Walkable and accessible environments can encourage pedestrian activity, and improve safety, livability, and economic competitiveness. Developing an asset management system for sidewalks, curb ramps, and other pedestrian features on the roadway is an essential step in tracking asset condition, managing repairs, and implementing the most cost-effective improvements. Creating an asset management plan and a budget for pedestrian infrastructure can also save cities considerable amounts of money by reducing the community's exposure to injury liability and costly ADA litigation. However, many communities struggle with addressing pedestrian accessibility due to a lack of accurate sidewalk inventory, condition data, and serious construction and maintenance backlogs.

Because the need and stakes for better pedestrian accessibility and connectivity are so great, strategic programs for managing sidewalks as a transportation asset are needed. Such an approach includes inventorying pedestrian transportation infrastructure, assessing system conditions, prioritizing improvements, and programming projects. Researchers at Georgia Tech have developed new methods for creating sidewalk networks, and easy to use tools for tablets and smartphones that inventory and assess sidewalks, curb ramps, crossings, and curb cuts. The research tools covered in this paper include:

1) Sidewalk Scout™: A crowdsourcing smartphone app used by agencies and the public to report sidewalk problems. The app allows users to submit a picture of a sidewalk problem (such as a pothole, obstruction, or surface discontinuity) along with the description of the problem and automatically geotags the location of the report. Crowdsourced data are made publicly available on an Open Streets Map overlay at http://sidewalkscout.ce.gatech.edu. An advanced user mode supports the entry of ramp and curb cut design and condition data for use in asset management tracking.

2) Sidewalk Sentry™: A tablet application used to inventory sidewalks and assess sidewalk quality. A smart tablet attached to a basic wheelchair collects vibration data and records video, tagged to the GPS. Data are used to evaluate where sidewalks may need repair or reconstruction. Post-processing provides width and other variables for analysis. Results are displayed through an online interface, which communities can use to assess overall system conditions and target areas for improvement.

3) The Sidewalk Prioritization Index builds upon previous work by Georgia Tech researchers (Frackelton, 2013; Frackelton and Guensler, 2015) and provides a prioritization and programming tool that utilizes the data collected through Sidewalk Scout™ and Sidewalk Sentry™, in conjunction with stakeholder input, to help program sidewalk projects that reflect the needs and desires of the community and maximize return on investment. An online survey gathers input from the community about their preferences for sidewalk investment, which are used to generate a ranking index for sidewalk segments based on current sidewalk conditions. Hence, community goals and objectives (e.g. mobility, ADA compliance, safety, etc.), and estimated cost can be reflected in the project prioritization.

This paper will provide an overview of the tools mentioned above, and how they operate together as a comprehensive asset management system.
Introduction

Accessibility and compliance with provisions of the Americans with Disabilities Act (ADA) ensure that public rights of way are able to provide all citizens, regardless of physical ability, with the best possible mobility options. Providing safe and accessible pedestrian routes in our communities is integral to ensuring equal access, and can also help encourage citizens to make the healthy and sustainable choice to choose walking as their mode of transportation.

The first step in creating a pedestrian-friendly and ADA-compliant sidewalk network is the development of a sidewalk infrastructure asset management system. This assists agencies in the implementation of sidewalk improvements through a consistent method of identifying problems, quantifying issues, and prioritizing sidewalk maintenance. Researchers at the Georgia Institute of Technology have developed a series of tools to:

- Collect and generate a spatial inventory of sidewalk and pedestrian route assets for specific geographic areas
- Assess the conditions of the sidewalks, paths, ramps, and other pedestrian infrastructure using low-cost equipment and semi-automated techniques developed in the research lab
- Integrate and aggregate the collected data into a GIS-based sidewalk network database
- Evaluate target area priorities for local sidewalk improvements through an online survey instrument
- Identify priority improvements based on target-area sidewalk project preferences.

The report is organized into four sections:

- **Section 1** outlines federal accessibility design standards and guidelines as they apply to the transportation network. These standards defined the parameters used by the asset management tools to determine the compliance of sidewalks and curb ramps.
- **Section 2** outlines how the Sidewalk Sentry™ and Sidewalk Scout™ systems are structured and used to collect qualitative sidewalk data and assess it for ADA compliance.
- **Section 3** describes the methodology for generating sidewalk network data and the methodology for integrating collected data into this network dataset.
- **Section 4** provides a summary of the survey tool used to collect local sidewalk project preferences and describes how this information is used in the Sidewalk Priority Index.

Section 1 - 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 or accessible routes, 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)). The USAB has also developed guidelines specific to pedestrian accessibility in the public rights-of-way that build upon ADAAG standards. However, USAB's Proposed Guidelines for Pedestrian Accessibility in the Public Right-of-Way have not been officially adopted, and are therefore considered guidelines and not standards at the writing of this document. For this reason, the team is currently evaluating sidewalks, curb ramps, and curb cuts based on their compliance with ADAAG standards only.

The ADAAG establishes minimum criteria for widths, surface condition, grade, and cross-slope for all accessible routes, including 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 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 ramp features for standard and parallel ramp types. A detectable warning surface must also be present to warn visually-impaired pedestrians that they are approaching the vehicle right-of-way (Figure 2). 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.

Figure 1 - Ramp Design Features (left image: standard ramp components, right image: parallel ramp components)

Figure 2 - Detectable Warning Surface

Section 2 - Data Collection and Visualization

Two technologies are used for collection and visualization of sidewalk and curb ramp condition data:

- **Sidewalk Sentry™** records continuous video, geographic coordinates, and vibration data from an app running on a wheelchair-mounted Android tablet. Data collected from Sidewalk Sentry™ are post-processed and can be viewed via an online server portal.

- **Sidewalk Scout™** allows a user to generate individual sidewalk and ramp reports while in the field (with a photograph and geographic coordinates), and also serves as a crowd-sourcing
application for collection of data anywhere in the world. Sidewalk Scout™ runs on Android and iOS (Apple) smartphones. Crowdsourced Sidewalk Scout™ data are viewed through an online map (http://sidewalkscout.ce.gatech.edu), which is open to the public. Sidewalk Scout™ is also used to facilitate sidewalk and ramp inspections. When run in advanced user mode, for users who have received training and have received approval to collect field data, the user starts the app, takes a photo of the location, selects the curb ramp type, and inputs standard measurements associated with the inspection. Detailed measurements for curb ramps, curb cuts, and sidewalks can be entered through the app by advanced users.

The following sections describe the two data collection technologies in further detail.

Sidewalk Sentry™ System

The Sidewalk Sentry™ data collection unit consists of a standard indoor wheelchair, modified to hold a Toshiba Thrive Android tablet. Rolling video, second-by-second GPS position, high-resolution vibration, and tilt data are collected by the tablet as the wheelchair is pushed along a sidewalk. The team can use the data to measure sidewalk surface vibration, identify maintenance issues, and estimate sidewalk width. Figure 3 shows the Sidewalk Sentry™ data collection system in operation.

![Figure 3 - Wheelchair-Mounted Sidewalk Sentry™ Data Collection System](image)

Sidewalk Sentry™ Web Interface

Stakeholders and practitioners can view project results on an interactive website using an open-source Open Street Map interface. The website displays a map of collected data, which are 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 5, which displays mapped sidewalk quality data and video data side by side. Some results are open to the public; while advanced users (such as agency staff) can view rolling video data and more detailed sidewalk quality data, such as problem reports identified through the rolling video review. The interface allows agency staff to review sidewalk issues and respond to public input before sending inspection crews out to address an issue.

For visualization purposes, and to limit the amount of data presented to the user at one time, the web interface currently requires users to select data and video by neighborhood. Polygon boundaries are established for each neighborhood using publicly-available data, and all video and other data in the Sidewalk Sentry™ system are 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. 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 4 below shows an example of the interactive interface.

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 showing the relative vibration data on a scale from worst to best (see Figure 5). The accompanying vibration data for the video traces appear under the video and on the map. Icons indicate the locations along the route where reviewers created problem reports during rolling video review. The letter in the icon indicates the type of problem identified at each location; whether it is a pothole, obstruction, debris issue, uneven surface, sidewalk width issue, or other problem. These issues are described in further detail in the next section of the report.

Figure 4 - Neighborhood-level Data Visualization Interface

Figure 5 - Trip-level Data Viewing Web Interface
The tablet vibration is presented on a scale from “Worst” to “Best.” These data are relative in nature based upon cluster analysis, using the range and variability of vibration data recorded when developing the Sidewalk Sentry™ system. 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 “Worst” and “Poor” levels indicate relatively high amounts of vibration. This could indicate that the sidewalk does not meet ADA standards and needs to be repaired due to displacements, uneven surfaces, or debris. Sidewalk vibration at or below the “good” index line typically indicate sidewalks that are in acceptable condition. Sidewalk vibration data should be checked against problem reports and rolling video to see if vibration data corresponds with sidewalk maintenance issues.

Post-Processing of Rolling Video Problem Reports

The research team developed a system to manually review rolling video and efficiently identify sidewalk defects under the ADA design standards. The high-resolution video facilitates the inspection of sidewalks 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 provides an archive that allows users to reassess identified issues at any time.

The Sidewalk Sentry™ video and GPS data streams are integrated and accessible through the Sidewalk Sentry™ Web Interface. 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 travel to the site. The general public currently does not have video access due to server 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. 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. Sidewalk problems that are identified on the Sidewalk Sentry™ website are categorized as “potholes,” “obstructions,” “debris,” “uneven surfaces,” “sidewalk width,” or “other.” Table 1 below details the type of problems that each of these categories indicates. Reviewers also have the option to add a comment to provide additional detail on the observed issue. More than one issue can be identified in a single problem report.

Table 1 - Standards for Sidewalk Design Features

<table>
<thead>
<tr>
<th>Sidewalk Problem Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potholes</td>
<td>Sidewalk depression or a hole in the sidewalk</td>
</tr>
</tbody>
</table>
| Obstructions | • Any permanent item that eliminates the ability of a walking or wheelchair-bound pedestrian to pass freely on the sidewalk  
• Obstructions reduce the horizontal clearance of the sidewalk to less than 3ft or the vertical clearance to under 80 inches |
| Debris | • A temporary obstruction such as fallen vegetation, traffic cones, trash, etc.  
• Either reduces the horizontal clearance of the sidewalk to less than 3ft or the vertical clearance to under 80 inches  
• May cause vertical displacements that would obstruct a wheelchair’s path of travel, or reduce the stability and/or slip-resistance of the surface |
| Uneven surfaces | • Disjointed pavement commonly resulting from tree root uplift or sidewalk settling.  
• Vertical displacements from 1/4 to 1/2 inch must be beveled to a slope no greater than 1:2 |
<table>
<thead>
<tr>
<th>Sidewalk Problem Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical changes greater than 1/2 inch must be smoothed so as not to exceed a ramp slope of 8.33%</td>
<td></td>
</tr>
<tr>
<td>36 inches minimum clear width per ADAAG</td>
<td></td>
</tr>
<tr>
<td>If the width is less than 60 inch width, a 60-inch by 60-inch passing space must be provided every 200 feet</td>
<td></td>
</tr>
<tr>
<td>Any other issue not discussed in the table. Issues classified as “other” require the reporter to enter a comment describing the issue</td>
<td></td>
</tr>
</tbody>
</table>

The team assigns several undergraduate researchers to review each sidewalk trip video for a defined area. A senior graduate research assistant (GRA) reviews all problem reports generated by the undergraduate research assistants (URA’s) to identify and resolve discrepancies, as well as assess which URA’s were the most consistently correct. The final problem reports are added to the server and displayed on the web interface.

**Sidewalk Scout™ System**

The Sidewalk Scout™ inventory system consists of the Sidewalk Scout™ app, designed to collect sidewalk problem reports, a web server to receive and archive the data, and an online web interface to visualize the data and generate summary reports. The Sidewalk Scout™ app is publicly available for Android devices via the Google Play store and for Apple iOS devices via the Apple App Store. The app has two data input modes, one which allows any user to report sidewalk issues they encounter anywhere. These data can be viewed by the public on the Sidewalk Scout™ website (http://sidewalkscout.ce.gatech.edu/). The second mode requires an advanced user login and allows users who have completed a training course and have the necessary equipment to inventory curb ramp locations and collect data on their ADA compliance.

**Sidewalk Scout™ Smartphone Advanced User Interface**

The Sidewalk Scout™ smartphone app allows users to submit qualitative sidewalk point data such as ramp inspections and sidewalk problem reports to an online database. Anyone can download the application from the Google Play Store for free and create a defect report; however, only users who have completed curb ramp data collection training and who have access to required curb-ramp measurement equipment are provided an advanced user login and password.

When a user in advanced user mode is ready to submit the report, the smartphone position is recorded using the onboard GPS, resulting in an accurate location report for the problem. The advanced user data collection begins with the user choosing ‘Create Ramp Entry’. If the user answers that there is no ramp at the current location, the user can take a photo of the location, report the angle from the center of the intersection, and a report is submitted that the ramp is absent and concludes the entry. However, if a ramp is present, the user takes a photo of the ramp and is then guided through a series of questions to deduce the ramp type. A number of questions with relevant helpful images are shown for the user to identify the ramp type, as seen in Figure 6. Figure 7 shows the possible ramp types that the app identifies (minus an “other” ramp type).
Figure 6 - Sidewalk Scout™ screens, in order, from left to right: first question, follow-up question one, follow-up question two, and final follow-up question as needed.

Figure 7 - Images of potential ramp types with labels (“other” ramp type not shown).

Following ramp type selection, the user measures and enters various ramp elements using a Smart Tool digital level, a measuring tape, and a Silva handheld compass.

Figure 8 shows app screenshots that highlight the data input prompts for a standard perpendicular ramp type. Because different ramp types are comprised of different components, not all ramp measurements will be applicable across all ramp types. The app adjusts the measurement prompts based on the type of ramp that is selected.
Section 3 - Sidewalk Network Generation

The third step of the inventory process is to develop a link and node network in ArcGIS representing potential sidewalk and crosswalk connections within the study area. The current methodology builds off of previous sidewalk network generation research by Georgia Tech researchers (Khoeini, 2015). The ArcGIS database was developed by combining GIS functions and spatial programming into an automatic methodology that generates sidewalk and crosswalk links based on existing parcel and road network data. The output is a base network of all potential sidewalk connections and crosswalk connections along area roadways, as seen in Figure 9 below.
The sidewalk link and node network is a geospatial database that can be used for storing and visualizing the sidewalk and ramp data collected by field teams. Sidewalk data collected via Sidewalk Sentry™ and Sidewalk Scout™ are integrated into the GIS network file through a series of GIS functions that follow the steps listed below:

- Divide the sidewalk links into existing sidewalk segments and sidewalk gaps
- Break the links with existing sidewalks into approximately 50ft segments
- Snap the vibration, sidewalk slope, problem report, and curb cut data points to the sidewalk links
- Average the vibration, width, and slope data by link, and count of the number of problem reports and deficient curb cuts for each link
- Associate detailed attributes with link and node IDs

The format of the database allows for clear visualization of the data and allows the data to be easily prioritized in GIS. The GIS framework also supports sophisticated sidewalk network analyses through tools such as ArcGIS Network Analyst. Examples of potential analyses that could be conducted using network analyst include multimodal traffic modelling, finding shortest walking time/distance among destinations, and identifying best possible accessible routes between destinations.

Section 4- Sidewalk Survey Preferences and Project Prioritization

An important element in prioritizing sidewalk repair and enhancement projects is understanding community preferences for sidewalk improvements. For example, improvements could focus on improving safety, accessibility, mobility, and/or walkability (walking comfort). The geographic distribution of projects may be important to stakeholders. The sources of funding for various project types may also be important. To assess community priorities and gather input for prioritization processes, the project team developed an online survey that asks community participants what types of sidewalk improvements they believe will have the greatest impact on the walking environment in their community, and where improvements should be focused.
The online survey is divided into two stages. The first stage of the survey takes approximately 15 to 20 minutes to complete and collects the following information from participants:

- Demographic and geographic identifiers
- Perceptions of the current local walking environment
- Desires for improvements that focus on pedestrian safety issues, sidewalk connectivity to important destinations, physical sidewalk conditions for those with mobility limitations, or walking environment comfort (walkability)
- Opinions about how funds for sidewalk improvements should be distributed geographically and/or politically
- Preferences for funding sources to pay for sidewalk projects

The second stage of the survey presents four optional four-minute surveys that ask for preferences about detailed design elements affecting pedestrian safety, mobility, accessibility, and walkability. The second part of the survey is optional due to concern for surveyor fatigue. Participants can exit the survey following the first stage, or complete one, several, or all of the second stage surveys.

This information is not only useful to the team in developing the Sidewalk Prioritization Index, but also for other agencies and researchers interested in better understanding public preferences for sidewalk improvements. In addition to serving as an input to the sidewalk prioritization index, the survey results can be useful to community leaders to gauging the general level of public interest in sidewalks and citizen mobility needs.

**Sidewalk Priority Index**

The Sidewalk Priority Index is a prioritization and programming tool that utilizes the data collected through Sidewalk Scout™ and Sidewalk Sentry™, in conjunction with survey and planner input, to identify priority segments for sidewalk installation, repair, or replacement. The methodology builds upon previous work by Georgia Tech researchers (Frackelton, 2013; Frackelton and Guensler, 2015). The index approach allows planners to change project priorities to match community desires, as shown in Figure 10.

For example, potential sidewalk improvement projects can be prioritized (i.e. the index can be weighted) based on community desires as expressed in the survey, targeting specific improvement goals (such as ADA compliance), or in response to funding cost sources, such as a landscaping/beautification grant.

![Figure 10 - A visual representation of Sidewalk Priority Index project weighting. Individual elements can be adjusted to match area priorities (e.g. Safety>Connectivity>Mobility>Walkability).](image-url)
Sidewalk segments are first scored in each category using a condition index of 0-10. For example, a sidewalk segment with no ADA problem reports and an average vibration rating of good or best receives an ADA mobility condition index score of 0. Sidewalk and crosswalk segments with problems or less than good vibration rating are ranked from 1-9 depending on the severity of the vibration and the number of problem reports. Sidewalk gaps are automatically ranked as a 10. Curb ramps are ranked in a similar fashion, with ramps having more ADA deficiencies receiving a higher condition index score. The system also allows weighting flexibility across a variety of parameters within each category. For example, surface roughness can be scored with a lower rating than pavement disjoints that render a sidewalk impassable to a wheelchair.

Following the calculation of the category condition indices, sidewalk corridors, crosswalks, and curb ramps are weighted across the primary categories to generate a new prioritization index score based on the preferences recorded in the public survey. For example, if the survey results indicate that that addressing pedestrian safety is much more important to the local community than achieving ADA design compliance, the safety index will receive a higher weighting, and sidewalk segments along high speed roadways with a history of pedestrian crashes will receive a higher net priority index.

Finally, sidewalk, crosswalk, and ramp prioritization indices can be further weighted to reflect geographic and other equity preferences. For example, if survey participants indicated that business improvement districts and low income neighborhoods should receive higher priority for funding, projects within these areas will receive higher priority scores. Project prioritization scores will be calculated using a master project table in excel and then via ArcGIS functions to arrive at final project priority scores. In forthcoming efforts, planning-level construction and lifecycle cost estimates (estimated from regional construction/maintenance cost sources such as bid documents) will also be linked with proposed improvements and factored into prioritization. Hence, a sidewalk segment that receives a lower independent priority, but is located immediately adjacent to a high-priority segment, may rise on the priority list because the marginal cost of repair is very low when the repair is combined with the high priority project. Cost integration should help communities select efficient combinations of repair and improvement projects.

**Summary**

Communities with serious sidewalk construction and maintenance backlogs often struggle with addressing pedestrian accessibility due to a lack of accurate condition data. Georgia Tech researchers have developed a suite of tools that provides a low-cost, semi-automated, and integrated/participatory approach to managing sidewalks as transportation assets. The Sidewalk Quality and Safety Assessment System utilizes smartphone and tablet-based technologies to inventory and assess sidewalk assets, organize this data into a sidewalk link and node network file, survey the community to identify public priorities for sidewalk assets, and prioritize and program sidewalk and curb ramp projects for repair.

**References**


