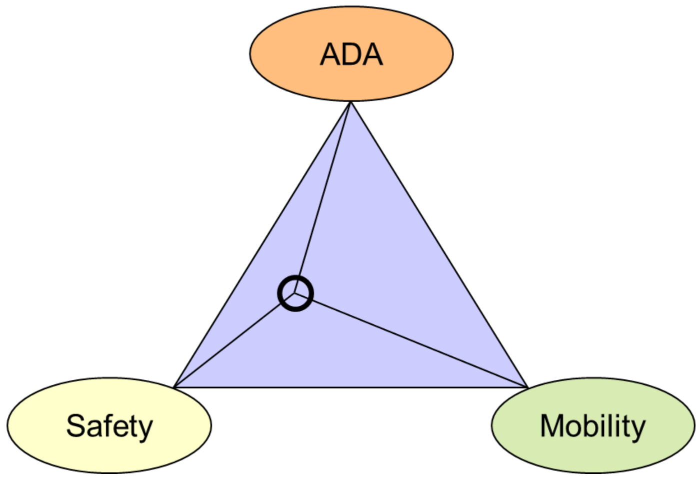

Figure 10. Example Priority Weighting Scheme

Based on the results of the survey of sidewalk professionals, and the planning and landscape architecture literature, sidewalk aesthetics and corridor look and feel are parameters that should probably be reflected in sidewalk quality criteria. Hence, a fourth dimension could also be added to the figure above for aesthetics, sense of community, or other factors. Future research can generate weighting scheme that can be modified and adjusted to fit a particular agency's or community's policy priorities. However, some criteria are difficult to measure objectively. Bringing in these parameters would probably be best handled using opinion surveys similar to the methods we employed with the technical experts in a future research effort. A multi-parameter sidewalk quality index can include aesthetics scores in project prioritization using a weighting approach (e.g., cleaning up ugly sidewalks as a parameter in project prioritization). Sidewalk ratings might also be based upon parameters identified in future surveys of individual members of the disability community, perhaps in conjunction with land use and pedestrian count data, to prioritize sidewalk repair projects that most directly benefit the disability community. However, before any kind of system for project prioritization can be developed, agencies need to establish basic data on the location and condition of their sidewalks and pedestrian infrastructure. The following chapters examine current and evolving sidewalk assessment methods and tools for gathering condition data.

4 Innovative Data Collection Efforts and Sidewalk Sentry™

Researchers and practitioners often lack pedestrian facility data to assess existing conditions and prioritize improvements. The dearth of local, regional, and statewide pedestrian facility data has been a barrier to assessing and enforcing ADA compliance (USGAO, 2007) as well as the development of regional transportation models incorporating non-motorized trips (Pratt, et al., 2012).

Traditional methods of sidewalk inventory data collection are time intensive and often cost-prohibitive, particularly for large-scale implementation. A literature review of 29 jurisdictions' pedestrian and bicycle data collection initiatives found a variety of methodologies used, including user surveys, facility inventory development, and spatial analysis (Schneider, et al., 2005). Among these 29 case studies reviewed, 13 included a pedestrian facility inventory element. Bicycle and pedestrian data collection provides evidence of existing and changing travel patterns, and can be used to evaluate infrastructure needs, identify locations for infrastructure improvements, and support bicycle and pedestrian planning efforts. Comprehensive built-environment inventory tools can provide detailed pedestrian-scale data, but may require substantial staff time and funding to inventory a large number of detailed built-environment variables over a large area (Boarnet, et al. 2011). One good example of such an inventory can be found in the city of Bellevue, Washington, where the city and Federal Highway Administration collaborated to complete a sidewalk and curb ramp inventory for its ADA transition plan (Quiroga and Turner, 2008).

The use of audit or survey data introduces potential data validity and reliability concerns, as many inventory tools use subjective scales to measure infrastructure condition (i.e., "poor," "fair," and "good" sidewalk quality). Only a few studies have tested the validity and reliability of typical built environment audit instruments. The Irvine Minnesota Inventory Audit instrument results were analyzed to test both predictive validity and inter-rater reliability (Boarnet, et al., 2006; 2011). During reliability testing of the Irvine Minnesota Index, audits were conducted in Minnesota and California with multiple raters in several audit sites. Most audit parameters had high reliability; with higher reliability in the Minnesota tests compared with the California reliability tests (99% vs. 76% of variables had greater than 80% agreement). Additionally, the authors noted that sidewalk raters in both locations found it necessary to only sample these sidewalk segments, given the time-consuming nature of the audit instrument (Boarnet, et al., 2006).

However, emerging technologies such as mobile devices and applications have enabled the collection of non-motorized infrastructure and travel behavior data without the use of costly and time-consuming built environment surveys. A review of ADA compliance efforts at state departments of transportation details the growing use of technology to make pedestrian data collection more cost-effective and to improve data quality (Quiroga and Turner, 2008). Based on their interviews with agency staff, best practices for cost-effective data collection include the use of volunteer labor, GIS-based data collection, and database integration.

Advanced technologies have the potential to reduce sidewalk data variability and improve sidewalk data accuracy. In 2009, the City of Bellevue, Washington collected sidewalk and curb ramp data using a Segway™ human transporter equipped with an inertial profiler and personal computer for GIS integration (City of Belleview, 2009). The Bellevue process has been identified by government agencies and research institutions as a best practice method for assessing ADA compliance for width, changes in level, grade, cross-slope, and quality of sidewalk surface. The Bellevue study provides a strong basis for data collection needs and methodology that is transferable to other communities. The Bellevue inertial profiler system appears to have realized a 70% savings compared with the estimated cost of conducting a traditional, manual sidewalk inventory (Khambatta and Loewenherz, 2011). However, equipment costs for transferability to other areas are high, and expert drivers (liability issue) are still required to collect and interpret data.

Mobile devices have also been utilized to automate the process of data collection and to collect infrastructure and travel behavior data using built-in sensors. The use of mobile phone data, particularly location capabilities, has a wide range of intelligent transportation systems applications, such as automatic vehicle location systems in public transit (Zhao, 2000). Mobile data collection has also been utilized within non-motorized transportation planning and research to track transportation activity. For example, researchers at Georgia Tech, in collaboration with the City of Atlanta and other partners, piloted an app to monitor the travel behavior of bicyclists within the city (Misra, et al., 2014). The data from this crowd-sourced app, Cycle Atlanta, is to be used to assess existing bicycle transportation travel patterns and to guide future planning and project implementation. In addition to GPS capabilities, video data from mobile devices has been used to detect and track vehicles and pedestrians (Zhang, et al., 2011). Image processing techniques and inertial profiling systems have been utilized to monitor roadway condition, including crack detection, integrated with GIS software (Chung, et al., 2004).

A review of best practices in pedestrian infrastructure planning demonstrates the potential of emerging technologies for accurate and cost-effective asset management. Quantitative inventories of sidewalk and curb ramp infrastructure assist in ADA compliance efforts and municipal repair prioritization to improve safety and increase walkability. However, current gaps in literature and practice indicated a need for development of a low-cost, replicable, objective, cost-effective system to assess pedestrian infrastructure quality and prioritize future pedestrian projects on local, regional, and statewide scales.

4.1 The Sidewalk Sentry™ System

To address current research gaps in pedestrian data collection and evaluation, researchers at the Georgia Institute of Technology (Georgia Tech) developed a prototype of the Sidewalk Sentry™ tablet-based Android™ application (app). An app-equipped tablet is attached to a standard manual wheelchair (Figure 11) using Velcro™ straps, a high-density polyethylene board, and clip mounts (Grossman, et al., 2013). Sidewalk Sentry™ automatically records video and concurrent tablet sensor data streams (see Frackelton, et al., 2013) while the standard issue wheelchair is rolled along sidewalks and ramps. The research team developed, tested, and calibrated the data collection system on Toshiba Thrive™ tablets, which met all desired system specifications (camera field of view, video resolution, accelerometer frequency, USB connectivity, etc.). The system collects high-resolution rolling video of the sidewalk, high-frequency gyroscope data, high-frequency accelerometer data, and second-by-second GPS data (including timestamp, latitude, longitude, and ephemeris data). The data are then used to evaluate sidewalks for repair under ADA accessibility guidelines.

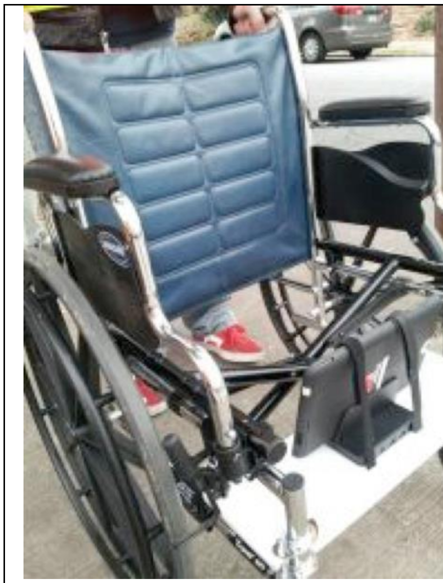

Figure 11. Sidewalk Data Collection System Setup

The Sidewalk Sentry™ tablet system is very easy to use. To record data using the Sidewalk Sentry™ app, the user first obtains a GPS location "fix," presses "record," and begins walking their assigned route at 2-3 miles/hour. Video and other sidewalk data are automatically collected as the user walks along the sidewalk. When the route is complete, the user presses "stop." Tablet memory is sufficient to collect many days of field data. Video and data are later downloaded in the laboratory for processing and analysis. The field data collection manual is provided in Appendix B: Sidewalk Sentry™ Field Data Collection Manual.

4.2 Data Collection to Assess Sidewalk-related ADAAG Criteria

The specific ADA design standards that must be met for sidewalks were presented in Chapter 2 (Table 2) with photographic examples (Table 4):

- Sidewalk width must be greater than or equal to 36 inches (if the width is less than 60 inches, a 60-inch by 60-inch passing space must be provided every 200 feet)
- Sidewalk running-slope must not exceed 5% (or match roadway slope if greater)
- Sidewalk cross-slope must not exceed 2%
- No obstructions may be present within the pedestrian access route
- The sidewalk surface must be "firm," "stable," and "slip-resistant"
- Vertical displacements up to 1/4 inch are allowed

- Vertical displacements from 1/4 to 1/2 inch must be beveled, no greater than 1:2
- Vertical displacement may not be greater than 1/2 inch unless a proper ramp (with a slope less than 8.33%) is present
- Vertical clearance must be greater than 80 inches

Each of the ADAAG criteria must be met for the entire sidewalk segment length. For example, an obstruction at any point along the pathway could constitute a violation of ADA standards for the entire pathway, as the obstruction makes the entire pathway segment inaccessible. This also means that all obstructions along the pathway need to be removed before the sidewalk segment will meet that specific design criteria.

The goal of the research team in developing the Sidewalk Sentry™ system was to be able to identify each kind of ADA design defect for the entire pathway, either through analysis of tablet data streams (accelerometer and gyroscope data) or post-processing of video. In reviewing video initially collected by Sidewalk Sentry™ it was immediately clear to the research team that the human eye could readily detect significant sidewalk problems, such as the presence of cracking, vertical pavement disjoints, potholes, and obstructions. But, manual assessment of other parameters, such as grade and cross-slope, would likely be much more difficult. Hence, one project objective was to develop a system that analyzed tablet data to assess ADA compliance. A second project objective was to develop a fully-automated machine vision system capable of post-process Sidewalk Sentry™ rolling sidewalk video and assessing ADA compliance frame-by-frame for: sidewalk width, sidewalk grade, sidewalk cross-slope, presence of significant cracking, presence of potholes, presence of vertical pavement disjoints, and presence of stationary obstructions. Table 7 is based upon Table 4 (sidewalk defects) and summarizes the data collection and defect evaluation methods originally proposed by the research team at the outset of the project.

The initial plans presented in Table 7 changed over time as the research team conducted feasibility analysis, developed initial video analytical systems, conducted quality assurance/quality control analyses (QA/QC), compared analytical results to field-measured data, and reassessed technical approaches. The vibration and gyroscope systems functioned as intended. However, the fully-automated video analytics were never fully-realized and semi-automated approaches were implemented in their stead. The following sections describe the control sections employed in QA/QC analyses, the successful implementation of the vibration and gyroscope analytical systems, the results of the QA/QC analyses of machine vision system outputs, and the final semi-automated video analysis system.

Table 7. Initially-proposed Sidewalk Defect Data Collection Method

Typical Sidewalk Problem	Proposed Data Collection and Evaluation Approach
Sidewalk width is less than 36 inches	**Video Post-processing:** Develop a technique to capture sidewalk width directly from rolling video review by applying machine vision tools developed for vehicle tracking to the calibrated tablet video field-of-view.
Sidewalk running-slope is greater than 5%	**Vibration/Gyroscope Data Analysis:** Use tablet gyroscope data to estimate sidewalk running slope. **Video Post-processing:** Assess whether sidewalk slope can be measured using the sidewalk vanishing point in the video field of view (the proposal acknowledged at the outset that such an approach might not work).
Sidewalk cross-slope is greater than 2%	**Vibration/Gyroscope Data Analysis:** Use tablet gyroscope data to estimate sidewalk cross-slope. **Video Post-processing:** Assess whether sidewalk cross-slope can be measured using the sidewalk vanishing point in the video field of view (acknowledged at the outset that such an approach might not work).
Sidewalk obstruction is present	**Video Post-processing:** Adapt existing machine vision tools for vehicle tracking to the calibrated tablet video field-of-view. Algorithms would differentiate between moving objects (e.g., legs) and stationary obstructions during rolling video review.
Pavement material is not firm, stable, and slip-resistant	**Vibration/Gyroscope Data Analysis:** Use tablet vibration data to grade sidewalks using cluster analysis or a similar technique, assuming that rough sidewalks are not firm and stable. **Video Post-processing:** Apply standard machine vision tools for crack identification and develop correlations between crack density and sidewalk surface ratings (cracked sidewalks are not firm and stable).
Vertical displacement is greater than 1/2 inch and a ramp (8.33%) is absent	**Vibration/Gyroscope Data Analysis:** Use tablet vibration and gyroscope data to identify hard accelerations and angle changes indicative of large vertical displacements. **Video Post-processing:** Apply standard machine vision tools for crack identification and investigate correlations between crack density clusters and presence of vertical displacements.
Vertical displacement is between 1/4 and 1/2 inch and surface is not beveled 1:2 (requires milling or patching)	**Vibration/Gyroscope Data Analysis:** Use tablet vibration and gyroscope data to identify hard accelerations and angle changes indicative of large vertical displacements. **Video Post-processing:** Apply standard machine vision tools for crack identification and investigate use of correlations between crack density clusters and presence of vertical displacements.
Vertical clearance is less than 80 inches	**NA:** The original proposal did not account for the vertical clearance standard.

4.3 Control Route and Control Area Data Collection

The research team collected detailed data from a control route in the Virginia-Highland neighborhood and conducted more than 30 runs on this route to develop a data set for use in quality assurance/quality control (QA/QC) analysis. Detailed hand measurement data were also collected in Midtown Atlanta for QA/QC purposes.

4.3.1 Virginia-Highland Control Route

As part of the system development process, the research team collected ground truth data from a 1.9 mile control route for use in development and verification of Sidewalk Sentry™ data. Researchers already knew that the neighborhood included sidewalks that had been recently repaired, sidewalks that were in significant need of repair, and some sections of missing sidewalk. The route was also because it included diverse topography, a wide-variety of pavement types, varying grades, varying widths, varying cross-slopes, and other variables present in close proximity with one another. The team scoped the area in person and via Google Earth before finalizing the control route. Researchers collected width, slope, cross-slope, and additional observation data by hand along the control route as well as Sidewalk Sentry™ rolling video, accelerometer, gyroscope, and GPS data. Ground truth data were collected every 20 feet along the control route and each measurement point was indicated with miniature orange traffic cones, which were visible in the rolling video collected with the Sidewalk Sentry™ system in the same deployments as the hand measurement data collection sections. Figure 12 shows a map of the control route in the Virginia-Highland neighborhood.

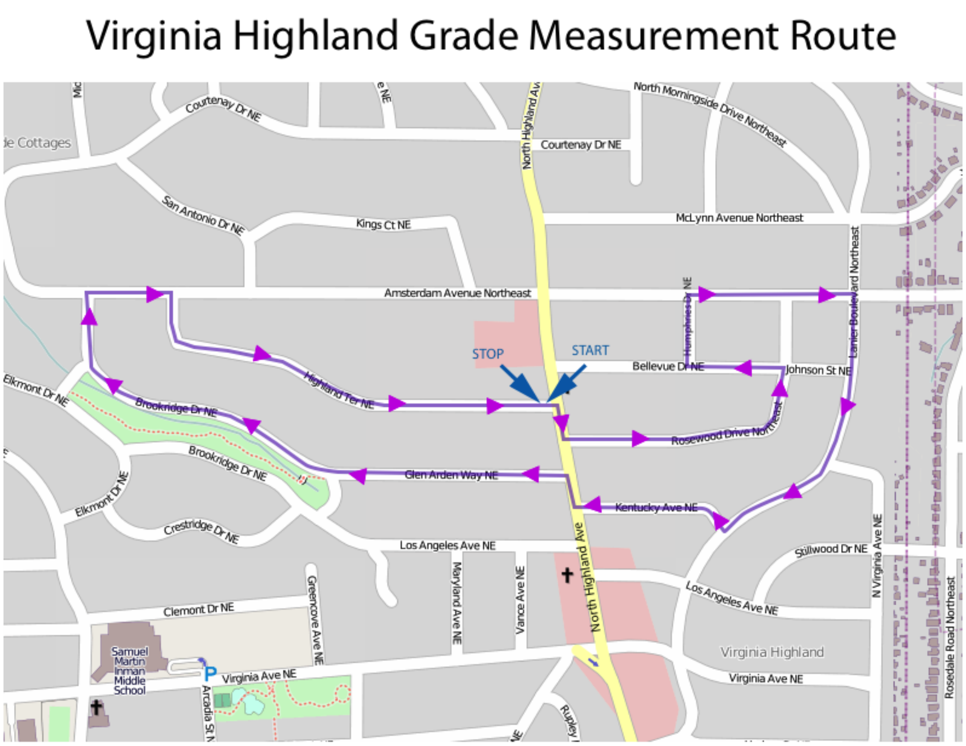

Figure 12. Control Route in Atlanta's Virginia-Highland Neighborhood

The Virginia-Highland control route data were used in testing slope and cross-slope algorithms, roughness parameters, and for training of data collectors and data analysts.

4.3.2 Midtown Control Area

Midtown Atlanta was also selected as a control area for the study. The research team collected sidewalk data by hand in this control area for use in assessing machine vision outputs and to provide field-verified data for use in the project prioritization case-study analysis (Chapter 7).

The research team collected ground truth data along approximately 11.7 miles of sidewalk in the Midtown control area. An Android app was developed to assist field data collectors navigate to each target location for recording "ground truth" comparative data. Field data collection target locations were set at about 150 feet apart to obtain a random subset of comparative data in the specific areas planned for the case study analysis. The field app uses current GPS location and a table of desired measurement locations (loaded prior to field deployment) and displays the 10 nearest target data collection locations. The point closest to the data collector's current position is displayed in blue, and the nine other data collection points are displayed in red. When the user reaches the target location, the marker changes from blue to green, allowing the user to enter data. The user enters the hand-measured value for sidewalk width (ground truth) along with any accompanying comments, which are recorded to a file along with GPS position. The data are later uploaded to the database for comparative analysis.

The QA/QC data collection app guides field personnel to within three feet of the video-processed location so that hand-measured data can be directly compared with machine vision data for sidewalk width. Figure 13 plots the locations where Sidewalk Sentry™ data were collected and processed and where the sidewalk width control data points were collected in Midtown, Atlanta. Sidewalk Sentry™ data are presented on the left and hand measured data are presented on the right of Figure 13.

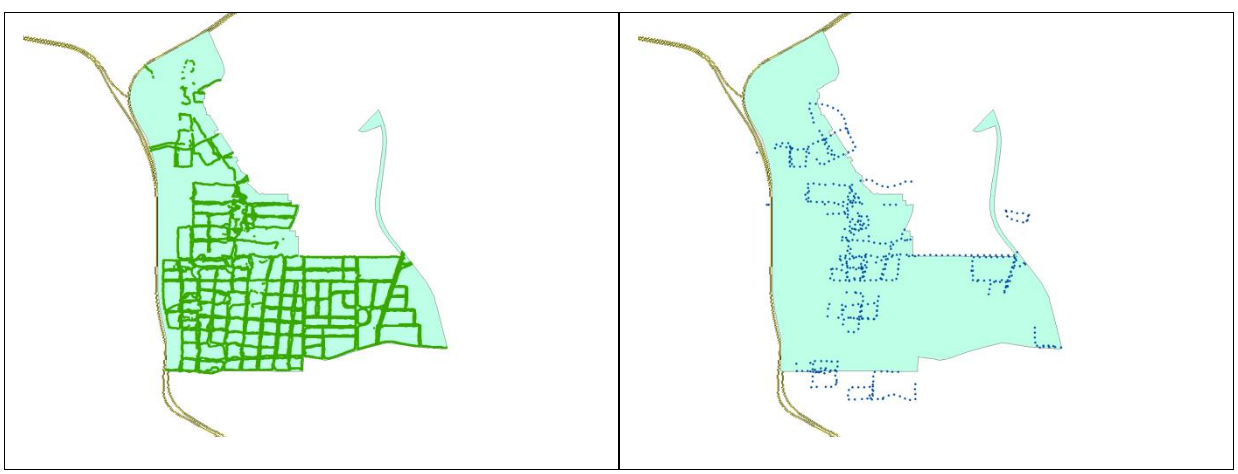

Figure 13. Control Area Data Collection in Midtown, Atlanta

The Sidewalk Sentry™ machine vision system was used to process the Midtown area video, creating 17,024 video-based second-by-second width measurements. Using the Android application described above, students visited 529 data collection sites to hand-measure sidewalk width where machine vision data were also collected. The team compared automated measured widths to hand-measured field data for just over two miles of sidewalks. Some of the sites selected for width measurement were not valid. Data were not collected when the user did not have a good GPS lock (GPS wander), and when data collection sites were on corners or in driveways or crosswalks. GPS data accuracy issues such as GPS wander are most likely to affect data near tall buildings, resulting from loss of satellite lock due to line-of-sight obstructions, and from multipath errors due to reflection of GPS signal off of building surfaces (Wolf, et al., 1999; Scheussler and Axhausen, 2009). The field team collected 355 valid sidewalk width measurements in the Midtown control area for use in QA/QC analysis.

4.4 Assessment/Deployment of the Accelerometer-based Surface Roughness System

One of the objectives of the sidewalk sensor system is to classify sidewalk surface roughness into separate and distinct clusters (or roughness ratings) using the 3-dimensional (x, y, z) accelerometer readings. This section presents results for sidewalk roughness estimation using the tablet-based accelerometers, compared with a standalone X16-1C accelerometer (Gulf Coast Data Concepts, 2013) affixed directly to a standard wheelchair. Roughness classification test data were collected from three different types of sidewalk surfaces with different degrees of roughness using the Sidewalk Sentry™ app on the Toshiba Thrive™ tablet. The goal of the analysis was to assess whether the accelerometer data could be statistically categorized into readily-recognizable data clusters. The roughness estimation approaches were evaluated by analyzing test data collected from repeated runs on several types of sidewalks of varying surface roughness. Roughness estimation was performed in both time and frequency domains. In the time-domain, wheelchair acceleration and jerk (rate of change of acceleration) are key metrics for assessing vibration. In the frequency-domain, power content in octaves critical for Whole-Body Vibration was the metric. Using time-domain techniques, estimation was successful using both standalone and tablet-based accelerometers, whereas the frequency-domain techniques performed poorly using the tablet equipment data. The roughness clusters created from the time-domain tablet accelerometer data for the surfaces tested contain no errors, as will be demonstrated later in this section, indicating that the tablets can be reliably used to classify vibration into useful roughness groups.

The ADA specification on surface roughness is vague, requiring “firm,” “stable,” and “slip-resistant” surfaces (USAB, 2011a). More objective measures have been identified in the medical literature (primarily associated with assessment of impacts of rough surfaces on wheelchair users with spinal injuries) using stand-alone high-sensitivity accelerometers on wheelchairs to measure accelerations for comparing roughness experienced by the wheelchair user (Requejo, et al., 2008; Vorrink, et al., 2008; Rory, et al., 2004; Cooper, et al., 2003). Cooper, et al. (2003) and Rory, et al. (2004) used the autocorrelation of the acceleration magnitude. The autocorrelation signal is treated with a Hamming window, and then discrete Fourier transform is obtained using the fast Fourier transform (FFT) to compare peak acceleration magnitudes and the frequencies of the peaks (2008; Rory, et al., 2004; Cooper, et al., 2003). Requejo, et al. (2008) used a Butterworth low-pass filter on the time-domain acceleration and compared statistics of the time-domain signal. Vorrink, et al. (2008) compared wheelchairs using both the peak acceleration obtained with a FFT along with root mean square (RMS) acceleration statistics in time-domain.

The wheelchair setup for accelerometer analysis consisted of the standard manual wheelchair setup with the front-facing Toshiba Thrive™ tablet (Figure 11) with a GCDC X16-1C accelerometer also affixed to the white board base. The GCDC X16-1C accelerometer is a USB-stick accelerometer that provides accurate readings at sampling rates up to 200Hz (Gulf Coast Data Concepts, 2013). The cross-axis sensitivity of the X16-1C accelerometer is up to 1% and the resolution is about 0.001g. The X16-1C accelerometer has a detection limit of 10g. In this work, the GCDC X16-1C was set to a sampling rate of 100Hz for accelerometer readings to allow direct comparison with 100Hz tablet data. The Toshiba Thrive™ tablet accelerometer is known to be less accurate than the GCDC X16-1C accelerometer. The tablet accelerometer has a much narrower acceleration range of -20m/s^2 to 20 m/s^2 in each axis directions, which is significantly lower than the 10g maximum of the standalone accelerometer unit. The lower limit on the Toshiba Thrive™ causes acceleration readings greater than the maximum limit to be recorded at the detection limit, i.e. lower than actually experienced. This potential bias was an initial concern, but analytical results indicated that the sensitivity range of the unit was sufficient to identify rough sidewalks. The Toshiba Thrive™ tablet accelerometer appears to have larger cross-axis sensitivity than the standalone unit, causing leaks of acceleration readings from one axis to another. Hence, the readings in each dimension on the Toshiba are not as accurate as the standalone unit. However, as noted earlier, this was not a critical issue because the tablet-based analytical results using mean and RMS readings were still sufficient to classify the sidewalks.

The wheelchair setup is shown in Figure 14, along with a close-up of the Toshiba Thrive™ Tablet, with the directions of the tablet accelerometer axes labeled on the right, and the GCDC X16-1C accelerometer base, with directions of X16 accelerometer axes labeled on the left. This setup was used to perform multiple runs on different surface types. Each run consists of pushing the unoccupied wheelchair over the surface to collect data.

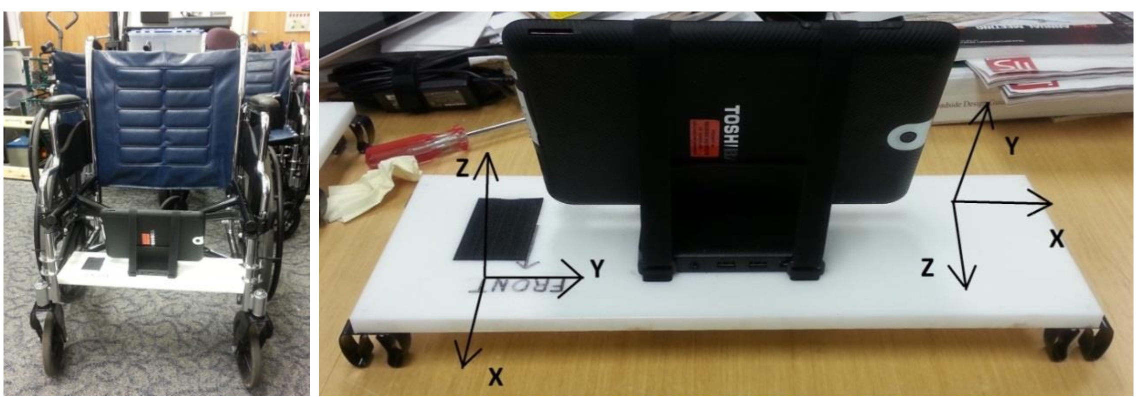

Figure 14. Wheelchair Setup and Tablet Platform for Accelerometer Analysis

Three different surfaces, arranged from left (Surface 1) to right (Surface 3) in Figure 15, were used to collect a total of 65 runs. Surface 1 was the smoothest surface, composed of standard concrete with joints approximately every 36”. Surface 2 was a rougher surface composed of red brick pavers. Surface 3 was the roughest surface comprised of an old metal ramp (washboard surface). Surfaces 1 and 2 were 19.2 meters in length (63.0 feet), whereas surface 3 was 9.3 meters (30.5 feet). The mean run speeds were 1.6 m/s (3.6 mph), 1.7 m/s (3.7 mph) and 1.7 m/s (3.8 mph), for surfaces 1, 2, and 3 respectively. The standard deviation of runs for all three surfaces was less than 0.1 m/s (0.2 mph).

Figure 15. View of the Three Surfaces Tested

High-resolution data (150 Hz) were collected over approximately 30-foot sidewalk segments and the mean and RMS values were taken for each repeat run. Mean and RMS acceleration and mean and RMS jerk (derivative of acceleration), in addition to frequency-domain power components, were computed for the different sidewalk runs. In the case of time-domain acceleration and jerk signals, the mean and RMS statistics of different run groups were compared using a Wilcoxon rank-sum test for statistically significant differences. In the case of frequency-domain approach, accelerometer signal power in the first five octaves of the frequency spectrum was estimated from a FFT-based periodogram approach by integrating the power in the first five octaves (Kirschbaum, et al., 2001). In addition, k-means clustering was performed using the L1 distance measure (city block measure), separating all 65 runs into three different roughness clusters using statistics from both time and frequency-domains. The statistics for the mean and RMS acceleration data for the 65 runs are shown in Table 8 below, grouped by surface type.

Table 8. Acceleration Statistics for Sidewalk Roughness Cluster Analysis

Accelerometer Source	Surface	Mean Acceleration (m/sec^2)	Std. Dev. Acceleration (m/sec^2)	RMS Acceleration	Std. Dev. RMS Acceleration
X16-1C	1	11.47	0.31	12.99	0.40
X16-1C	2	15.27	0.43	17.88	0.53
X16-1C	3	22.53	1.13	27.02	1.37
Tablet	1	11.61	0.27	12.56	0.30
Tablet	2	14.21	0.22	15.31	0.21
Tablet	3	18.50	0.41	19.64	0.38

The statistics for the mean and RMS jerk data for the 65 runs are shown in Table 9 below, grouped by surface type. The Wilcoxon rank-sum tests indicate that all three surface type clusters have statistically significant differences in means.

Table 9. Jerk Statistics for Sidewalk Roughness Cluster Analysis

Accelerometer	Surface	Mean Jerk (m/sec^3)	St. Dev. Jerk (m/sec^3)	RMS Jerk	St. Dev. RMS Jerk
X16-1C	1	1102.77	82.10	1274.37	91.81
X16-1C	2	1869.99	80.40	2165.07	90.21
X16-1C	3	2995.91	189.34	3651.12	227.49
Tablet	1	1193.32	67.72	1323.97	73.66
Tablet	2	1712.10	46.01	1887.50	39.64
Tablet	3	2436.12	76.87	2687.47	77.40

The tablet variation in mean acceleration for surface 1 (smooth) was comparable across the Toshiba Thrive™ and the X16-1C standalone accelerometers. However, the Toshiba Thrive™ tablet occasionally reaches its maximum accelerometer detection limits during data collection for the two rougher surfaces. Acceleration rates for the Thrive are ‘clipped’ at the maximum acceleration detection value; not reaching the same peak acceleration values collected from the higher-end standalone accelerometer (see Figure 16).

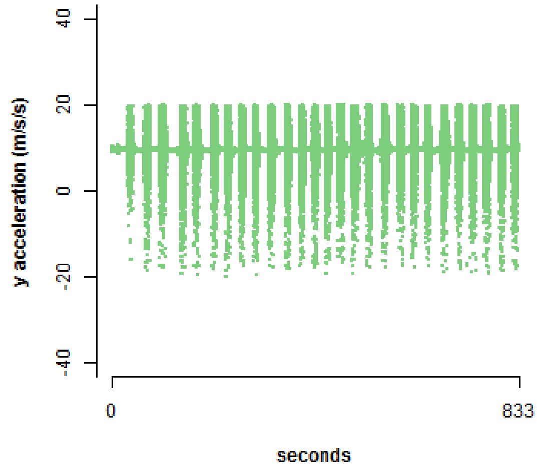

Figure 16. Toshiba Thrive™ Accelerometer Detection Limit (20 m/sec^2)

Given the detection limit for the Toshiba Thrive™, the variation in tablet acceleration values is lower for surfaces 2 and 3. The variation in jerk (rate of change of acceleration) readings is also smaller and more pronounced, because differences in acceleration are being employed and both values used in the tablet data calculation may be 'clipped', compared to that of the X16-1C accelerometer. Nevertheless, the k-means clustering algorithm is still successful at differentiating between the three sidewalk surface types 100% of the time using the tablet data. All 65 runs are successfully clustered to the three different sidewalk surfaces from which the data were collected, using either the Toshiba Thrive™ or the X16-1C data (Figure 17 and Figure 18**)**

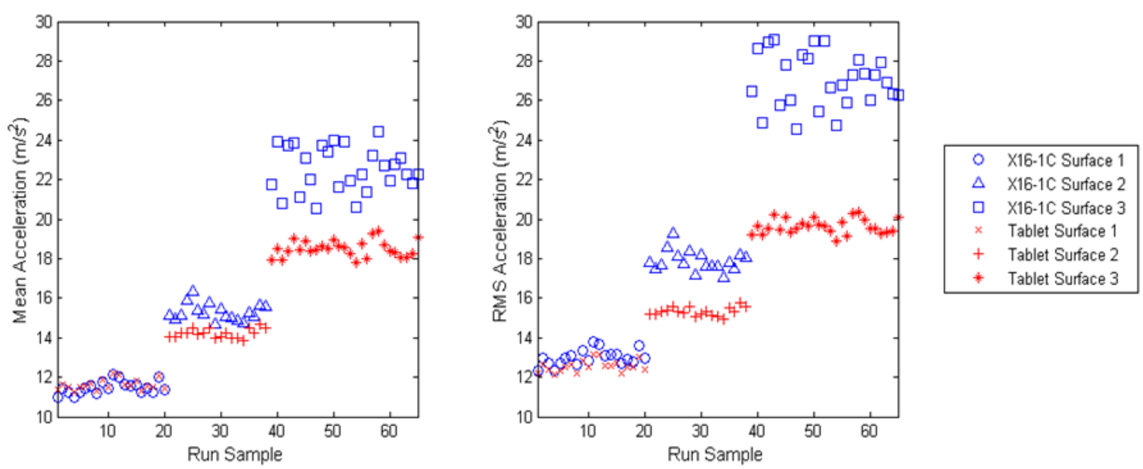

Figure 17. Mean and RMS Acceleration Results for Three Different Sidewalk Surfaces

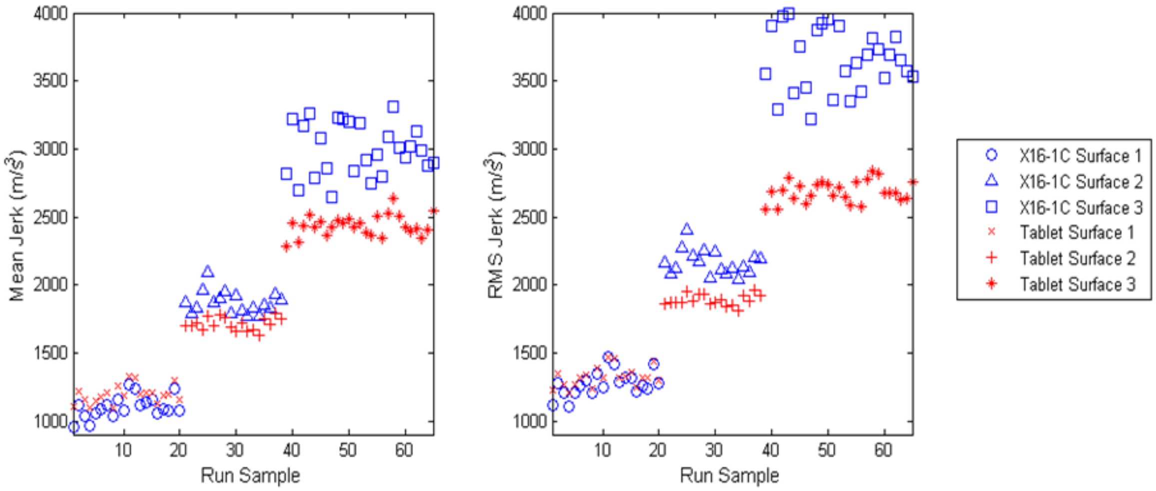

Figure 18. Mean and RMS Jerk Results for Three Different Sidewalk Surfaces

Frequency-based accelerometer signal data (5-dimensional vector of octave power estimates for each sidewalk run) was also tested as an input for a K-Means Clustering Algorithm. However, clustering the runs using this 5-dimensional-vector for frequency was not successful for either type of accelerometer.

The cluster analysis of time-based accelerometer data clearly indicates that Sidewalk Sentry™ data can be used to classify sidewalk surfaces. The nuance, however, is establishing an appropriate threshold for unacceptable surface roughness. ADA standards require that vertical displacements not exceed ¼ inch without proper beveling, but there is no specific criteria or test method to assess whether sidewalks are "firm," "stable," and "slip-resistant." Furthermore, the survey of experts undertaken in Chapter 3 identified that the presence of sidewalk cracks contribute negatively to sidewalk ratings, but no numerical threshold can be derived from the survey data. On the other hand, it is easy to argue that both Surface 2 (brick pavers) and Surface 3 (rough ramp) employed in the analyses reported are unacceptably rough and yield high acceleration values. In the absence of a clear standard for compliance, and given the clear promise of the statistical clustering approach, the research team elected to proceed with the development of natural sidewalk clustering, allowing the sidewalks to self-classify into five roughness groups, and then evaluate the results to ascertain whether the results were reasonable. The rationale is that the smoothest sidewalks cluster together (not in need of resurfacing), the roughest sidewalks cluster together (clearly in need of resurfacing), and that the three grades between the extremes can be further assessed to decide how the values should be interpreted.

The research team set these thresholds using the idea of minimum distance from the cluster means. Using the k-means clustering technique, cluster means were iteratively updated to minimize the aggregate L1 (city block) distance (from each cluster mean to all cluster members). This technique resulted in the definition of thresholds defining the five clusters so that their locations are optimal using the L1 distance metric.

4.5 Assessment of the Gyroscope-based Sidewalk Slope and Cross-Slope System

The purpose of the initial on-campus field experiment was to assess the basic capability of the Toshiba Thrive™ tablet wheelchair-mounted system to capture linear sidewalk grade. A simple experiment was devised to test a small grade section at the Georgia Tech campus. If the initial tests on the campus control section were successful, the team would then conduct more detailed tests on the Virginia-Highland control route with greater variability in grade and sidewalk condition (because vibration levels could affect grade accuracy). Reference grade (degrees) data were measured using a SmartTool™ digital level for each successive concrete slab on the sidewalk (Figure 19). For each slab, grade measurement (in degrees) were collected four times using the SmartTool™ digital level (two measurements used the equipment facing uphill, and two were facing downhill). Table 1 contains the SmartTool™ measurements. For the final estimate, the four results are averaged. The team then deployed Sidewalk Sentry™ on the Toshiba Thrive™ and deployed the GCDC X16-1C accelerometers on the same wheelchair to collect grade data for the same stretch of sidewalk.

Figure 19. Initial Grade Field Data Test Location and SmartTool™ Digital Level

Table 10. Sidewalk Grade Measurements via SmartTool™ for each Sidewalk Slab

	Sidewalk Slab Grade (Degrees)					
Measurement	**1**	**2**	**3**	**4**	**5**	**6**
1	8.20	9.30	9.30	7.80	8.40	9.50
2	8.20	9.50	9.40	7.80	8.50	9.10
3	8.20	9.20	9.10	7.50	8.30	9.40
4	8.20	9.20	9.00	7.60	8.30	9.20
Average	8.20	9.30	9.20	7.68	8.38	9.30

Percent grade for the whole hill path is estimated by the following equation:

$$grade = \frac{\sum_i d_i * \sin(\theta_i)}{\sum_i d_i * \cos(\theta_i)} \quad \textbf{(1)}$$

Where:

d is the length of the sidewalk slab *i*

θ is the angle (degrees) of the sidewalk slab

The final estimated percent grade for the path is approximately 15.3%.

The next step was to collect grade data using the GCDC X16-1C accelerometer and the Toshiba Thrive™ tablets. These two instruments were mounted on the wheelchair as previously presented in Figure 14. Acceleration offsets (due to mounting orientation relative to ground level) for both accelerometers were estimated by placing the system on level ground. Three different stationary tests were completed for each device to assess x, y, z bias/calibration values. The offset values were subtracted from acceleration data for the experiment to account for bias in the specific wheelchair set-up, and for any potential internal accelerometer system biases (even if the mounting is perfectly level with the ground, the accelerometer mounting may not be level inside the units or may have other sensor biases).

The wheelchair-mounted system was pushed up and down the sidewalk segment 13 times in each direction for a total of 26 runs, pausing for 10-15 seconds between runs. The goal was to try to maintain a constant speed throughout each run to minimize forward and lateral acceleration readings. It is important that the starting and ending points for data collection occur a few feet away from the control route start/end points so that the data can be trimmed to exclude the initial acceleration (from standing stop) and final deceleration (back to stop).

The raw accelerometer data for both instruments are presented in Figure 20. The data clearly indicate that the tablet accelerometers have low/high cutoff points of -20 and 20 m/s^2. This is important because a significant number of positive data points are capped at the maximum detection limit on the Toshiba Thrive™ tablet y-axis in Figure 20. The GCDC X16-1C data and the Toshiba Thrive™ data do not match in the x, y, and z dimensions, because the axis orientations are different as noted in Figure 14. On the GCDC X16-1C accelerometer, the z-direction experiences all the gravitational force when the platform is level with the ground. On the other hand, the Toshiba Thrive™ tablets are mounted at a 75.2 degree angle, and the gravitational force is felt in both the Y and the Z directions. Trigonometric transformations are used to align Toshiba Thrive™ tablet accelerations to the same reference axis as the GCDC X16-1C accelerometer.

Figure 21 shows a time-series comparison of grade for the GCDC X16-1C and Toshiba Thrive™ measurements. It is easy to tell when the wheelchair was stationary between each run, because the acceleration values remain flat for 10-15 seconds. It is also easy to tell when the wheelchair was going downhill (negative values) and uphill (positive values). Only values that fall within the segment were used for comparative analyses. A y-y plot for grade collected by the Toshiba Thrive™ vs. the GCDC X16-1C is presented in Figure 22. The tablet accelerometer and GCDC X16-1C measurements correlate, but the differences are highly variable and appear to differ systematically at the extremes of the y-y plot. The bias is potentially attributed to factors affecting the relative accuracy of the tablet-based accelerometer and maximum sensor value data clipping.

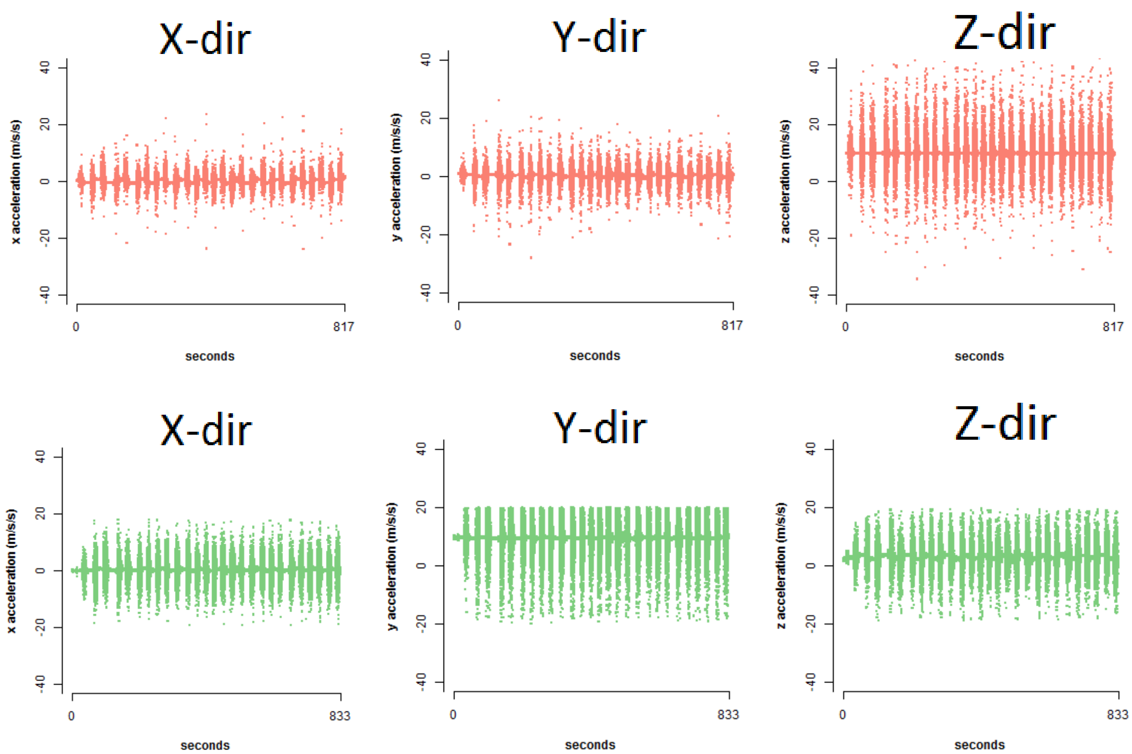

Figure 20. Accelerometer Data: GCDC X16-1C (top) vs. Toshiba Thrive™ (bottom)

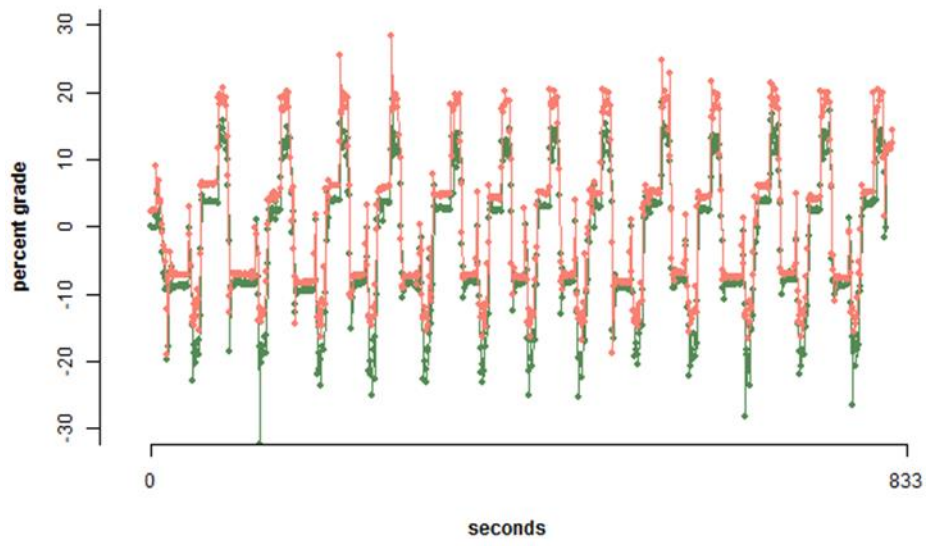

Figure 21. Grade Comparison for Toshiba Thrive™ (green) vs. GCDC X16-1C (red)

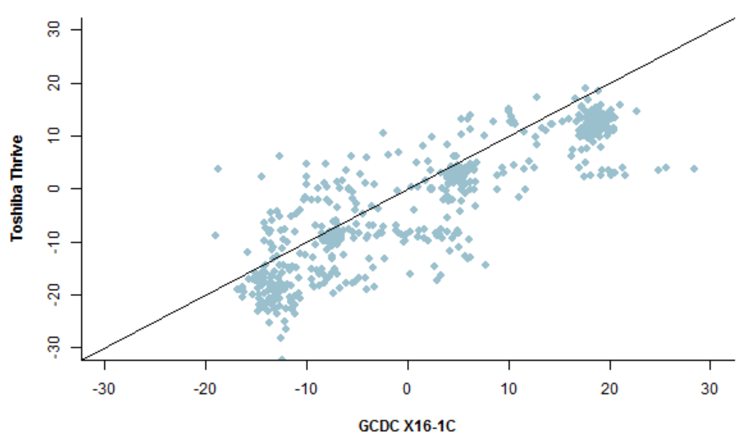

Figure 22. Grade y-y Plot Toshiba Thrive™ vs. GCDC X16-1C

Figure 23 shows the GCDC X16-1C and Toshiba Thrive™ uncalibrated and calibrated estimates for percent grade compared with the ground truth measured value of 15.2% (plotted as a dotted line). While the calibrated GCDC X16-1C estimates are satisfactory (average percent grade 15.7%) neither the calibrated nor the uncalibrated Toshiba Thrive™ estimates are reasonable. However, if a pair of uphill and downhill runs is consolidated for the Toshiba

Thrive™ accelerometer, the average estimate also becomes 15.7%. In other words, the results suggest that the Toshiba Thrive™ is accurate for estimating grade if two runs on opposing directions are performed to obtain an average value. A method that requires duplicate runs is not very practical; field data collection would involve twice the mileage and person-hours of labor.

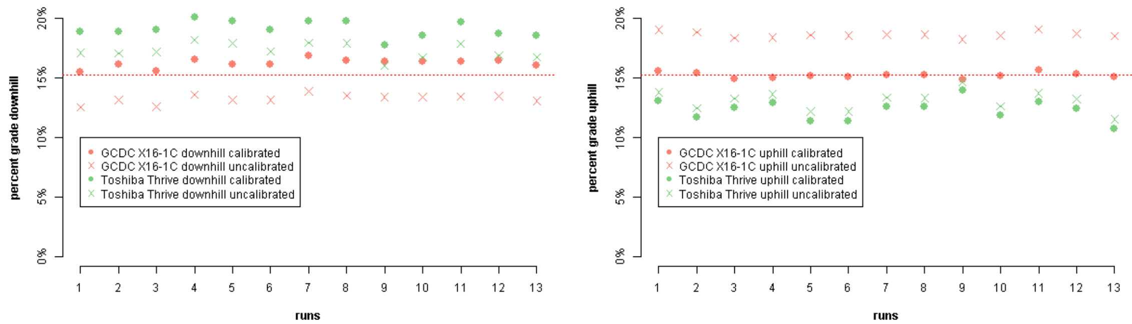

Figure 23. Accelerometer Grade Downhill (left) and Uphill (right)

Grade estimation was successful with the GCDC X16-1C accelerometer, but the Toshiba Thrive™ tablet accelerometer did not provide reasonable estimates of grade, unless uphill and downhill run pairs are averaged. Given the failure on the initial control route, additional detailed analyses of grade were not performed on the Virginia-Highland control route. The research team also concluded that given the sensor response variability, the system would not likely be useful for cross-slope analysis. As such, the research team proposes that slope and cross-slope measurements need to default to manual methods until a tablet with more accurate and sensitive accelerometers can be integrated into the system.

4.6 QA/QC Analysis of Automated Video System Sidewalk Width Data

Figure 24 illustrates the initial video processing system implemented for sidewalk width assessment. The machine vision system employs Canny Edge Detection to identify sidewalk edges, calculates the location of the sidewalk vanishing point based upon the intersection of the identified left and right sidewalk edge lines, and then uses the video's calibrated field of view (given known camera height, camera angle, and focal length) to estimate sidewalk width frame-by-frame from the rolling video. The machine vision software provided consistent analytical results. There are no stochastic elements involved in the process from run to run, every time. Hence, every time a video is processed starting from the same frame, and utilizing the same edge-detection parameters, the processed videos provide the exact same output data stream, without error.

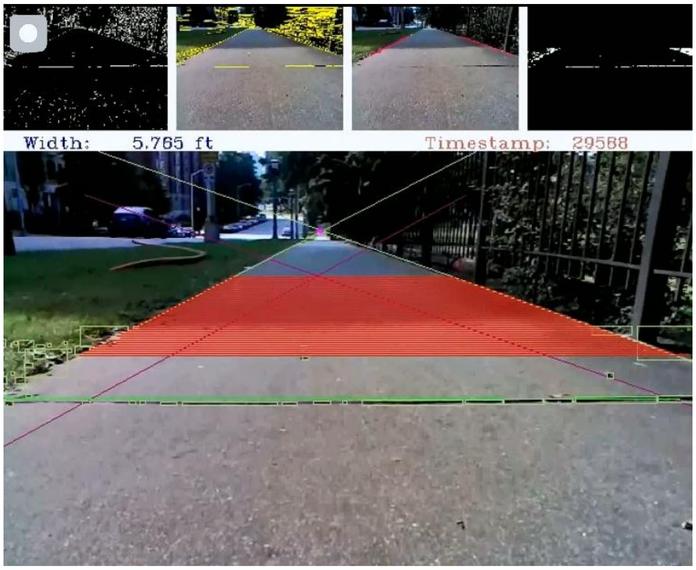

Figure 24. Initial Video Processing System

The research team conducted a comprehensive quality assurance/quality control effort to assess the validity of the automated, video-based methods. As discussed in Section 4.3, the research team hand-measured sidewalk width data in Midtown, Atlanta in 355 locations where width measurements were also processed by the machine vision system. The 355 data points used in the comparison excluded corners and curbcuts where driveways cut through the sidewalk (where automated width measurements might include the width of the sidewalk plus driveway bib). The y-y scatter plot of the machine-vision width estimates vs. field measurements are presented in Figure 25. Table 11 shows the cumulative distribution of absolute sidewalk width error, which is unacceptably high.

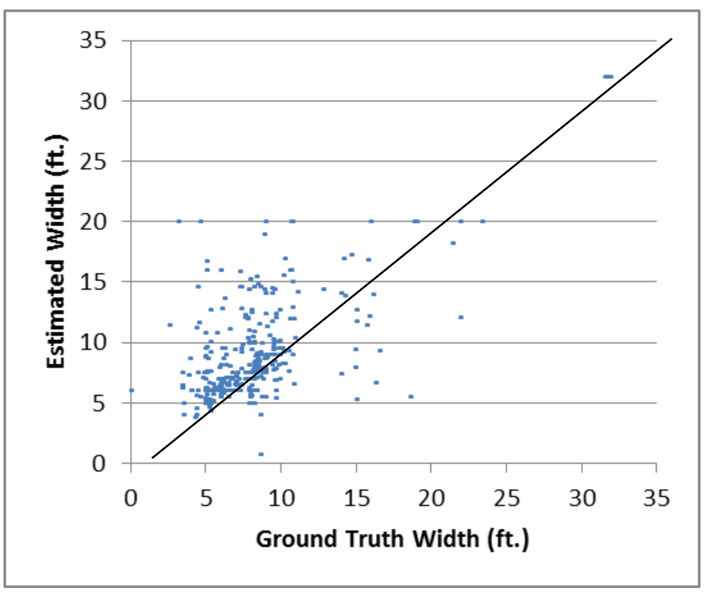

Figure 25. Scatter Plot of Machine-vision Width Estimates vs. Hand-measurements

Table 11. Absolute Width Error for Machine-vision Sidewalk Width Estimates

Absolute Width Error (inches)	Percentage of points
0 - 3 inches	15.2
0 - 6 inches	27.6
0 - 9 inches	38.6
0 - 12 inches	45.1
0 - 24 inches	61.2

The majority of video-system-estimated width data did not fall within 12 inches of hand-measured ground truth data. Similar results were found in the assessment of the accuracy of automated edge-detection for width estimation for the Virginia-Highland control route. The sidewalks in Midtown tend to be wider than sidewalks in Virginia-Highland, so the absolute errors based upon the calculated vanishing point were larger for Midtown compared to Virginia-Highland. Regardless, the Virginia-Highland runs also yielded unacceptable absolute error distributions.

The research team conducted extensive supplemental analysis of the machine vision approach over a period of about five months, with special focus on the sensitivity of edge detection algorithms. By adjusting Canny Edge Detection threshold values (video-by-video), researchers were able to identify additional sidewalk edges and significantly reduce the fraction of null data values (no width detected). However, even the best results returned unacceptably-low-percentages of valid data. A variety of additional QA/QC assessments and comparative analyses were conducted by the research team during this effort.

Based upon supplemental review of individual videos that obtained poor data returns, the research team concluded that accurate and reliable sidewalk width data could only be generated by the automated system for very high-quality sidewalks, with stark pavement contrast and clean edge lines. The presence of leaves, shadows, sun glare, and encroachment of vegetation made edge identification nearly impossible using the algorithms developed by the research team. Unfortunately, the majority of the sidewalks in the comparative analysis data set are simply not high enough quality (nor are most sidewalks in older residential Atlanta neighborhoods). Based on QA/QC analysis of machine-vision-produced sidewalk width data, the research team concluded that none of the versions of the video processing developed during the research effort were able to produce sufficiently accurate results for use in assessing Atlanta sidewalk widths. At that time, the research team abandoned the fully-automated approach and began developing a semi-automated method designed to use the same conceptual and mathematical approach, but substituting manual identification of sidewalk edges for automated detection.

4.7 Final Semi-Automated Video Processing System

The research team developed an interactive web page that would allow registered users to review video and manually detect sidewalk edges. The system then automatically estimated sidewalk width using the calibrated field of view. The GPS data and elapsed time from the start of the video are employed to show the reviewer a frame from the video approximately every 50 linear feet. The interactive page allows the user to adjust sidewalk edge detection bars until they align with the edge of the sidewalk (see Figure 26). For each frame, researchers indicate two points on each side of the sidewalk by dragging the blue squares to match up with the picture. The orange dotted lines guide the researcher to line the boxes up accurately by aiming for the orange lines to align with the sides of the sidewalk. Once this information is entered, researchers have an automated system to convert the distance between pixels to dimensions in real life thus giving an estimate for the width of the actual sidewalk.

Figure 26. Width Estimation Interface

Research assistants are trained and provided a registered user login. The training shows them to look for the portion of a street between the curb line and the adjacent property line that is paved or improved and intended for use by pedestrians (AASHTO, 2004). In some cases, the edges of the sidewalk are not visible. In these cases, the user is able to select a reason as to why an edge could not be identified. The manual edge detection instruction guide is presented in Appendix C: Video Processing for Sidewalk Width - User Guide.

Once the edges are identified, the 2-D pixel coordinates of the edges are transformed back into the 3-D real-world coordinate system. First, a set of temporary coordinates (d_x, d_y, d_z) are calculated based on the rotation of the camera around the x, y, and z-axes $(\theta_x, \theta_y, \theta_z)$, the position of the object, and the position of the camera in 3-D space (Guiducci, 2000).

$$\begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_x) & -\sin(-\theta_x) \\ 0 & \sin(-\theta_x) & \cos(-\theta_x) \end{bmatrix} \begin{bmatrix} \cos(-\theta_y) & 0 & \sin(-\theta_y) \\ 0 & 1 & 0 \\ -\sin(-\theta_y) & 0 & \cos(-\theta_y) \end{bmatrix} \begin{bmatrix} \cos(-\theta_z) & -\sin(-\theta_z) & 0 \\ \sin(-\theta_z) & \cos(-\theta_z) & 0 \\ 0 & 0 & 1 \end{bmatrix} \left[\begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} - \begin{bmatrix} c_x \\ c_y \\ c_z \end{bmatrix} \right]$$

For the purpose of estimating sidewalk width, we assume that rotations around the y and z-axis are zero. When θ_x equals 90, the transformation matrix is for a camera pointed in the positive y-direction, perpendicular to the y-plane. When θ_x equals 0, the transformation matrix is for a camera pointed in the negative z-direction, perpendicular to the z-plane. Given θ_y and θ_z are equal to 0, the matrices for transformation around each respective axis become the identity matrix, resulting in the simplified equation:

$$\begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_x) & -\sin(-\theta_x) \\ 0 & \sin(-\theta_x) & \cos(-\theta_x) \end{bmatrix} \left[\begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} - \begin{bmatrix} c_x \\ c_y \\ c_z \end{bmatrix} \right]$$

Assuming that the camera is a constant 1.35 feet above ground, and all transformed points are on the plane z=0, further simplifies the equation:

$$d_x = a_x - c_x$$

$$d_y = (a_y - c_y)\cos(-\theta_x) - \big((a_z - c_z) - 1.35\big)\sin(-\theta_x)$$

$$d_z = (a_y - c_y)\sin(-\theta_x) + \big((a_z - c_z) - 1.35\big)\cos(-\theta_x)$$

The temporary coordinates (d_x, d_y, d_z) are converted to the final pixel coordinates (b_x, b_y) using the equations below, where R is dependent on the focal length, which is a constant across all Toshiba Thrive cameras.

$$b_x = \frac{d_x R}{d_z} \qquad\qquad b_y = \frac{d_y R}{d_z}$$

All points in front of the camera appear below the vanishing point, and all points in back of the camera appear above the vanishing point (view of the direction opposite of where the camera is pointing). The ratio is a focus-dependent number that properly scales the image to the correct units.

The calculation from pixel coordinates to 3-D coordinates is relatively simple, provided a few assumptions are made. The first assumption is that the identified sidewalk edges are parallel in the real world. This allows the vanishing point to be estimated, and the angle of the camera to be estimated. The second assumption is that the camera is at the same pitch as the sidewalk (no undulations). The final assumption is that the sidewalk is level with respect to the camera, at the sidewalk surface is the plane defined by z = 0. The distance between the parallel lines is then taken as the sidewalk width estimate.

$$\theta_x = \arctan\left(\frac{R}{VP_y}\right)$$

$$a_x = b_x \frac{a_y \cos(-\theta_x) + c_z \sin(-\theta_x)}{b_y}$$

$$a_y = c_z \frac{-R\sin(-\theta_x) - b_y \cos(-\theta_x)}{R\cos(-\theta_x) - b_y \sin(-\theta_x)}$$

Because the estimation of sidewalk width is dependent on user-identified sidewalk edges, it is important to assess potential biases across users. It is unlikely that users will be able to replicate the exact points chosen for drawing edge-detection lines. Edge detection requires placement of four coordinates on the screen. Given the coordinate transformation assumptions, the estimated width can only equal the ground truth width when all four edge-detection pixels are exactly where they are supposed to be. The sensitivity analysis considers the movement of one of the pixels furthest away from the camera. Movement of one of the edge vertices from ground truth will result in error in the width estimation. The distance this point is away from the camera and its spatial relationship to other points will influence the sensitivity of moving the point. Figure 27 below shows the sensitivity of moving the upper left edge-detection point up to 10 pixels in any direction from the ground truth point. As expected, there are many other points along the ground-truth edge that can be selected resulting in an accurate width estimate. The further away from the edge, the larger the width estimation error that can be expected.

Figure 27. Width Estimation Sensitivity Example

4.8 Post-Processing of Video for Cracking, Disjoints, Potholes, and Obstructions

As outlined in earlier sections, the research team was not able to implement reliable machine visions systems to automatically identify pavement disjoints (other than when they are highly correlated with surface roughness), to quantify crack density, and to identify the presence of potholes and sidewalk obstructions. The research team developed an alternative system to manually review rolling video and efficiently identify these types of sidewalk defects. This system enables sidewalk inspections for these defects to be conducted in the laboratory setting rather than having to identify all of the problems while in the field. The system increases the speed of sidewalk inspections and allows users to reassess field-identified issues at any time via re-review of the video archive.

The Sidewalk Sentry™ video and GPS data streams are integrated and accessible through the Sidewalk Sentry™ Web Interface (see Section 4.9). Users with approved video review accounts on the server can access each sidewalk video through the user-interface, allowing the user to simultaneously view the rolling video of the sidewalk and the sidewalk feature data. This video review feature was originally designed to allow infrastructure managers to conduct preliminary sidewalk reviews from the office and examine potential sidewalk quality issues without having to return to the field to verify the need for repairs or develop initial cost estimates. The general public does not have video access due to bandwidth constraints.

The research team added an interactive feature to the video review interface, allowing reviewers to identify sidewalk problems during the rolling video review. When the user's mouse crosses into the bottom ½ of the video review screen, the mouse pointer converts to a target icon. When the user clicks on the screen, a popup menu allows users to select the sidewalk problem types associated with the location clicked. For example, the user can identify a pavement disjoint, surface roughness problem, and sidewalk width narrowing all associated with a tree root encroaching into the path. The system creates a sidewalk problem report, posting the GPS location associated with the video frame selected and the codes for the problem types identified into the Sidewalk Sentry™ database. Figure 28 displays the video view, video review interface, and the web interface to access video and data.

Because the development of the user-interface for sidewalk video review came toward the end of the project, the research team was only able to post-process the video for about nine of the Atlanta neighborhoods for which video data were collected. These neighborhoods serve as a completed sidewalk testbed and are being used in sidewalk network analysis research and also feed into the case study analyses presented in Chapter 7. Officials at the City of Atlanta and Atlanta Regional Commission have been furnished accounts with video review authority so that ongoing reviews can be conducted after the research project is complete.

Figure 28. Video Reviewer Interface with Mouse Targeting Icon

4.9 Sidewalk Sentry™ Web Interface

Project results are presented to stakeholders and practitioners on an interactive website using an open-source Open Street Map interface. The website displays a map of collected data, which is color-coded based on sidewalk quality evaluation results from field data post-processing. An example of the web interface in development is shown in Figure 29, which displays mapped sidewalk quality data and video data side by side. Some, easier to share, results are open to the public; while more advanced users (such as agency staff) can view rolling video data and more detailed sidewalk quality data, such as width measurements and the presence of obstructions. The interface allows agency staff to review sidewalk issues and respond to public input before sending inspection crews out to address the issue. Local, regional, and state agencies can also utilize sidewalk quality ratings in ongoing and future pedestrian planning, project prioritization, and implementation.

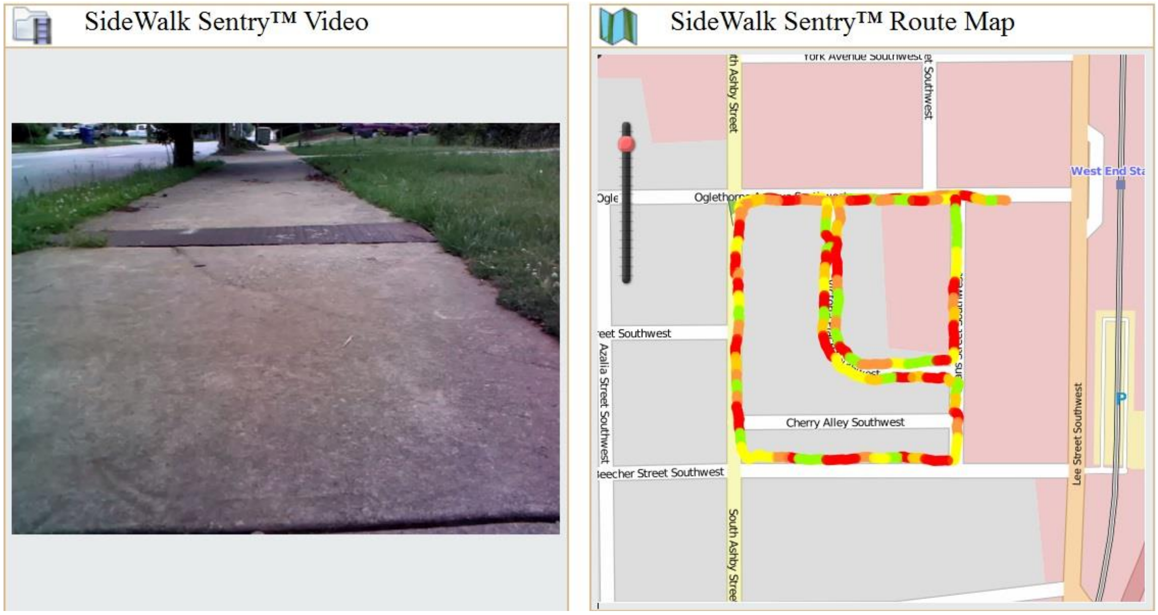

Figure 29. Sidewalk Sentry™ Interface Sub-components

For visualization purposes, and to limit the amount of data presented to the user at one time, the web interface requires a user to select data and video by official Atlanta neighborhood. From a practical perspective, given that 1,352 miles of sidewalks were processed, the amount of point data available for display in the system would overwhelm the user-interface page if the user were given the option to select the entire City of Atlanta. Polygon boundaries were established for each neighborhood using City data, and all video and other data in the Sidewalk Sentry™ system were then assigned to their applicable neighborhood using the GPS coordinates. Users choose the neighborhood they wish to look at from a drop down menu on the Sidewalk Sentry™ homepage, as seen in Figure 30. Once users choose the neighborhood of interest, they are able to see second-by-second data points with the option to see color coded ratings by layer for width, vibration, or overall rating (data layers can be turned on and off). Figure 31 below shows an example of the interactive interface. The current interface employs a Flash interface for data display. The research team is improving the online system in 2015-2016 as part of a new project for the Atlanta Regional Commission, which includes conversion to a JavaScript interface to improve usability.

Icons on the map show users what is viewable at that location. Pothole or obstruction icons indicate the locations along the route where reviewers created Sidewalk Sentry™ problem reports during rolling video review. When a user clicks on a video icon, the rolling video review interface opens for that roadway segment. The rolling video plays next to a map indicating the location at each second that also shows a color coded trace of the segment on the 1 to 5 rating scale (see Figure 32). The accompanying vibration data for the video traces appear on the 1 to 5 scale chart under the video and map.

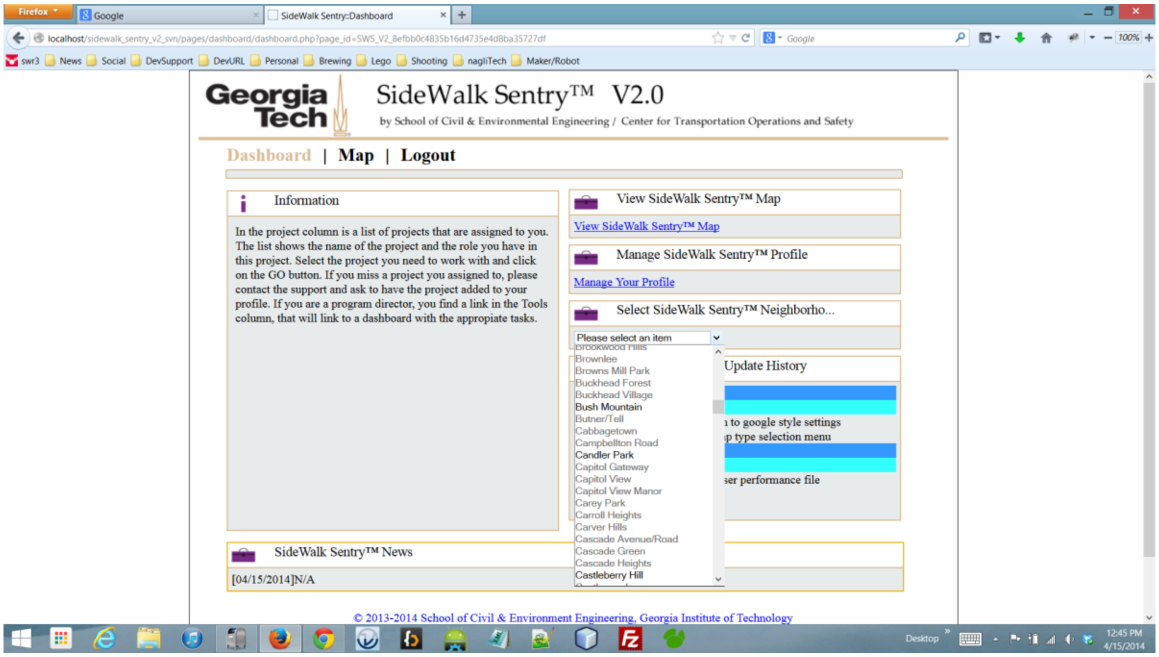

Figure 30. Web Interface to Select Neighborhood for Data Visualization

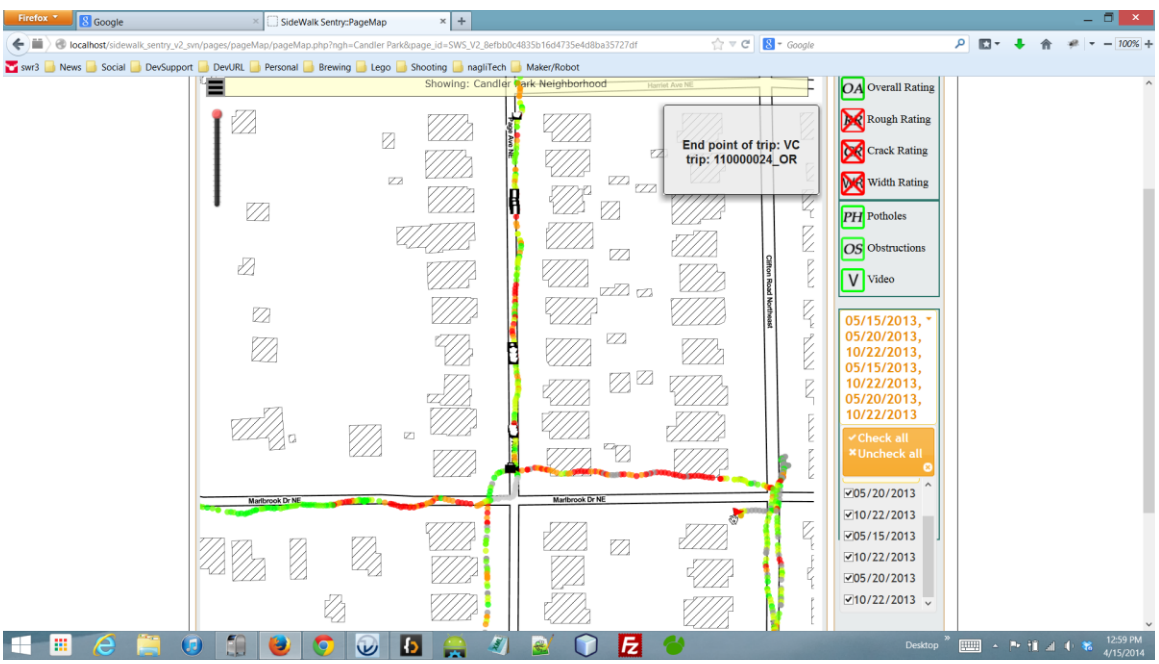

Figure 31. Interactive Data Visualization Interface

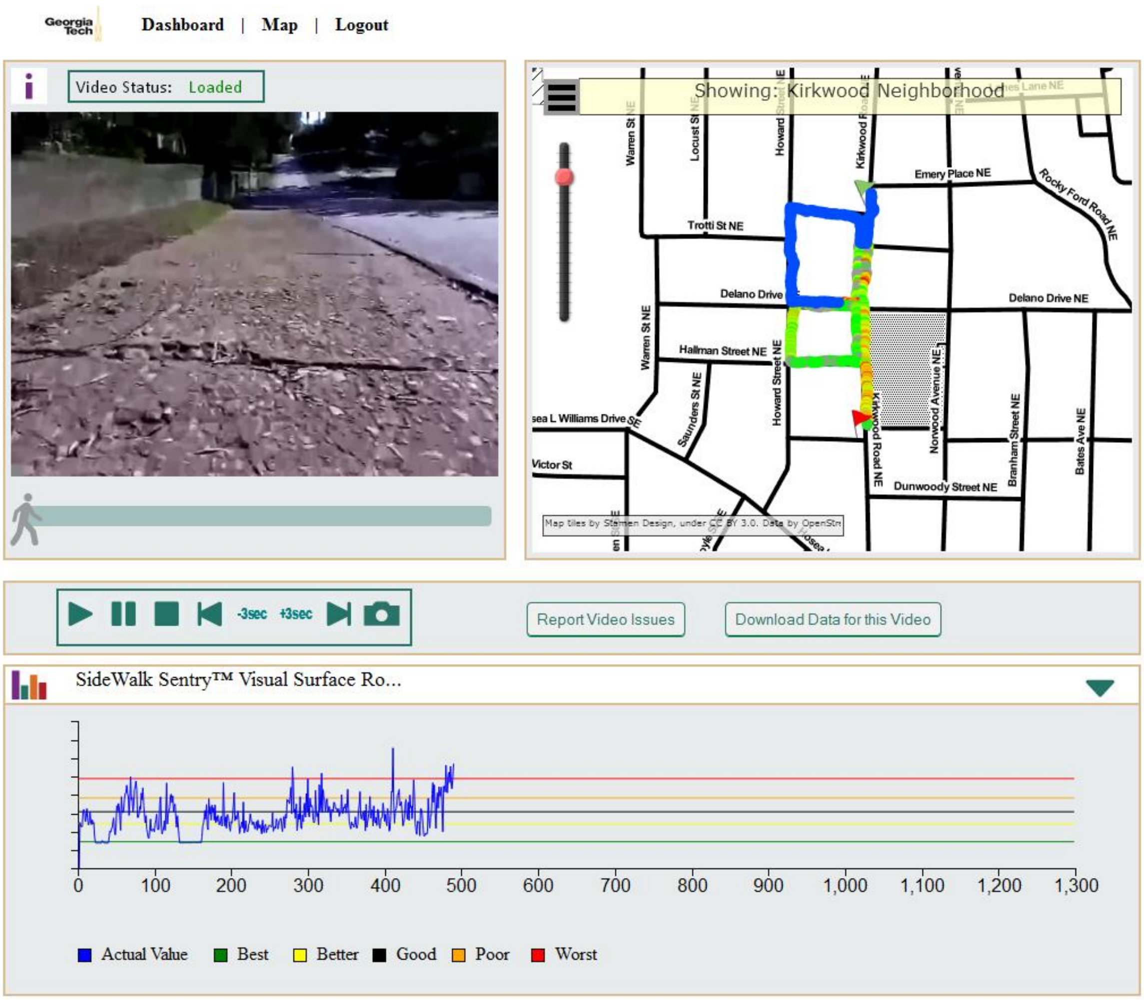

Figure 32. Data Viewing Web Interface

The blue line on the Visual Surface Roughness chart in the web interface indicates the amount of vibration and the colored lines behind it show the rating level. Ratings in the red and orange levels indicate high amounts of vibration that are unlikely to meet ADA standards and likely correlate with areas of the sidewalk that should be replaced or repaired. Sidewalk vibration at or below the center black line is low enough that the sidewalk is likely to be in acceptable condition.

User permissions and access levels sit on a sliding scale from the general public, who can see only the sidewalk ratings, through the highest level of researchers and public office holders who can review raw data and identify problems in rolling video review. Reviewers can also create and download reports of specified areas showing raw data outputs. The research team is working on a new interface in JavaScript that will allow super users to remove problem sites as repairs are made.

4.10 Testing of Alternative Tablet Technologies

As the current data collection system uses Toshiba Thrive™ tablets that are no longer being manufactured, the research team put efforts into testing other tablets to find the best replacement that is both economically efficient and collects data of an equal or higher quality as the Toshiba Thrive™. The most comprehensive round of testing included the Nexus 7 tablet, the Nexus 10 tablet, the Samsung Galaxy Tab 2 tablet, and the iPad Mini tablet. The team also tested a variety of smartphones as phones have the same capabilities needed to run the Sidewalk Sentry™ App, namely GPS, an accelerometer, a gyroscope, and a video camera. For initial scoping of each of these devices, researchers visually estimated the video frame rate, which was adequate for all tablets, however the video collected with the Nexus 7 tablet in the Sidewalk Sentry™ App showed a visual distortion (occasional blurriness and physical offsets) so the tablet was not tested further and is not recommended for future use unless specifications change to fix this problem. Researchers measured the field of view for the devices in question to assess whether the image processing could be conducted on video collected by the devices. Field of view testing was done by placing the phones and tablets on the edge of a table (at a height of 29 inches) and measuring the heights and widths of the area on the ground that could be seen in the camera. Results from the field of view testing are shown in Table 12 below.

With respect to the operating system and GPS elements, almost all the phones and tablets have comparable numbers and up-to-date operating systems. The GPS components of all the phones and tablets (except for the Toshiba Thrive™) had both A-GPS support and GLONASS. All of the Android devices tested were upgradable to the newer Kit Kat operating system, and the Apple products were all upgradable to iOS 7.1. The detailed statistics can be seen in the attached Excel spreadsheet, as differences in operating systems are both quantitative and qualitative. Camera specifications were recorded and the result showed that the Galaxy Note 3 phone, Moto X phone, IPhone 5s, and the Nexus 5 phone had the most pixels. Both the Apple IPad Mini and IPhone 5s have the A7 chip set, while all the Android devices have some form of Snapdragon chip set.

Unfortunately, none of the potential alternative technologies met the needs of the ongoing project. The primary problems arose from limited fields of view, poor in-motion video resolution (blur in video processing), and accelerometer frequency on the alternative systems. For the time being, the research team has purchased additional used and refurbished Toshiba Thrive™ units via the Internet. The team plans to conduct a new round of tablet testing in 2015 to try to find an alternative technology. Once that technology is identified, the vibration algorithms will need to be updated using the same approach presented earlier as the sensors will likely have different ranges and sensitivities and responses when attached to the wheelchair. Furthermore, the camera field of view employed in width estimation will also need to be updated once a new tablet is selected. The research team recognizes that the future transferability and longevity of the Sidewalk Sentry™ app dependent upon finding an alternative tablet technology.

Table 12. Testing Results for Alternative Devices

	Width (inches)	Height (inches)	Viewing Area (in²)	Chip Set	Operating System	GPS	Screen Resolution	Camera Specs
Toshiba Thrive™ Tablet	29.5	22.0	649.0	Nvidia Tegra 2 T20	Android OS, v3.0 (Honeycomb), upgradable to v3.2 (Honeycomb)	A-GPS support	1280 x 800 pixels	5 MP, 2592 x 1944 pixels
Nexus 10 Tablet	28.5	17.0	484.5	ARM 1.7 GHz Dual-core Cortex-A15	Android OS, v4.2.2 (Jelly Bean), upgradable to v4.4 (KitKat)	A-GPS support and GLONASS	2560 x 1600 pixels	5 MP, 2592 x 1936 pixels
Nexus 5 Phone	32.0	21.0	672.0	Qualcomm MSM8974 Snapdragon 800	Android OS, v4.4 (KitKat), upgradable to v4.4.2 (KitKat)	A-GPS support and GLONASS	1080 x 1920 pixels	8 MP, 3264 x 2448 pixels
Samsung Galaxy Tab 2	28.5	21.0	598.5	TI 1.0 GHz Dual-Core OMAP4430	Android OS, v4.2.2 (Jelly Bean), upgradable to v4.4 (KitKat)	A-GPS support and GLONASS	1024 x 600 pixels	3 MP
Moto X Phone	37.0	21.0	777.0	Qualcomm MSM8960Pro Snapdragon	Android OS, v4.2.2 (Jelly Bean), upgradable to v4.4 (KitKat)	A-GPS support and GLONASS	720 x 1280 pixels	10 MP, 4320 x 2432 pixels
Galaxy S4 Phone	30.0	16.5	495.0	ARM 1.6 GHz Quad-core Cortex-A15	Android OS, v4.4 (KitKat), upgradable to v5.0.1 (Lollipop)	A-GPS support and GLONASS	1024 x 600 pixels	13 MP, 4128 x 3096 pixels
iPad Mini	30	22.5	675	Apple A7	iOS 7, upgradable to iOS 7.1	A-GPS support and GLONASS	1536 x 2048 pixels,	5 MP, 2592 x 1944 pixels
iPhone 5s	32	24	768	Apple A7	iOS 7, upgradable to iOS 7.1	A-GPS support and GLONASS	640 x 1136 pixels,	8 MP, 3264 x 2448 pixels
Galaxy Note 3	30.5	17.5	533.75	Qualcomm Snapdragon 800 (N9005, N9002)/ Exynos 5 Octa 5420 (N9000)	Android OS, v4.3 (Jelly Bean), upgradable to v4.4.2 (KitKat)	A-GPS support and GLONASS	1080 x 1920 pixels	13 MP, 4128 x 3096 pixels,

5 Atlanta Sidewalks

Despite Atlanta's reputation as a car-centric city, according to the 2013 American Community Survey (ACS) data, 4.7% of commuters in Atlanta walked to work and 10.3% took public transportation, which often includes up to a quarter mile walk on one or both ends of the trip (ACS, 2013). Sidewalks and pedestrian pathways encourage more people to walk, which can reduce congestion, reduce fuel consumption and emissions, and enhance the local quality of life. To ensure the safety of those who walk or take transit to their destinations, pedestrian infrastructure is necessary. In fact, poor quality sidewalks can end up costing cities more money than sidewalk repairs, due to injury-related lawsuits, which have become a significant cost burden for cities across the country (Carrillo, et al., 2012). The Federal Highway Administration has identified Atlanta as a Pedestrian Safety Focus City due to its relatively high rate of pedestrian fatalities (Redmon, et al., 2012).

The City of Atlanta Department of Public Works (DPW) estimates that about 2,200 miles of sidewalks are present in the city of Atlanta. DPW estimates are based upon the number of known road miles in Atlanta, and estimates of percentage sidewalk presence by neighborhood, given that there is no comprehensive sidewalk inventory or sidewalk infrastructure management system in place at this time. A more detailed inventory of sidewalks and ramps is needed. The City of Atlanta Department of Public Works estimates a $152 million sidewalk repair backlog, with sidewalks degrading and crumbling faster than they can fix them (City of Atlanta, 2011). However, it is especially difficult to prioritize and organize repairs, given the lack of specific knowledge about the citywide distribution of sidewalk problems and their severity. This chapter explores the background issues associated with Atlanta's sidewalks and describes the field activities undertaken by the research team to collect video and data for more than 1,200 miles of Atlanta sidewalks.

5.1 A Brief History of Atlanta's Sidewalks

Sidewalks in some areas of Atlanta have been around since the 19^{th} century, but have not received proper upkeep. Historic commercial areas (i.e., downtown) and trolley-oriented "suburbs" (e.g., Midtown, Grant Park, West End, Virginia-Highland), have sidewalks that were built from 1890 to1930 and have seen varied amounts of maintenance since that time. By the 1940s and 1950s, with the rise of automobile ownership and automobility, the trolley systems were dismantled. Land development turned toward suburbanization, with the middle class and wealthy Atlanta residents moving away from the city center. Over time, sidewalks fell into greater disrepair and questions regarding sidewalk ownership and repair responsibility begin to arise. Sidewalks that have been around for 40 to 70 years have reached the end of their useful lifespans. Today, property owners in Atlanta are responsible for the abutting sidewalks per City Ordinance, but owners often leave sidewalks neglected due to prohibitive costs in low income areas and local equity concerns regarding who should actually be responsible for sidewalk repairs. Issues of repair and replacement costs and how costs might fall under the city budget or property tax policy are currently being explored.

Given the lack of any complete database or inventory of sidewalks in Atlanta, the best estimate to date is that there are over 2,200 miles of sidewalks in City of Atlanta. The 2010

Department of Public Works State of the Infrastructure Report stated that 18% or 395 miles of sidewalks were in disrepair, 10% or 216 miles of curb ramps were in disrepair. The report listed system maintenance costs at $152 million to eliminate backlog of disrepair and a needed $15 million annual maintenance budget. In contrast, the 2010 fiscal year budget allotted only $42,000 for repairs (City of Atlanta, 2010). In 2011 the budget increased to $50,000, $245,000 in 2012, and $860,000 in 2013. By 2013, the City hired a new sidewalk program manager and sidewalk inspector.

On March 17th, 2015, Atlanta residents voted on the "Renew Atlanta" 2015 infrastructure bond. The referendum passed, allotting $187.9 million to transportation projects (City of Atlanta, 2015). Initial documents indicated that as much as $40 million would go toward pedestrian infrastructure projects; however, recent indications are that it could be as little as $5 million. Unfortunately, it is not possible to determine how much of the bond funding will actually go to sidewalk repair and ramp installation because "complete streets" projects and special projects within City Council Districts lack specificity (Nord, et al., 2015). Even if the total amount were to reach $20 million, a gap of more than $120 million in sidewalk repairs would still remain.

Liability under the ADA for poor condition sidewalks has cost cities millions of dollars across the country in recent years. Over the last decade, the City of Atlanta has settled ADA compliance and injury lawsuits for millions of dollars. Figure 33 shows that the City of Atlanta has spent about $4.4 million between 2008 and 2012, based upon data from Young (2012) and McWilliams (2012). Most recently, the City of Los Angeles agreed to spend $1.3 billion on sidewalk repairs as a result of a lawsuit filed against the City on behalf of people with disabilities (Reyes, 2015).

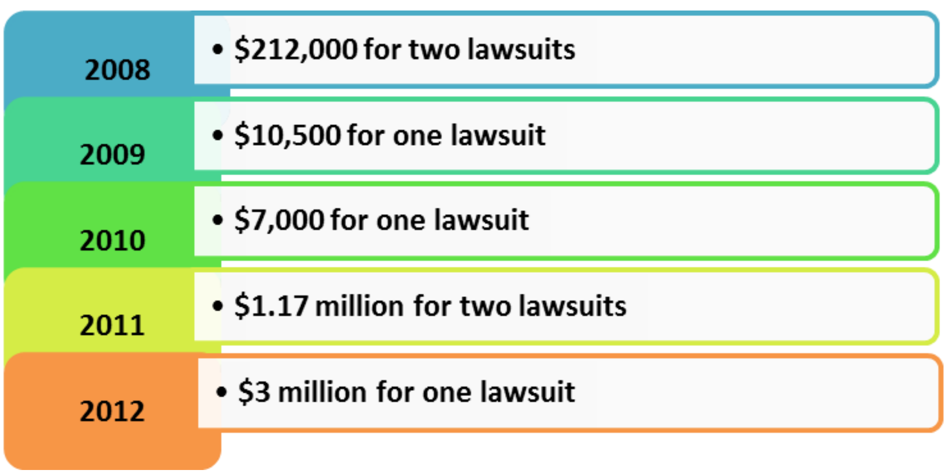

Figure 33. Sidewalk Liability in the City of Atlanta Settlements

ADA compliance, pedestrian safety, and legal liability are clearly issues that need to be addressed in Atlanta. However, given the results of the expert panel survey reported in Chapters 3, there are still a variety of ways in which sidewalk quality can be evaluated and how a high-quality sidewalk might be defined (which will be addressed in Chapters 6 and 7).

This chapter provides a summary of the data collection efforts and data collected in the City of Atlanta for use in ADA compliance assessments and sidewalk quality evaluation using the Sidewalk Sentry™ system presented in Chapter 4.

5.2 Atlanta Field Data Collection

The City of Atlanta estimates a total sidewalk network of approximately 2,158 miles (City of Atlanta, 2008a; City of Atlanta, 2011); however, the exact sidewalk network distance and state of good repair estimates are somewhat uncertain. The 2008 State of the City's Infrastructure report estimated that 18% of the sidewalk network to be deteriorated and assumed that 395 miles of sidewalk are defective. The City of Atlanta Public Works Department estimated that the pedestrian infrastructure repair backlog is more than $150 million, approximately $118,800 per mile of sidewalk, as shown in Table 13 (City of Atlanta, 2008a).

Table 13. Sidewalk Inventory Backlog Estimate, City of Atlanta

	Inventory (miles)	Estimated Fraction	Backlog (miles)	Backlog Cost ($/mile)	Total Cost ($ million)
Sidewalk	2,158	18.3%	395	$118,800	$109
Curbing	2,158	10 %	216	$132,000	$ 29
Incidentals	--	10%	--	--	$ 14
TOTAL					$152

The City of Atlanta has faced litigation from the U.S. Department of Justice (USDOJ) under the Americans with Disabilities Act for non-compliant sidewalks and ramps (USDOJ, 2009). As a provision of the settlement agreement, the City of Atlanta was expected to provide curb cuts and pedestrian walkways for all new construction and alterations within three months of December 2009. Pedestrian infrastructure is legally considered part of the "public right of way" and local governments can be liable for physical injury resulting from inadequate maintenance of infrastructure. Injury lawsuits related to deteriorated sidewalk facilities have cost the City of Atlanta millions of dollars in the last few years; which is substantially more than it would cost to repair a sidewalk. For example, the city negotiated a multimillion-dollar settlement in 2012 to resolve injury claims due to a sidewalk that would have cost $2,000 to repair (Diggs, 2012).

Using volunteer and student labor, the research team began large-scale deployment in early 2013 throughout the City of Atlanta. Figure 34 shows a map of the video and data collected. The research team prioritized data collection within the urban core areas (defined as inward from the BeltLine Overlay District, plus a one-half-mile buffer surrounding the District), the Midtown, Downtown and Buckhead Community Improvement Districts, and a half-mile buffer around MARTA rail stations within the city boundaries. This prioritized area consisted of approximately 659 roadway miles, 12,089 intersections and contained 3,489 Census blocks. Video and data were collected for this entire area, comprising 1,352 miles of sidewalks. Approximately 10% of the data collected during field activity will need to be recollected due to failure of the field teams to obtain GPS lock, failure to install the unit properly, component failure of a specific tablet, or other operator errors.

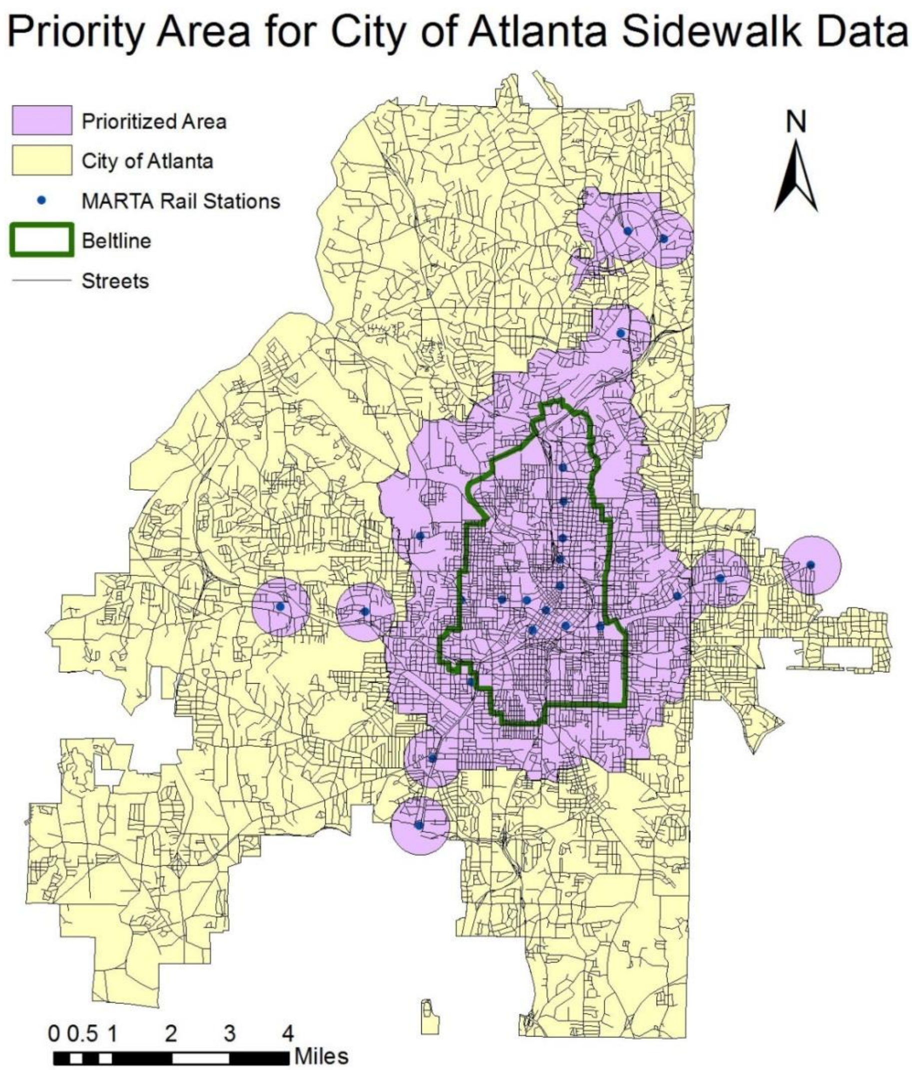

Figure 34. Sidewalk Data Collection Coverage Map

5.3 Field Data Collection

In 2013, the team began large-scale data collection with Sidewalk Sentry™ across the City of Atlanta. Initial field data collection included the 1.9 mile control calibration route, discussed Chapter 5 of this report, and the 40 sidewalk segments selected for inclusion in the Sidewalk Quality Assessment Survey discussed in Chapter 3. The 40 survey segments were spread across the City of Atlanta. These segments exhibit varying qualities and conditions, and are located near different land use classifications. Initial data collection was performed by groups of graduate students, undergraduate students, and the project principle investigator. Data collection efforts later included high school students, as well as community volunteers.

Upon completion of system calibration, trained researchers, undergraduate assistants, and neighborhood volunteers recruited by outreach efforts began data collection at the neighborhood level. Routes ranging in length from 1.0 to 2.0 miles are selected from block-sized polygons from street network data in ARC GIS and are mapped out and accompanied by written directions. These illustrated and verbal directions guide pairs of data collectors along safe walking routes within a neighborhood. For field data collection, each team is assigned prescribed route maps and equipment, including a wheelchair, tablet mounting board, Toshiba Thrive™ tablet, and safety vests for each data collector. Teams usually complete multiple routes during each deployment, collecting data for three to four hours.

5.4 Stakeholder Engagement in Data Collection

The research team engaged stakeholders and decision-makers throughout the project to aid future implementation of the sidewalk quality assessment system to improve pedestrian facility planning and asset management on a local, regional, and state level. The research team consulted on sidewalk quality indicators and data collection priorities with the Georgia Department of Transportation staff, City of Atlanta planning and engineering staff, the Atlanta Regional Commission, and Pedestrians Educating Drivers on Safety (PEDS). The research team also obtained information regarding existing sidewalk assessment processes at the local and regional scales. In September 2012, the research team conducted kickoff meetings with key staff members at the City of Atlanta Department of Public Works, who were very interested in the potential of this research to improve sidewalk inspection and maintenance prioritization within the City of Atlanta (Mendoza, 2012).

To improve the cost-effectiveness of field data collection, the research team employed undergraduate students as data collectors and coordinated several field deployments with community volunteers. The research team routinely presented at neighborhood planning unit (NPU) meetings and at local neighborhood association meetings to engage with local neighborhoods, increase public awareness about the data being collected in their area, and generate interest in volunteering. After conducting numerous collaborative efforts with high schools and local community volunteer groups, the research team concluded that while the outreach efforts may have been worthwhile from a public relations and community-building standpoints, data collection by the undergraduate field teams was much more efficient and cost-effective (even though community labor was free). The amount of time and effort to undertake the community efforts cost more than the team saved in data collection labor costs.

The team presented a session at the 2014 transportation “un-Conference” attended by local transportation practitioners and stakeholders to solicit feedback on key sidewalk quality indicators. Based on a review of ADA guidelines and walkability indicators, the researchers identified sidewalk width, surface roughness, pavement crack density, and presence of obstructions as key indicators of sidewalk quality (Frackelton, et al., 2013).

6 Sidewalk Project Prioritization

The City of Bellevue conducted a ranking analysis to prioritize non-compliant infrastructure features for repair. The ranking analysis calculated activity and impedance factors based on demographic, transportation, and land use data as well as inventory results (City of Bellevue, 2009). Table 14 shows the detailed indicators included in the City of Bellevue activity and impedance scores used in the ADA barrier ranking analysis. According to the ADA Self-Evaluation Report, "narrow sidewalks" was included within the sidewalk obstructions indicator. Currently, four other cities plan to utilize inertial profiling systems for ADA compliance inventory: The County of St. Louis, Missouri, and San Carlos, Clovis, and San Marcos, California (Khambatta and Loewenherz, 2011). Beyond ADA compliance, the City of Bellevue identifies sidewalk maintenance as important due to economic concerns of letting sidewalks deteriorate; costs of maintenance, accessibility improvements, and lawsuit settlements (Loewenherz, 2009).

Table 14. Accessibility Indicators used in the Bellevue Barrier Ranking Analysis

Index	Indicator
Activity Score	Proximity to households with disabilities
	Traffic volume
	Proximity to places of public accommodation
	Housing density
	More than 6% Population Older Adults
	In Major Employment Center
	Proximity to Parks
	Proximity to Schools
	Proximity to Retail
Impedance Score	Density of Fixed Obstructions
	Density of Changes in Level Violations
	Density of Cross Slope Violations
	Density of Grade Violations
	Presence of Ramp Obstructions
	Alignment with Marked Crosswalks
	Presence of Detectable Warning Surface
	Presence of Smooth Ramp Transition
	Size of Curb Ramp Landing
	Curb Ramp Landing Slope
	Curb Ramp Width
	Curb Ramp Flare Slope
	Curb Ramp Panel Grade
	Curb Ramp Panel Cross-Slope
	Gutter Grade
	Gutter Cross Slope

Several agencies incorporated sidewalk inventories into their annual paper-based roadway inventory procedures and later digitized these data into GIS or other database systems. For example, Oregon DOT conducts both sidewalk and roadway inventory using manual data entry from video logs. New technologies such as GIS-enabled devices have been utilized to improve the efficiency and database integration of built environment inventories. For example, University of Oregon researchers collected data on sidewalk width and condition using GPS-enabled personal digital assistant (PDA) units (Schlossberg, et al., 2008). This audit tool was utilized by Oregon DOT to supplement their sidewalk inventory data with digitized curb ramp field data.

Methods and best practices for pedestrian transportation data and prioritization are still emerging. In 1994, the City of Portland developed two indices to prioritize pedestrian projects, the Pedestrian Potential Index, or PPI, and the Pedestrian Deficiency Index, or PDI (Schwartz, et al., 1999). The PPI consisted of three factors (designation of urban activity centers, pedestrian activity variables, and proximity to pedestrian generators), while the PDI included variables such as sidewalk presence, street connectivity and traffic characteristics. The City of Portland utilized ArcMap to score pedestrian projects based on their current pedestrian deficiencies and potential for pedestrian activity. As a proxy for pedestrian demand, the original model utilized short trips (two miles or less) from the regional travel demand model. Combined with community and cost-effectiveness input, projects were ranked highly if they scored high on both the PDI and PPI indices (Schwartz, et al., 1999). This methodological approach has been used in many later pedestrian prioritization studies.

Applying Portland's potential and deficiency indices, another study tested methods to prioritize pedestrian investments in suburban areas in the Seattle metropolitan area (Moudon, et al., 2002). Demonstrating two approaches to pedestrian prioritization tools, Moudon, et al. (2002) utilized census-block level and parcel-level land use and density data to identify clusters of latent pedestrian demand. However, the authors noted that future research will require additional transportation infrastructure and travel behavior data to link transportation and land use considerations into pedestrian infrastructure project prioritization.

Two recent studies detail the pedestrian prioritization methods utilized at a regional scale by the North Jersey Transportation Planning Authority (Matley, et al., 2000; Swords, et al., 2004). In preparation of its comprehensive transportation plan, the NJTPA developed a PPI theoretical framework that conceptualized pedestrian travel demand as the link between "proximity" and "connectivity" (Matley, et al., 2000). Thus, PPI indicators might include variables related to land use, density, urban design, and sidewalk network extent. In the case of the NJTPA index, the variables selected included land use mix, and employment, population and street network densities at the census tract scale (given the broad geographic scope of the MPO). Although recognized as a key element in pedestrian travel demand, data on sidewalk availability was not available at a regional scale.

To update the statewide bicycle and pedestrian master plan, New Jersey DOT identified priorities for transportation investment based on both transportation demand and infrastructure "supply" (Swords, et al., 2004). The intent of this update was to provide an analytical framework for selecting priority corridors for bicycle and pedestrian projects.

Similar to Portland's PPI index method, areas were prioritized that scored high on the potential demand analysis and low on the existing infrastructure analysis.

NJDOT analysts did not assess current conditions and existing transportation demand due to the lack of sidewalk inventory and pedestrian trip data. However, NJDOT developed an approach to assess the "barrier severity" of crossing a roadway, based on roadway characteristic data and a calculation of available gaps in traffic. NJDOT analysts estimated pedestrian demand based on a combination of population and employment data with a transit accessibility measure. More detailed information on the estimation of the statewide pedestrian demand index was not publicly available. Land-use data were not utilized in this study because it was not available on a statewide basis. The results of this combined supply/demand analyses indicated that 55% of roadway miles should be prioritized for pedestrian projects, largely in urban and suburban areas in New Jersey (Swords, et al., 2004).

6.1 Planning Prioritization and Policy

The Atlanta City Council convened a Sidewalk Task Force to research public policy issues associated with sidewalk maintenance, pedestrian facility funding, and pedestrian safety. The Sidewalk Task Force held several planning meetings in 2013, and presented recommendations to Atlanta City Council in May 2013. Several expert stakeholders, including staff at the City of Atlanta Office of Planning, Department of Public Works, and the Atlanta Regional Commission have noted the outstanding need for a comprehensive inventory of Atlanta's pedestrian facilities to prioritize repairs and future infrastructure development (Rushing, 2013; Mello, 2013; Flocks, 2013a and 2013b). An inventory and assessment of existing conditions would cost approximately $1.2 million, and this assessment was listed as a high priority for future studies conducted by the Department of Public Works (City of Atlanta, 2011). According to the Department of Public Works, functional classification, facility connectivity (schools, transit, parks, commercial centers), safety, and population density data should be used to prioritize sidewalk repairs and reconstruction (Wynn, 2012).

The City of Atlanta has not yet released a stand-alone pedestrian master plan. In 2007, the City published its first comprehensive transportation plan, the Connect Atlanta Plan. The Connect Atlanta Plan focused on promoting transit ridership, walking, and bicycling to improve connectivity and livability within the urban core (City of Atlanta, 2008b). Additionally, the plan recommended specific transportation improvement projects within each sector of the city. The Connect Atlanta Plan included street and transit project concepts evaluated on the basis of several prioritization metrics, including reduction of vehicle-miles-traveled, promoting multi-modal options, and connectivity as well as pedestrian accessibility.

The Connect Atlanta Plan also included street design guidelines for projects within city right-of-way, with sidewalk width recommendations for each street design context (i.e., high-density mixed-use boulevard, commercial street, etc.). The City of Atlanta is currently in the process of developing detailed "Complete Streets" design guidelines to implement the policy goals and recommendations of the Connect Atlanta Plan. This draft design manual, entitled "Move Atlanta: A Design Manual for Active, Balanced and Complete Streets," was based on the Los Angeles County "Model Design Manual for Living Streets" and adapted to conform to state and national transportation design standards as well as city regulations. The City of Atlanta plans to conduct a citywide bicycle study and a citywide pedestrian study to further the development and prioritization of active transportation projects (Mello and Jones, 2013).

In 2004, the Atlanta Regional Commission (ARC) conducted an inventory of pedestrian facility conditions near rail transit stations and key bus transfer stations. This inventory was completed using GIS-enabled PDA devices and included land use, sidewalk presence and condition, driveway accessibility, buffer and pedestrian crossing attributes (ARC, 2004a; ARC, 2004b). The ARC released its first bicycle and pedestrian plan in 2007. Major regional pedestrian planning goals were to provide accommodations to pedestrian Level of Service (LOS) "B" within Livable Centers Initiative (LCI) areas and "Regional Places" and pedestrian LOS C on other roadways, prioritizing pedestrian improvements near schools, transit stations, and greenspace (ARC, 2007a). The plan proposed a level of service model based on the work of Landis, et al. (2005), which defined LOS as pedestrian "suitability," based on sidewalk presence, roadway width, and traffic characteristics. Selected regionally-significant roadways were evaluated using these criteria. The ARC's regionally-significant transportation system includes Interstates, highways, roadways serving existing and future transit, and inter-county arterials (ARC, 2007b). The 2007 bicycle and pedestrian plan identifies a prioritization scoring process for regional pedestrian planning, calculating a pedestrian score as a function of pedestrian level-of-service, potential for walking activity, congestion (as measured by the Travel Time Index), project cost, and whether the project is located within a Station Community or Livable Centers Initiative site (ARC, 2007c).

In recent years, metropolitan planning organizations have incorporated non-motorized transportation into regional travel demand models to enhance the sensitivity of regional modeling and to reflect changes in development and travel behavior. According to a review of non-motorized transportation within regional travel demand models, a majority of large MPOs include non-motorized transportation in their models (Clifton and Singleton, 2011). The long-range regional transportation plan for Atlanta, Plan 2040, allocated $1.6 billion to bicycle and pedestrian infrastructure projects. Pedestrian project selection within Plan 2040 depended on conformity with regional planning goals and performance measures, such as the "bicycle and pedestrian network expansion" policy filter. Within the Transportation Improvement Program, pedestrian projects are typically funded under the Last Mile Connectivity and General Purpose Roadway Operations and Safety programs. For example, the installation of ADA-compliant sidewalks and pedestrian crossings is listed explicitly as an example project type within the Last Mile Connectivity program (ARC, 2013a).

In addition to the historic trip-based model, the Atlanta Regional Commission is developing an activity-based model (ABM). Rather than using individual trips as the unit of analysis, the activity-based modeling approach focuses on travel as a function of demand for activities (Davidson, et al., 2007). The Atlanta Regional Commission's ABM is based on the CT-RAMP platform of activity-based travel demand models. The major data inputs for the ABM include highway and transit network data, zonal data and synthetic population data (ARC, 2009). During trip generation, a mode choice log sum is calculated for each mode (including walking) to generate zonal accessibilities that are used in the multinomial logit destination choice model for every worker in the synthetic population (ARC, 2009). This mode choice log sum is calculated based on distance to the workplace and assumes peak period travel between zones. The mode choice model is based on the round-trip Level of Service by mode available. Mode choice model LOS parameters relevant to walk trips include walk access time, walk time up to 1 minute, and walk time over one mile (ARC, 2009). Currently, pedestrian trips are generated but are not assigned to the transportation network, due to the lack of pedestrian network link data and "ground truth" validation of pedestrian activity (Kim, June 19, 2013, personal communication). However, modeled pedestrian trips could be used in the future to estimate future non-motorized travel demand on a regional scale.

In the Atlanta region, several jurisdictions have established "Complete Streets" policies, which affirm the need to design for and accommodate all modes of transportation within plans and projects (ARC, 2013b). In 2012, the Georgia Department of Transportation (GDOT) adopted a "Complete Streets Policy" that is incorporated into the agency-wide Design Policy Manual (GDOT, 2012). This policy includes criteria for consideration of bicycle, pedestrian and transit accommodations. The criteria for pedestrian accommodation states that pedestrian facilities "shall be considered" near to pedestrian travel generators, given the presence of "desire lines," if three-year crash records exceed ten pedestrian crashes per half-mile roadway segment, or when a planning study identifies a need (GDOT, 2013).

A review of research and best practices related to evaluating walkability and prioritizing pedestrian infrastructure investments indicates a relationship between variables such as existing infrastructure condition, pedestrian activity and travel demand, land use and roadway characteristics. In general, prioritization "sketch planning" methods often utilize a conceptual framework that combines a "pedestrian potential" (or demand-side) index with a "pedestrian deficiency (or supply-side) index to prioritize projects that may increase pedestrian activity while addressing current barriers to walkability and accessibility.

Based on the results of many walkability assessment studies and projects, the lack of pedestrian-scale data sources has been a barrier to refined analyses on local, regional, and statewide scales. Particularly, sidewalk condition data and pedestrian activity data often limit the ability of researchers and practitioners to identify specific infrastructure needs and plan for future non-motorized travel demand. However, recent technological advances such as GPS-enabled mobile applications have the potential to address these data gaps and improve the cost-effectiveness of collecting disaggregate non-motorized transportation data.

Within the Atlanta region, programs and policies are emerging to promote active transportation and promulgate "Complete Streets" projects. Local, regional, and statewide plans and policies indicate desired criteria for prioritizing pedestrian projects, which largely conform to foregoing best practices. Currently, sidewalk repairs are completed on an ad-hoc basis and local planners do not routinely inventory the condition of pedestrian infrastructure. Therefore, the development and application of a cost-effective sidewalk evaluation system has the potential to aid ongoing pedestrian planning and asset management. The following chapter illustrates a case study application of the concepts presented in this chapter, using data collected from the Sidewalk Sentry™ system.

7 Midtown Atlanta Project Prioritization Case Study

A review of best practices for pedestrian planning suggests that many jurisdictions prioritize pedestrian projects based on high pedestrian activity, safety, accessibility to transit, and mobility for persons with disabilities. As technology to collect and employ pedestrian activity data continues to improve, methodologies are needed to prioritize pedestrian projects at various scales. Based on a review of prior research and best practices (see Chapter 6), many pedestrian prioritization frameworks apply the conceptual framework of a "pedestrian potential index," representing variables related to travel demand, and a "pedestrian deficiency index," incorporating infrastructure and safety indicators. Each index can include several pedestrian project suitability indicators, which are then utilized to generate weighted spatial pedestrian prioritization rankings.

The objective of the research presented in this chapter is to develop and implement a methodology to incorporate app-collected sidewalk data with other available data sources to prioritize pedestrian projects. The ultimate goal of the research effort is to demonstrate a prioritization approach that is transferable to jurisdictions nationally and can be adjusted to fit agency priorities using different weighting schemes and locally available data. The proposed weighted ranking system can be used to prioritize pedestrian projects using the Sidewalk Sentry™ app-collected pedestrian facility data, as well as monitored and modeled pedestrian activity data, pedestrian safety data, and demographic data. The ranking system uses block-level pedestrian potential and pedestrian deficiency indicators to prioritize planning investments within a subarea of Atlanta, Georgia. The approach developed by the research team for prioritization could ultimately be employed in the City of Atlanta to help prioritize the estimated $152 million backlog of sidewalk repairs.

The results of the proposed rank-order prioritization analyses for the Midtown Atlanta case study indicate that blocks near rail stations and mixed-use developments should be prioritized for pedestrian investment. However, the overall system allows for different weightings to be assigned in response to local planning needs, further extending the application to larger geographic scales. Future availability of project cost information, and more comprehensive pedestrian activity and pedestrian network monitoring data, will also help planners and engineers to quantify the most cost-effective sets of projects for implementation. The full analysis associated with this research activity is presented in a Master's Thesis by Alexandra Frackelton (2013). The materials presented in this Chapter are a shorter version of the full thesis, also published as a peer-reviewed paper at the 2015 annual meeting of the Transportation Research Board (Frackelton and Guensler, 2015).

7.1 Midtown Atlanta Case Study Area

The geographic scope for this paper was 42 Census blocks within the Midtown Atlanta neighborhood, a small enough area to illustrate the approach, mechanisms, and sensitivity to ranking variables. Census blocks are employed as the spatial unit of analysis for the prioritization rankings as Census blocks are the smallest geographic scale that can be employed with Census data. Hence, demographic variables from the U.S. Census and the American Community Survey could be incorporated into the analyses. Pedestrian count data were also available for the Midtown area, collected by the Midtown Alliance, as well as sidewalk width data collected by the research team. This study area is in the vicinity of several public parks, a high school, the BeltLine Eastside Trail, the Technology Square mixed-use development, and three MARTA rail stations (see Figure 35).

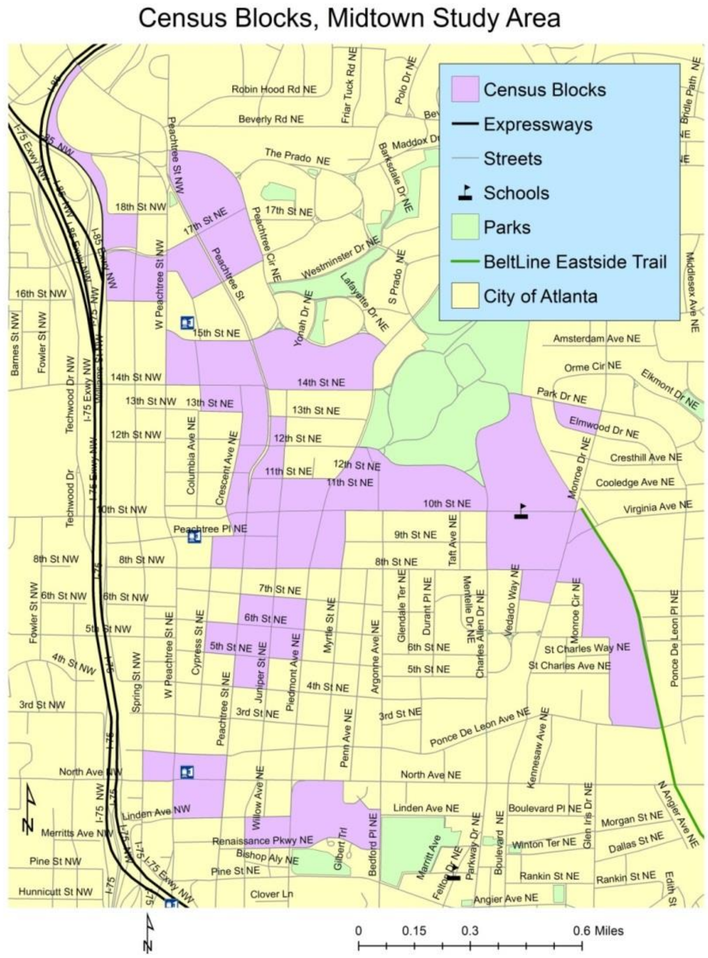

Figure 35. Pedestrian Prioritization Case Study Area in Midtown Atlanta, GA

7.2   Data Sources and Data Reduction

To prepare the pedestrian potential and pedestrian deficiency indices, a variety of datasets were obtained, linked to spatial information, and aggregated to the Census block scale using routines developed in ArcGIS, ArcMap, IBM SPSS, Microsoft Access, and Microsoft Excel. The following datasets were used in developing pedestrian potential and pedestrian deficiency indices: pedestrian activity (count data), population density, transportation commute mode share, marketing demographic data, sidewalk width data, and pedestrian-vehicle crash data. The result of data preparation and data reduction was a database table with the set of underlying data and prioritization indicators compiled by Census block. This allows the Census blocks in the study area to be ranked and prioritized using the independent indicators. The indicator-specific rankings (rank order of the census blocks for each criteria) are summed (for unweighted analysis), or weighted and summed (for weighted analyses) to generate index ratings. Table 15 shows the pedestrian indicators and variables utilized in the pedestrian potential and pedestrian deficiency indices.

Table 15. Prioritization Indices: Indicators and Data Sources

Index	Indicator	Variable	Data Source
Pedestrian Potential Index	Pedestrian activity	Maximum six-hour pedestrian count	Midtown Alliance
	Population density	Population per acre	2010 Census
	Transportation mode share	Percentage of transit, walk and bicycle commute mode	ACS
	Households, and persons with disabilities	Percentage of households with disabilities/young children	Private Data Source
Pedestrian Deficiency Index	Sidewalk width	Percentage of GPS point sidewalk widths <5 feet	Georgia Tech
	Pedestrian crash density	Pedestrian crashes per acre	GDOT

Indicators were selected based on availability of data and studies indicating the significance of these factors. For example, data on crosswalk markings, sign locations, and traffic signals may be useful to include, but were not publicly available for the study area. However, these variables could be collected in the future, integrated into the City's asset management system, and used in index development. Information on citizen complaints was not publicly available at the time of writing. However, future applications of this prioritization process could also incorporate a citizen feedback element (crowdsourcing) in prioritization indices. The following subsections describe the data sources employed. More detailed information on the assembly and processing of these data can be found in Frackelton (2013).

7.2.1 Pedestrian Activity Data

Pedestrian count data were obtained from Midtown Alliance, a non-profit organization that represents members of the Midtown Community Improvement District. This dataset included pedestrian, motor vehicle, bicycle and bus/truck counts for weekday peak periods and a nine-hour weekend period, and the dataset included X-Y coordinates of each count location. Weekday counts were collected on Tuesday, March 26, 2013 with peak totals collected in the morning, midday and evening (Midtown Alliance, 2013a). Weekday counts were collected at 100 intersections in the vicinity of Midtown, and the dataset included morning, midday and evening count totals as well as overall weekday totals. Weekend counts were collected on Saturday, June 1, 2013 between 10am and 7pm at 17 intersection locations in Midtown. Fewer counts were conducted in residential areas, leading to some potential bias in the data, but these are the best data currently available.

The weekday pedestrian count data were utilized within the pedestrian prioritization analysis due to the greater geographic scope of the weekday pedestrian count data compared with the weekend count data. First, total weekday pedestrian counts were calculated for each intersection within the spreadsheet. Then, the X-Y coordinates of each pedestrian count intersection were plotted using ArcMap. The pedestrian count point data were joined to the Census block using a spatial join of all pedestrian count data locations intersecting within 100 feet of Census block polygons. The point data that were located on the boundary of two Census blocks were joined to both blocks, and therefore the resulting dataset included 200 Census blocks. Finally, the maximum pedestrian count total (at a single intersection location) for each Census block was calculated using the summarize function in ArcMap. This resulting variable, "Max_Ped," was used as an indicator of block-level pedestrian activity for the rank-order prioritization analysis. Figure 36 shows the pedestrian count intersection locations within the study area. The map indicates that a majority of pedestrian count intersection locations from the Midtown Alliance dataset were located in the vicinity of the "Midtown Mile" along Peachtree Street.

Figure 37 shows the maximum weekday pedestrian count location within each Census block within the study area. The map indicates that the highest weekday pedestrian count intersections were located within the vicinity of Colony Square and the Arts Center MARTA station, with a secondary pedestrian activity area near the North Avenue MARTA station (and to a lesser extent, near the Midtown MARTA station). In addition to the presence of rail transit stations, the highest pedestrian activity areas include office buildings and restaurants/shopping.

7.2.2 Population Density Data

Population density was calculated as the total block-level population per block acreage using ArcMap with data from the 2010 Census. Figure 38 shows the population density (persons per block acre) within the study area. The map indicates that the Census blocks with the highest population density are located near the North Avenue MARTA station and within the Midtown residential area. Additionally, blocks at Crescent Avenue and at 14th Street had high population densities, although the surrounding blocks had lower densities. These results indicate the presence of high-density residential buildings adjacent to other uses (i.e. commercial buildings) with low or no population.

Given that the commute mode share data were available only at the Census tract level; these results may indicate the effect of high-density blocks surrounded by low-density blocks within tract-level Census data. For example, although the blocks between Peachtree Place and 14th Street were rated within the second highest quartile for aggregate commute mode share, the population density data indicates that the block-level population density is very high within one block and very low in surrounding blocks. In future research, parcel-level land use data is needed to calculate micro-level population and building unit densities for use in pedestrian potential analyses.

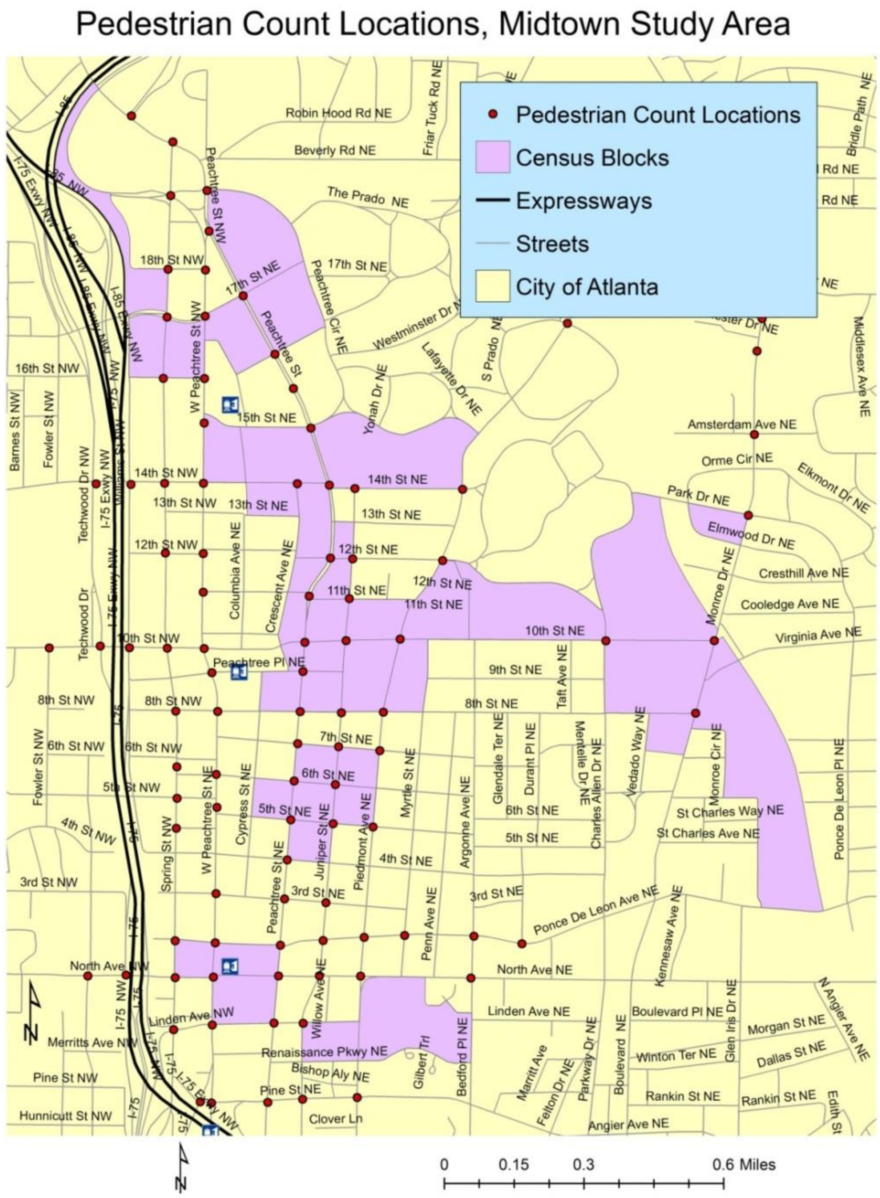

Figure 36. Pedestrian Count Intersection Locations

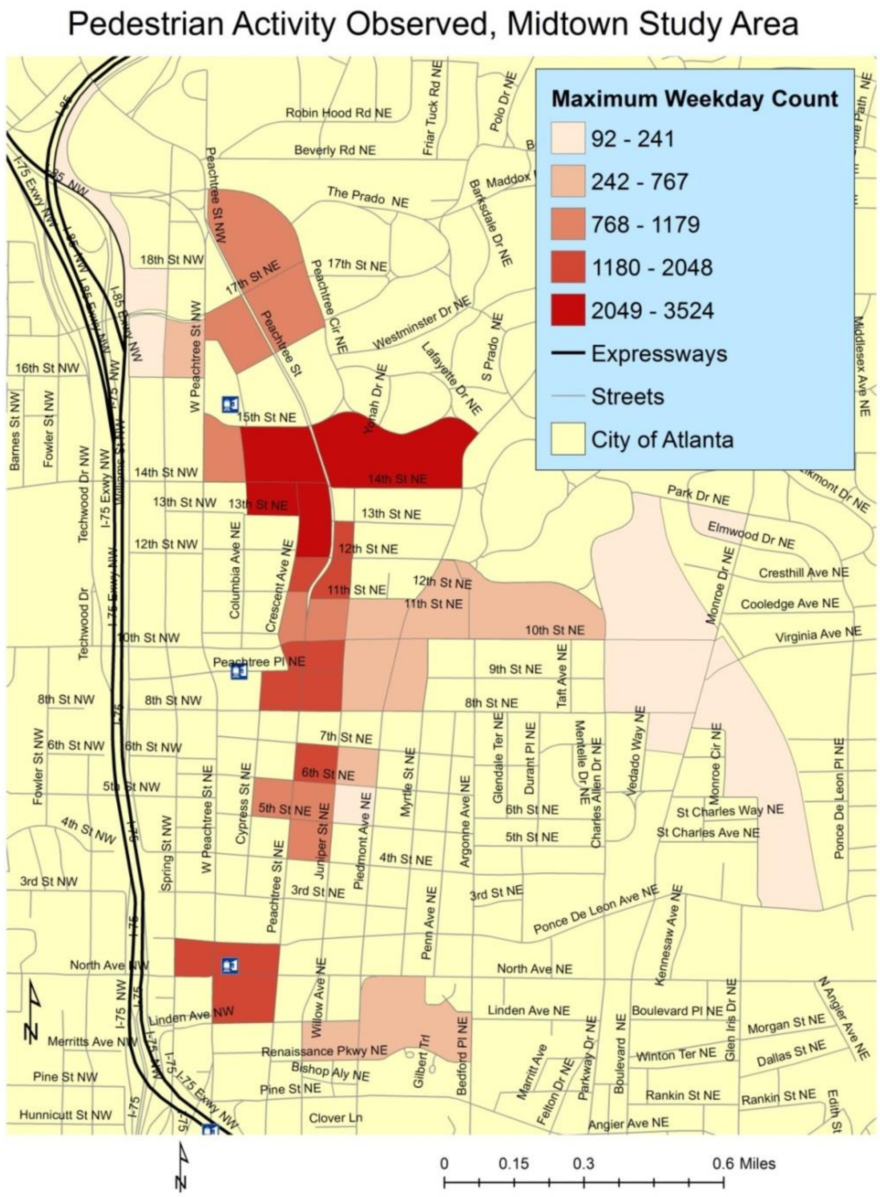

Figure 37: Pedestrian Activity by Census Block

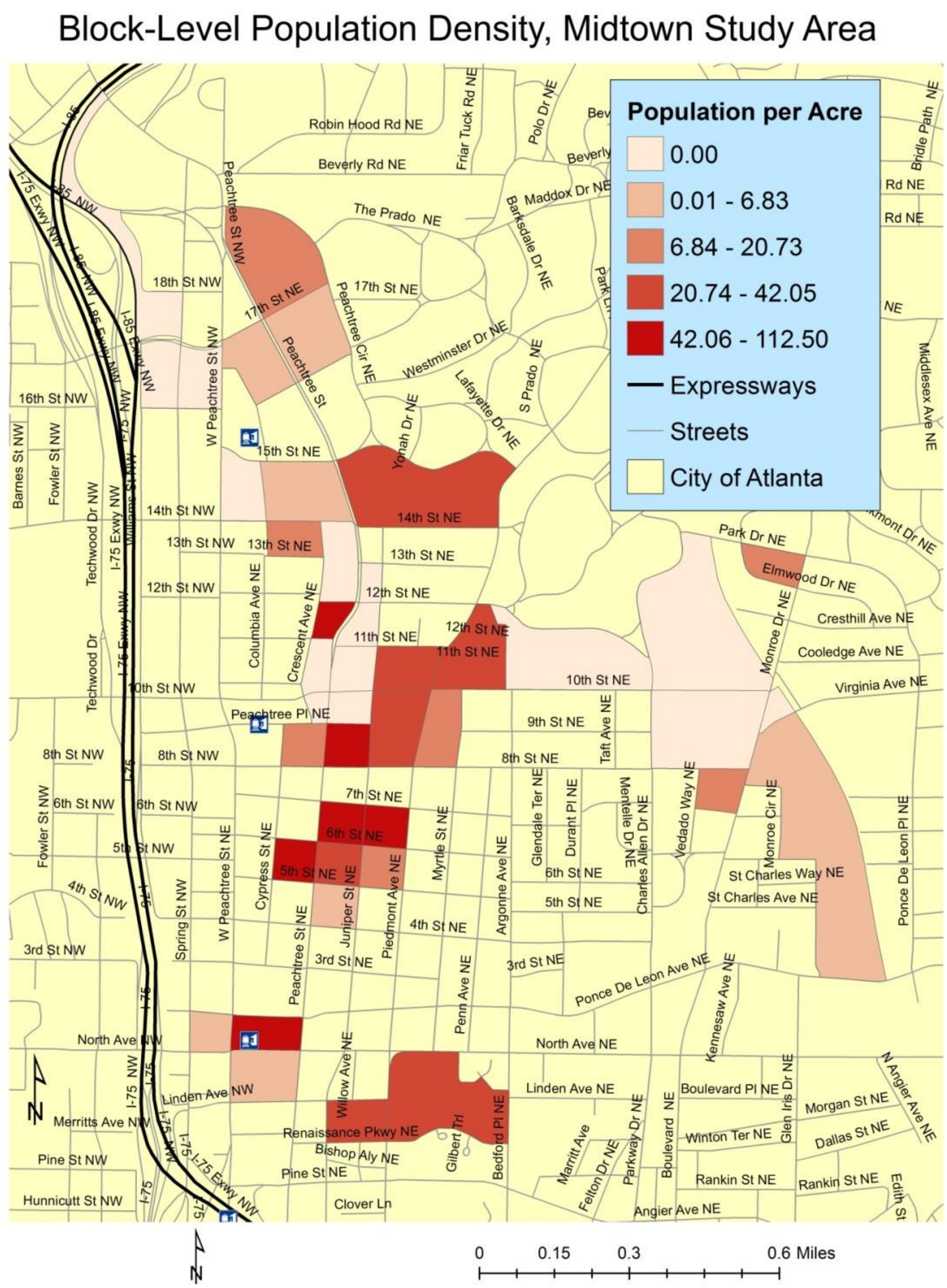

Figure 38: Population Density by Census Block

7.2.3 Transportation Mode Share Data

The percentage of residents that commuted by walking, bicycling, or riding transit was calculated as a measure of the number of residents in each tract that commute using "alternative" modes. The variable "means of transportation to work" by transportation mode was available from the 2010 American Community Survey at the Census tract scale. Given that this variable was not available at the Census block scale, the tract-level transportation mode share data were joined to each Census block located inside the Census tract. Although the mode share values by Census tract do not correspond exactly to the specific residents within each Census block, it is still useful as a potential commute mode indicator within the prioritization index.

Figure 39 shows the percentage of non-auto commute mode share aggregated to the Census block within the study area. The map indicates that the Census blocks with the highest tract-level percentage of total transit, and bicycle and pedestrian commute mode share are located near the Midtown and North Avenue MARTA rail stations. Furthermore, several blocks within the Midtown residential neighborhood had a high percentage of non-auto commute mode share. Several of these blocks (between 4th and 7th Street, and surrounding the intersection of North Avenue and Peachtree Street) are located within walking distance of the Technology Square mixed-use development and the Georgia Tech campus.

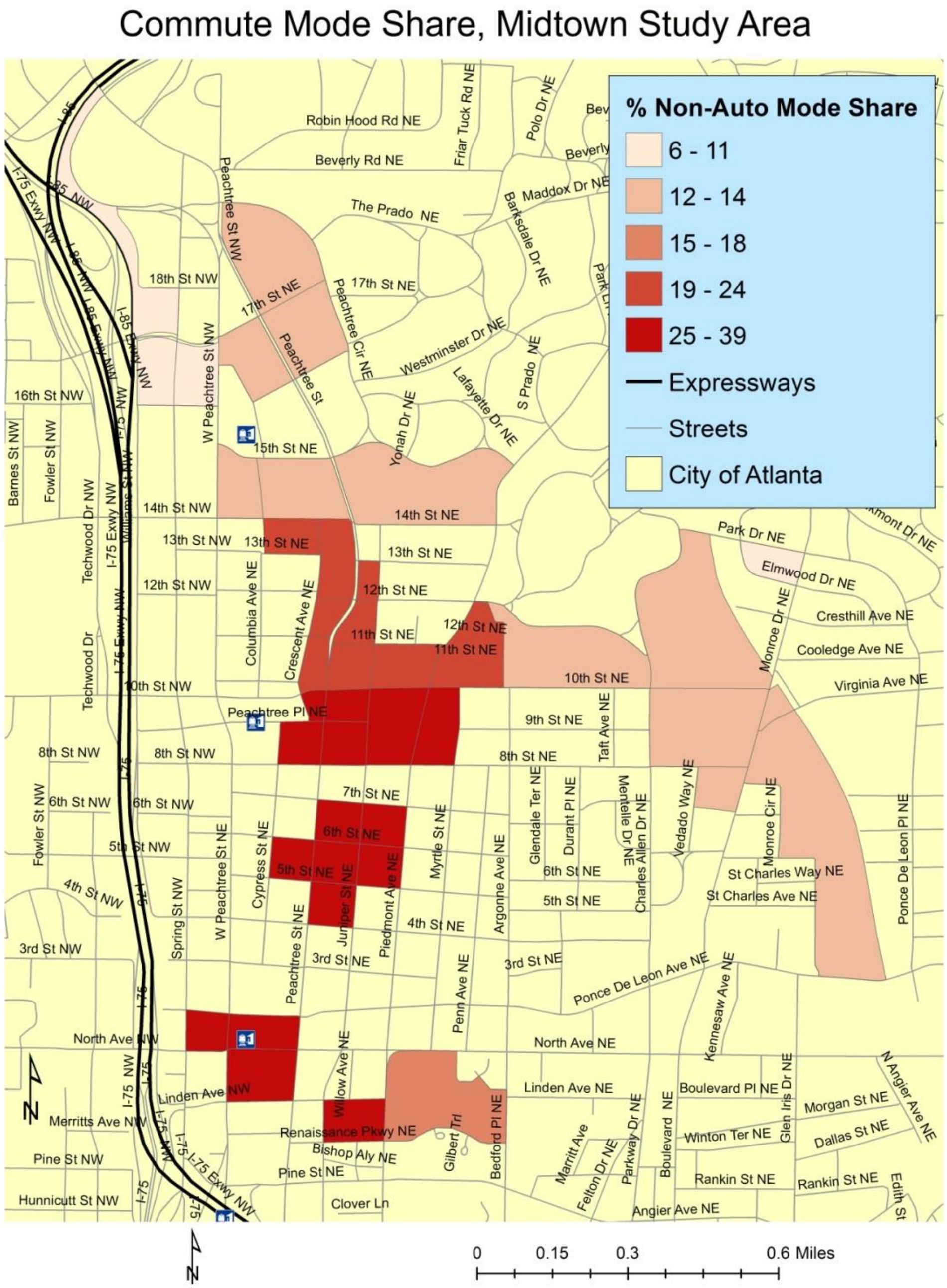

Figure 39: Tract-Level Commute Mode Share, Aggregated to Census Block

7.2.4 Households/Persons with Disabilities Data

Georgia Tech purchased demographic data from a private data source to identify households within Fulton, DeKalb, and Cobb counties with children ages 0 to 2 years and/or with residents with physical disabilities (survey results indicate use of a mobility aid or wheelchair). The household-level marketing data were geocoded and aggregated to the Census block level using ArcMap. The percentage of households per Census block with mobility impairments or with young children within the Midtown study area was calculated using the number of applicable persons and housing units in each Census block. The purpose of this indicator is to identify areas that may have greater accessibility needs in prioritizing pedestrian improvements. Recent research incorporating private marketing data in socioeconomic analysis has identified some potential data accuracy and data quality limitations (Khoeini and Guensler, 2014), but on average (i.e. through error cancellation) the data appear to be useful and are incorporated in this case study for illustrative purposes.

Figure 40 shows the block-level percentage of households with accessibility needs within the study area. The map indicates that the Census blocks with the highest percentage of households with mobility impairments and young children are located near the Arts Center, Midtown, and North Avenue MARTA stations. Additionally, the block near 10th Street and Monroe Drive was in the second-highest quartile based on commercial demographic data on mobility impairments. One block had 100% of its housing units had households with disabilities (the percentage value of 1.0), likely due to the presence of a multi-story retirement home in this block.

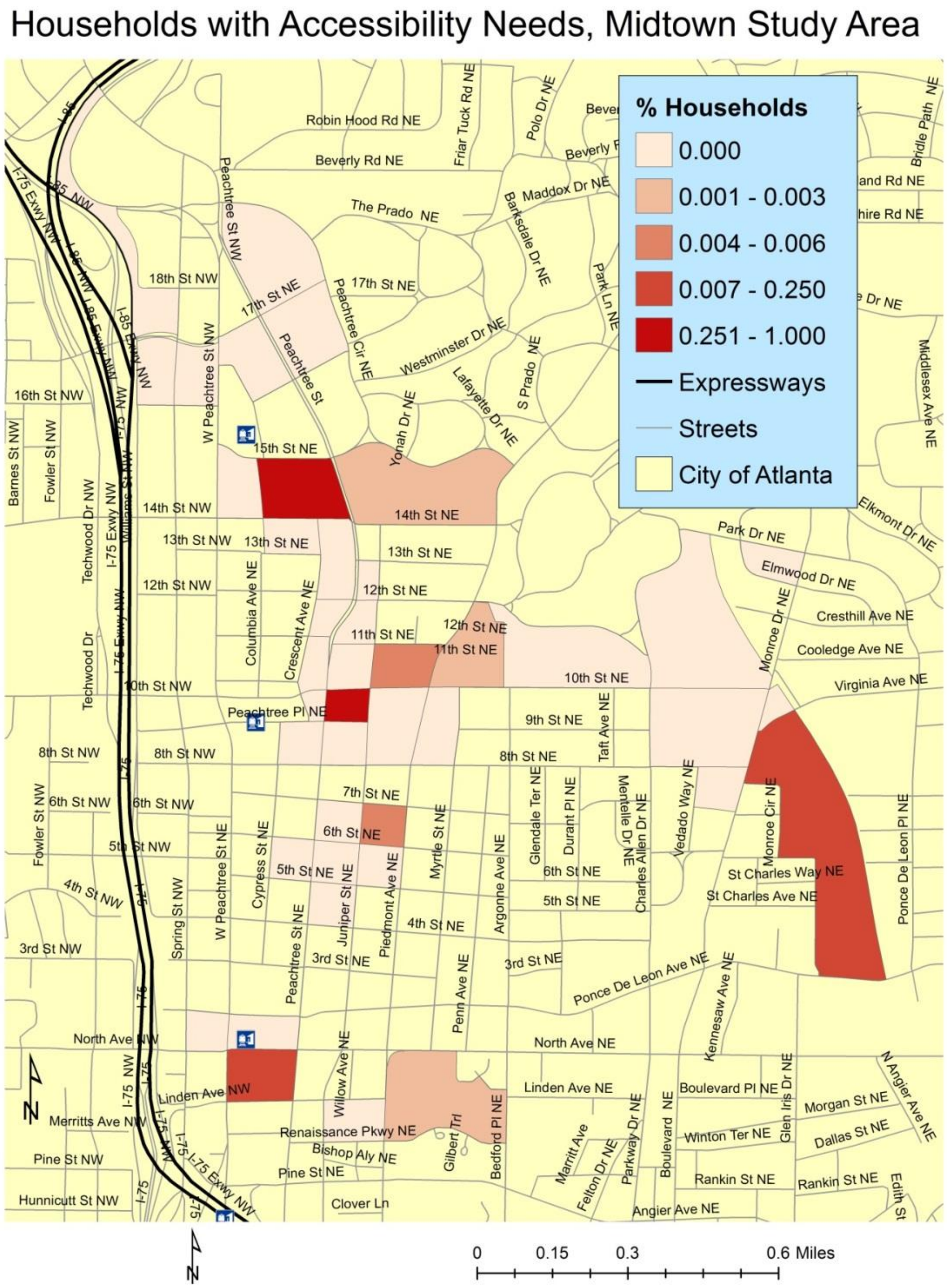

Figure 40: Percentage of Households with Accessibility Needs by Census Block

7.2.5 Sidewalk Width Data

To incorporate sidewalk width data into a pedestrian prioritization framework, the video data were identified and processed for the study area. Because the semi-automated width estimation system was not yet available, and given that the study area was manageably small, students were sent to the field to manually measure sidewalk width at a higher spatial resolution so that a directly-measured width could be assigned to each second-by-second GPS location in this case study. The measured sidewalk width data were transferred to a database table that contained sidewalk width, X-Y coordinates, and Census block ID for each GPS point within the study area. Using SPSS, numerical sidewalk width data were recoded into categories to calculate block-level indicators in relation to particular width thresholds based on accessibility guidelines and best practices.

Sidewalk width data were coded into five categories, representing thresholds for minimum and recommended sidewalk widths for accessibility and walkability based on ADA and AASHTO standards (Table 16). A rating of “1” represents an existing sidewalk that is not sufficiently wide for one wheelchair user to traverse safely. This category of sidewalk segment does not meet the minimum standard for accessible routes established by the ADA design guidelines (3 feet). A rating of “2” meets the ADA minimum standard for one wheelchair user to pass, however it would be necessary to provide additional width for wheelchair users to pass each other, for one wheelchair user to change direction, and to accommodate greater pedestrian traffic. The “3” sidewalk rating category meets the minimum standard of the proposed guidelines for accessible rights of way (PROWAG), as well as the minimum width stated by AASHTO pedestrian design guidelines (United States Access Board, 2011a; AASHTO, 2004). A rating of “4” meets the minimum sidewalk width established in the City of Atlanta code, provides sufficient width for wheelchair passing spaces or multiple pedestrians walking side-by-side. Additionally, this width conforms with industry best practice recommended by the Institute of Transportation Engineers, the Federal Highway Administration, and the Safe Routes to School program (ITE, 2010; FHWA, 1999; Pedestrian and Bicycle Information Center, 2013). Finally, a sidewalk rating of “5” exceeds the recommended practice for sufficient sidewalk width for all users to pass, and would accommodate greater pedestrian volumes.

Table 16: Categories for Sidewalk Width Ratings

Sidewalk Rating	Description (in feet)
Null	No Data
0	No Sidewalk
1	0.001 < x < 3.000
2	3.000 <= x < 4.000
3	4.000 <= x < 5.000
4	5.000 <= x < 6.000
5	x >= 6.000

Figure 3 shows the distribution of sidewalk data within each width category (less than 3 feet, 3 to 4 feet, 4 to 5 feet, 5 to 6 feet, and greater than 6 feet). Although sidewalks less than 5 feet in width can accommodate one wheelchair user safely, it is necessary to provide 5-ft wide passing spaces every 200 feet to be compliant with ADA accessibility guidelines (USAB, 2002). Therefore, identifying the percentage of sidewalk data points with widths less than 5 feet may indicate either accessibility concerns or a need for further inspections to ensure full compliance. The percentage of sidewalk points with width less than 5 feet was utilized as the block-level sidewalk width indicator for rank-order area prioritization analysis. The majority of sidewalk data (74.4%) in the Midtown area have widths greater than six feet, while 17.7% of data have widths between five and six feet. Frackelton (2013) presents separate figures for each sidewalk rating.

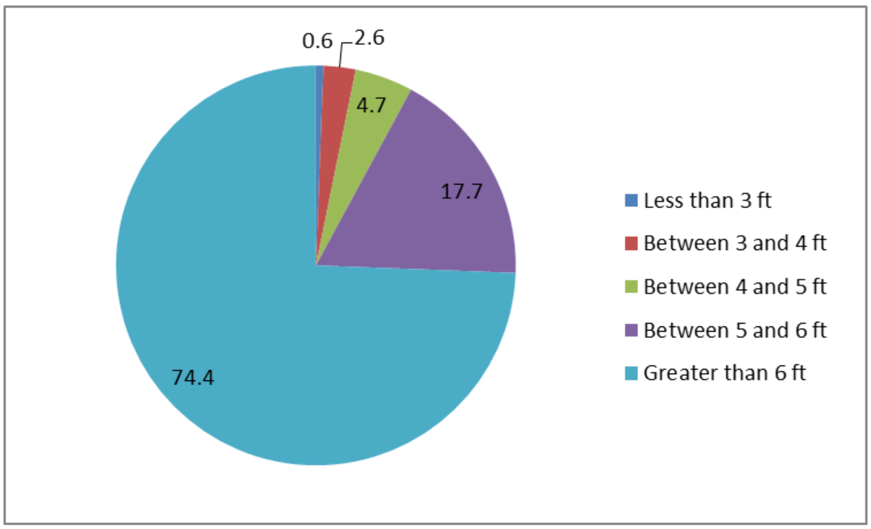

Figure 41. Percentage of Sidewalk Width Data in Each Category

Descriptive statistics for the sidewalk width data are presented in Table 17. The mean of measured sidewalk width was 8.11 feet and the median sidewalk width was 7.8 feet. Less than 25% of the sidewalk width data were narrower than 6 feet. The majority of sidewalk width data within this particular study area exceeded accessibility width guidelines (and receive a rating of “5”). However, the standard deviation (3.85 feet) indicates a high degree of variability within the data. A substantial number of cases had sidewalk widths greater than 10 feet, which is not generally the case in most Atlanta neighborhoods.

Table 17. Descriptive Statistics, Sidewalk Width Data

N		344
Mean Width		8.11 feet
Median Width		7.80 feet
Mode of Width		6 feet
Std. Deviation of width		3.85 feet
Minimum Width		0.0 feet
Maximum Width		31.95 feet
Percentile	**25**	5.95 feet
	50	7.80 feet
	75	8.96 feet

Using ArcGIS, thematic maps were generated for the study area representing the percentage of sidewalk width data within each rating category. Figure 42 shows the percentage of sidewalk width data within each Census block with a width rating of 3. The highest quartile represents Census blocks with the highest percentage of sidewalk data that are between 4 feet and 5 feet. The blocks with the highest percentage of data greater than six feet were found along the Peachtree Street corridor from 8th Street to 15th Street. This trend is largely due to the initiatives of Midtown Alliance, a community improvement district that has spearheaded capital improvement and transit-supportive land use planning and urban design guidelines within Midtown. The Special Public Interest 16 (SPI-16) zoning overlay district within the Midtown commercial area includes supplemental requirements for sidewalk width. Specifically, districts along the Peachtree Street corridor are required to have a 15 feet "pedestrian clear zone" in addition to any space for building frontage, landscaping and street furniture (Midtown Alliance, 2013b). Since its formation in 2001, Midtown Alliance has sponsored many streetscape projects and constructed more than 14 miles of new sidewalks (Midtown Alliance, 2013c).

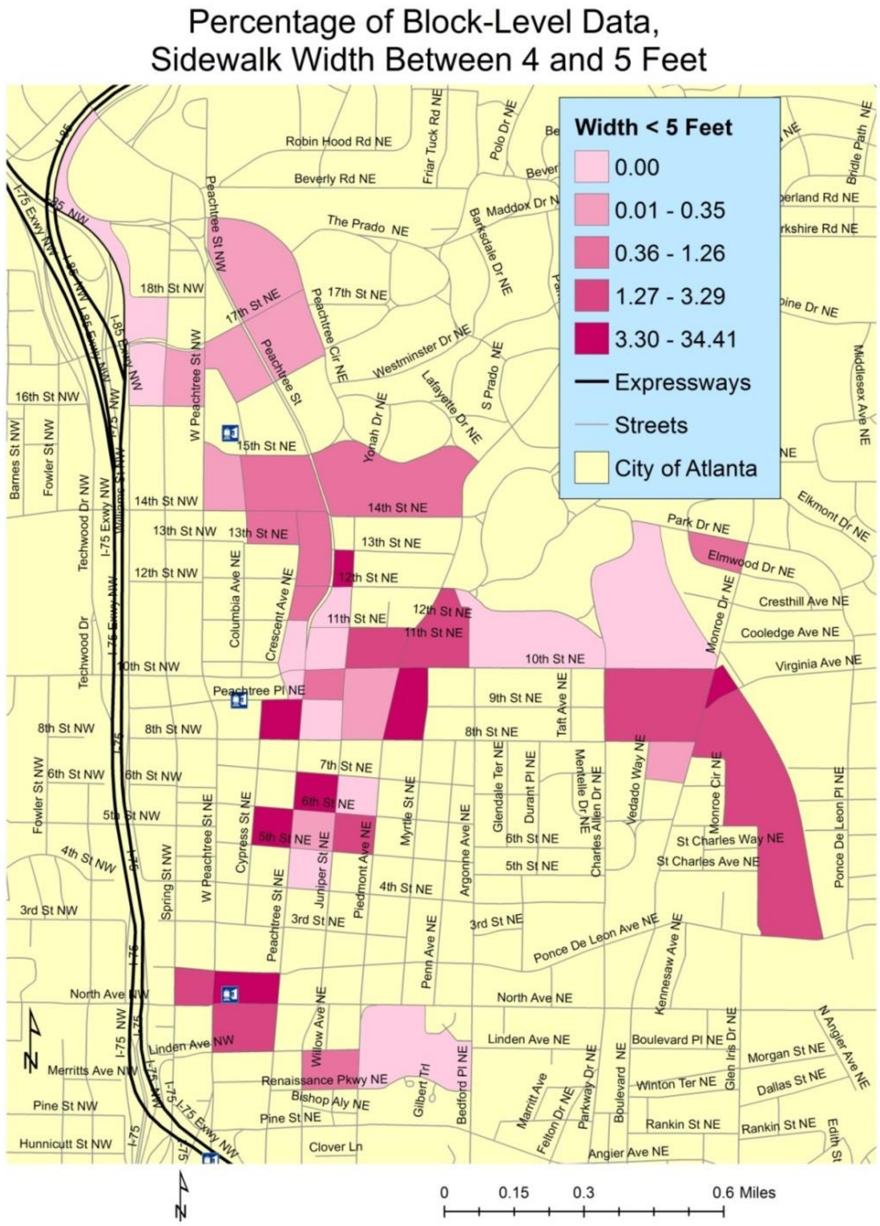

Figure 42. Percentage of Sidewalk Width Data, Rating 3

7.2.6 Pedestrian Crash Data

Pedestrian crash density was included in the deficiency index to facilitate the prioritization of improvements in areas that exhibit demonstrated safety issues. A causal relationship was not assumed between sidewalk condition and density of pedestrian crashes. Future indicators could incorporate the presence of specific sidewalk defects that may become categorized as causal factors in pedestrian incidents (but no direct link could be found in the literature).

Pedestrian crash records for the years 2002-2009 were obtained from the GDOT incident database. The years of analysis were selected based on the most recent years of data that contained both a pedestrian incident table and a location table. For each year, the pedestrian incident table was joined to the location table in Microsoft Access to generate a table of pedestrian crashes with location information. Although 80% of crash records included X-Y coordinate information, 95% of incident records included RCLINK data. Therefore, the RCLINK field was used to calculate the number of crashes per Census block, which was added as a variable to the database table for each unique RCLINK identifier.

First, the statewide roadway Geographic Information System (GIS) shapefile was clipped to the Midtown study area within the City of Atlanta. The pedestrian incident table was joined to the roadway GIS shapefile using the RCLINK identifier code. The sum of pedestrian incidents per RCLINK was calculated using the summarize function in ArcMap to identify the crash density per roadway segment. Next, the RCLINK-level crash database table was joined to the Census block GIS shapefile so that the data for segments intersecting a single block were applied to the block polygon. Data for roadway segments located on the boundary of two Census blocks were applied to both Census blocks. The sum of pedestrian incidents per each RCLINK segment within a Census block was calculated using the aggregate function in IBM SPSS. Finally, the "Crash_sum" table was joined to the Census block GIS shapefile in ArcMap and the crash sum variable was divided by block acreage to obtain block-level pedestrian crash density.

Figure 43 shows the block-level pedestrian crash density within the study area. The map indicates that the Census blocks with the highest pedestrian crash density are located along higher-volume roadways and near the three MARTA rail stations. For example, several blocks within the highest pedestrian crash density quartile are located near Peachtree Street and West Peachtree Street and in the vicinity of entrances onto the interstate system, which are likely to have heavy traffic volumes and high speeds.

Additionally, several blocks adjacent to Monroe Drive were in the highest and second-highest quartile for pedestrian crash density, which may indicate a concern for pedestrian safety along that corridor. It is worth noting that the pedestrian crash data included in this analysis were collected before the completion of the BeltLine Eastside Trail as well as the pedestrian safety improvements at 10th Street and Monroe Drive adjacent to Piedmont Park. In essence, prioritization schemes are an evolving process that must be responsive to changes in infrastructure, travel demand, and community needs.

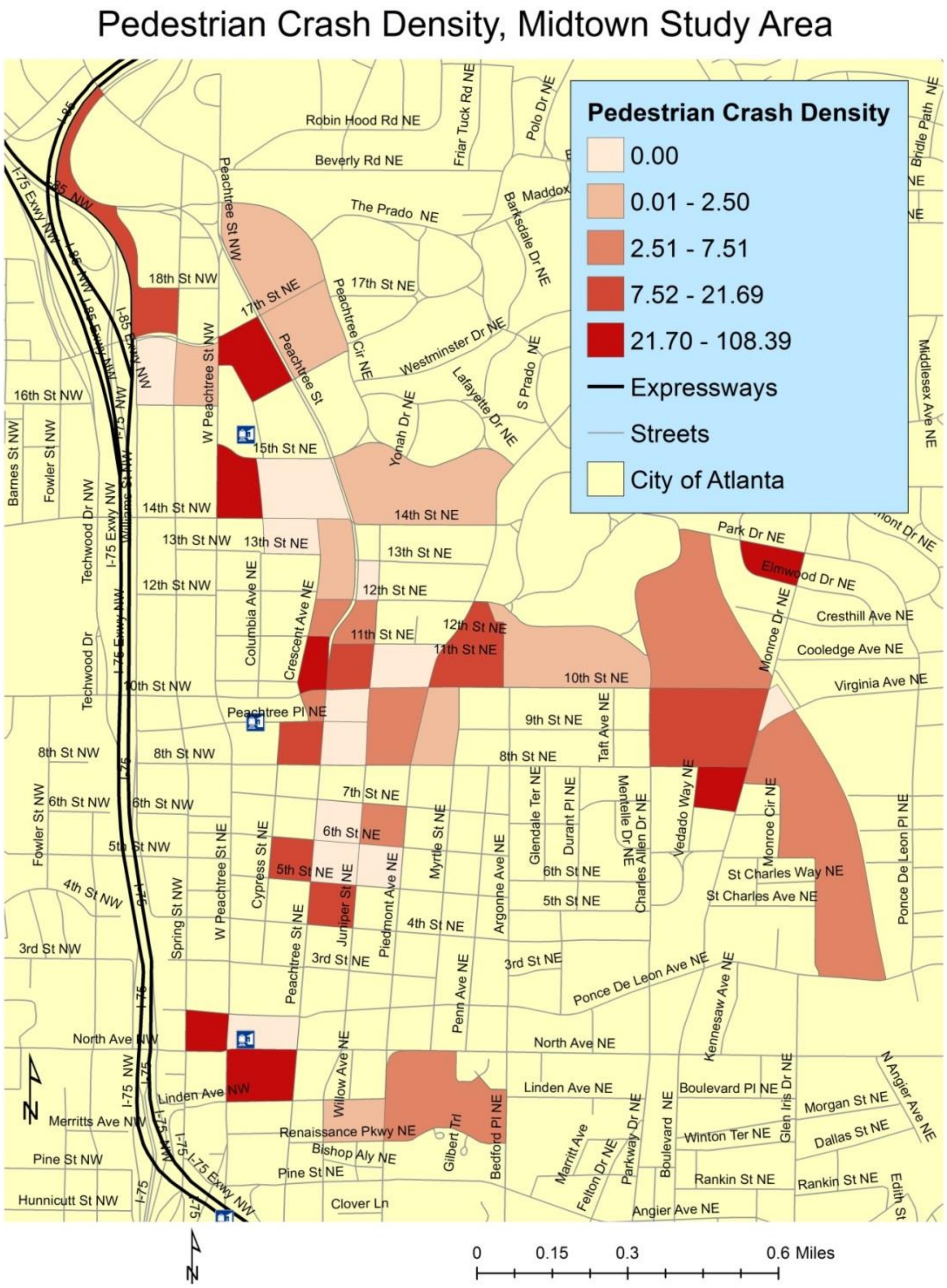

Figure 43: Pedestrian Crash Density by Census Block

7.3 Calculation of Pedestrian Potential and Deficiency Indices and Rank Ordering

The pedestrian potential index (PPI) is comprised of demographic and travel demand variables. The pedestrian deficiency index (PDI) is comprised of sidewalk quality and pedestrian safety variables. For each index, a GIS database table is prepared that includes the values of each PPI and PDI variable for each Census block assessed. Census blocks are then rank-ordered within each variable. For example, within the PDI table, census blocks are rank ordered for sidewalk width, from highest percentage of data points with a width rating of 1 to 3 (sidewalk width between 0.001 and 4.999 feet), to lowest percentage of data points with a width rating of 1 to 3. In the PDI table, Census blocks are also ranked in descending order by pedestrian crash density (highest crash density to lowest crash density). Hence, for both variables, the Census blocks have been ranked from worst to best in each variable. To calculate the PDI for each Census block, the rank-order results for each variable are summed. In the example above, if one of the 42 Census blocks in the analysis was rank-ordered as 6th for sidewalk width (very bad sidewalks) and 30th for crash density (not too many crashes), the PDI value is 36. The rank order of the combined PDI values is then used to rank order the Census blocks for improvement, with the lowest PDI value being the highest priority for improvement. Table 18 shows an example of individual variable rankings and PDI rank scores of seven Census blocks for illustrative purposes. In the final analyses, rankings were prepared for the entire dataset of 42 blocks. The first Census block is the worst in terms of both crash density and sidewalk width issues. However, it is also important to note that the variability in crash density by Census block is very high, and that some regions or local agencies may desire to more heavily weight the crash density variable in making funding decisions for sidewalk improvements.

Table 18: Example of a Rank-order Prioritization Index

Census Block ID	Crash Variable	Width Variable	Crash Rank Score	Width Rank Score	PDI Score	PDI Rank Score
131210002005005	25.55	2.65	3	3	6	1
131210004001002	0.24	0.78	5	4	9	6
131210004001003	0.05	2.71	6	2	8	4
131210004001006	108.39	0.11	1	6	7	2
131210004001015	0.00	2.99	7	1	8	4
131210004001016	94.54	0.17	2	5	7	2
131210004002008	3.84	0.00	4	7	11	7

If a weighting approach is employed, to increase the impact of a variable on a calculated PPI or PDI, each rank order value for each variable is weighted by an assigned percentage weighting, and then summed. Table 19 presents the weightings that were employed in Frackelton (2013) to demonstrate the potential impacts of weighting approaches. Note that unweighted combined scores result in the same rank order as combined scores where each variable is equally weighted. Thematic maps are prepared for each PPI and PDI result by

Census block within the study area in Frackelton (2013) and a subset are provided in the following sections.

Table 19: Pedestrian Potential and Pedestrian Deficiency Index Weightings

Weighting Approach	Pedestrian Potential Index	Pedestrian Deficiency Index
Unweighted	*Activity + Mode + Disability + Density*	*Width + Crash*
Equally Weighted	*Activity*0.25 + Mode*0.25 + Disability*0.25 + Density*0.25*	*Width*0.50 + Crash*0.50*
Pedestrian Activity	*Activity*0.6 + Mode*0.1333 + Disability*0.1333 + Density*0.1333*	--
Mode Share	*Activity*0.1333 + Mode*0.6 + Disability*0.1333 + Density*0.1333*	--
Disability	*Activity*0.1333 + Mode*0.1333 + Disability*0.6 + Density*0.1333*	--
Population Density	*Activity*0.1333 + Mode*0.1333 + Disability*0.1333 + Density*0.6*	--
Sidewalk Width	--	*Width*0.6+ Crash*0.4*
Crash Density	--	*Width*0.4+ Crash*0.6*

The results of the PDI and PPI rankings can also be employed to generate a pedestrian composite index (PCI), where the sum or weighted sum of PPI and PDI values are used to generate a PCI value. Frackelton (2013) generated unweighted PCI composite ranking scores and weighted PCI scores using the formulas in Table 20. The PCI score employs both the PPI and PDI results to identify the highest priority Census blocks based on their potential for pedestrian demand as well as current infrastructure and safety deficiencies. The use of PPI and PDI rankings, with or without weighting factors, allows local agencies to tailor the final PCI value as a function of their local needs.

Table 20: Composite Index Ratings

Weighting	Composite Index Method
Unweighted	$PDI_{unweighted} + PPI_{unweighted}$
PPI	$PDI_{unweighted}*0.4 + PPI_{unweighted}*0.6$
PDI	$PDI_{unweighted}*0.6 + PPI_{unweighted}*0.4$

Rank-order prioritization results were mapped in ArcGIS for each pedestrian potential and deficiency index by Census block within the study area. The ranking scores were color-coded by quantile; the highest-rated Census blocks are represented as warmer colors (reds) and the lower-rated Census block are represented as cooler colors (greens). The intent of presenting each variable and index weighting separately is to enable comparisons between the effects of different pedestrian prioritization indicators. Although there were 42 Census blocks in total, several rank-order prioritization maps had a maximum ranking less than 42 due to identical values within the ranking calculation. For the pedestrian potential index, unweighted outputs were generated by equally weighting the pedestrian activity, population density, commute mode share, and persons with disabilities variables (25%). For the pedestrian deficiency index, unweighted outputs were generated by equally weighting the sidewalk width and pedestrian crash data variables (50%). An unweighted pedestrian composite index (PCI), which combines the impact of PPI and PDI, is then developed to identify areas that are highly ranked for both indices. Generating a PCI ranking that employs both the PPI and PDI results will identify Census blocks that would be prioritized based on their combined potential for meeting pedestrian demand and for addressing current infrastructure and safety deficiencies. As will be discussed in the following sections, the PPI and PDI values can be internally weighted to favor one or more variables. Similarly, the PCI composite index can be weighted by PPI or PDI to provide improvements designed to improve pedestrian activity potential or to provide improvements to remove existing barriers to access.

7.4 Pedestrian Potential Index (PPI) Results, Unweighted

Figure 44 shows the rank-order prioritization results within the study area for the unweighted pedestrian potential index (PPI), where pedestrian activity, population density, commute mode share, and persons with disabilities are weighted equally. The map indicates that Census blocks in the vicinity of the Midtown and North Avenue rail stations, as well as within the Midtown neighborhood near Tech Square, would be prioritized (color coded red). Several blocks near Colony Square/Arts Center MARTA station were ranked within the second quartile of pedestrian prioritization, and Census blocks north of 15th Street and east of Argonne Avenue ranked in the lowest quartile (color coded green) based on unweighted pedestrian potential indicators.

Pedestrian Potential Index, Unweighted Ranking

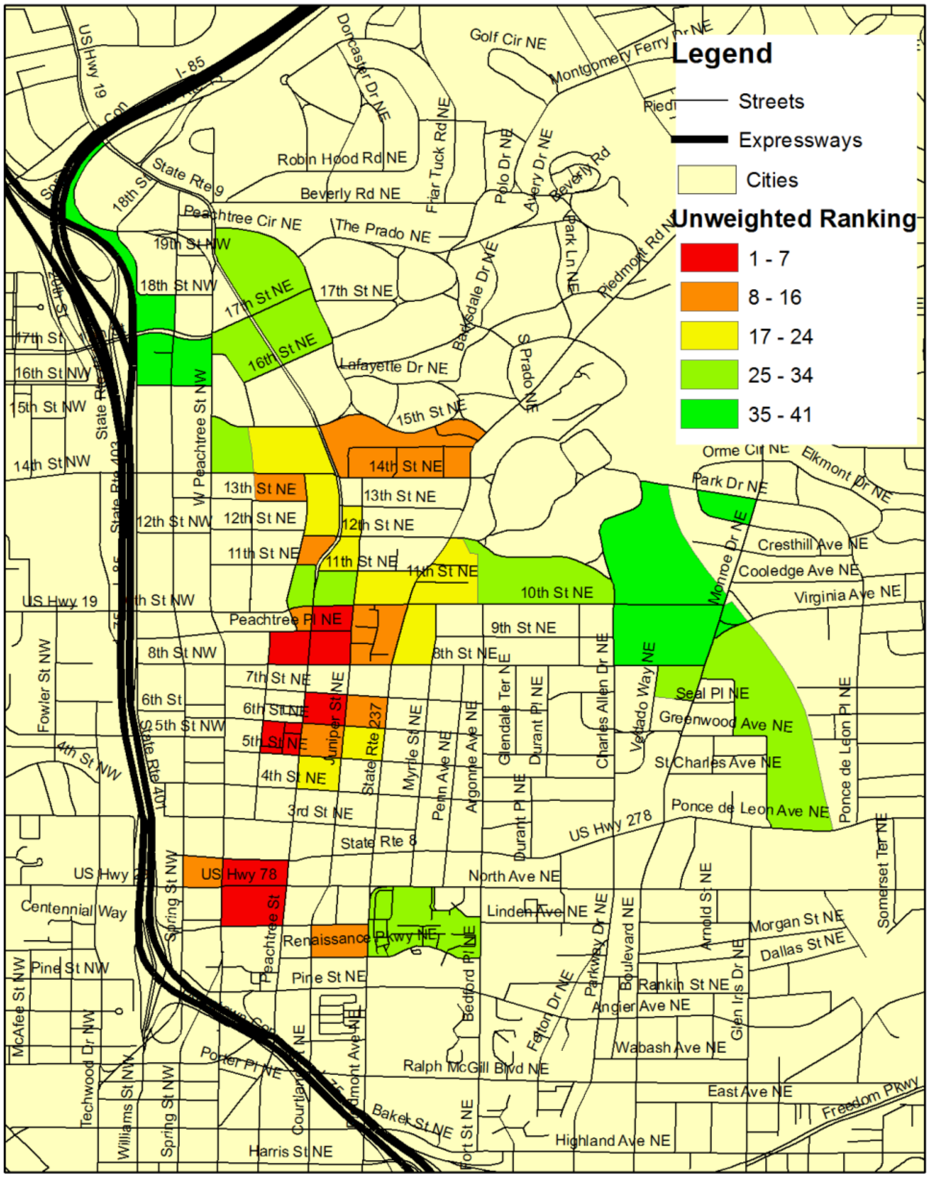

Figure 44. Pedestrian Potential Index Rank-Order Prioritization, Unweighted

7.5 Pedestrian Potential Index (PPI) Results, Weighted by Variable

In each of the analyses presented below, one of the four variables of interest was weighted by 60% to increase its relative importance in calculating the PPI, and the other three variables were weighted by 13.33% to decrease their relative importance in the calculated PPI. The rank-order prioritization results within the study area based upon weighted rankings will typically differ from the unweighted values, because a higher importance is placed on a single variable. By examining each variable and index weighting separately, impact comparisons can be assessed across these pedestrian prioritization indicators.

Figure 45 shows the PPI weighted 60% by the pedestrian activity variable. The map indicates that Census blocks in the vicinity of the Arts Center, Midtown and North Avenue MARTA stations (blue icons) would be highly prioritized using a pedestrian activity weighted PPI. In contrast with the unweighted PPI results, the activity weighted results more highly prioritized blocks near the Arts Center station (in the first quartile instead of the second quartile). The least-prioritized blocks weighted by pedestrian activity data are located near the intersection of 10th Street and Monroe Drive and in the vicinity of Spring Street near the entrance to Interstate 85 (I-85).

Figure 46 shows the rank-order prioritization results within the study area for the PPI weighted 60% by commute mode share. The map indicates that Census blocks in the vicinity of the Midtown and North Avenue stations as well as near Tech Square would be highly prioritized using a mode share weighted index. In contrast with the activity-weighted PPI results, the mode share weighted results did not prioritize blocks near Arts Center Station. Several blocks near the Arts Center/Colony Square were ranked in the third quartile. Similarly to the activity weighted index results, the least-prioritized blocks are located near the intersection of 10th Street and Monroe Drive and on Spring Street near the I-85 entrance.

Figure 47 shows the rank-order prioritization results within the study area for PPI, weighted by percentage of households with young children or mobility impairments. The map indicates that Census blocks in the vicinity of the Arts Center, Midtown and North Avenue stations as well as near Tech Square would be highly prioritized using a demographic (accessibility) weighted index. The results show variability across adjacent blocks throughout the study area, particularly between 10th Street and 15th Street. Similar to the activity weighted and mode share weighted index results, the least-prioritized blocks are located near the intersection of 10th Street and Monroe Drive and in the vicinity of Spring Street near the entrance to I-85.

Figure 48 shows the rank-order prioritization results within the study area for PPI, weighted by population density. The results indicate variability in population density across adjacent blocks throughout the study area, with the exception of the Midtown residential area between 5th Street and 10th Street. In contrast with the activity weighted PPI results, the population density weighted results did not prioritize blocks near Arts Center Station. Similar to the activity weighted and mode share weighted index results, the least-prioritized blocks are located near the intersection of 10th Street and Monroe Drive and in the vicinity of Spring Street near the entrance to I-85.

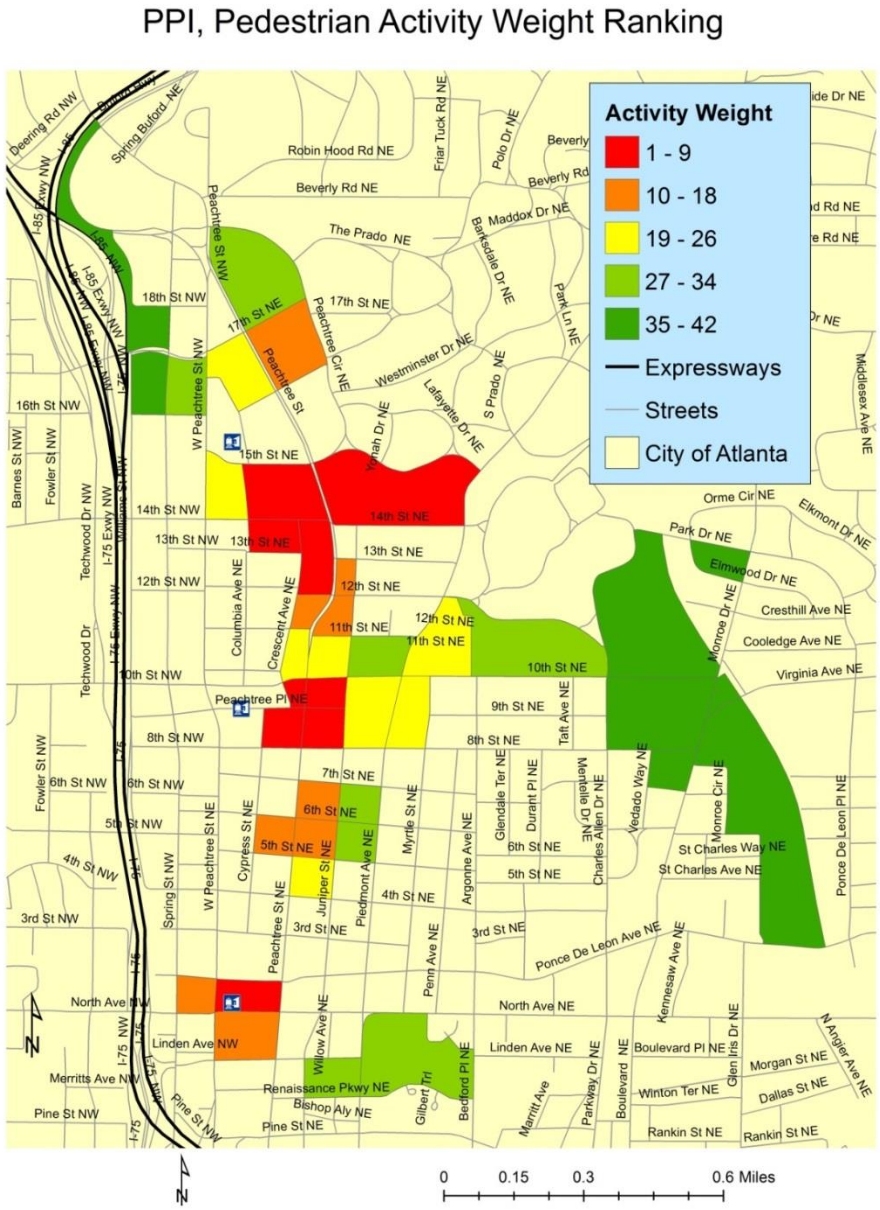

Figure 45. PPI Rank-Order Prioritization, Weighted by Pedestrian Activity

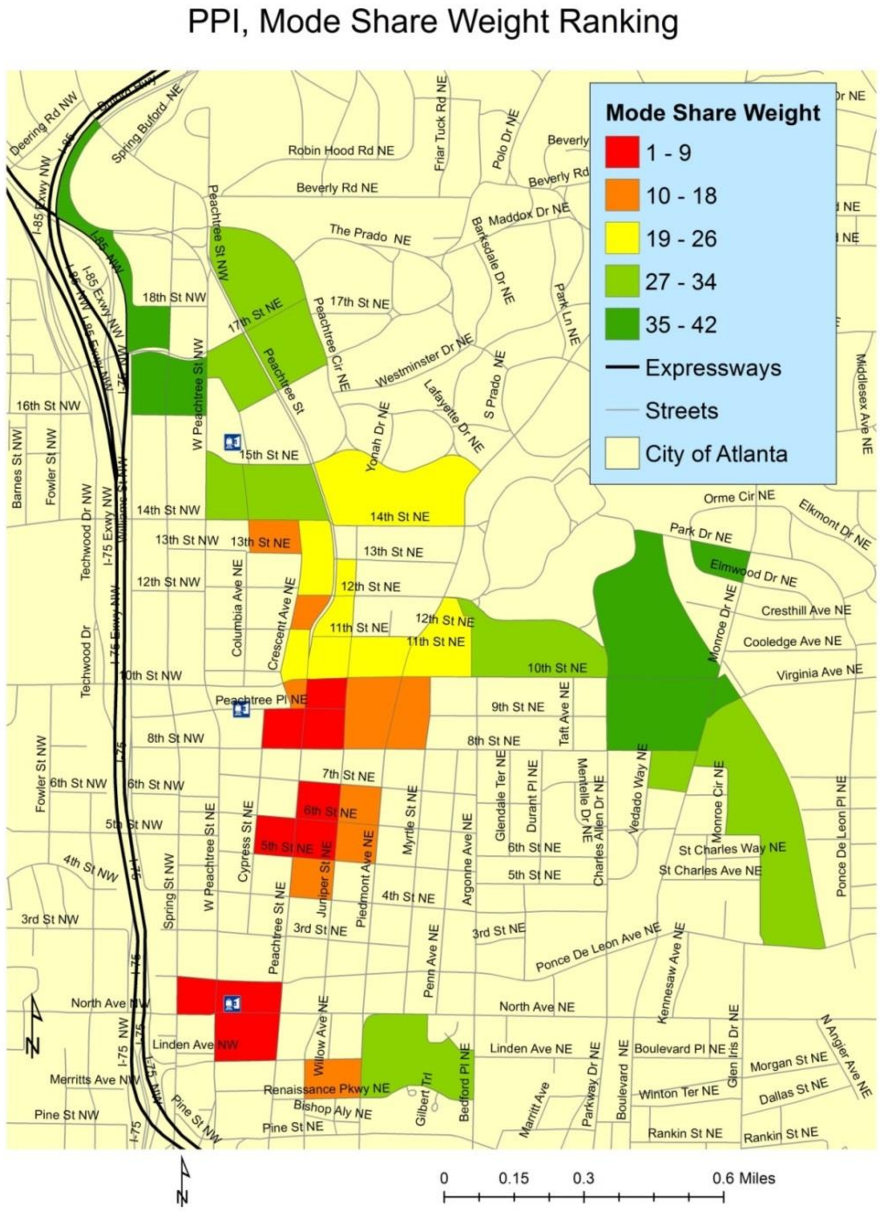

Figure 46: Pedestrian Potential Index Rank-Order Prioritization, Mode Share Weight

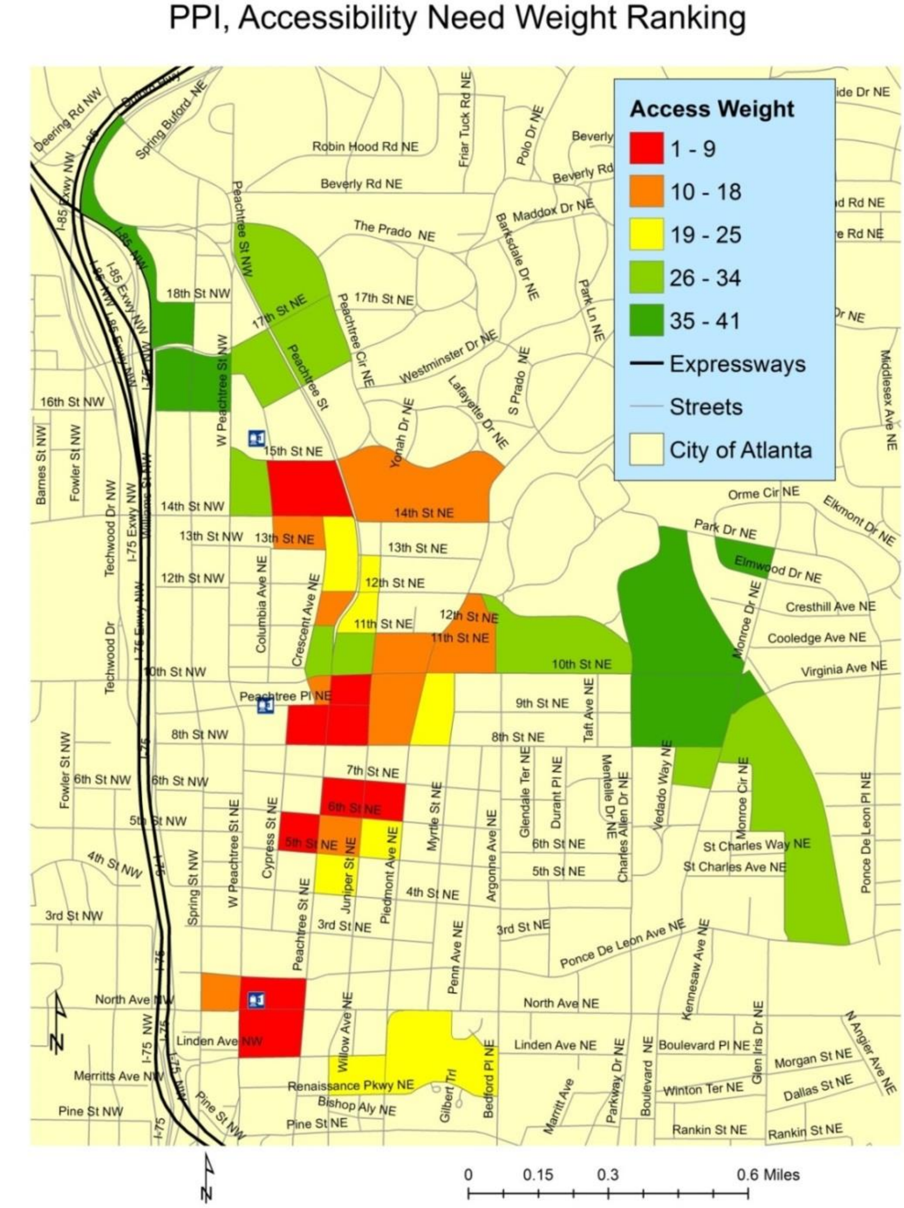

Figure 47: Pedestrian Potential Index Rank-Order Prioritization, Accessibility Weight

PPI, Population Density Weight Ranking

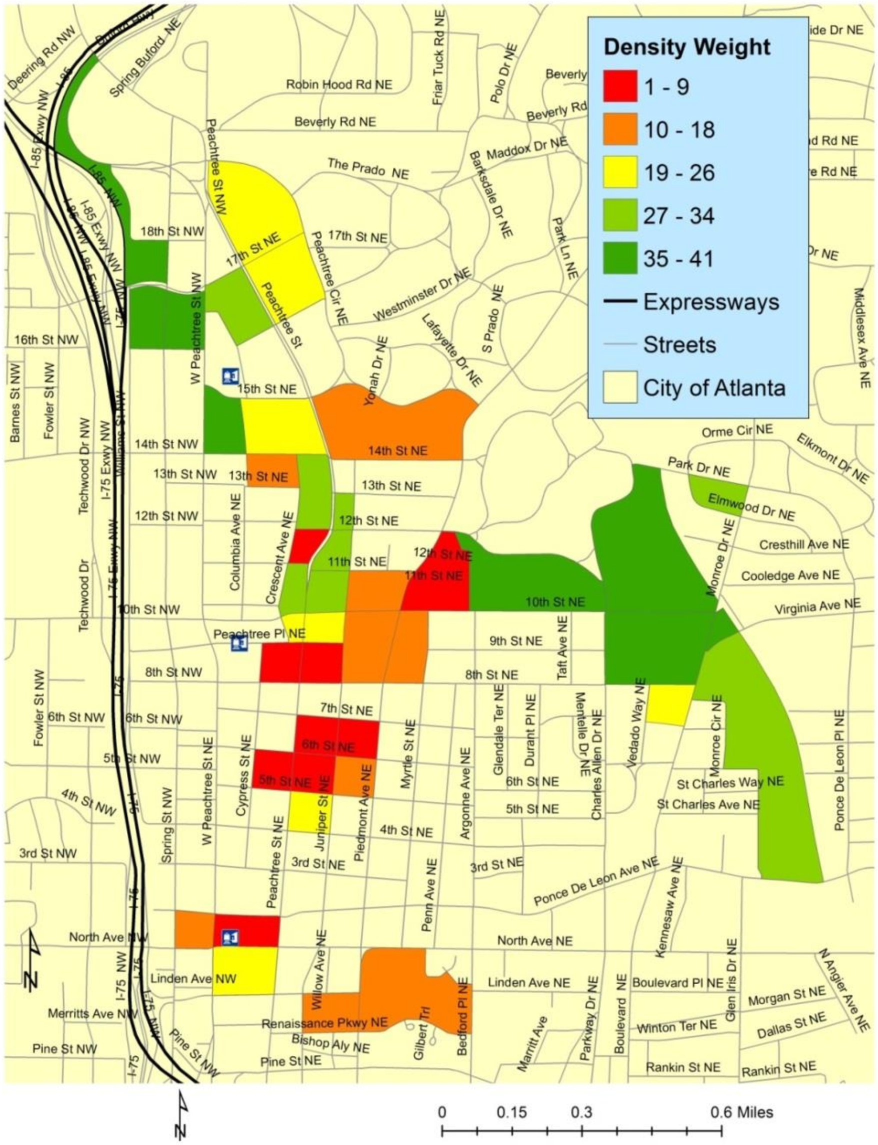

Figure 48: Pedestrian Potential Index Rank-Order Prioritization, Population Density Weight

7.6 Pedestrian Deficiency Index (PDI) Results, Unweighted

Figure 49 shows the rank-order prioritization results within the study area for the unweighted pedestrian deficiency index (PDI). The map indicates that Census blocks in the vicinity of the Midtown and North Avenue MARTA stations and near the intersection of 10th Street and Monroe Drive (adjacent to the BeltLine trail) would be highly prioritized based on sidewalk width and pedestrian crash data (unweighted, or weighted equally). Blocks within the Midtown neighborhood that are within walking distance of Tech Square were also highly prioritized by the unweighted pedestrian deficiency index. These PDI results contrast with the unweighted PPI results, where blocks near Monroe Drive were prioritized in the fourth quartile.

7.7 Pedestrian Deficiency Index (PDI) Results, Weighted

In the PDI weighting analysis, PDI rankings were generated by weighting the variable of interest by 60% and other variable by 40%. In this case study analysis, these variables included sidewalk width and pedestrian crash density.

Figure 50 shows the rank-order prioritization results within the study area for the pedestrian deficiency index (PDI), weighted by the percentage of sidewalk data with widths less than 5 feet. Similar to the unweighted index results, the map indicates that Census blocks in the vicinity of the Midtown and North Avenue MARTA stations and near the intersection of 10th Street and Monroe Drive would be highly prioritized using a sidewalk width weighted index. The sidewalk width weighted ranking results indicate spatial variability of sidewalk width data, with several blocks in the first quartile located adjacent to blocks in the fourth quartile.

Figure 51 shows the rank-order prioritization results within the study area for the pedestrian deficiency index (PDI) weighted by pedestrian crash density. Pedestrian crash events are correlated with high pedestrian activity as well as vehicle volume and speeds and can be mediated due to the effects of safety treatments. Therefore, it is important to consider these interactions when interpreting spatial patterns of pedestrian crash density. Similar to the unweighted index results, the map indicates that Census blocks in the vicinity of the North Avenue MARTA station and near the intersection of 10th Street and Monroe Drive would be highly prioritized using a crash density weighted index. However, the crash density weighting prioritizes the blocks along Monroe Drive more highly than the blocks within the Midtown residential neighborhood. Additionally, the block at Peachtree and 17th Street is ranked in the first quartile using the crash density weighting and in the third quartile using the sidewalk width weighting. Because only two variables are employed in the PDI for this case study, the weighing analysis only shifted the variable contributions from 50% (i.e. unweighted) to 60% (weighted). The significant shift in prioritization noted in the crash density weighted analysis is testimony to the fact that there is significant variability across these Census blocks for crash density. A small shift in weighting moves higher crash density blocks up the priority list. In preparing a weighted PDI, it is very likely that many areas would want to weight toward crash density as a policy decision (given the potential benefits that improvements might bring in crash reduction).

Pedestrian Deficiency Index, Unweighted Ranking

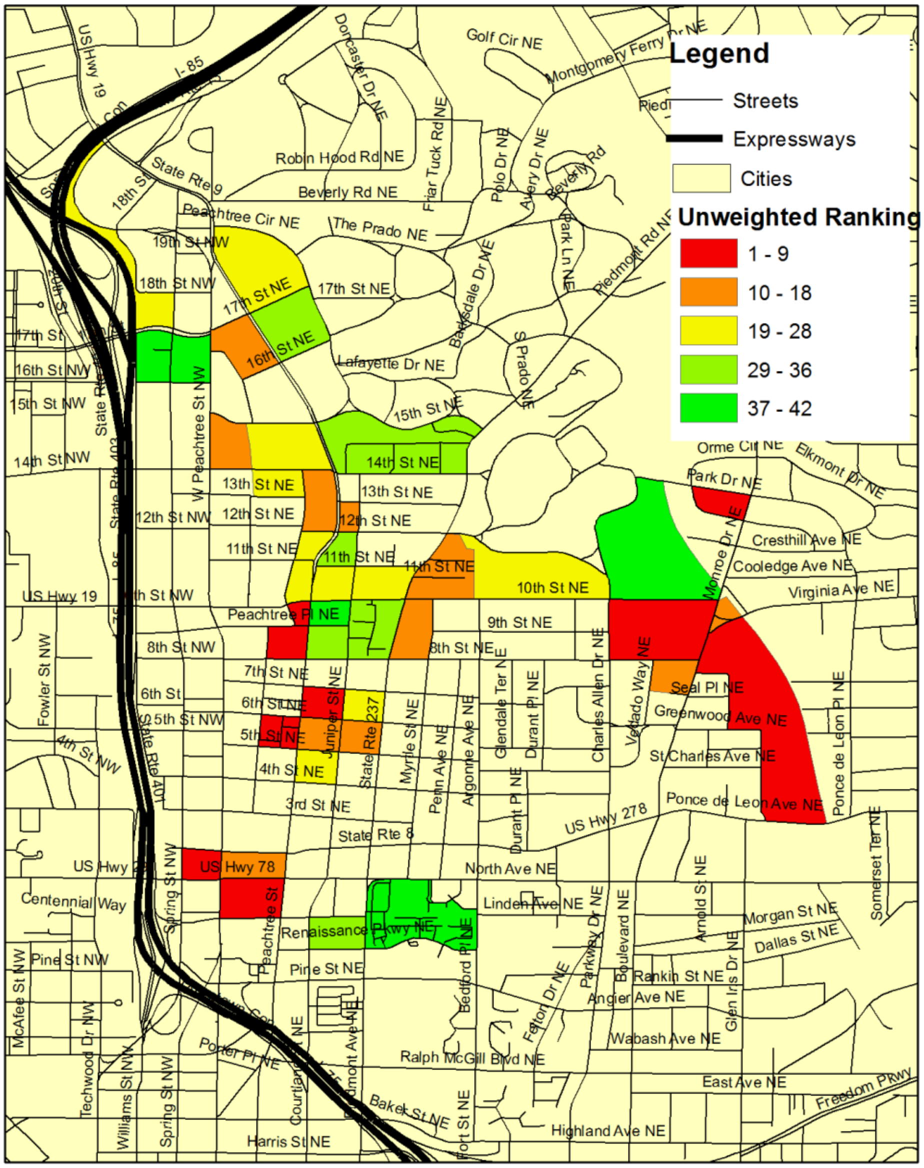

Figure 49. Pedestrian Deficiency Index Rank-Order Prioritization, Unweighted

PDI, Sidewalk Width Weight Ranking

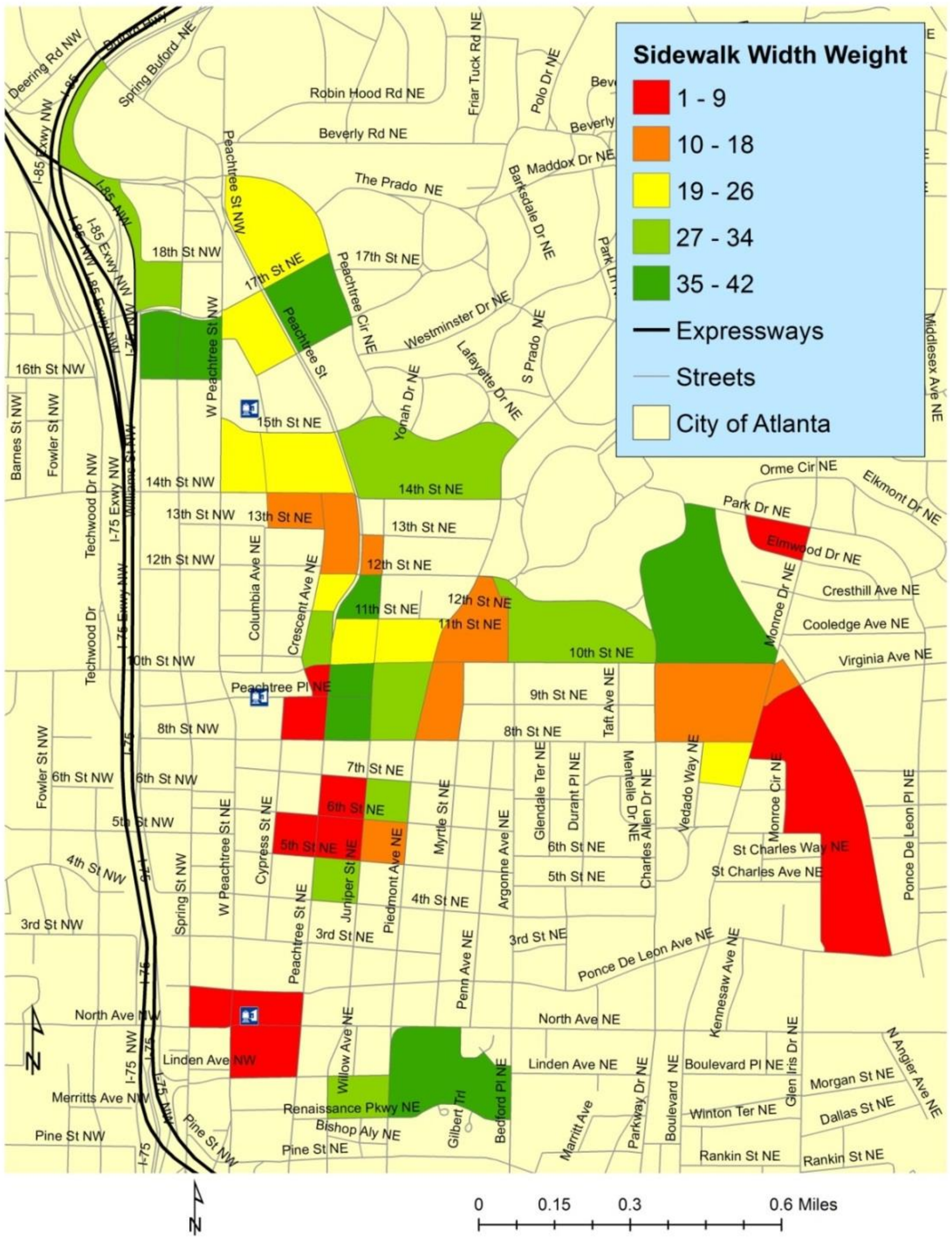

Figure 50. Pedestrian Deficiency Index Rank-Order Prioritization, Sidewalk Width Weight

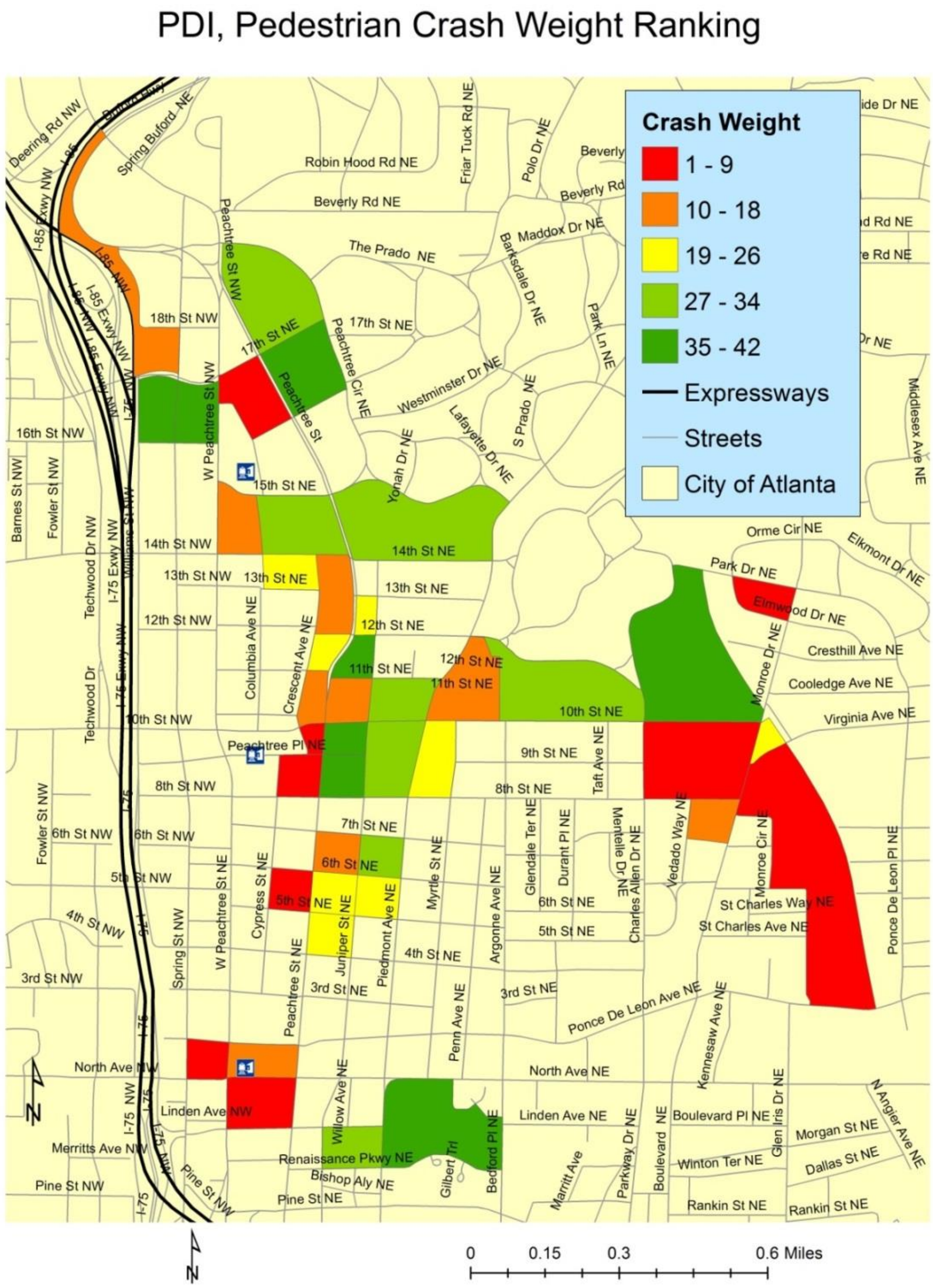

Figure 51. Pedestrian Deficiency Index Rank-Order Prioritization, Pedestrian Crash Weight

7.8 Composite Index Results

Figure 52 shows the rank-order prioritization results within the study area for the unweighted pedestrian composite index. These index results indicate which Census blocks would be prioritized based on the greatest potential for pedestrian activity as well as the greatest existing deficiencies. The results indicates that Census blocks adjacent to the Midtown and North Avenue MARTA stations and blocks along Peachtree Street should be prioritized for pedestrian improvements within the study area. This is because high-density residential housing, office buildings, and shopping surround these rail stations, increasing the PPI rankings based on pedestrian activity, mode share, and population density. Although the blocks along Monroe Drive were highly prioritized based on PDI indicators, the unweighted PPI results did not rank these blocks as highly and therefore the composite index did not rate these blocks within the first quartile. If a higher weighing is assigned to PDI than to PPI in the PCI calculation, the priority of these blocks increases.

Based on pedestrian indicator data, the Arts Center station area experiences high weekday pedestrian activity but would not be prioritized based upon population density nor based upon non-automobile commute mode share. The existing land use within this subarea suggests that the weekday pedestrian activity is likely due to office workers and may not extend to population density or resident mode commute share. However, overall mode share for all trips in this zone may be a factor to consider. Additionally, blocks within Midtown with primarily commercial or office uses did not rank highly based on population-dependent metrics (such as density and mode share), which is demonstrated by the blocks with higher tract-level commute mode share but with a population density of zero. Based on the rank-order prioritization results, the Colony Square area ranked highly in the activity-weighted index, but ranked lower in other weightings and in unweighted composite index results due to the lower rankings in other pedestrian potential and deficiency indicators. Interpretation of ranking results over time can help policy makers refine the PPI and PDI values to best reflect the needs of the local community. For example, an updated PPI should probably include hotel capacity as a PPI variable.

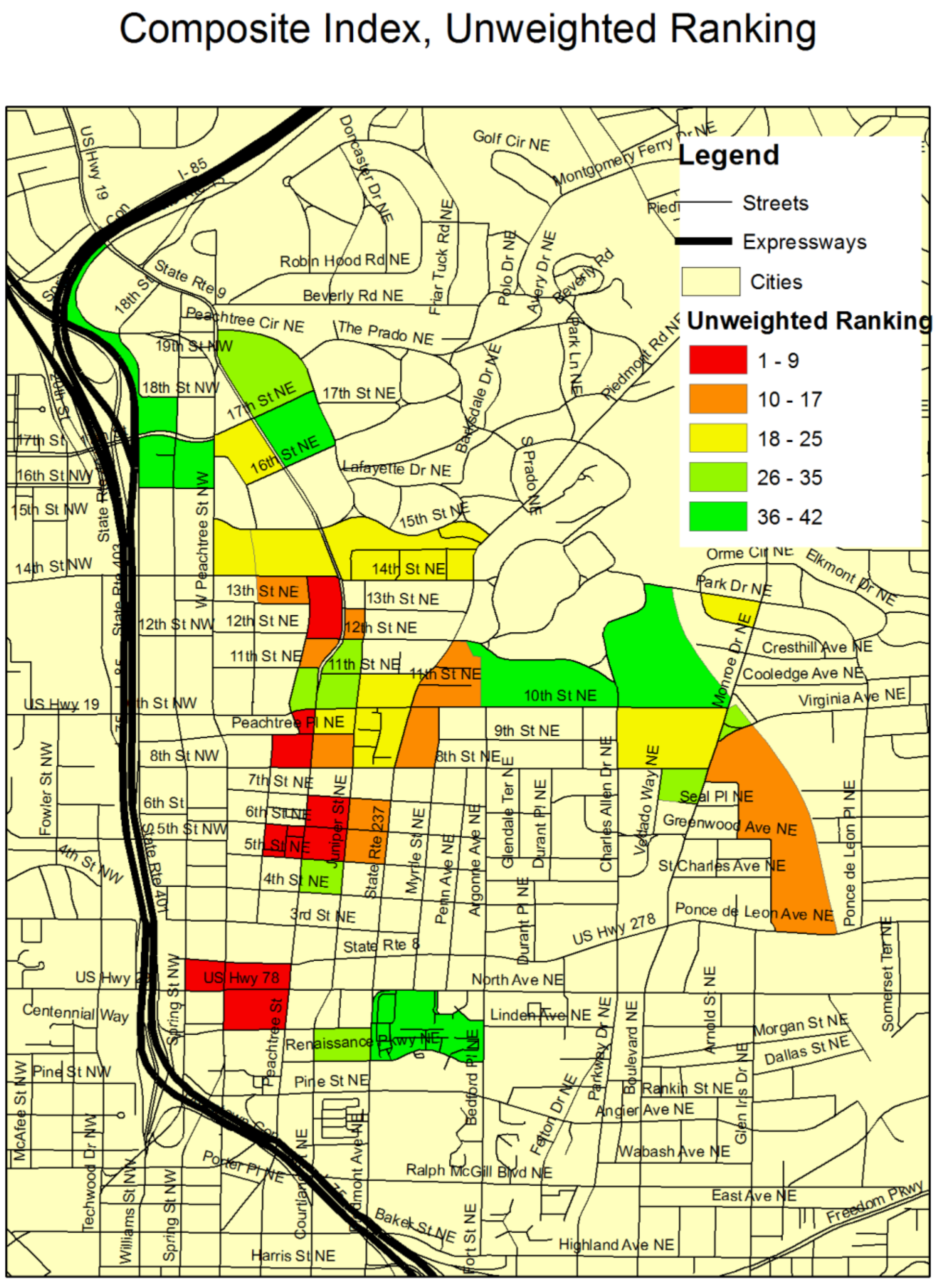

Figure 52. Pedestrian Composite Index (PCI) Rank-Order Prioritization, Unweighted

7.9 Discussion of Results

The research presented in this chapter employs existing data sources and field-collected data to provide a baseline framework for pedestrian project prioritization. For the purposes of this exploratory prioritization analysis, sidewalk width was utilized as a proxy for sidewalk infrastructure condition. Although sidewalk width has been used in prior studies, a more comprehensive evaluation framework would incorporate other factors, such as surface roughness, vertical displacements, presence of obstructions, perceived comfort, compliance with other ADA standards, and/or land use designations.

Based on the individual PPI and PDI rank-order prioritization results, the blocks adjacent to rail stations were highly prioritized using the composite index. High-density residential housing, office buildings, and shopping surround these rail stations. Hence, the blocks surrounding the stations ranked highly based on pedestrian activity, mode share, and population density. Based on pedestrian indicator data, the Arts Center station area experiences high weekday pedestrian activity but would not be prioritized based upon population density nor based upon non-automobile commute mode share. The existing land use within this subarea suggests that the weekday pedestrian activity is likely due to office workers and may not extend to population density or mode commute share. However, overall mode share for all trips in this zone is a factor to consider in future analyses.

Another element that should play a role in future analyses is the presence of many large, non-residential buildings (primarily commercial or office uses). Some blocks in Midtown with lots of office space did not rank highly based on population-dependent metrics. These land uses see a lot of pedestrian activity and have a high mode-share component, but with zero population density they may not migrate toward the top of the rankings (especially if pedestrian count data are not available). Also, Census-based data do not include hotel residents, requiring a further refinement to the PPI.

7.9.1 Example: Monroe Drive: Deficiency vs. Potential

The pedestrian crash data suggest that blocks along high volume and/or higher speed roadways are correlated with higher pedestrian crash densities. In addition to roadway characteristics and infrastructure safety, the number of pedestrians can increase exposures to traffic crashes. Thus, pedestrian crash densities along Peachtree Street may also relate to the high weekday pedestrian activity along that corridor.

As discussed previously, the blocks along Monroe Drive near Piedmont Park received higher prioritization using the PDI weighted ranking and lower prioritization using the PPI weighting. Based on the PPI rank-order prioritization results, blocks near Monroe Drive and Spring Street near I-75 were less prioritized based on pedestrian “demand” indicators. Additionally, these blocks also ranked low on population density and commute mode share indicators due to lower housing/population values. For example, several blocks along 10th Street actually correspond to locations within Piedmont Park and therefore impact the average score on population-dependent measures.

In the PDI prioritization results, blocks near Piedmont Park/Monroe Drive were prioritized due to relatively high pedestrian crash density and sidewalk width deficiency rankings. These results indicate that although some blocks were prioritized by both pedestrian potential and deficiency rankings, areas may be prioritized within one index but not the other. The low composite ratings along Monroe Drive raise the issue of directionality in the relationship between infrastructure condition, safety, and pedestrian travel demand. For example, the lack of pedestrian activity in certain areas may be related to the lack of infrastructure and safety concerns in addition to other built environment and demographic variables. Similarly, high pedestrian activity may be an indicator of high quality facilities. In the case of Monroe Drive and 10th Street, a multi-use path (BeltLine Eastside Trail) opened and a new pedestrian crossing was installed only a few months before the collection of pedestrian count data utilized for this analysis. It is likely that these infrastructure changes will affect long-term pedestrian activity patterns at this location, which may need to be reflected in future pedestrian planning analyses and in ongoing assessment.

7.9.2 Midtown Residential: Spatial Variability in Sidewalk Width Deficiencies

Within the study area, the blocks near the Technology Square mixed-use development (at 5th Street between West Peachtree Street and Williams Street) ranked highly in terms of pedestrian potential as well as deficiencies in sidewalk condition. Specifically, these blocks were highly prioritized based on population density; commute mode share and sidewalk width deficiency (and less prioritized based on pedestrian crash density and pedestrian activity). These data may suggest the effect of Georgia Tech students, of which approximately 22,000 live within the “Midtown core” (Midtown Alliance, 2013d). According to the 2011 Georgia Tech Commute Survey, 9.9% of students walk to campus (Georgia Institute of Technology, 2011), which suggests that areas with student housing and access points to campus or to the Tech Trolley may have additional need for infrastructure that supports walking.

The Midtown residential area south of 10th Street had highest percentage of low-rated sidewalk width data. This subarea within Midtown lies outside of the SPI-16 zoning district and has not benefited from recent streetscape projects. When compared with the new construction along the “Midtown Mile” within the Peachtree Street corridor, the neighborhood also contains older housing stock. The age of the Midtown residential area may contribute to the presence of sidewalk deficiencies, in addition to the conversion of single-family homes to apartments within this section of the neighborhood. This trend is indicated by the population density data, as many blocks ranked highly based on population density despite the presence of many older single-family homes. Both the age of the neighborhood and population density suggests that many existing sidewalks may be aging or deteriorated and less likely to be maintained, given that the legal responsibility for sidewalk maintenance rests on the adjacent property owner. Future analyses should probably incorporate parcel-level land use data to test whether housing age and condition may be correlated with sidewalk maintenance and overall quality.

The sidewalk width weighted PDI index results indicate a lack of consistency spatially in terms of block-level rankings. Several Census blocks within this subarea were ranked highly for sidewalk width deficiency and located next to blocks that were ranked low for sidewalk deficiency. However, it is important to note that even the highest ranked blocks did not have a majority of data points with sidewalk width measurements less than five feet. Based on this micro-scale prioritization analysis, more geographically extensive sidewalk width data may be needed to assess the extent and impact of this observed spatial variability. Given the legal framework of sidewalk maintenance within the City of Atlanta, where adjacent property owners are deemed responsible for sidewalk repair, it is plausible that sidewalk quality may vary considerably even from parcel to parcel within the same block.

7.9.3 Influence of Zoning and Infrastructure and Capital Improvements

The majority of sidewalk width data within this particular study area exceeded accessibility width guidelines (rating of "5"). Further, a substantial number of cases had sidewalk widths greater than 10 feet, which is not generally the case in Atlanta. The blocks within the study area with the highest percentage of data greater than six feet were found along the Peachtree Street corridor from 8^{th} Street to 15^{th} Street. This trend is largely due to the initiatives of Midtown Alliance, a community improvement district that has spearheaded capital improvement and transit-supportive land use planning and urban design guidelines within Midtown. For example, the Special Public Interest 16 (SPI-16) zoning overlay district within the Midtown commercial area includes supplemental requirements for sidewalk width. Specifically, districts along the Peachtree Street corridor are required to have a 15 feet "pedestrian clear zone" in addition to any space for building frontage, landscaping and street furniture (Midtown Alliance, 2013b). Since its formation in 2001, Midtown Alliance has undergone many streetscape projects and has constructed over 14 miles of new sidewalks (Midtown Alliance, 2013c).

7.9.4 Methodological Considerations: Objective Built Environment Data

Researchers and practitioners recognize both the time and resource intensive nature of audit instruments and in-person observation for the purposes of built environment data collection. The state of the practice also recognizes the potential for technologies such as GIS, PDAs and mobile applications to improve the cost-effectiveness of built environment and travel behavior data collection. The Sidewalk Sentry™ sidewalk data collection and assessment system reduces the time needed for field data collection as well as data collector training (it only takes a couple of hours to train and verify the performance of an undergraduate research assistant for video processing). When compared with a walkability audit instrument that may require urban design or engineering expertise to assess the built environment, an automated data collection system may improve cost-effectiveness of data collection due to the decreased need for staff time as well as expert training. The system also creates a video archive that can be reviewed at any time in the office. However, automated systems utilizing advanced technologies and field data collection do require additional time and resources for system development, calibration as well as data cleaning and preparation.

The Census block was selected as the geographic scale of analysis to assess pedestrian indicators on a relatively micro-scale. Additionally, the use of Census geography allowed the researcher to incorporate Census demographic data. However, the Census block geometry depends on the existing road network and may not accurately reflect a reasonable walking distance in all cases. To operationalize a pedestrian prioritization framework, it will be necessary to evaluate individual sidewalk segments or parcels for infrastructure repair or replacement. It may be useful to first identify the specific Census blocks within a larger area for further consideration within planning and prioritization, and in the future utilize fine-grained sidewalk quality data to pinpoint specific locations requiring ADA improvements.

7.10 Case Study Conclusions

The research presented in this chapter demonstrates the application of a rank-order spatial prioritization framework for evaluating the suitability of Census blocks for sidewalk repair or replacement. This framework employs pedestrian activity, pedestrian crash, demographic, population density and sidewalk quality data to rank Census blocks using a pedestrian potential index (PPI), a pedestrian deficiency index (PDI) and a pedestrian composite index (PCI) to rank Census blocks for pedestrian infrastructure improvements based on both potential and deficiency variables. This chapter also discusses how different variable and index weightings can affect block-level prioritization results. In preparation for implementation within local jurisdictions, the indices and variables demonstrated in this framework may be weighted as desired, depending upon local policy goals and objectives, such as pedestrian safety or pedestrian travel demand.

Additionally, local municipalities may be interested in developing index weightings or additional variables to prioritize sidewalk repair or reconstruction projects separately or in combination. To operationalize this prioritization framework for use in local, regional, and statewide pedestrian planning, future research should incorporate sidewalk quality, demographic and travel behavior data across larger geographic scales. Additional data from the Sidewalk Sentry™ app, such as presence of obstructions, crack density, and curb ramp presence (Frackelton, et al., 2013) can also be integrated.

This exploratory analysis proposed and tested a methodology for pedestrian prioritization utilizing objective sidewalk width data in combination with other data sources. The results of this analysis identified patterns in pedestrian potential and deficiency rankings based on a subarea within Midtown, Atlanta. Future research is needed to enhance the application of app-collected sidewalk data within this prioritization framework within planning and prioritization processes on local and regional scales. Refinements in data analysis will enable researchers to test the applicability of the exploratory analysis results, add further indicators, and expand the geographic scope of the sidewalk quality dataset.

8 Public Outreach

In September 2012, the research team conducted kickoff meetings with key staff members at the City of Atlanta Department of Public Works and at the Georgia Department of Transportation (GDOT). Researchers made contacts at these and other key organizations such as the Atlanta Regional Commission (ARC), and a local pedestrian advocacy organization, PEDS, with whom they were able to keep in touch throughout the project. In addition to public and advocacy organizations, key stakeholder groups identified were the general public as users of the sidewalk network, the general public as property owners currently held responsible for sidewalk upkeep, and members of the research and academic community who would benefit from the advancement of the state of the practice in this research project.

8.1 Outreach to Planning Agencies and the Public

Throughout the field efforts of the project, communication with staff members at the City of Atlanta, Georgia Department of Transportation, Atlanta Regional Commission, and PEDS was ongoing. Graduate students also participated in the City of Atlanta Sidewalk Task Force that was led by two city councilwomen and met regularly to discuss problems and solutions related to sidewalks in the City. Login privileges for the Sidewalk Sentry™ data viewing website were provided to agency contacts.

The research team developed outreach materials to disseminate to the public during data collection, public and community meetings, or other interactions with the community. These materials had basic information about the research project, a contact email, and the project informational website hosted by the Georgia Institute of Technology (Georgia Tech) at transportation.ce.gatech.edu/sidewalks.

The project team attended and presented their research at numerous Neighborhood and Neighborhood Planning Unit (NPU) meetings before and during the data collection phase of the project. At these meetings, researchers explained the project and usually demonstrated showed the data collection unit, alerted residents that there may be data collectors in their area, and put out a call for volunteers to conduct data collection. The team also put out a call for volunteers through the local pedestrian advocacy group, PEDS. Researchers then held two training sessions centrally located on Georgia Tech's campus for members of the general public who wished to assist in data collection. Although both the training sessions had attendance of between 5 and 15 people, the coordination and scheduling of these volunteers after training never worked out. At meetings and through contacting the research team, members of the public signed up for a volunteer list to hear about upcoming trainings and volunteer data collection deployment.

The more effective method used for engaging the public in data collection efforts was in day-long neighborhood data collection sessions. For these engagement sessions, researchers would bring multiple data collection units and a team of researchers to a central location in a given neighborhood. They would put out a call in advance to all volunteers on the compiled email list to alert them that they could come by at the specified window of time and location and assist in data collection. Members of the public would team up with trained undergraduate or graduate researchers (as data collection is always conducted in pairs) and if they stayed for enough time to feel comfortable with the data collection system or attended multiple sessions, could also pair up with one another.

8.2 K-12 Outreach

Members of the research team conducted extensive outreach activities with two local public schools at the high school and middle school levels. The initiatives relied heavily on volunteer time from researchers (and students in the case of the high school program) and consisted of data collection and analysis and focused on teaching the middle and high school students about the research process and about transportation engineering as a career. Program objectives were designed to:

- Show students that Engineering encompasses many aspects of everyday life and skill sets including:
    - Mathematics
    - Presentations
    - Critical thinking
    - Organization
    - Team work
- Cultivate social responsibility by showing students that engineering can improve safety and quality of life including for people with limited access and mobility
- Encourage young women and minorities to consider engineering
- Give students an overview of areas of transportation engineering
- Showcase real-world applications of Engineering through project-based learning
- Provide mentorship and volunteer opportunities for high school, undergraduate, graduate level students

8.2.1 Middle School Outreach at Centennial Place Academy

The middle school initiative took place Centennial Place Academy with students as they transitioned from the 5^{th} grade to the 6^{th} grade. The school was also transitioning to become a charter school; the first instance of this happening in the City of Atlanta. The diverse student body at Centennial (49.8% Female, 86% African American, 5% Caucasian, 2% Asian, 3% Hispanic, 4% Multi Racial, 71% low-income as designated by federal standards) meant the outreach activities reached many students in groups that are typically underrepresented in STEM subjects (Grossman, et al., 2015).

The initiative was led in two sessions: an initial overview and introduction for the entire class and a second, in depth two-day research session for a small group of interested students. The first session in May, 2014 introduced over 80 fifth graders to elements of engineering such as measurements, data analysis, presentation, and teamwork. The session focused on interactive transportation activities covering accessibility challenges using wheelchairs, mode choice mapping and modeling, and paper and electronic travel diary activities. The follow-up sessions in October, 2014 involved 17 sixth graders who choose to participate. These sixth graders worked directly with Georgia Tech researchers to conduct, analyze, and present their data for three modules of traffic operations, human factors and the roadway environment, and accessibility design. The modules for each session and the materials and leadership needed for each one are transferable to other schools and student populations including various ages and educational levels as indicated by the considerable overlap in activities undertook by the middle school students with previous outreach at public high schools and undergraduate research initiatives.

The research team easily recruited volunteers to help lead the initiative through student groups with a commitment to service such as the Institute of Transportation Engineers (ITE), and Women's Transportation Seminar (WTS). The outreach activities were conducted by high school, undergraduate, graduate, and post-doctoral researchers, lending to a fluid relationship between the roles of mentor and mentee throughout the program (Grossman, et al., 2015).

8.2.2 High School Outreach at Decatur High School

Education initiatives aimed at the high school level provide exposure to transportation engineering at a time when students may be making decisions about college and future career choices. Decatur High School, in Atlanta's neighboring city of Decatur, encourages its students to engage in afterschool activities and requires those students in the International Baccalaureate (IB) program to participate in volunteer activities to graduate. Although working with the research team on this project would have counted towards fulfilling volunteer hour requirements, discussion with the students revealed that the majority of those who chose to participate had already completed all necessary volunteer hours and were interested in engineering and/or accessibility and were participating out of their own interest without any direct benefit or requirement fulfillment. The initiative consisted of members of the research team traveling to Decatur High School once a week in the spring and summer trimesters with data collection equipment and working with the high school students to develop a data collection plan and then collect data in the area around their school. The graduate, undergraduate, and high school students then looked at the collected data together and discussed sidewalk conditions and accessibility in the local area. Figure 53 below shows an undergraduate research assistant (left) with two Decatur High School students during data collection.

The program at Decatur High School also allowed undergraduate students to take on the role of a mentor and to teach high school students what they had learned from working on the project. Graduate researchers at Georgia Tech brought undergraduate mentees to Decatur High School to carry out research planning and data collection activities related to Georgia Tech's Sidewalk Quality research project and guide the high school students in their data collection planning and implementation.

Figure 53. High School and Undergraduate Researchers Collecting Data

8.3 University Outreach

Georgia Tech undergraduate researchers performed important roles in the research project, including: 1) collecting data in the field; 2) working with local high school student volunteers to plan, carry-out, and develop an understanding of data collection methods; 3) testing new tablet models and operating systems to assess whether new technologies could be adapted for the project; 4) conducting literature reviews for topics related to the scope of the project; and 5) furthering the scope of research by taking on related research topics such as tree encroachment on sidewalks and the development of ADA transition plans.

The university outreach portion of the project culminated in the implementation of a Civil Engineering undergraduate honors course, Boulevard of Broken sidewalks (CE4803). The honors course was taught by Dr. Randall Guensler and Alice Grossman in Fall 2014 and was attended by 17 undergraduate students across a variety of majors. Topics ranged from ADA requirements, ADAAG design guidelines, sidewalk materials, mixing and laying concrete, measuring pedestrian activities, and various planning, engineering, and policy related issues associated with walking, accessibility, and public health.

For the final class research project in the undergraduate honors course, the students worked in teams to develop elements of an ADA Transition plan for the Atlanta Hotel District. The Atlanta Hotel District is located in central downtown Atlanta, and includes MARTA heavy rail train stations and many work locations for Atlanta area residents. The hotels, structures, sidewalks, and crossings included in the scope of the honors course project are used for many large conferences and conventions, including the annual Dragon Con, which draws tens of thousands of attendees each year at a constantly growing rate. The students used Dragon Con as an example of a time when the area would need to simultaneously accommodate thousands of pedestrians, including those with limited mobility. In the field, students used SmartTool™ digital levels, wheelchairs, tape measurers, and took photos to measure and document locations where buildings and pedestrian infrastructure failed to meet ADAAG design requirements, as well as additional potential safety hazards. Students used the ADA regulations and design criteria, previous ADA Transition Plans, and guidance on how to develop a transition plan to inform their research and final products, which they presented in both report and oral presentation format.

After the conclusion of the class, one of the students worked intensively with Dr. Randall Guensler and Alice Grossman to compile, verify, supplement, and polish the report as an independent study research effort (Mudrinich, et al., 2015). The report provides the project background, stakeholder analysis, methodology, analyses, and results of the inspections carried out by the students. The report also outlines the basics requirements for ADA Transition Plans, such as organization, accountability, budgeting, timelines, and prioritization. Extensive appendices in the report provide details of each individual problem examined with photographic evidence, measurements, cost estimates, and reasoned repair priority for each identified problem. Given the overall report size of the ADA transition report (especially the volume of appendices), the Atlanta’s Hotel District: ADA Transition Plan is published under separate cover. This ADA transition plan was transmitted to the City of Atlanta department of Public Works. Once implemented, the sidewalk and ramp improvements are expected to bolter downtown walkability, which should provide Atlanta residents and visitors with economic and public health benefits.

9 Conclusions and Recommendations

The Americans with Disabilities Act (ADA) recognizes that sidewalks play a vital role in the accessibility of transportation infrastructure and that sidewalks improve the quality of life for persons with disabilities. Furthermore, ADA-compliant infrastructure promotes safety, mobility, and accessibility for all users, not just the disability community. Sidewalks that do not meet ADA criteria can expose wheelchair users, stroller users, and other pedestrians to unnecessary risk. Pedestrian facility assessment is necessary to ensure compliance with the ADA, and cities can be held liable for neglect of infrastructure maintenance. On a local and regional level, the lack of pedestrian facility inventory and condition data and pedestrian-oriented data has been a barrier to ADA compliance and to the development of robust pedestrian travel demand models. Given limited public resources for infrastructure, there is a need for improved data collection, data quality, and objective evaluation systems to inform pedestrian project prioritization. This project assessed the state of the practice for collecting objective sidewalk data, identified sidewalk quality indicators important to planners, developed and implemented a system to collect sidewalk condition data, collected relevant data for the city of Atlanta, and demonstrated a flexible system that can be adapted by local and regional planning authorities to objectively prioritize sidewalk infrastructure repairs and upgrades based upon parameters that relate to pedestrian activity, pedestrian safety, transit accessibility, and mobility for persons with disabilities, children, and older adults.

9.1 Defining Sidewalk Quality

Sidewalk quality encompasses more than just ADA compliance. To identify various factors related to sidewalk quality that would likely need to be employed alongside physical sidewalk characteristics, the research team conducted a survey of technical experts. Experts reviewed sidewalk videos (across a range of sidewalk conditions) and were asked to rate the sidewalks and identify factors that contributed to their evaluation. There was a tendency for experts to identify sidewalk cracking, gaps, and presence of obstructions as negative sidewalk quality indicators, and the presence of buffers and amenities (benches and street trees) as positive sidewalk quality indicators. The expert panel survey results did not necessarily correlate well with some important ADA compliance parameters. Cross slope, for example, is a significant issue for wheelchair users but was not identified as a critical factor by experts, despite the significant number of curbcuts with cross-slopes in excess of ADA requirements in the sample. The research team suspects that the survey responses may have been biased towards readily-perceived visual cues in the video (such as cracks and the presence of trees), and that some important accessibility parameters may not have perceived as readily. If true, there is even more reason to believe that collection of objective sidewalk condition elements for use in evaluation is needed. Cities focusing time and money on aesthetic aspects of the pedestrian environment such as planting strips, benches, and street trees, rather than on sidewalk ADA compliance, could end up on the losing side of ADA legal challenges focused on sidewalk accessibility.

Based upon the literature review and expert panel survey results, the researchers concluded that there is no clear-cut set of criteria that should be used to assess sidewalk quality. Hence, the research team concluded that the development of a system that allows communities to decide which factors are important (and how to weight each factor) would be more beneficial than prescriptively implementing a system. The research team also concluded that the system needs to include objective sidewalk condition measures related to ADA compliance.

9.2 Collection of Sidewalk Condition Data

The research team developed, calibrated, and field-deployed the Sidewalk Sentry™ Android™ app, which collects sidewalk video, GPS location data, and surface vibration data. The rolling sidewalk video frames and data are location-tagged for mapping and analysis. The accelerometer and gyroscope data are used directly to assess and categorize surface roughness, via a cluster analysis approach. By adapting video processing tools previously developed by Georgia Institute of Technology (Georgia Tech) researchers for vehicle tracking, the researchers developed systems to post-process the video and estimate sidewalk width, identify cracks and potholes in need of maintenance, and record the localized presence of walkway obstructions. The original project goal was to completely automate the system, using machine vision video techniques to estimate sidewalk widths and identify crack density and other parameters directly from the rolling video. However, the fully-automated processes did not yield sufficiently accurate and precise measurements and requires further research and development. Instead, the team developed, tested, and implemented a semi-automated method for width estimation and identification of sidewalk defects under ADA design standards. Analysts review video frames and align on-screen icons to mark sidewalk edges; once marked, the system uses the calibrated field of view and vanishing point to estimate baseline sidewalk width. For obstructions and surface discontinuities, data collectors watch video playback and flag problems through a Web-based user-interface. The cost savings associated with data collection are still significant (because the detailed identification activity is handled in the laboratory and all analyses are repeatable), but the biggest advantage is the availability of the video archive of the sidewalk pathways. The system allows infrastructure managers to view the video and perform a remote inspection and estimate project costs without having to go into the field to assess repair needs. The research team developed a Web interface allowing users to map sidewalk condition data, view video archives, and create data summaries by neighborhood.

Another project goal was to develop real-world data that could be used in assessments after the project was complete. The researchers collected and analyzed sidewalk data for 1,352 miles of sidewalks in the City of Atlanta. The archival videos have been made available to the City of Atlanta, Atlanta Regional Commission, and the Georgia Department of Transportation (GDOT) via the Web interface. Vibration data are available for about 90% of the sidewalk mileage and the research team has post-processed the videos for Downtown, Midtown, Atlantic Station Morningside, Virginia-Highland, Candler Park, and a few other centrally-located neighborhoods to obtain width, cracking, surface disjoint, pothole, and obstruction data. Additional resources will be needed to post-process the video for the rest of the City. City staff can also perform this work independently through the Web interface.

9.3 Sidewalk Condition Indices and Repair Prioritization

In consultation with local transportation planners and public interest groups, the research team demonstrated an adaptable sidewalk infrastructure prioritization system (rank-order spatial prioritization framework by Census Block) for evaluating sidewalk repair or replacement. The case study employed a testbed of 42 Census blocks in Midtown Atlanta. Adapting approaches previously applied in the literature, the framework employs pedestrian activity, pedestrian crash, demographic, population density, and sidewalk quality data to rank Census blocks using a pedestrian potential index (PPI), a pedestrian deficiency index (PDI) and a pedestrian composite index (PCI) for pedestrian infrastructure improvements. The composite index approach allows local and regional agencies to select and incorporate variables that suit the needs of their communities. The system includes variable and index weighting parameters to allow agencies to prioritize specific variables or indices to meet local policy goals and objectives, such as pedestrian safety, ADA compliance, or enhancing pedestrian mobility in areas with high pedestrian travel demand. The analyses demonstrated how different variable and index weightings can affect block-level prioritization results. The analyses also demonstrated how width data impacted prioritization, paving the way for the use of other objectively-measured sidewalk deficiency data (i.e., presence of severe cracking, pavement disjoints, potholes, obstructions, etc.) in the rank-order process.

Pedestrian indices can be tailored for specific regions or local areas and based upon some combination of ensuring compliance with ADA standards, enhancing walkability or mobility, improving safety, reducing liability, or a variety of other factors. For an agency focusing on ADA compliance, specific ADA design considerations could be integrated into an ADA-weighting index, such as: sidewalk width, surface roughness, presence of obstructions, grade, cross-slope, presence of compliant curb ramps, or connectivity to transit. The predominant weighting presented earlier in the case study focused on pedestrian mobility. But even this element could be expanded to include other considerations, such as user comfort, perceived safety, as well as supporting environmental elements that may increase walking trips. An agency focused on mobility may consider factors such as predicted walk trips (derived from travel demand modeling) or observed walking activity (e.g., video counts), presence of contiguous sidewalk surfaces, presence of high-density land use, presence of transit stops, or special event locations. Transit ridership data (boarding and alighting) and pedestrian trip data from the regional travel demand model are worth investigating. Other data sources may be needed to forecast pedestrian demand over larger areas. A city desiring to improve pedestrian safety might focus improvements in areas where pedestrian-vehicle incidents have occurred, or are likely to occur. Areas with high vehicle volumes and/or high vehicle speeds combined with high pedestrian volumes could receive additional attention in a pedestrian safety index. The research team plans to continue to refine the indices using new data, add further indicators, explore analytical results, and work with local planning agencies to expand the geographic scope of the sidewalk quality dataset and implement a rank-order system for the City of Atlanta.

9.4 Public Involvement

Over the course of this project, the research team made presentations at numerous Neighborhood Planning Unit (NPU) meetings, before and during data collection efforts. The team also put out a call for volunteers through PEDS, a local pedestrian advocacy group. Some of these volunteers assisted in field data collection for their neighborhoods. Members of the research team conducted extensive outreach activities with a local high school and middle school. The public initiatives relied heavily on volunteer time from researchers (and students in the case of the high school program) and consisted of data collection and analysis. Activities focused on teaching the middle and high school students about the research process and about transportation engineering as a career. The final outreach and education project involved development of an ADA transition plan for the Downtown Hotel District by a class of 17 Georgia Tech undergraduate honors students (Mudrinich, et al., 2015).

9.5 Additional Research Needs

The Sidewalk Sentry system and rank-order prioritization approaches developed during this research process can help communities evaluate sidewalk condition and ADA compatibility, and results can help agencies prioritize sidewalk and pedestrian infrastructure improvements. The exploratory analysis proposed and tested a methodology for project prioritization, utilizing objective sidewalk width data in combination with other data sources. The results of this analysis identified patterns in pedestrian potential and pedestrian deficiency rankings for a subarea within Midtown, Atlanta. As demonstrated in this research, agencies can adjust variable weightings and composite prioritization indices to suit local priorities for safety, mobility, etc. Additional research is still needed to enhance the application of app-collected sidewalk data within this prioritization framework for use in planning and project prioritization processes at urban and regional scales. However, refinements in data analysis will enable researchers to test the applicability of the exploratory analysis results, add further indicators, and expand the geographic scope of the sidewalk quality dataset.

To implement a data-driven pedestrian prioritization system, it is important to coordinate with local planning initiatives and policy priorities. The City of Atlanta is currently in the process of implementing “Complete Streets” projects and policies supporting walkability. In selecting the relevant data sources and walkability indicators for prioritization in the City of Atlanta, it is important to consider existing plans, project selection criteria, and existing conditions to streamline implementation. Given the data collected, analyzed, and disseminated in this research, and the successful demonstration of a sidewalk repair/replacement prioritization system, the research team recommends an increase in policy efforts and funding to support the collection and use of such information.

Finally, the research team recommends that local, regional, and state agencies integrate pedestrian prioritization and suitability measures into agency-wide infrastructure performance measures, and project selection criteria. Future research should consider approaches to operationalize sidewalk quality and pedestrian activity metrics within existing and future infrastructure analysis methods and project prioritization frameworks.

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11 Appendix A: ADAAG Transit and Parking Discussion

People who take transit often walk to access the train, bus or other transit option they use as their primary mode of transportation. Design guidelines for accessible pedestrian infrastructure recommend minimum clear width and clear length at transit boarding areas, as well as a “level and stable” surfaces. Every station, bus stop, bus stop pad, terminal, building, or other transportation facility must comply with applicable provisions of the ADA, including features associated with: site selection; accessible design; connectivity to activity centers; specific design criteria for ticketing, terminals, vehicles, and access points; signage, lighting, and safety; etc.

Parking facilities also must comply with ADA regulations and contain the appropriate number of accessible parking spots as outlined in Table 21 below. The accessible parking spaces must be located close to, and with a direct route to, the traveler’s destination. Additional requirements include proper ground surface and the presence of a safe, continuous route to the intended destination. Accessible spaces must be 8’ wide for a regular automobile plus a 5’ aisle, or 11’ wide for a van plus a 5’ aisle, and other specific design criteria. The relevant aspect of parking requirements and sidewalks is the connectivity that is required between the parking locations and intended destinations. Accessible sidewalks or pathways are required for making this connection.

Table 21. Accessible Parking Space (Disabled Access) Requirements

Total Parking in Lot	Required Accessible Spaces
1 to 25	1
26 to 50	2
51 to 75	3
76 to 100	4
101 to 150	5
151 to 200	6
201 to 300	7
301 to 400	8
401 to 500	9
501 to 1000	2 percent of total
1001 and over	20 plus 1 for each 100 over 1000

Evaluating the condition of transit stops and design of parking lots and conformance with ADA design guidelines is essential to the development of local and regional ADA transition plans. However, evaluation of transit stops, parking lots, and features other than sidewalks themselves was outside of the scope of this sidewalk study and not presented in this report. Separate efforts in these areas will be undertaken by the research team in the near future.

12 Appendix B: Sidewalk Sentry™ Field Data Collection Manual

Information

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Introduction

This document comprises the Sidewalk Sentry™ field data collection manual. The Sidewalk Sentry™ Android tablet application can be used to collect vibration and video data that are post-processed to sidewalk width, slope, and other features that affect sidewalk comfort and utility for residents, visitors, and tourists. Sidewalk features have a decidedly strong effect on people with disabilities. The procedure in this manual should be followed for all sidewalk data collection using the Sidewalk Sentry™ system.

Safety Precautions and Information

All data collectors must have completed a safety form and the Human Subjects training course, and submitted their certificate. Volunteers under the age of 18 years must also complete and submit a waiver and parental release form prior to conducting any fieldwork. During data collection, specific precautions must be taken by all data collectors at all times:

- Data collectors shall check in with supervisor when leaving for site, arriving at site, returning from site, and arriving at base.
- Data collectors shall always wear a reflective orange traffic safety vest
- Data collectors shall always wear closed toed shoes
- Data collectors shall always cross the street at marked crosswalks unless no crosswalk exists
- Data collectors shall obey all traffic signals and walk/don't walk lights
- Data collectors shall avoid entering the vehicle right of way at all times
- Data collectors will only enter the roadway to cross the street or when no sidewalk is present and when safe to do so, otherwise data collectors will return to their vehicle and drive around the inaccessible area
- Under no circumstances shall data collectors walk in the vehicle right of way in the same direction as oncoming traffic (data collectors must face oncoming traffic so that they can see oncoming vehicles)

- Data collection shall be performed on the sidewalk such that data collectors are facing oncoming traffic whenever possible (see photo below)
- Whenever off campus, a minimum of two data collectors will collect data together for safety
- Data collection teams will carry at least one working cell phone for emergency use
- Data collection teams will carry drinking water
- Any injuries or property damage shall be reported to supervisors immediately

Objectives

- Collect a comprehensive data set of sidewalk segments across the City of Atlanta and surrounding areas
- Work with local residents in an outreach program that gives back to the volunteers' communities
- Provide the opportunity for undergraduate students to learn about the research process in a University research lab including data collection procedures, data analysis, and the overall impacts of a project on the community

Field Data Collection Materials

- 2 or 3 Toshiba Thrive tablets
- 1 standard issue wheelchair
- Safety vests for all members of the data collection team
- Data collection manual and route maps
- Pen and paper for taking notes
- Water and one or more personal cell phones
- Tablet cases and backpack for carrying materials (carry tablets in protective bags and in a backpack when not attached to a wheelchair)

Data collectors should use the most recent version of Sidewalk Sentry™ software (v 2.0 as of 2/11/2013) on Toshiba Thrive Tablets that are using the "Honeycomb" version of Android software (3.x), NOT the later "Ice Cream Sandwich" (4.x).

Equipment Set-up Procedure

Field Data Collection Unit Setup

1) Turn on tablet, unlock tablet
2) Open "Sidewalk Sentry" app
1) Login to Sidewalk Sentry, using your assigned username and the tablet number (marked on the side of each tablet)
2) Snap the white tablet mounting board onto the bottom wheelchair bars *below* the location where the seat would normally be (see photo), **not onto the top black folding bars.** The board will click into place with all four connectors.
3) Mount the tablet to the black tablet mount on the white mounting board such that the screen is horizontal and facing towards the person pushing the wheelchair (allowing the camera on the back side to point down at the sidewalk).
4) Once the Tablet is secured in the mount, tighten the 2 Velcro straps over the top of the tablet to reduce excess vibration.

Walking Procedure

Field Data Collection in Progress

1) Go to the denoted start point on the route map.
2) Setup the wheelchair and tablet at the start point facing in the proposed direction of travel.
3) Open the sidewalk Sentry™ application and press "get GPS fix."
4) Wait for GPS fix to be established. You will hear a beep and see the "Get GPS" button change to "REC" button.
5) Press "Rec."
6) Wait 10 seconds.
7) Push wheelchair at a normal walking speed (between 2 and 3 mph) along route. Let wheelchair bounce along the route (do not dampen vibrations by holding the wheelchair down)
8) Walk along route in direction of arrows…

ALWAYS cross at a marked crosswalk when present

9) At curbs where ramps are present, push the wheelchair up the ramp in a continuous motion.
10) At curbs where ramps are absent, push the front wheelchair wheels up to the curb, tip the wheelchair back to lift front wheels, move the wheelchair forward until the back wheels reach the curb, lift the back wheels, and continue with data collection
11) Stop at the end of your route (the app will collect video automatically and continuously breaking videos into 10 minutes pieces as you go).
12) Press "stop recording" on the tablet before removing the tablet from the mount.
13) Remove tablet from mount
14) Check to make sure your video recorded correctly by clicking on the "File manager" folder and finding the folder with the date and time stamp of your data collection. Click this folder and you can click on and watch the videos collected.

12) Turn off the tablet.
13) Collect equipment and move on to your next route.

IF NO SIDEWALK EXISTS, DO NOT CONTINUE THE ROUTE

MARK THE ABSENSE OF SIDEWALK ON YOUR ROUTE MAP

DRIVE TO YOUR NEXT LOCATION IF THERE IS NO SAFE WALKING ROUTE

13 Appendix C: Video Processing for Sidewalk Width - User Guide

The goal of the sidewalk video processing is to extract information from each frame of video to estimate sidewalk width. Width estimation is a single part of a larger sidewalk inventory project. This user's guide provides instructions to users that are using the sidewalk width interface to record the location of sidewalk edges used in width calculations.

Process

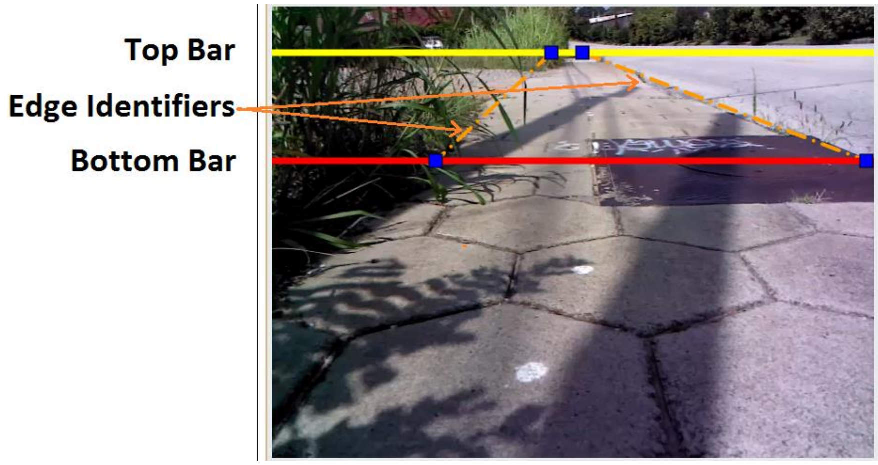
The research team operates a script that has pre-identified frames of the rolling sidewalk video that are approximately 50 feet apart. The width data entry user-interface presents these frames to the reviewer one at a time. For each frame of video presented to the user, the user will identify to the best of their ability, each edge of the sidewalk when edges exist, or provide a comment as to why the edges cannot be manually identified. In trying to identify whether a sidewalk is in the camera view, consider the definition of a sidewalk:

> A sidewalk is that portion of a street between the curb line, or the lateral line of a roadway, and the adjacent property line or on easements of private property that **is paved or improved** and intended for use by pedestrians (MUTCD).

In the case where sidewalk edges exist, the user will move the edge identifiers until the line falls on the edges of the sidewalk. The best method for moving the edge identifiers is outlined below:

1. Slide the lower bar (click and drag) until it is just above both edges of the sidewalk.
2. Slide the upper bar until is roughly coincides with the horizon line.
3. Slide the endpoints of the edge identifiers along the upper and lower bars until they coincide with each sidewalk edge.
4. Select the "Save Coord" button at the right of the image

Figure 54. Placement of the Sidewalk Edge Identifiers in the Field of View



In the real world, sidewalk edges are parallel to each other. That is, the distance between the two orange lines, in the real world, remains the same from end to end. In the camera view, the edge lines angle off into the horizons and meet at what is known as the "vanishing point" in the camera view perspective. Because a mathematical equation is used to calibrate the camera field of view using the location of the vanishing point, it is important that the edge lines follow the sidewalk edges as accurately as possible.

There are times when the user must select the "Skip Frame" option. The user is prompted to select the reason why the frame was skipped. Figure 55 shows a list of reasons for skipping individual frames and examples.

Because accuracy of edge detection is important, users should skip frames with bad video image, locations where the view is blocked, and cannot edges are not readily identifiable. Sidewalk width excludes driveway pavements, so users should skip images that include driveway curbcuts such as parking lot entrances. When sidewalks curve around corners, the vanishing point cannot be reliably established and such images should also be skipped. Locations were no sidewalk is present are skipped, but recorded as not having a sidewalk present.

If the user makes a mistake on a frame and has already proceeded to the next frame, the "Go Back" button can be selected, and the frame can be reprocessed. There are instances where the camera mounting equipment was not installed properly, and the entirety of the video has a camera view unsuitable for edge detection. If a video such as this is encountered, the "Skip Video" button at the right of the video can be selected.

Figure 55. Skipped Frames - Reasons and Examples

Measuring Sidewalk Width in the Vicinity of a Driveway/Road Crossing

Because sidewalks are intended for use by pedestrians, it is important to remember the strip of driveway between the sidewalk and the street is **not** a sidewalk. This is very important to remember when there is a strip of grass between the sidewalk and the street (see Figure 56). If there is no grass separation where a driveway crosses, the edge of the sidewalk is at the edge of the roadway because a wheelchair could use that entire space (see Figure 57).

Figure 56. Correct Sidewalk Edge Identification at Driveways

Correct Edge Identification	Incorrect Edge Identification

Figure 57. Correct Edge Identification at a Large Commercial Driveway

Crosswalks are not sidewalks. But as long as the user can see enough of the sidewalk edges (see Figure 58), the lines can be placed and width can be estimated. Otherwise, the user employs the skip frame option and selects "No Sidewalk" as the reason.

Figure 58. Correct Edge Identification at Crosswalks

Edges can be Estimated	Select *Skip Frame -> No Sidewalk*

Other Frequently Encountered Problems

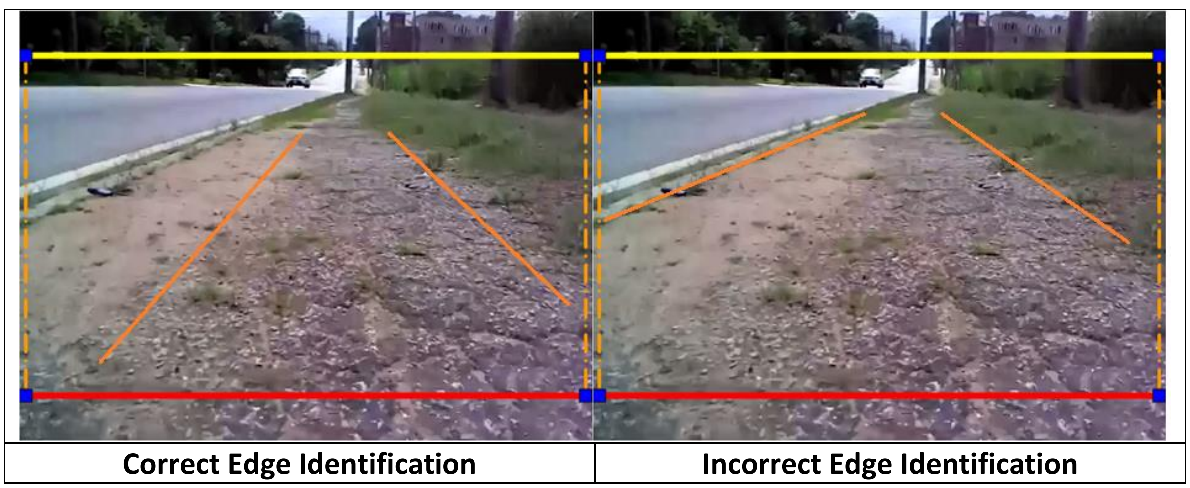
Pavement between tree planters is not considered part of the sidewalk because only the narrowest portion of this sidewalk is traversable via wheelchair. Users select the narrowest potion of the pathway (see Figure 1Figure 59). It is important that the user only select paved portions of the pedestrian infrastructure (see Figure 60and Figure 61).

Figure 59. Correct Edge Identification near Tree Planters

Correct Edge Identification	Incorrect Edge Identification

Figure 60. Correct Edge Identification in Overgrown Areas

Figure 61. Correct Edge Identification with Pavement Loss



If the sidewalk changes widths, measure the width closest to the camera, unless the edges closest to the camera are too short to make an accurate estimate, or the actual sidewalk edges closest to the camera are not really parallel with each other. Only estimate sidewalk edges where a true edge exists. Figure 62 contains additional examples of correct and incorrect edge identification.

Figure 62. Additional Examples of Edge Identification