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Improving Inventory of and Investment in Bicycle and Pedestrian Facilities Through Targeted Public Outreach

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16. Abstract:

The Virginia Department of Transportation (VDOT) is committed to providing and maintaining transportation infrastructure for a transportation system of multiple modes, including bicycling and walking. A complete and well-maintained bicycle and pedestrian facility inventory is critical for that mission. Given the large number of bicycle and pedestrian facilities, it is impractical to rely exclusively on VDOT staff for all data collection, processing, and maintenance efforts. A crowdsourcing approach that leverages inputs from volunteers, student interns, or both offers an attractive alternative. In addition, VDOT needs better communication channels to reach out to facility users and collect feedback on facility conditions and needs.

The objective of this project is to develop a practical and effective crowdsourcing method for engaging targeted users of VDOT bicycle and pedestrian facilities to improve the existing inventory and meet the data needs for investment prioritization. To achieve this objective, this project reviewed mainstream crowdsourcing approaches that have been applied in the field of transportation and evaluated their applicability in the context of this project. The project team also interviewed agencies of localities in Northern Virginia to understand their practices and bicycling and pedestrian advocacy groups to understand the perspective of potential users. On the basis of these findings, this project developed a hybrid framework to achieve the research objective by integrating geoanalysis, crowdsourcing approaches, and targeted public outreach efforts.

The results of this project led to the following conclusions: (1) among the mainstream crowdsourcing approaches, the method based on a dedicated platform and targeted public outreach will be the most effective in helping VDOT improve its bicycle and pedestrian facility inventory and the investment prioritization process; (2) VDOT needs to periodically improve its existing bicycle and pedestrian inventory, which can be addressed by gradually applying the methods developed in this study; (3) practices of local agencies such as the DDOT curb ramp data collection program and the retrofit prioritization process can inform VDOT about opportunities for future improvement; and (4) InfraHub and the associated data collection process developed in this study can complement myVDOT and assist VDOT in targeted public outreach.

The study recommends that (1) VDOT's Traffic Engineering Division should gradually adopt the framework developed in this study and share information about the InfraHub tool as a means to improve both its bicycle and pedestrian facility inventory and the prioritization process for curb ramp retrofits; (2) VDOT's Traffic Engineering Division should share information about the differences between the two curb ramp inventories and the strengths of each with appropriate agency staff in the VDOT central office and the districts drawing on findings from this research; and (3) VDOT's Transportation and Mobility Planning Division should further evaluate InfraHub's value as a tool for targeted public outreach and geoanalysis for assessing pedestrian accessibility.

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FINAL REPORT

IMPROVING INVENTORY OF AND INVESTMENT IN BICYCLE AND PEDESTRIAN FACILITIES THROUGH TARGETED PUBLIC OUTREACH

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ABSTRACT

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INTRODUCTION

The Virginia Department of Transportation (VDOT) is committed to providing and maintaining transportation infrastructure for a transportation system of multiple modes, including bicycling and walking. This strong commitment is reflected in the adoption of the Policy for Integrating Bicycle and Pedestrian Accommodations by the Commonwealth Transportation Board (CTB) in 2004 (CTB, 2004) and of the State Bicycle Policy Plan (VDOT, 2011) and the State Pedestrian Policy Plan (VDOT, 2014) by VDOT. In addition, VDOT is committed to compliance with the Americans with Disabilities Act of 1990 (ADA) and the provision of travel accommodation to people with disabilities such as mobility limitations and visual impairments.

To meet these commitments, VDOT needs to effectively plan, engineer, and manage transportation assets that are critical for different modes and user groups. These assets include bicycle lanes, sidewalks, curb ramps, and accessible pedestrian signals (APS). However, VDOT does not always have perfect data on the presence and condition of these assets. For example, a Virginia Transportation Research Council (VTRC) report (Kastenhofer, 2010) concluded that VDOT has no statewide or district-level inventory of missing sidewalks, a situation which poses challenges for developing a systematic prioritization process for retrofit sidewalk projects. An NCHRP Report, *Pedestrian and Bicycle Transportation Along Existing Roads—Activetrans Priority Tool Guidebook* (Lagerwey et al., 2015), presented a step-by-step methodology for prioritizing improvements to pedestrian and bicycle facilities. However, the methodology requires a lot of data as inputs, which only helps to highlight the data challenges VDOT may face.

Considering the size of the network and the diversity of transportation assets, it is impractical to rely exclusively on VDOT staff to complete all the data collection, processing, and maintenance tasks. In the literature, many alternative data collection approaches have been proposed and evaluated. For example, the Michigan Department of Transportation (Dennis et al., 2015) evaluated four sources of transportation system data based on crowdsourcing approaches: aggregated crowdsourced data from a third party, social media data, Internet as a sensor, and dedicated platforms such as smartphone apps designed for a specific data collection effort. Each method showed great potential for a specific area of application, but not necessarily all areas because of the method's shortcomings. As a specific type of crowdsourcing approach, Internet-based citizen science projects have been able to rely on volunteers for scientific data collection that has to be done in a diverse geographic area and repeatedly over a long time. The work was pioneered by the Laboratory of Ornithology at Cornell University for bird observation (Bonney et al., 2009) and was later expanded to cover a wide range of phenomena of climate change (Leiserowitz and Smith, 2011). This method addressed challenges similar to those DOTs face when collecting bicycle and pedestrian facility data. However, the quality of crowdsourcing data is hard to control, and its applicability to support VDOT practice requires further assessment. For example, social media data may have low relevance compared with established data intake practices such as the myVDOT web portal. However, VDOT does not have to rely on a single data collection approach. A hybrid approach based on multiple data sources and supported by new technologies and targeted public outreach efforts may be more effective.

To better leverage the crowdsourcing approach to meet the data needs for improving the inventory and investment prioritization of bicycle and pedestrian facilities, VDOT commissioned this study to identify and evaluate a practical and effective crowdsourcing method that can fit into VDOT business processes.

PURPOSE AND SCOPE

The objective of the proposed project is to develop a practical and effective method for engaging targeted users of VDOT bicycle and pedestrian facilities to help improve (1) the inventory of these facilities and (2) investment prioritization based on inputs from targeted user groups. This study reviewed existing practices in bicycle and pedestrian facility data collection using crowdsourcing approaches. The research team also interviewed staff at localities in the Northern Virginia area to learn their current practices and interviewed representatives of advocacy groups to understand the perspective of facility users. The method proposed in this study was customized on the basis of existing VDOT resources. During the study (fall 2018), VDOT developed a new curb ramp and sidewalk inventory based on video stream to support the development of the VDOT ADA transition plan. This effort reduced the need of developing an inventory from the scratch but highlighted the need of periodically updating and improving the existing inventory. This study was recalibrated to consider the impact of that effort.

The scope of the work was limited to three types of bicycle and pedestrian facilities—bicycle lanes, sidewalks, and curb ramps—because of data availability. The APS system was not included because of the small number of intersections equipped with such a system (84 in total by September 2019, according to ArcGIS data available at virginiaroads.org). However, the

method developed in this study could be extended to cover other types of facilities with minimal modification. The field test was proof-of-concept in nature, but the deployment may scale up easily because of the small marginal costs.

METHODS

The following tasks were conducted to achieve the study objectives:

1. *Conduct a Literature Review*: The research field of crowdsourcing approaches and their applications is very dynamic because of rapid improvements in technology. The goal of this task was to gain an understanding of existing crowdsourcing approaches adopted by DOTs and localities, and particularly those designed for enhancing bicycle and pedestrian facility inventories. The research team analyzed the applicability of different crowdsourcing methods and identified the one with the highest potential to meet the needs of this project.

2. *Conduct a Review of the Existing VDOT Inventory*: The goal of this task was to better understand the data needs of VDOT to make sure the method developed in this research complemented and enhanced existing VDOT efforts. The research team reviewed and analyzed the following datasets shared by VDOT:
   - Bicycle facility inventory shared by the Transportation and Mobility Planning Division (TMPD)
   - Curb ramp inventory collected by the Traffic Engineering Division (TED)
   - Curb ramp, sidewalk, and barrier inventory developed by contractors using video stream and provided by TED

3. *Conduct Public Outreach to Advocacy Groups for Tool Design*: The main goal of this task was to learn from advocacy groups and, through them, the facility users about how they usually voiced their needs for bicycle and pedestrian facilities and about the pros and cons of different existing communication channels. A second goal was to introduce the smartphone app and the information collection process to be developed in this study to stakeholders, invite them to test the tools in a later phase of this study, and collect feedback from them for assessment and future improvement. This study focused on the Northern Virginia area for demonstration. A list of advocacy groups for bicyclists and pedestrians in the region was compiled using contacts developed in previous research conducted at George Mason University (GMU), suggestions from regional agencies during this study, and recommendations from facility users during this study (e.g., one user suggested Bike Arlington through comments left at the Facebook post about this project on the GMU Facebook page). An email or a phone message (see Appendix A) was sent to interviewees using the contact information provided on the advocacy group websites. The message briefly explained the objectives of the project and the purposes of the interview, and asked about their availability. A flyer (see Appendix B) that explains the smartphone app was also enclosed as an attachment to emails to facilitate the discussions during the interview. Six interviews were conducted. The advocacy groups that were interviewed and the names and titles of the interviewees are listed in Table 1. The interview protocol is provided in Appendix C. The protocol served only as a guideline on major topics to be covered, while

the actual conversation varied depending on the answers to the initial questions and the topics the interviewees wished to cover. The length of the interviews also varied, depending on how knowledgeable the interviewees were on the topics to be covered and their willingness to share; interviews went on for more than an hour in some cases. Responses from interviewees were then summarized and compared with those collected from local agencies to learn the perspectives from both sides. Lessons learned were then summarized to inform both the other tasks included in this project and VDOT's related business processes.

Table 1. Advocacy Groups Interviewed in This Study

Advocacy Group Name	Name and Title of the Interviewees
Bike Arlington	Henry Dunbar, Director*
Walk Arlington	Henry Dunbar, Director* Katy Lang, Program Manager
Washington Area Bicyclist Association	Ursula Sandstrom, Outreach Manager
Fairfax Association for Better Bicycling	Bruce Wright, Board Member
Bike Loudoun	Dennis R Kruse, President
Alexandria Families for Safer Streets	Mike Doyle, Board Member

*Henry Dunbar serves as the director of both Bike Arlington and Walk Arlington.

4. *Conduct Public Outreach to Local Agencies*: The goal of this task was to learn the current practice of local agencies in developing bicycle and pedestrian facility inventories, collecting feedback from facility users (including those related to ADA compliance), and using such data to prioritize facility retrofitting or new construction. The process was similar to that used for interviewing advocacy groups, but the interview protocol was different (see Appendix D). In total, 11 interviews were conducted. The National Park Service (NPS) was not on the list of local agencies to be interviewed, but Anne O'Neill from NPS participated in the phone interview with the Northern Virginia Regional Commission because of her work in Arlington. The local agencies that were included in the interviews and the names and the job titles of the interviewees are listed in Table 2.

Table 2. Agencies and Organizations Interviewed in This Study

Agency Name	Name and Title of the Interviewees
George Mason University	Ruth J. Townsend, ADA Coordinator
Fairfax County	Kenneth L. Saunders, ADA Coordinator
Fairfax County Department of Transportation	Tom Biesiadny, Director
Arlington County Transportation Division	Sarah Crawford, Assistant Director of Transportation Karina Ricks, Director of Mobility and Infrastructure
Loudoun County	Catherine Motivans, Accessibility Services Manager, ADA Coordinator
Loudoun County, Department of Transportation and Capital Infrastructure	Laura E. Ghosh, Transportation Engineer
City of Fairfax	Lesley Abashian, ADA Coordinator
City of Fairfax Public Works Department	Chloe Ritter, Multimodal Transportation Planner
Prince William County	George Phillips, Transportation Planner III
Northern Virginia Regional Commission	Debbie Spiliotopoulos, Senior Environmental Planner
National Park Service	Anne O'Neill, National ParkRx Coordinator
District of Columbia Department of Transportation	Cesar Barreto, ADA/Section 504 Coordinator Vivian Guerra, Accessibility & Inclusion Coordinator

ADA: Americans with Disabilities Act

The research team summarized the best practices from all local agencies that were interviewed. The findings were used to guide the development of the inventory and investment enhancement process based on targeted public outreach.

5. *Design a Hybrid Method for Improving Inventory of and Investment in Bicycle and Pedestrian Facilities*: This study developed a hybrid framework that leveraged the existing resources at VDOT, resources and expertise at George Mason University, and support from local agencies and advocacy groups to collect inputs from facility users in a cost-effective way with the goal of enhancing bicycle and pedestrian facility inventories. Figure 1 shows the overall framework of the hybrid method developed in this project for bicycle and pedestrian inventory enhancement and targeted public outreach.

   The method was dubbed as "hybrid" because it did not rely exclusively on anonymous data contributors. Instead, the researchers were actively involved in various steps of the entire process (blue cells in Figure 1). A smartphone app, InfraHub, was developed to help facility users report issues with bicycle and pedestrian facilities. All submissions were automatically geotagged and stored in a database hosted in the cloud (Amazon Web Services). The submissions were then projected in ArcGIS and validated by a research assistant using the photos submitted. The submissions were then used to update existing VDOT inventory or compiled as requests for new facilities. The later list could be used for the facility prioritization process.

   This core function of collecting facility condition data and needs for new facilities through targeted public outreach was supported by other components within the framework. A geoanalysis was conducted to identify discrepancies between two existing VDOT curb ramp inventories.

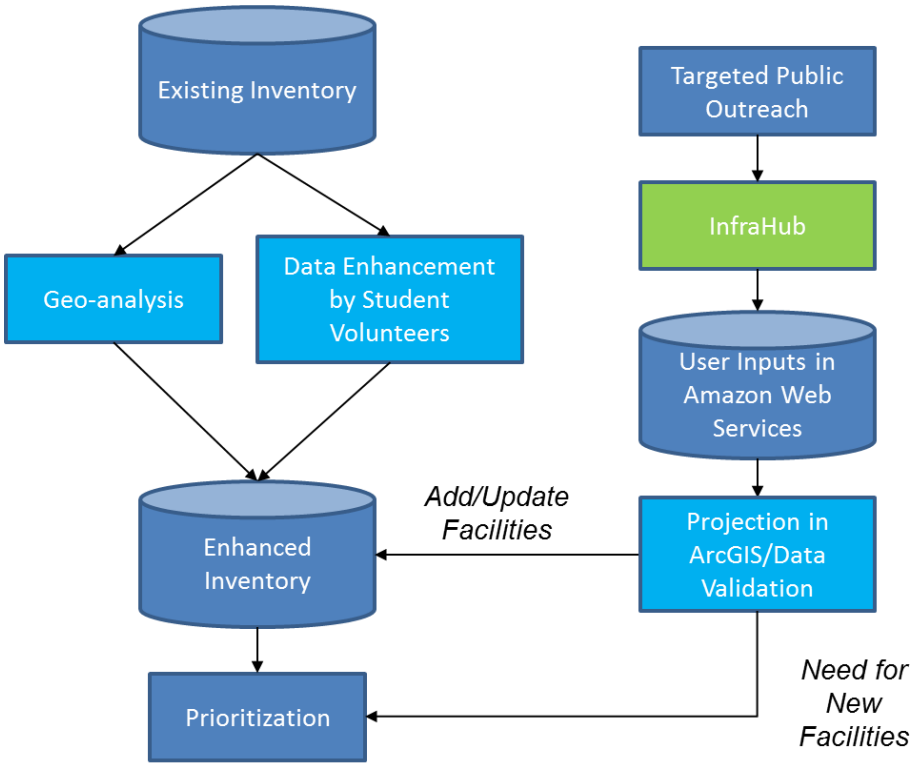

Figure 1. Overall Framework of the Hybrid Method for Bicycle and Pedestrian Inventory Enhancement and Targeted Public Outreach

6. *Evaluate the Hybrid Method Through a Field Demonstration*: The research method was then applied to demonstrate its capacity and to assess its performance related to efficiency, cost-effectiveness, and data quality. For demonstration purposes, the application focused on the enhancement of curb ramp inventory, but the smartphone app and the analysis process are generic enough to cover other types of bicycle and pedestrian facilities.

   The alpha version of InfraHub was presented to the Technical Review Panel members and other VDOT stakeholders during the spring 2019 Transportation Planning Research Advisory Committee (TPRAC) meeting. The major comments were to stay focused on curb ramp and bicycle facilities and to keep the list of facility issues consistent with the VDOT inventory. The app was revised on the basis of the feedback. Additional internal testing on its usability and functionality was conducted at George Mason University. Issues such as compatibility with different generations of iPhones (different screen resolutions affected the display of the interface) were addressed. The beta version was released in July 2019 to support the field test. Minor updates were released periodically to fix issues found in testing in a timely manner. To install the app, users could either search InfraHub in the iPhone App Store or scan the QR code in the recruiting flyer, which is provided in Appendix A.

7. *Provide Training and Recommendations*: Employing the results of the field evaluation, the research team identified the strengths and weaknesses of the crowdsourcing and targeted public outreach approaches. Accordingly, the research team made recommendations on potential ways for VDOT to use InfraHub to inform its stakeholders about the characteristics

and enhancement opportunities of the existing bicycle and pedestrian facility inventory and to target public outreach opportunities.

RESULTS

Literature Review

The crowdsourcing approach is a practice of obtaining information or inputs for a task by enlisting efforts of a large number of individuals, typically volunteers or users of a service. It promises to offer a cost-effective way to accomplish a task that is geographically distributed in nature or requires small input from a large number of people. In the field of transportation, crowdsourcing approaches are usually based on data from one of three sources: third-party crowdsource data providers, social media, and dedicated platforms.

Applications Based on Third-Party Crowdsourced Data

Many third-party data providers consolidate travel trajectories from individuals and produce data products through crowdsourcing/big data methods. Examples of such data are travel time (e.g., INRIX) and Origin-Destination matrices (e.g., Streetlight, AirSage). DOTs have been routinely using such data for traffic operations and planning studies. Waze data is another example of crowdsourcing data that DOTs commonly use to support travel information services and incident management. Table 3 lists additional examples in which state DOTs and local agencies have used crowdsourcing approaches (mostly third-party crowdsourcing data) to support traffic operations, according to a Federal Highway Administration study (FHWA, 2019). However, none of these applications or studies based on a third-party data source focused on bicycle and pedestrian facilities.

Table 3. Examples of State DOTs and Local Agencies Using Crowdsourcing Data for Operations (Source: FHWA Center for Accelerating Innovation)

Agency	Data Source	Focus
Utah DOT	Mobile app	Enlisting volunteers to report weather conditions
Indiana DOT	Third-party probe data	Supporting active traffic management
Kentucky Transportation Cabinet	Two crowdsource providers and a third-party probe	Improving road maintenance
Delaware DOT	Mobile app	Reporting traffic or roadway issues
Florida DOT	Third-party data	Improving the response for crashes and road closures
City of Louisville, KY	Third-party data	Assessing the effects of signal retiming
City of Austin, TX	Third-party data	Prioritizing signal retiming

DOT: Department of Transportation; FHWA: Federal Highway Administration

Methods Based on Social Media Data

In recent years, social media such as Twitter, Foursquare, and Facebook have become popular data sources for transportation studies based on crowdsourcing approaches. For

example, researchers have used Twitter data to infer personal trip purposes (Hasan and Ukkusuri, 2014; Pianese et al., 2013), travel activity patterns (Cao et al., 2014; Hasan and Ukkusuri, 2014; Zhang et al., 2017), and drivers' routing behavior (Pan et al., 2013). Researchers have also leveraged tweet data to predict traffic flow in the San Francisco Bay Area (Ni et al., 2014) and transit ridership in New York City (Ni et al., 2017) under event occurrences with optimization models. Most of these studies rely on the geotag associated with the postings. Other studies have explored the content of the postings to detect special events, such as sports games, social riots, or transit service disruptions through semantic analysis. However, most issues related to bicycle and pedestrian facilities were not the subject of extensive social media activities. The existing crowdsourcing approaches may not apply here because of the low relevance of most postings related to bicycle and pedestrian facilities in social media. To better illustrate the point, the research team analyzed a set of more than 4 million tweets collected during the period of January 2016 through February 2017 in the Washington, D.C., metropolitan area. As shown in Table 4, the relevance of tweets to bicycle and pedestrian facilities was very low. Even among the 126 and 161 tweets that did contain key words related to bicycle and pedestrian facilities, those tweets were usually about issues other than the facilities themselves. One example was "we need parking enforcement sidewalk chalk," which contained the key words, but was actually about parking enforcement.

Table 4. Semantic Analysis of Twitter Data on Bicycle and Pedestrian Facilities

Data Set	Number	Percentage
Full dataset	4 million	100
Northern Virginia	1,094,734	27.1
Data mining using sidewalk, pedestrian, zebra crossing, or crosswalk	126	0.00315
Data mining using biking, bike, cycling, bicycle, or bicycling combined with lane, trail, share, path, crosswalk, sidewalk, or signal	161	0.004

Methods Based on Dedicated Platforms

Crowdsourcing approaches can also be implemented in an active way rather than having staff members just passively analyzing data. Some studies in the literature enlisted volunteers, mostly on the Internet, to help with data collection or to provide inputs. In most cases, a dedicated platform that was either web-based or smartphone app–based had to be developed to support the data collection, sharing, post-processing, and/or applications. For example, Li et al. (2018) enlisted volunteers to create a crosswalk inventory based on parcel boundaries data through an ArcGIS platform for six communities in Atlanta. A group of researchers at the University of Maryland (Hara et al., 2012; Saha et al., 2019) developed an online platform to enlist volunteers to create a sidewalk inventory and identify accessibility issues using Google Street View data. The researchers showed that untrained crowd workers could identify sidewalk accessibility issues with a fair accuracy rate (about 80% on average). A similar concept was adopted by the IBM Sidewalks application (Shigeno et al., 2013). A research team at the Georgia Institute of Technology (Cebe et al., 2016) developed Sidewalk Sentry, an application for Android tablets, to help researchers and volunteers collect sidewalk data by scouting the neighborhood. Bennett et al. (2009) enlisted students to evaluate curb ramps in Halifax, Nova Scotia, to identify ADA-related accessibility issues. Erraguntla et al. (2017) discussed the idea of developing a smartphone app, MySidewalk, to help people to create a pedestrian inventory as volunteers and to report facility issues as users. This research idea is similar to the concept of

this study. However, a quick search in the iPhone App Store did not show any availability of that app. Table 5 summarizes a few well-known examples in the literature of projects that applied the crowdsourcing approaches based on a dedicated platform for bicycle or pedestrian data collection. Most applications based on dedicated platforms focus on tracking bicycle trips, and only a few focus on facilities. Among the ones that focus on facilities, very few platforms focus on curb ramps and none focus on helping users report issues related to curb ramps.

Table 5. Examples of Crowdsourcing Approaches in Bicycle or Pedestrian Data Collection Based on Dedicated Platforms

Product	Platform	Focus
COORD by Sidewalk Labs	Mobile App	Capturing curb assets, such as parking signs, curb paint, and ADA ramps
CycleTracks by San Francisco County	Mobile App	Understanding bicycle traffic demand
Strava Metro	Mobile App	Understanding bicycle traffic demand
Cyclopath by the University of Minnesota	Mobile App	Tracking bicycle trips
SidewalkScout by Georgia Tech	Mobile App	Reporting sidewalk problems, such as potholes, obstructions, or surface discontinuity
Cycle Atlanta	Mobile App	Tracking bicycle trips and reporting issues
Project Sidewalk by the University of Washington and the University of Maryland	Web App	Digitizing curb ramps using online workers

ADA: Americans with Disabilities Act

Other Studies on Bicycle and Pedestrian Facility Data Collection

Finally, some researchers have focused exclusively on technology and have tried to develop artificial intelligence (AI) or advanced sensing technologies to extract data for bicycle and pedestrian facilities. For example, researchers at the University of California, Riverside (Luo et al., 2019), tried to train machine learning algorithms to automatically extract sidewalk inventory from aerial images. Abbott et al. (2018) proposed using deep-learning algorithms to extract sidewalk data from Google Street View data. Ai and Tsai (2016) developed a method to automatically generate sidewalk inventory using three-dimensional mobile lidar data.

Summary

The literature review showed that crowdsourcing approaches have been widely used by state DOTs and local agencies to support their missions. Among the three types of approaches based on different data sources, one based on dedicated platforms was the most relevant for bicycle and pedestrian data collection. None of these existing approaches or platforms addressed all data needs identified in this project, and there were no dominant/mainstream platforms in this area. Another common weakness of these existing efforts is the lack of emphasis on collecting feedback from facility users, which is critical for the prioritization process. Therefore, the general concept needs to be customized to address the specific data needs at VDOT. Further, the framework needs to leverage existing resources and established business processes at VDOT. This study will address those issues by integrating the concept of crowdsourcing and efforts of targeted public outreach.

Review of the Existing VDOT Bicycle and Pedestrian Facility Inventory

To meet VDOT's data needs for bicycling and pedestrian facilities and to better support VDOT business processes, the agency has recently expanded its efforts in developing data inventories in related fields and has made significant progress. To better understand the data needs and to make sure the data collection methods to be developed in this research would complement and enhance these existing efforts, the research team first reviewed and analyzed related datasets shared by VDOT.

Bicycle Facilities Inventory

Bicycle facilities data is an important input for the multimodal planning process the Transportation and Mobility Planning Division (TMPD) oversees. Each VDOT district office has a district bicycle and pedestrian coordinator, and TMPD at the VDOT central office coordinates all statewide efforts. Over the years, TMPD has accumulated significant georeference data for bicycling facilities. Figure 2 shows the bicycle facilities documented in the TMPD dataset, and Figure 3 shows a detailed map of Northern Virginia, where most of the bicycle facilities are located. The definitions of different types of access for bicycle facilities were inherited from the original data creators (counties and cities, or data providers such as Strava) and could be sometimes confusing. For example, "sidewalk" means bicyclists were allowed to use a segment of sidewalks between two bicycle facilities.

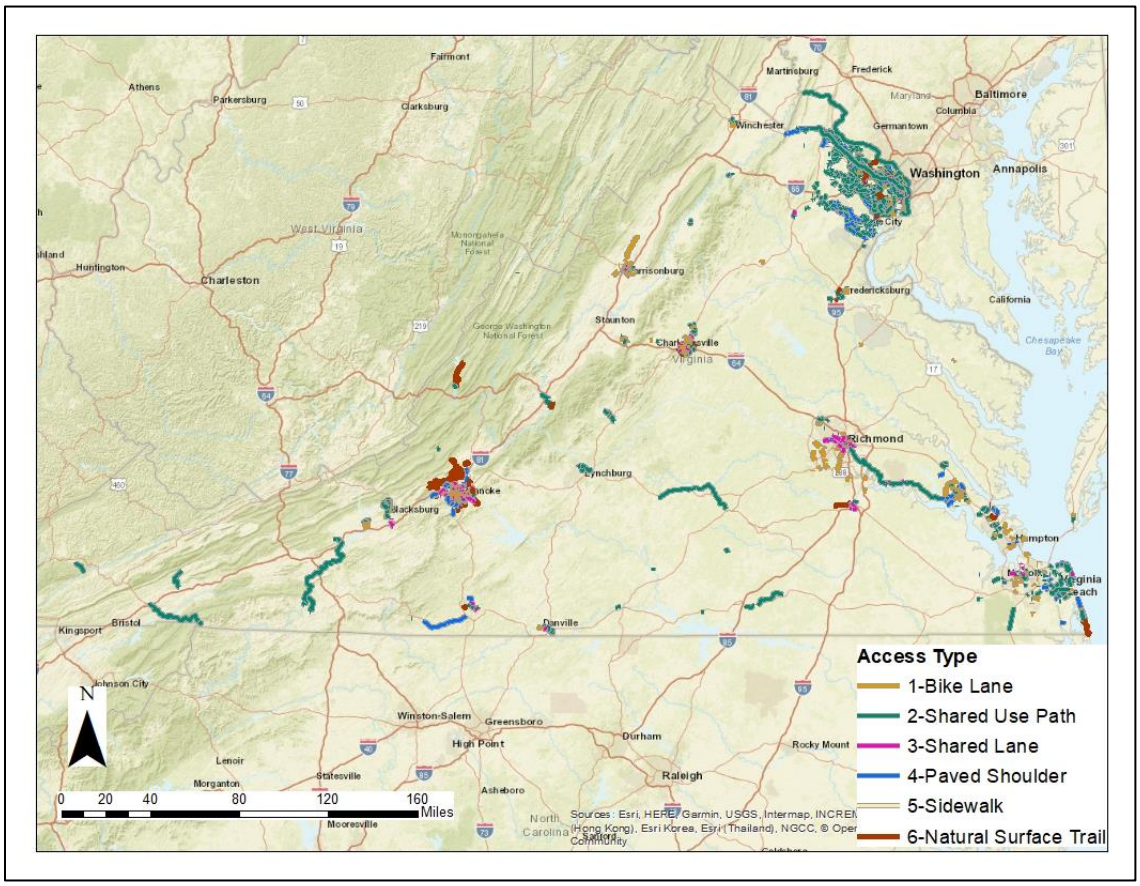

Figure 2. Bicycle Facilities in Virginia

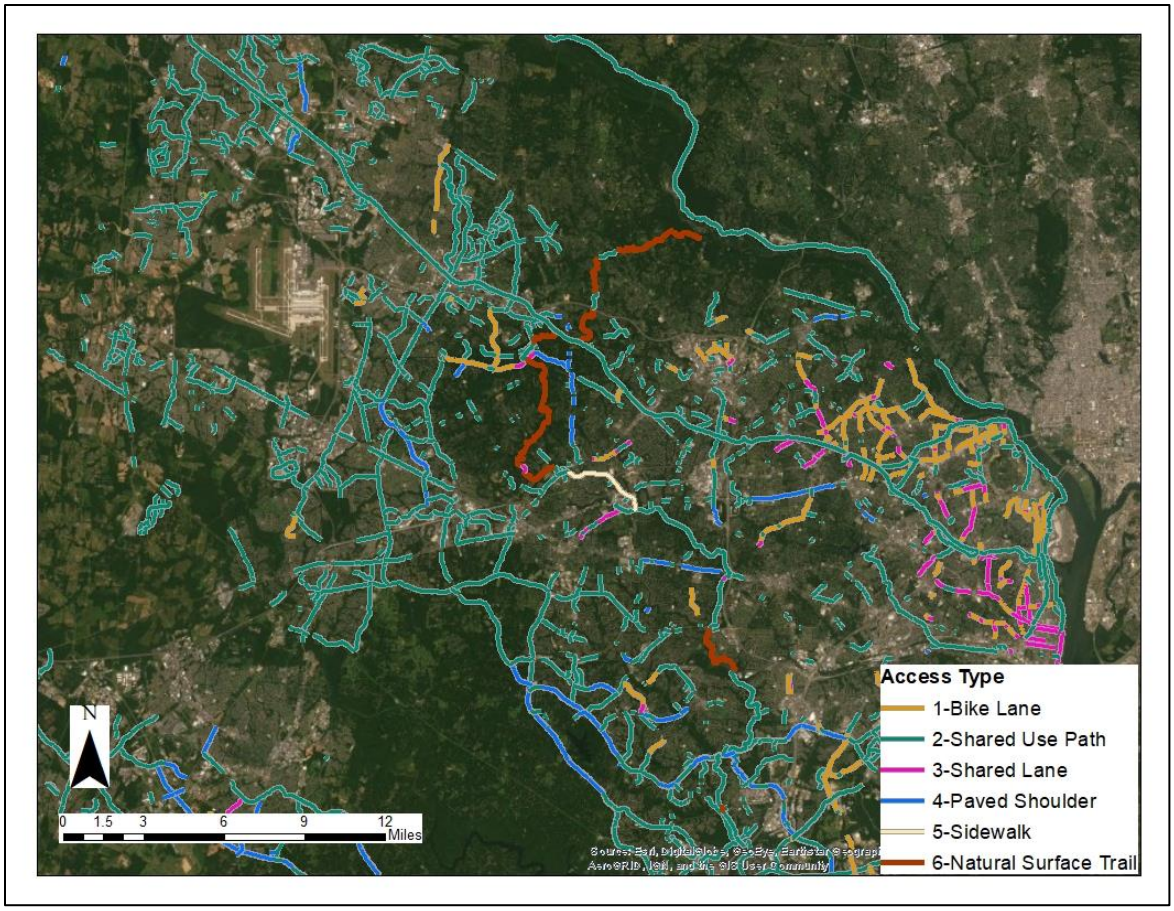

Figure 3. Bicycle Facilities in Northern Virginia

Table 6 shows the number of different bicycle facilities recorded in the TMPD geodatabase and the total length of these facilities by category. Conversations with TMPD staff have indicated that this database is very comprehensive and includes most of the bicycle facilities in Virginia.

Table 6. Number of Bicycle Facilities and Total Length by Facility Category in VDOT TMPD Bicycle Facility Inventory

Facility Type	Number of Segments	Total Length (miles)
1-Designated Bicycle Lane	940	392.6
2-Shared Use Bicycle Path	3,192	1,245.5
3-Shared Lane	642	227.1
4-Paved Shoulder	389	256.5
5-Sidewalk	17	4.9
6-Natural Surface Trail	221	197.4

The database also includes important information about each bicycle facility, such as its location (in various formats to support different business purposes), related jurisdiction, related metropolitan planning organizations (MPOs), VDOT district, length, lane miles, pavement conditions, starting year of accommodation, facility type, and types of roads it parallels. A complete list of attributes is provided in Appendix E. Although the data is very comprehensive, it still could be enhanced in several ways to better support policy and investment decision-

making. For example, the current database does not include lane width information. According to the *AASHTO Guide for the Development of Bicycle Facilities* (2012), the minimum width of a bicycle lane should be 1.5 meters (5 feet) against a curb or adjacent to a parking lane. It is unclear whether all the bicycle lanes listed in the TMPD inventory meet such requirements. In addition, the topological structure of the bicycle lanes (one-way or two-way; connectivity with other facilities) is not reflected in the geodatabase. This may prevent effective analysis of connectivity or accessibility (whether a lane is one-way or two-way is an attribute, but it is not reflected in the data structure; the data is largely based on the centerline of the parallel road, and the connectivity of adjacent bicycle lanes is not clear).

Curb Ramp and Sidewalk Data

Compared with the bicycle lane inventory, a pedestrian facility inventory is much more challenging to develop because of the diversity of facility types, the large number of facilities, and the huge geographic area. To address this challenge, VDOT TED created a tool based on the ArcGIS Online platform to record curb ramps, a facility type that is critical for the ADA transition plan, in a georeferenced environment. The tool can be accessed through an iPad. VDOT staff, contractors, or both can then create the facility feature (a point in ArcGIS) through an interactive interface. TED has accumulated a huge database over time, and Figure 4 shows an example for the area close to the George Mason University campus in Fairfax. The database classifies each curb ramp into one of the six conditions based on its characteristics. Condition A is the best and requires the presence of truncated domes and fair or better material conditions. Condition B usually means those curb ramps have only exposed aggregate surface as the detectable warning surface and see moderate cracking, faulting, or spalling in materials. Condition C implies no detectable warning surface or very poor material conditions. Condition D is the worst and implies a curb ramp is warranted but currently does not exist. N/A means a curb ramp is not needed at that location. In some cases, the attribute column for a point was empty (usually an error in data collection) and such points were labeled as Null in ArcGIS. Table 7 shows the number of features in each category.

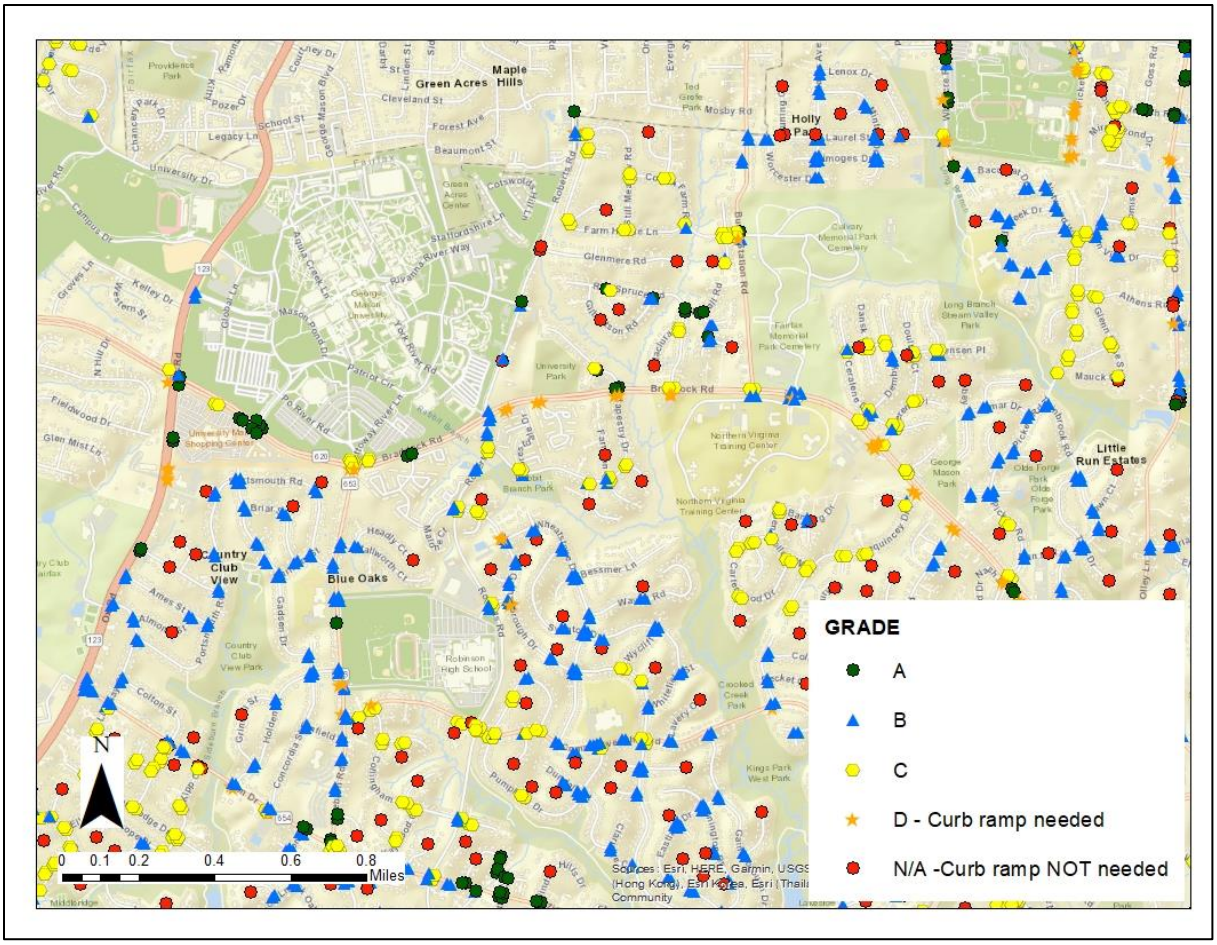

Figure 4. ADA Curb Ramps Close to the George Mason University Fairfax Campus, Based on the VDOT TED Inventory

Table 7. ADA Curb Ramp Grade and the Number of Features in Each Category

Grade	Number of Facilities	Percentage
A	7,285	17.4
B	15,135	36.2
C	10,682	25.6
D—A curb ramp is needed	3,136	7.5
N/A—A curb ramp is not needed	5,309	12.7
Null*	214	0.5
Total	41,761	100

*Null indicates information in this column is missing for these points.

In addition, this inventory includes other curb ramp attributes that are important for TED business processes, such as the type of the detectable warning system and its condition. Appendix F provides a complete list of attributes. This inventory shows a complete log of when and what type of improvements VDOT has implemented, information that is critical for performance evaluation.

The data quality of this inventory is very satisfactory, because it was mostly developed by VDOT staff through fieldwork. However, it is not complete because of the huge number of facilities and limited staffing. In order for VDOT to develop the ADA transition plan, a more

complete inventory of pedestrian facilities is needed. In fall 2018, VDOT developed a more comprehensive pedestrian facility inventory using visual inspection based on video stream that VDOT recorded for multiple business purposes (Figure 5). Tables 8 through 10 show the ADA curb ramp classification based on the number of barriers (e.g., utility poles at the curb ramp location), the conditions of the detectable warning system, and the overall observed conditions.

Table 8. ADA Curb Ramp Classification Based on the Number of Barriers in the Fall 2018 Inventory

Number of Barriers	Number of Facilities	Percentage
A - 0 Barriers	65,770	75.7
B - 1–2 Minor Barriers	210	0.2
C - > 0 Major Barriers or >2 Minor Barriers	105	0.1
Null*	20,775	23.9
Total	86,860	100

*Null indicates information in this column is missing for these points.

Table 9. ADA Curb Ramp Classification Based on the Conditions of the Detectable Warning System in the Fall 2018 Inventory

Detectable	Number of Facilities	Percentage
A - Truncated Dome	14,640	16.9
B - Exposed Aggregate Surface	27,917	32.1
C - No Detectable Warning Surface	23,545	27.1
None	11	0.0
Null*	20,747	23.9
Total	86,860	100

*Null indicates information in this column is missing for these points.

Table 10. ADA Curb Ramp Grade and the Number of Features in Each Category, Based on the Fall 2018 Inventory

Observed Condition	Number of Facilities	Percentage
A - No Deficiency	14,355	16.5
B - Minor Deficiencies	27,478	31.6
C - Major Deficiencies	24,302	28.0
D - No Access Where Required	6,779	7.8
N/A - No Required Access	13,945	16.1
Null*	1	0.0
Total	86,860	100

*Null indicates information in this column is missing for these points.

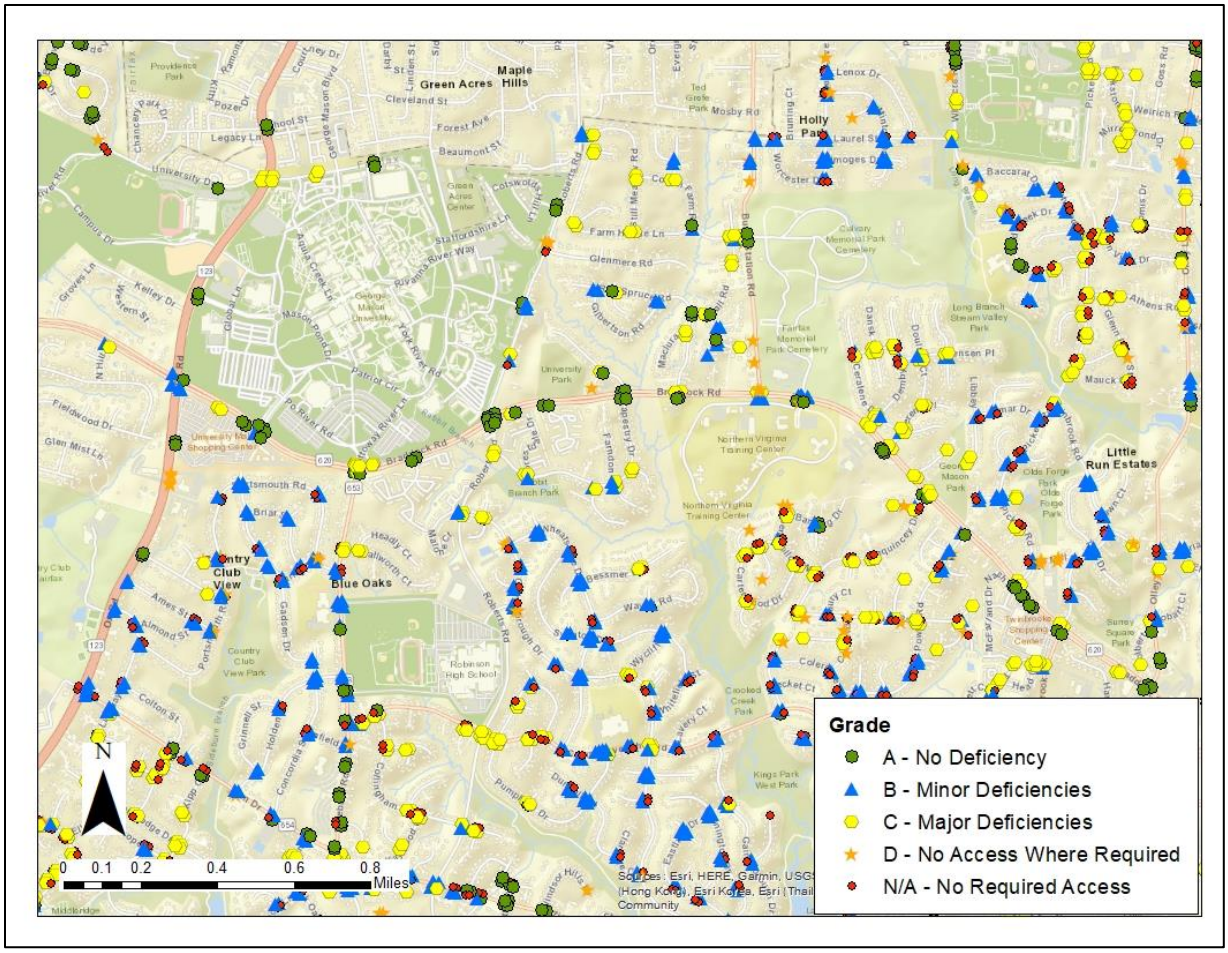

Figure 5. ADA Curb Ramp Near George Mason University, Fairfax Campus, in the 2018 Inventory Based on Video Stream

Comparing the VDOT curb ramp inventories developed through the ArcGIS online platform and those developed through visual inspection based on the video stream shows they differ in several ways. The total number of curb ramps (or features based on ArcGIS terminology) in the former inventory is 41,761, and the total number in the 2018 inventory is 86,860. However, this does not mean the inventory based on the ArcGIS Online platform is just a subset of the 2018 curb ramp inventory based on the video stream. Figure 6 compares the curb ramps recorded in the inventory based on the ArcGIS Online platform and the 2018 inventory based on video stream. Each inventory includes curb ramps that do not exist in the other, and their grades in the two databases are not necessarily the same. Given the different data collection methods, different time of collection, and the complexity of the data collection process, such discrepancies can be expected. Visual inspection revealed that most of the curb ramps from the two inventories are consistent in grade and location. As indicated earlier, both inventories have a unique role to play in VDOT business processes. To better support VDOT missions, including the development of the ADA transition plan and the scheduling and prioritization of improvements, it would be helpful if the data discrepancies were fully analyzed and the two databases integrated.

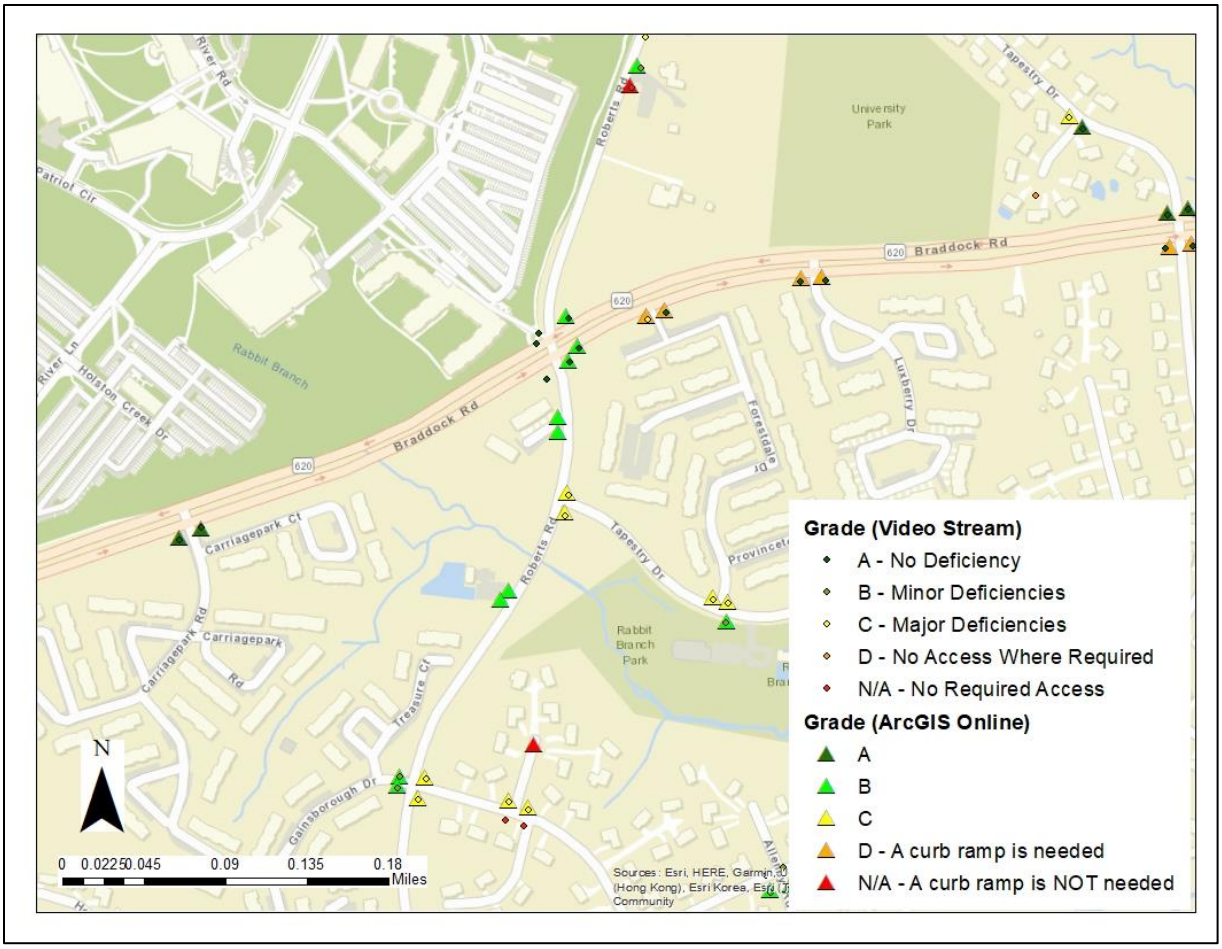

Figure 6. A Comparison of the Curb Ramps Recorded in the Inventory Based on the ArcGIS Online Platform (triangles) and in the 2018 Inventory Based on Video Stream (dots)

In addition, the 2018 inventory based on video stream also includes sidewalks and barriers. The sidewalk inventory includes 44,028 georeferenced segments with a series of attributes related to service conditions. Examples include width, pavement conditions, and overall serviceability assessment. Figure 7 shows the sidewalks near George Mason University in various conditions, and Table 13 shows the percentage of sidewalks in different conditions. One major difference between the sidewalk and the curb ramp inventories is that the sidewalk inventory does not show anything if a sidewalk does not exist, but the curb ramp inventory is likely to show that a curb ramp is needed at that particular location. Appendix G shows an example of the barrier inventory for an area close to the I-495 Beltway. It includes 931 features in total and ranges from unreasonable slope (both lateral and vertical) to missing sections. The full list of barriers can be found in the legend for Figure G1 in Appendix G.

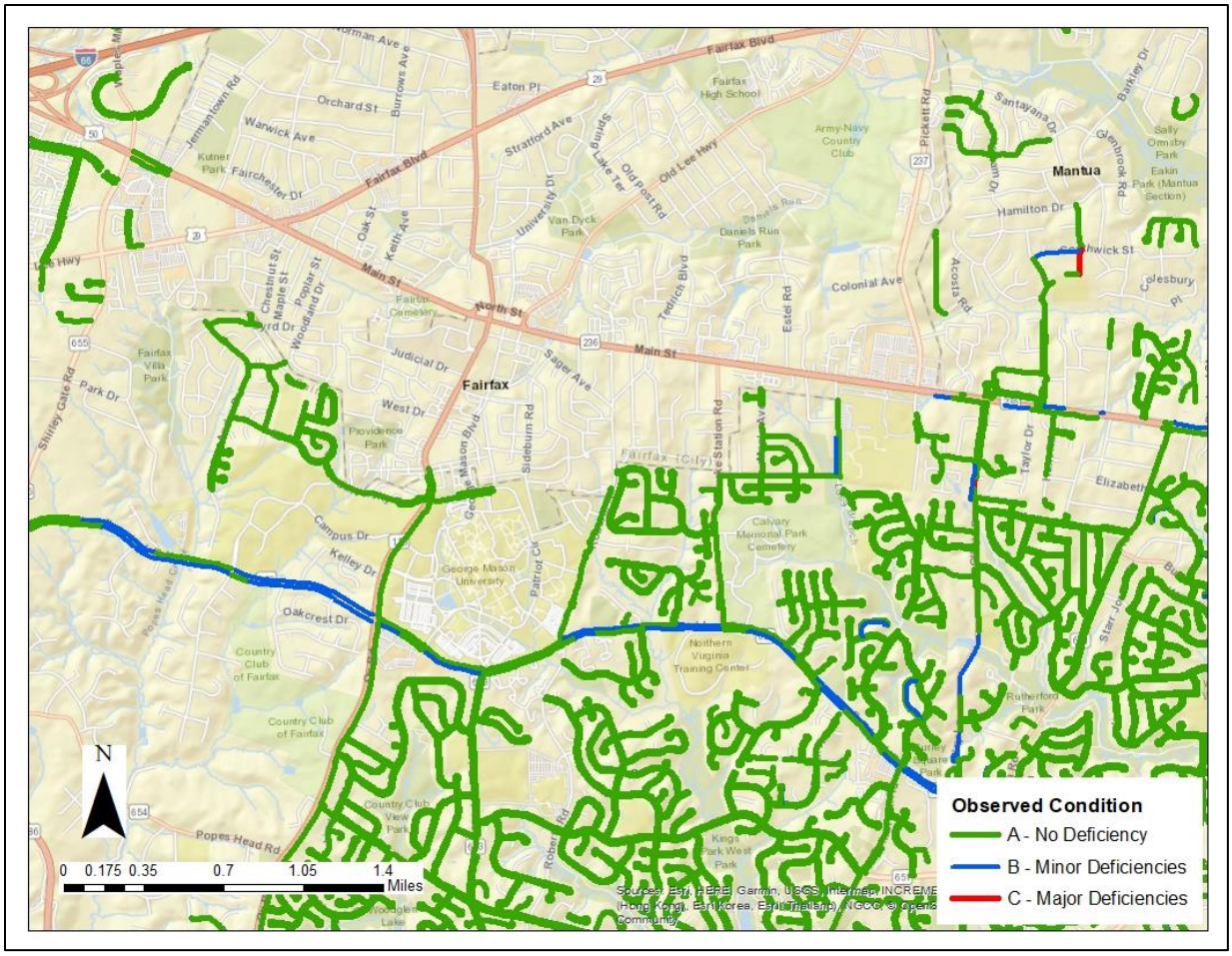

Figure 7. VDOT Sidewalk Inventory Based on Video Stream

Table 11. Sidewalk Classification and the Number of Features in 2018 VDOT Inventory

Observed Conditions	Number	Percentage
A - No Deficiency	41,510	94.3
B - Minor Deficiencies	1,586	3.6
C - Major Deficiencies	923	2.1
Null*	9	0.0
Total	44,028	100

*Null indicates information in this column is missing for these points.

Data Summary

A review of the existing VDOT bicycle and pedestrian facility inventories shows that VDOT has invested heavily in this area and has made significant improvements over the years. Given the complexity of the bicycle and pedestrian facilities, some data gaps still exist and are summarized as follows:

1. The existing bicycle inventory is very comprehensive but still lacks some attributes, such as lane width. The topology of bicycle facilities is not fully coded, which may prevent advanced geoanalysis for planning purposes (e.g., accessibility).

2. The two curb ramp inventories have good geographic coverage, but it is unclear whether they are complete given the huge number of facilities. Although the 2018 inventory based on video stream includes more curb ramps, it also includes more than 20,000 features with no attributes (showing as null). In addition, both inventories serve unique VDOT business processes. One provides a more comprehensive list to support the development of the ADA transition plan, while the other provides a history of facility improvements and is likely to have better data quality and more attributes because it was directly collected by VDOT staff in the field. It would be very valuable if the two inventories were linked or integrated.

3. Both the sidewalk and curb ramp inventories are valuable assets for VDOT business processes. The information could be even more valuable and could better support the prioritization processes if this data were integrated in a georeferenced database where advanced geoanalysis could be conducted. For example, the curb ramp and sidewalk data are not linked, and a user of the data does not know whether a person with a wheelchair can go freely from one location to the other. VDOT may need to add its crosswalk inventory into the pool and connect all three inventories to support such analysis. In addition, it would be helpful if such data could be integrated with the parcel or census data to enable consideration of the number of users to such facilities, which is critical for the prioritization process.

4. The addition of the 2018 curb ramp inventory based on video stream eliminated the need to develop a curb ramp and sidewalk inventory from scratch. However, there is still a need to continuously update the conditions of existing facilities registered in the database and to add new facilities as the field conditions change over time. The geoanalysis to be shown in the later subsections also highlights the need for a mechanism to keep the inventory up to date.

5. The conditions of existing bicycle and pedestrian facilities are fluid, and the inventories need to be updated periodically. New facilities will be built and will need to be added. It would be very costly for VDOT to repeat the exercise of inventory development every few years. Therefore, VDOT needs to explore a more cost-effective way to collect feedback from the users and to update the database in a less resource-intensive way.

The existence of these inventories and the issues identified in this task were considered in the design and implementation of the framework.

Targeted Public Outreach

This section summarizes the findings from the targeted public outreach efforts.

Inventory Development, Maintenance, and Usage Among Localities

To better understand the current practices in the Northern Virginia region, this study included interviews with localities about whether and/or how they developed inventories of bicycle lanes, sidewalks, and curb ramps and how the data was used. In Virginia, all cities,

incorporated towns, and Arlington and Henrico counties manage the secondary highways within their jurisdiction (VDOT, 2011) and thus are responsible for the bicycle/pedestrian accommodations on those roads. In addition, localities also develop their own comprehensive plans and/or bicycle master plans that provide guidance to VDOT project managers on the location and type of bicycle/pedestrian accommodations. Therefore, local practices related to bicycle and pedestrian facilities may also inform VDOT. Table 12 summarizes major findings from these interviews. Most localities have developed a bicycle lane inventory in ArcGIS via dedicated platforms such as Google Maps, Open Street Maps, and/or Strava. However, the availability of sidewalk inventory is less common and only the District of Columbia Department of Transportation (DDOT) maintained a curb ramp inventory. None of the localities has an established plan to continuously update and maintain the bicycle and pedestrian facility inventories except for DDOT, a situation that illustrates the challenge of keeping the inventories up to date. DDOT's practices will be presented in detail in the following subsections.

Most localities used their data to support the development of the county/city master plan. However, most applications were qualitative (e.g., showing the facilities on a map in public hearings), and there was no formal process to consider bicycle and pedestrian facilities quantitatively, or to conduct geoanalysis by integrating them with other facility data, demographic data, or both. Only DDOT has a formal process to use such data to support the curb ramp retrofit prioritization process and the development of an ADA transition plan.

Table 12. Bicycle and Pedestrian Facility Inventory Development, Maintenance, and Data Usage Among Selected Northern Virginia Localities

Localities	Inventory Availability			Updating Plan	Applications
	Bicycle Lanes	Sidewalks	Curb Ramps		
Arlington	Yes	Yes	In progress	No	Master plan, pavement scheduling
Fairfax City	Yes	No	No	No	Master plan
Fairfax County	Yes	Yes	Not sure	No	Pavement scheduling
Loudoun County	Yes	Yes	No	No	Master plan
Prince William County	Yes	Yes	No	No	Comprehensive plan
DDOT	Yes	Yes	Yes	Video-based	ADA Transition Plan, curb ramp retrofit prioritization, public outreach, pavement scheduling

DDOT: District of Columbia Department of Transportation; ADA: Americans with Disabilities Act

Usual Communication Channels for the Public

Most local agencies were working in compliance mode in their provision of bicycle and pedestrian facilities. If a pedestrian inventory was developed, the effort was usually dedicated to the development of the city/county master plan and/or in support of other business processes at the agency. Many agencies exhibited a reactive approach to addressing needs for bicycle and pedestrian facilities. There was no formal process for actively reaching out to facility users. Instead, most agencies would wait for facility users to submit requests through established communication channels. Figure 8 summarizes the typical channels for voicing a bicycle/pedestrian facility need or reporting an issue with existing facilities to a local government.

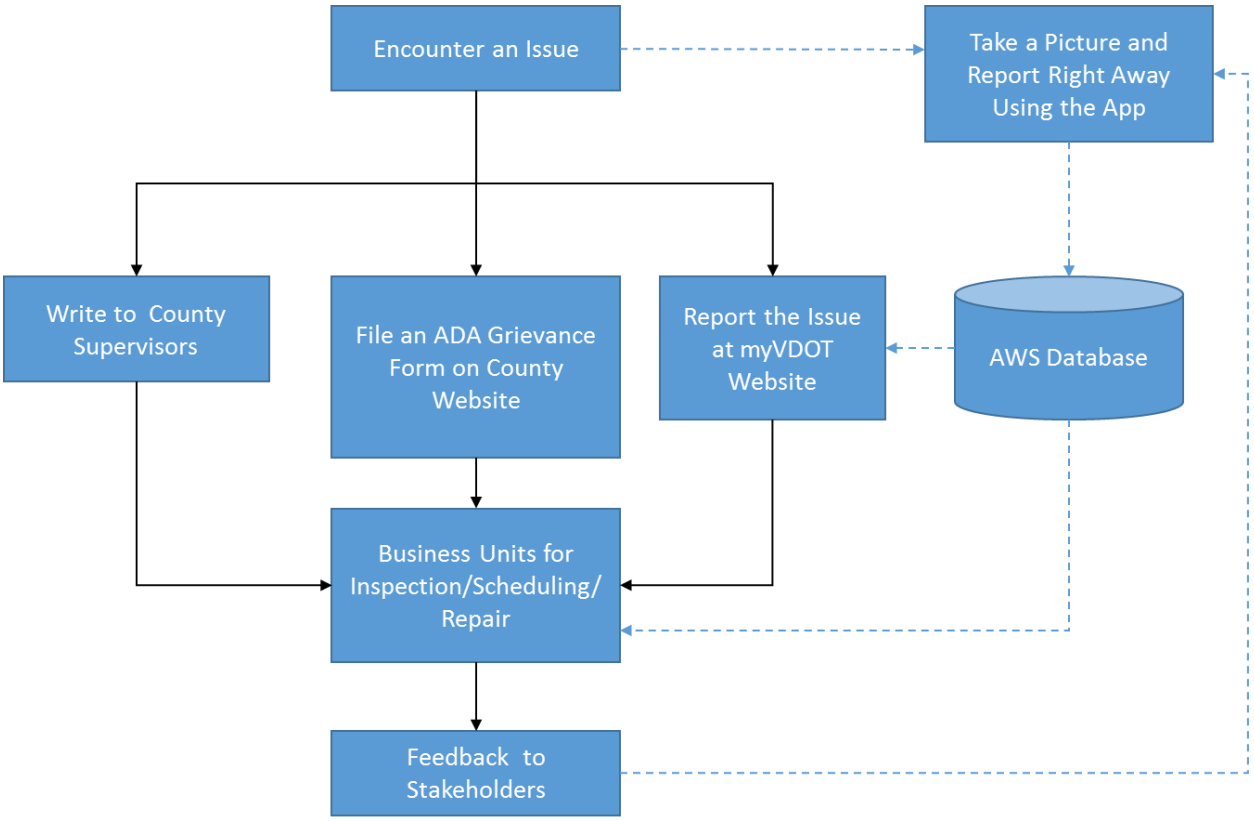

Figure 8. Typical Process for Voicing a Need for or Reporting an Issue With Bicycle and Pedestrian Facilities and the Complementary Process Developed in This Project
ADA: Americans with Disabilities Act; AWS: Amazon Web Services

Users or stakeholders can usually voice a bicycle or pedestrian facility need or report an issue with an existing facility through one of the three communication channels: (1) write to or call the office of one of the county supervisors (we use county as an example here, but the process for a city is similar), (2) file an ADA grievance form (if applicable) by following instructions on a county or city website, or (3) visit the myVDOT website and report a need by following the step-by-step guidelines on the website.

Facility users would typically use a computer to write an email to a county supervisor or to fill out an ADA grievance form. They have to describe the facility location using an exact address, crossing street names, or other anchors (e.g., commercial properties along the street). They can also attach a photo to substantiate their claims. Describing the location is easier on the myVDOT website because it provides an interactive map that allows users to locate the facility by clicking on the map directly.

After receiving the report, agencies usually send their staff to the field to inspect the facility in question and take action if needed. However, describing the location verbally or using an interactive map is not always easy. Some interviewees from the advocacy groups indicated that they sometimes receive calls from the county or VDOT field staff requesting more information about the facility location. In addition, although using these conventional reporting channels may be easy for people who are familiar with them, users who rarely use these tools

may find them difficult because of the need to remember the exact location or to take a photo for uploading later. A tool that can support reporting anytime and anywhere could be very useful for ordinary users.

Needs from Advocacy Groups' Perspectives

The research team interviewed six advocacy groups to learn their perspective on the bicycling and pedestrian facility needs and the communication channels to express such needs. In general, advocacy groups for bicycling were more vocal and raised a wide range of issues. The most common issues were about potholes and dysfunctional push buttons at crosswalks. However, both the Fairfax Association for Better Bicycling and Bike Loudoun indicated that their major concerns were the missing segments between existing bicycle lanes. They wanted a better tool to identify those missing segments and to raise awareness about them among policy makers and the public. Table 13 summarizes the different issues about bicycle facilities discussed during the interviews.

Table 13. Bicycle Facility Needs and Issues Identified in the Interviews with Advocacy Groups

Facility Issues Discussed	BA	WABA	FABB	BL
Potholes	X	X	X	X
Dysfunctional push buttons	X	X	X	
Lighting along bicycle trails		X		
Strips worn away		X		
Snow plowing		X		
Graffiti on or along bicycle lanes		X		
Missing connections between bicycle lanes			X	X
New bicycle lanes	X			X

BA: Bike Arlington; WABA: Washington Area Bicyclist Association; FABB: Fairfax Association for Better Bicycling; BL: Bike Loudoun

The issues raised by the pedestrian advocacy groups were more generic. Their major issue was safety. For example, a board member of the Alexandria Families for Safer Streets would like to see a tool that would help people report near misses involving vehicles and pedestrians on streets. His hypothesis was that the concentration of near misses could be an indicator of potential facility problems and that such a tool could help agencies address the facility problems proactively. Because the scope of this project was limited, such a function was not added to the InfraHub app developed as part of this study.

Interviewees indicated that their members usually reported issues with existing bicycle and pedestrian facilities using tools offered by localities (for example, the 311 city services system in DC and the Arlington service requests system; these offer both web and app options). A board member of the Fairfax Association for Better Bicycling indicated that he was a frequent user of the myVDOT web portal. Some issues with these existing tools were also raised during the interviews. The Washington Area Bicyclist Association indicated that the city service system required a physical address of the facility reported, which is difficult when the facility is located on a bike trail. In addition, these tools are not designed for identifying needs for new facilities.

Perspective Toward a Dedicated App Platform

In their communication with both local agencies and advocacy groups, the research team presented the prospect of a smartphone-based tool that would support the ability to report bicycle and pedestrian facility issues or to identify the need for new facilities (dash lines in Figure 8). The team asked interviewees if such a tool would be helpful. The research team further asked what features would be preferable if such a smartphone app were developed.

All interviewees were familiar with the concept of a smartphone app. The major design features that were preferable included

- Simple interface
- Large and easily visible buttons and icons
- Quick responses from the jurisdiction in charge

Although the first and second suggestions have been incorporated in the interface design, the third one is beyond the scope of this study. However, the third suggestion illustrated users' frustration that they do not necessarily know which jurisdiction oversees a particular facility and that they may be confused when their request is forwarded between different agencies. It also illustrated the importance of explaining the purpose of this study and the use of the collected data.

Best Practice Among Local Agencies

Among all the local agencies that were interviewed, the District Department of Transportation (DDOT) has the most sophisticated system for developing its bicycle and pedestrian facility inventory and for using such data to prioritize facility retrofits. Since 2011, DDOT started to develop an ADA data collection and evaluation software system, based on high-resolution imagery, with the help of consulting companies. This system will generate georeferenced ADA facility inventory by processing high-resolution imagery recorded through a field vehicle. It covers 50% of the District and provides information on all assets' compliance within the Pedestrian Access Routes. This system is complemented by an ADA Preliminary Asset Collection program, which uses interns to generate ADA facility inventory by visually inspecting the same high-resolution imagery. The preliminary asset collection program helps cover a wider area than the comprehensive program, at a faster speed. It also helps keep the database up to date by periodically reevaluating the facilities. However, the visual inspection used in the preliminary program can only designate the facility as in good, fair, noncompliant, or missing condition. Unlike the comprehensive program, it cannot provide any measurement such as the grade or width of curb ramps. Therefore, both programs serve a purpose and complement one another. Figure 9 summarizes the ADA compliance–related business processes at DDOT.

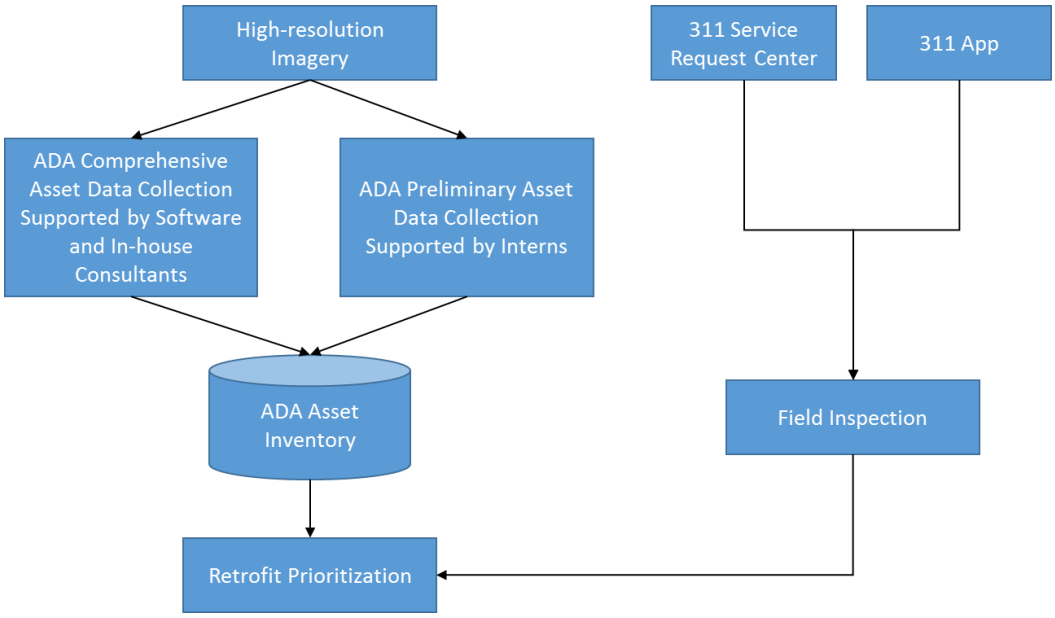

Figure 9. Flow Chart of ADA Compliance–Related Business Processes at DDOT
ADA: Americans with Disabilities Act

The ADA asset inventory developed through the comprehensive and the preliminary asset data collection programs serves as the foundation for the District's ADA transition plan and the retrofit prioritization process. Additional data to support the decision-making process comes from the 311 Service Request Center and the associated 311 Smartphone App, through which DC residents can voice their concerns or needs about bicycle and pedestrian facilities among other requests for city services. When a request is received, the DDOT ADA team will work with the scheduling unit for field inspections. Table 14 summarizes the retrofit prioritization process proposed in the DDOT ADA transition plan. The process is largely driven by accidents or grievances/complaints that have been filed. However, objective data such as the current accessibility assessment, as shown in the asset inventory, and pedestrian traffic volume also play an important role in deciding the prioritization ratings. Although VDOT and DDOT are facing very different environments for asset management (diverse geographic areas versus a single compact urban area), many of these quantitative measures (e.g., pedestrian volume, presence of schools or transit stops, and so on) could apply in different geographic areas with some adjustments.

Table 14. Priority Settings Proposed by DDOT ADA Transition Plan (Source: DDOT Presentation)

Asset Inventory Priority Rating Scale			
Rating Key	**8–10**	**4–7**	**1–3**
Usage	High volume of pedestrian traffic (71+/day)	Medium volume of pedestrian traffic (~40–70)	Low volume of pedestrian traffic (<39/day)
Location	High pedestrian generator (e.g., shops, senior centers, medical facilities, schools, transit stops, residential, entertainment) OR accident has occurred at this site OR grievance/complaint has been filed at this site.	Moderate pedestrian generator.	Low pedestrian generator.
Accessibility	Not accessible to users of wheelchairs/scooters, canes, or crutches, or people with visual impairments.	Currently accessible but needs improvements.	Accessible in current condition.
Condition	Pretty likely to very likely to cause injury to any user of this asset.	May cause injury if one is not cautious, but not dangerous.	Safe but may need improvement.
Priority	**High Priority – fix asap!**	**Medium Priority – fix next available date.**	**Low Priority – fix when due for replacement.**

Design of the InfraHub and the Data Collection Framework

A smartphone app developed by the researchers (InfraHub) is the major tool to support the facility data collection and targeted public outreach framework. This smartphone app was developed to engage users and enable them to identify unmet needs or report issues with bicycle and pedestrian facilities anywhere, anytime. After taking the I-Corps training (a National Science Foundation program that trains researchers in customer identification skills and communicating with potential users), the research team designed an interface and a three-step reporting process that emphasizes simplicity and ease of use. Figure 10 shows the main interface, the report history tab, and the interactive map of InfraHub.

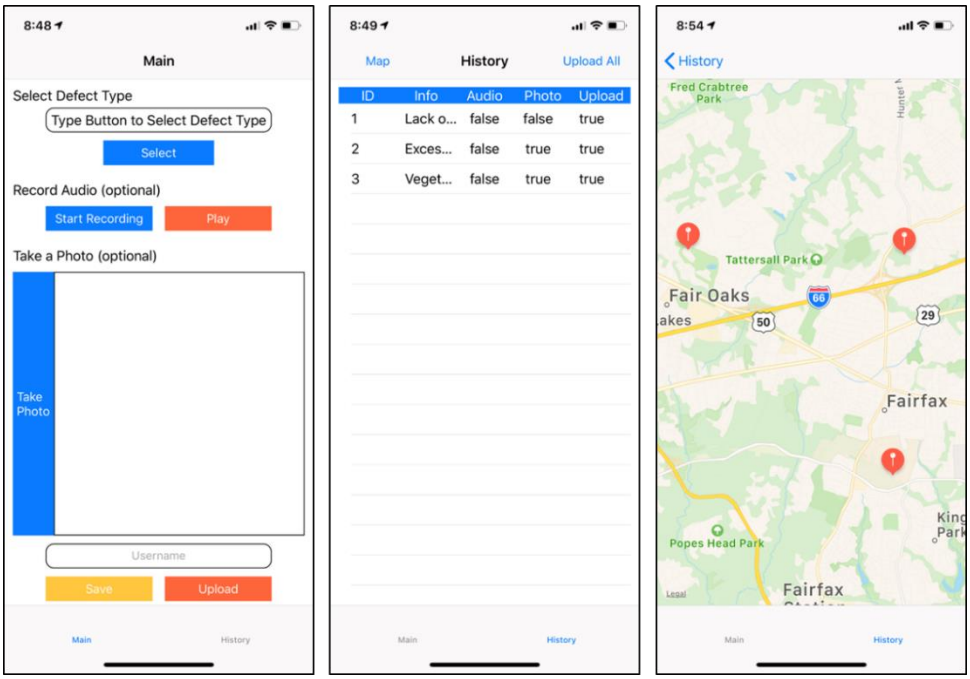

Figure 10. Main Interface, the Report History Tab, and the Interactive Map of InfraHub

If a user wishes to provide feedback about an existing bicycle or pedestrian facility, the process takes only three steps: (1) choose an issue from a predefined list that is consistent with the classification of current VDOT facility inventory, (2) take a photo or record a voice message to substantiate the claim, and (3) hit the upload button to finish the reporting. Users can give themselves a nickname, but that is optional. All three steps can be completed within the main interface, and it takes less than a minute. Users can save the comment or complaint temporarily by hitting the Save button and submit the issue later—for example, when Wi-Fi access becomes available. Users can review previous submissions by selecting the history tab. The submission history can be checked both as a list and as icons on an interactive map. Users can review the details of previous submissions by choosing a particular icon or row in the list.

The list of infrastructure issues that may be reported with InfraHub is as follows:

Curb Ramp

- Lack of Curb Ramp
- Missing Section/Connection
- Unreasonable Slope
- Excessive Cracking
- Protruding Object
- Utility Barrier
- Lack of Truncated Dome
- Other

Sidewalk

- Lack of Sidewalk
- Gaps or Disconnected

- Excessive Cracking
- Vegetation Overgrowth
- Too Narrow
- Utility Barrier
- Other

Pavement

- Pothole

Bicycle Lane

- Lack of Bicycle Lane
- Too Narrow

The database for all updates was hosted in the cloud by Amazon Web Services (AWS) to ensure data security and 24/7services. The database was managed through an administrative interface that was also hosted by AWS. All submissions were automatically geotagged using the built-in location services in each smartphone. The data was then downloaded and projected into a GIS layer in ArcGIS. A trained graduate research assistant would review the photos submitted and validate the reported issues. These submissions were then compared with an existing VDOT database of corresponding facilities (for curb ramp, this could be either one; in the future, it could be the integrated database that may be gradually developed). Depending on whether the submission was about an existing facility or a new facility that did not exist in the VDOT database, the research team would either update the VDOT database with the changed facility conditions or add the submission to the VDOT database. If the issue was about a need for new facilities (classified as lack of bicycle lanes, curb ramps, or sidewalks), it would be added to a separate GIS layer and used for the investment prioritization process.

At the fall 2019 VDOT Transportation Planning Research Advisory Committee meeting, it was suggested that users might not want to report facility issues while on site. In those cases, the geotagged locations generated at the moment of submission would be misleading. It was determined that an alternative option for locating a facility (e.g., a textbox that would allow users to type in addresses) should be provided for those users. A link to the myVDOT website from InfraHub was also suggested to help users who are not familiar with the myVDOT services but who wish to have a quick response to an urgent request. Those options were not part of the field test but were included in version 4.0. Version 4.0 also allowed users to slide up and down by tapping the screen to accommodate different screen resolutions after the new features were added.

This iPhone app played two important roles in the inventory development and targeted public outreach efforts. Findings from the targeted public outreach indicated that the app complements existing VDOT services, such as the myVDOT web portal, and provides a way for facility users to report facility issues or voice needs anytime and anywhere. The reported issues could be compared with existing facility inventory and would provide a source of information for inventory updates. When combined with targeted public outreach efforts, the app would be used mostly by facility users, and the collected data would be very relevant to the designed purpose and to VDOT business needs. These designed goals would be validated in the field test.

Demonstration and Assessment

Enhancing Curb Ramp Inventory Through Geoanalysis

Some objectives of enhancing the bicycle and pedestrian facility inventory can be achieved through geoanalysis, with necessary domain expertise and inputs from graduate research assistants, student volunteers, or both. One data need identified in the review process is to link and integrate the two existing VDOT curb ramp inventories created using different technologies and business processes. The NEAR geoanalysis function has been used to link the corresponding curb ramps in the two inventories on the basis of their locations. Because the database is very large, the searching threshold must be carefully defined to avoid false matching and unreasonable searching time. The two geodatabases are also created in different coordinate systems. The 2018 curb ramp inventory is based on the NAD83 system (commonly seen in professional geodatabases because of its higher resolution for a chosen region), while the curb ramp inventory created through the ArcGIS Online platform is based on the WGS84 system (good resolution for worldwide applications and commonly seen in Google Earth and outputs from GPS units). These two systems will generate detectable discrepancies in the study area because of different definitions of coordinates and distortions in the projection process. The minor difference in locations of the same facility in the two databases can also come from different survey locations. The research team visually inspected the map and compared the two inventories in ArcGIS by randomly selecting a stretch of corridors. The research team inspected a section of Braddock Road and found curb ramps registered in both inventories were within 2 meters using the measure function in ArcGIS. A safe buffer of 5 meters was chosen to search for the same facility in the other inventory in ArcGIS. This buffer avoids relating one curb ramp to a different one crossing the street in the other inventory because the width of a two-lane road is about 7.3 meters (24 ft). The NEAR geoanalysis tool was then applied to link the two geodatabases. Figure 11 shows the results in the same area that had been shown previously, and matched facilities are marked in pink. A new attribute NEAR_FID was created to link the two databases.

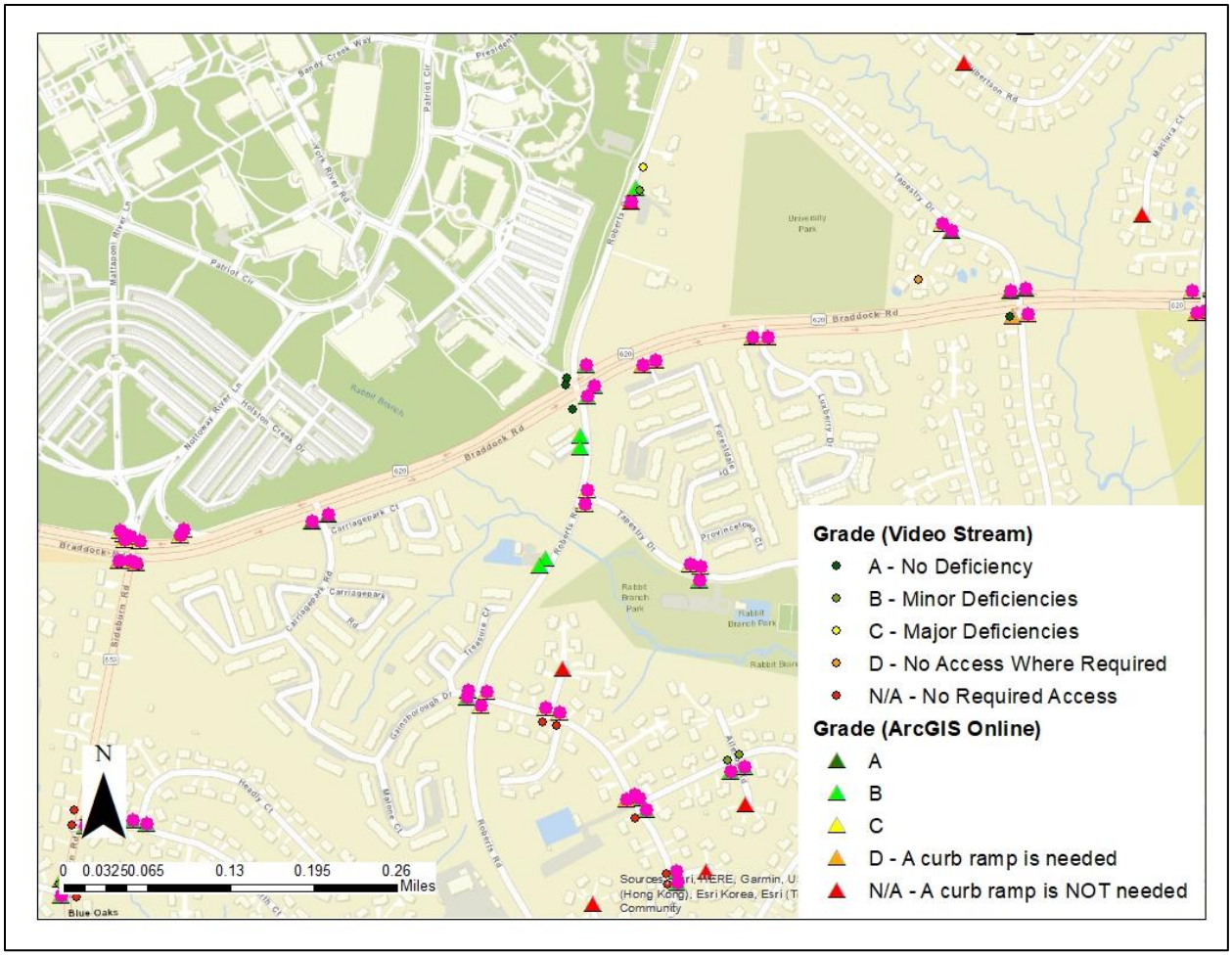

Figure 11. Examples of Matched Features in the Two Curb Ramp Inventories (in Pink).

Of the 41,761 curb ramps recorded through the ArcGIS Online system, only 24,475 have a match in the 2018 curb ramp inventory based on the video stream. Feedback from VDOT TED indicated that the most significant reason for this is that many of the curb ramps in the former database may belong to commercial properties and thus are not VDOT's responsibility. However, differentiating curb ramps under different purviews requires significant local knowledge and expertise, and cannot be done easily. In contrast, there are also cases in which a curb ramp feature was created in the 2018 curb ramp inventory but marked as "curb ramp not needed" (13,945 such features, accounting for 16.1% of all records).

For curb ramps that exist in both inventories and have matches, the ratings are not necessarily the same. Table 15 shows the comparison matrix between the two inventories; the numbers in bold that fall on the diagonal show the number of matched records in each condition category. The majority of curb ramps were graded the same (77.2%), signaling high consistency between the two inventories, given the complexity of the issues. All curb ramps with different grades in the two inventories are marked in the geodatabase, and Figure 12 shows an example. The total number of such curb ramps is 4,837. The first column in Table 15 shows the number of curb ramps that were classified in A condition by the 2018 inventory based on video stream, but not in the inventory based on the ArcGIS Online platform. By visually inspecting randomly

selected curb ramps in this column, the research team learned that a common reason for rating discrepancies appears to be that a curb ramp might have been improved since it was registered in the ArcGIS Online platform, but the condition had not been updated (most of the curb ramps based on the ArcGIS Online platform were last updated in 2016). When such curb ramps were excluded, the number of curb ramps categorized with different conditions in the two inventories was much smaller. Future research could help further resolve such discrepancies and better integrate the two inventories. This analysis also showed the need for a method to periodically update the conditions of curb ramps in the inventory.

Table 15. Comparison Matrix Between the Curb Ramp Inventories Based on ArcGIS Online (Row) and Video Stream (Column)

Condition	A	B	C	D	N/A
A	**3,081**	307	153	24	7
B	1019	**8,899**	700	32	11
C	1,142	971	**5,900**	51	14
D	366	212	245	**584**	40
N/A	82	58	29	50	**435**
Null	19	28	10	5	1

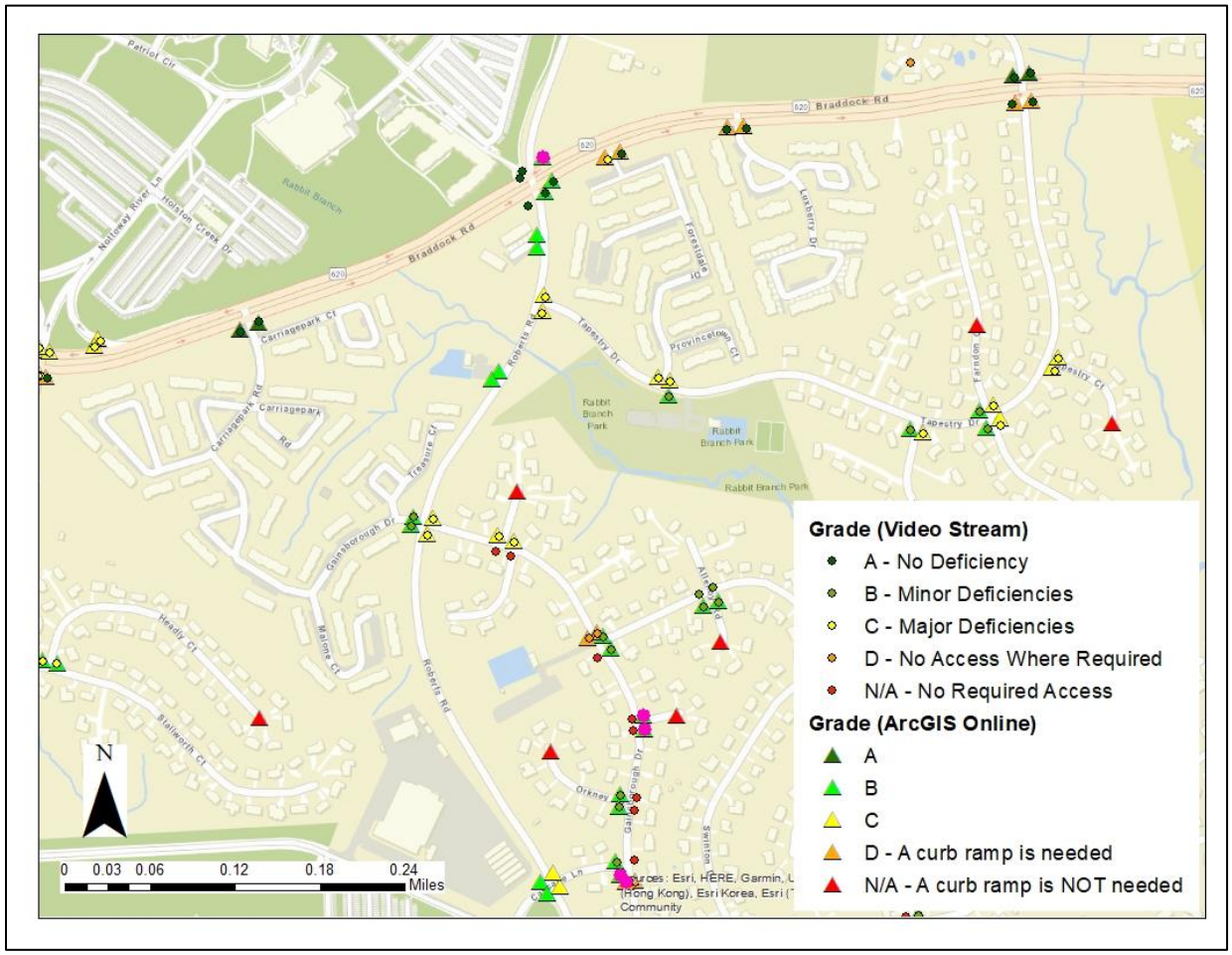

Figure 12. Examples of Matched Curb Ramps with Different Grades in the Two Inventories (in Pink)

Supporting Accessibility Analysis by Linking Curb Ramps, Sidewalks, and Crosswalks

A huge advantage of the VDOT sidewalk inventory compared with databases commonly seen in the literature is that it is not coded using the centerline of the road that a sidewalk parallels but is coded using the exact location of the sidewalk. Therefore, sidewalks are coded as two features if they are present on both sides of the street, instead of as one segment in the database with one annotation in attributes. Because it is complete in its topology, the VDOT sidewalk inventory offers great potential for further accessibility analysis when integrated with curb ramp and crosswalk data. For example, is a neighborhood fully accessible for people in wheelchairs? If one curb ramp is missing or a sidewalk is closed because of maintenance, how is that going to affect accessibility? We can further assess its impact on residents if a Census layer is added and linked. Census data provides the prevalence of disabilities for people in different age groups at the Census tract level; additional assumptions are needed to project such data into finer resolutions (e.g., parcel level), which can then be related to the pedestrian facility network. This framework may offer a way to assess the accessibility for people with special needs beyond the density measures through network analysis.

The curb ramp inventory has been well developed and is ready for use. However, there is no crosswalk inventory available right now. Unlike the curb ramp inventory, which requires professional expertise to conduct assessments, coding crosswalks is relatively straightforward and can be done using Google Earth imagery. A test run with George Mason University students shows that student volunteers have no problem recognizing crosswalks from aerial images. In the example shown in Figure 13, sidewalks are available on both sides of Braddock Road. With all the curb ramps at the intersection to the left (in dark triangles) and four-way crosswalks, pedestrians have no problem accessing all properties in the neighborhood. At the intersection to the right, because two curb ramps are in orange, people with special needs may not be able to reach the south side of Braddock Road (the east-west corridor in the map) without special help. The connectivity for pedestrian paths also is not guaranteed if one or more crosswalks are not available.

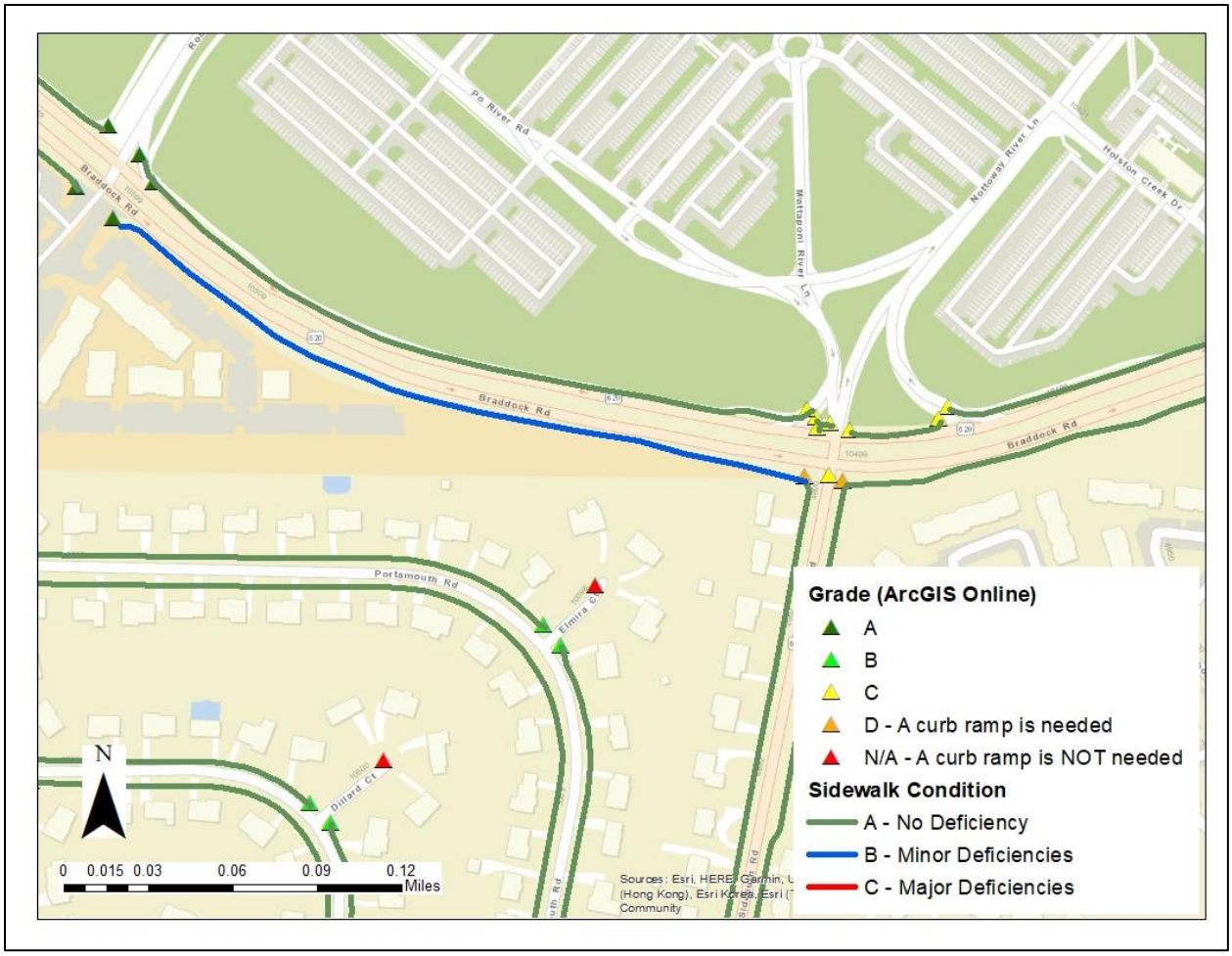

Figure 13. Integrating Sidewalk, Curb Ramp, and Crosswalk Data to Assess Accessibility

Collecting Data Among Facility Users for Inventory and Investment Decision-Making Improvements

To demonstrate the feasibility, capacity, and effectiveness of the proposed framework and the tools developed in this research, the proposed framework has been applied to address the bicycle and pedestrian facility inventories and targeted public outreach needs in Northern Virginia. A flyer was created to introduce InfraHub to its potential users. This flyer was presented to all agencies and advocacy groups the research team contacted through the targeted public outreach efforts. The flyers asked people to test the app, provide feedback, and introduce it to more users if they thought it was helpful. Among them, GMU, Fairfax Association for Better Bicycling, Bike Arlington, and Walk Arlington promoted InfraHub on their social media web pages or their online forums to help reach out to more users. All local government agencies, while appreciating the effort, declined to promote the app due to policy reasons. However, some contacts at those agencies indicated that they would test the app personally. In total, 10 users provided feedback either through emails or on the phone. Among them, one was the contact from a local agency, one was a board member of an advocacy group, and the others were users recruited by the social media/forum posts. One individual who provided feedback identified

herself as a person with special needs, but her special needs did not relate to visual impairment or mobility.

Seven interviewees compared InfraHub with the myVDOT web portal because of the similarity in their functionality and the fact that many people have been using the myVDOT web portal to report bicycle and pedestrian facility issues. Figure 14 compares the interfaces of the two tools side by side. As indicated by interviewees and as shown in Figure 14, the myVDOT web portal is a generic tool for all kinds of services VDOT provides. Therefore, it is slightly more difficult to navigate through that site's lists if a user would like to report bicycle or pedestrian facility issues. The predefined list of issues is very limited, and most of the options in the myVDOT list are unrelated to the bicycle and pedestrian facility issues that VDOT addresses in the existing inventories. Users did have the option to report the details of the issues in a text box. However, that would significantly increase the amount of effort required if VDOT wished to filter the relevant submissions through the myVDOT web portal to focus on the bicycle and pedestrian facility issues in which VDOT TED or TMPD may be interested. In addition, crossing street names were required as part of the submissions. Users did have the option to locate the facility through an interactive map, but it was difficult to manage on the small screen of a smartphone. Six out of seven interviewees agreed that InfraHub has advantages over the myVDOT web portal for reporting bicycle and pedestrian facility issues. The other interviewee indicated that the functionality between the two looks similar for most issues he usually reports. The other three users who provided feedback did not compare InfraHub with the myVDOT web portal but indicated that InfraHub was easy to use. Some interviewees asked about the data usage and feedback mechanism, which will be discussed in the discussion section.

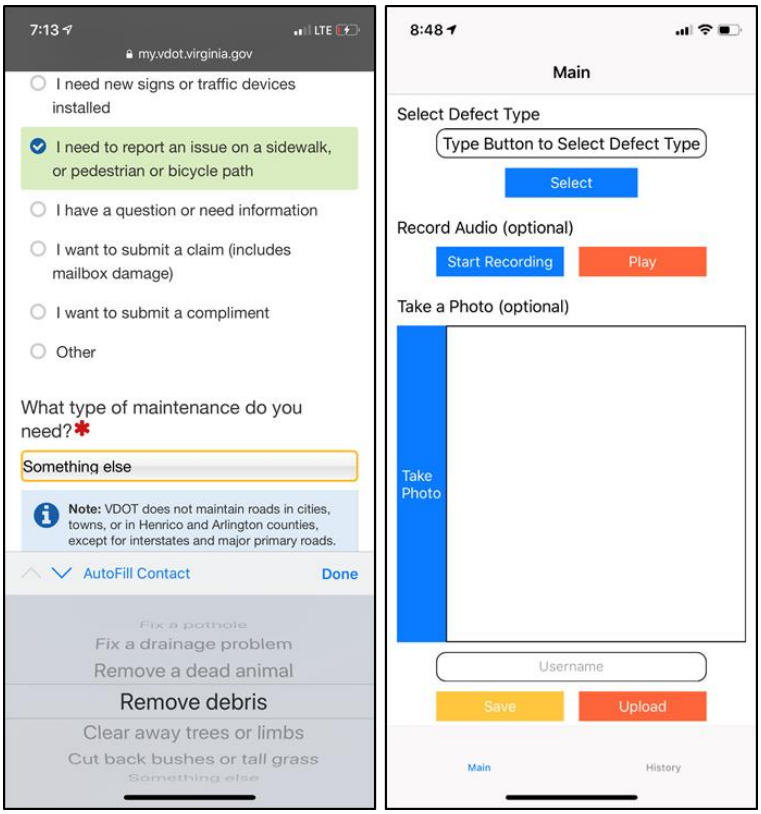

Figure 14. Comparison of myVDOT Web Portal (Left) and InfraHub Interface (Right) on an iPhone

The app has been downloaded 84 times, and 108 reports were collected in one month. As shown in Figure 15, the locations of 100 submissions were correctly identified by projecting the geotagged coordinates of reported issues in ArcGIS. The other 8 had invalid locations when the projected locations were compared with the background maps of the Northern Virginia region. This glitch most likely occurred because the users denied the app access to location services on their phones. The privilege of accessing location services as well as the camera and microphone on a user's phone is critical for the functioning of the app. Some users may deny access due to privacy concerns, and this issue has to be addressed through better public outreach.

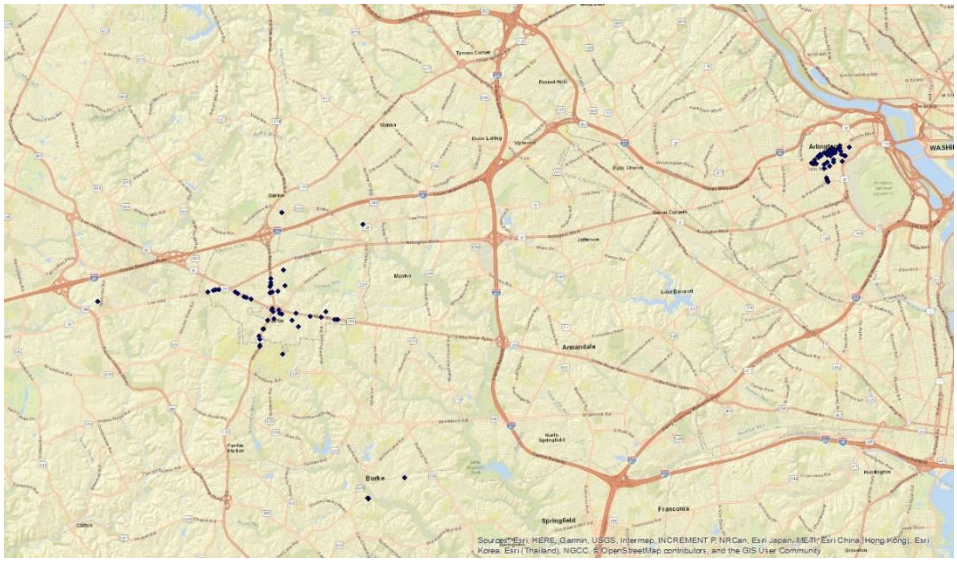

Figure 15. Locations of Reported Infrastructure Issues Through InfraHub

The early submissions were concentrated in the areas of the George Mason campus in Fairfax, the City of Fairfax, and Arlington County, where outreach efforts have been more extensive. The issues submitted were very diverse, ranging from lack of truncated domes to utility barriers. Table 16 summarizes the categories of issues submitted through InfraHub, and Figure 16 shows examples of photos sent as part of the submissions. For more than 90% of submissions, facilities users also included a photo to substantiate the claim. A graduate research assistant compared the issues classified by the users based on the predefined list and the photo and thus validated the reporting. The classifications of facility issues were very straightforward, and people chose the correct category 100 out of the 108 cases. Two common categories of false reporting were related to utility barriers (many were handrail pillars installed by restaurants that occupied sidewalk spaces; see Appendix H for an example) and the lack of curb ramps (street-level sidewalks do not require a curb ramp at access points from commercial properties). The large number of submissions in the demonstration for the lack of truncated domes may not reflect the actual usage of such facilities so much as the fact that it was an easy to identify those targets for the trial of InfraHub.

Table 16. Number of Issues by Category Submitted Through InfraHub

Type of Issues	Frequency of Reports	No. of Valid Reports
Utility Barriers	13	8
Lack of Truncated Domes	50	50
Lack of Sidewalk	6	6
Lack of Curb Ramp	6	3
Vegetation Overgrowth	6	6
Excessive Cracking	5	5
Lack of Bicycle Lanes	3	3
Unreasonable Slope	1	1
Others	18	18
Total	108	100

Figure 16. Examples of Photos Submitted Through InfraHub (Vegetation Overgrowth on the Left and Utility Barriers on the Right)

The initial field test shows that users were able to use InfraHub correctly to submit concerns about bicycle and pedestrian facilities. As long as users yielded the privilege of accessing the corresponding functions on their smartphones, InfraHub was able to correctly capture locations, photos, and voice messages and submit them to the database hosted by AWS. The service is uninterrupted 24/7. To integrate the data submitted through InfraHub with the existing VDOT sidewalk and curb ramp inventories, InfraHub submissions should be categorized as needs for new facilities and conditions of existing facilities. The data is further divided as those for sidewalk, curb ramps, or bicycle lanes. Depending on the data category, the NEAR geoprocessing function is invoked to associate the submitted facilities with existing facilities in the corresponding VDOT inventory. The matched facilities will be compared and if the conditions have been changed, the inventory will be updated. Figure 17 shows an example of submitted locations and existing VDOT inventories in Arlington. Inspecting the imagery and the submitted locations determined that the location accuracy was very high. Unfortunately, VDOT does not manage facilities along secondary roads in Arlington County (another location where early submissions concentrate is the City of Fairfax, where VDOT does not manage facilities along secondary roads either) because independent cities, towns, and Henrico and Arlington counties oversee their own secondary roads in Virginia. Therefore, the research team was not able to run the NEAR function to identify the matched facilities and update their conditions.

However, this step does not take much time to run, and its execution is relatively straightforward. It will be more time consuming to visually inspect the submitted photos and validate the issues if the number of submissions becomes large. However, using student interns, this step could be completed within 20 seconds for each submission.

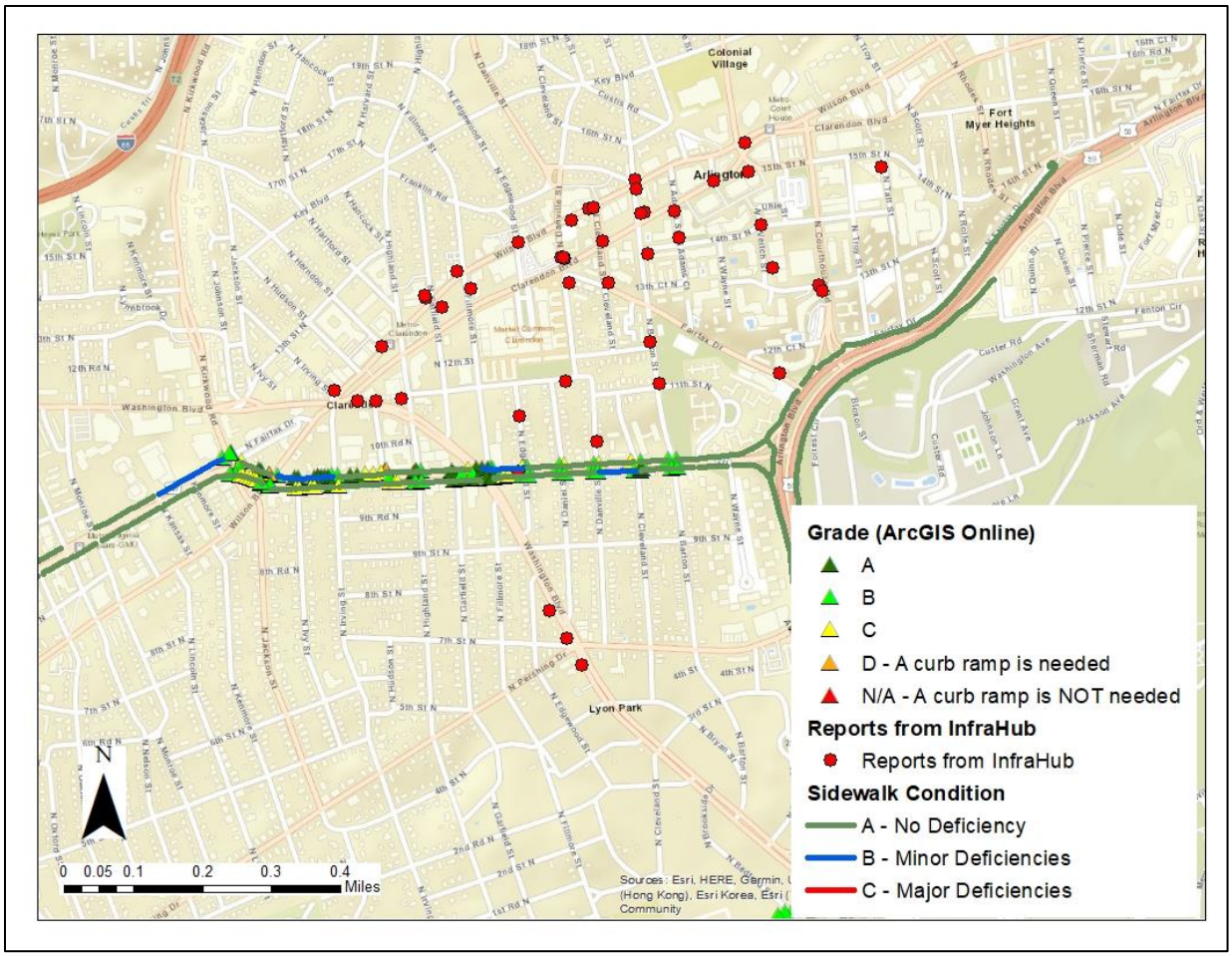

Figure 17. Comparison Between Data Collected Through InfraHub and VDOT Sidewalk and Curb Ramp Inventory

The costs of sustaining the operation of InfraHub and the data collection process is less than $200 per year (renting the AWS services for maintaining the database and iOS developer license for submitting updates). Actually, more users and more submissions could help VDOT to cross-validate the submissions. It does take some effort to validate the submissions by visually inspecting the photos submitted, to compare the submitted data with existing VDOT facility inventory, and to update the inventory accordingly. Depending on the data needs, such work could be done at relatively long intervals (e.g., once a year) and using student interns, similar to the practice of DDOT. Therefore, this framework based on InfraHub is feasible and cost-effective. The data collected is highly relevant and of high quality. However, the initial outreach efforts showed that it takes time to convince users to install a new smartphone app and to accumulate users. Given the small marginal cost for supporting additional users, the service through InfraHub could be sustained for the foreseeable future.

DISCUSSION

This study developed a framework using a hybrid method for inventory enhancement and targeted public outreach and demonstrated its capacity through a proof-of-concept study. Several lessons were learned through the process:

- *Qualitative Versus Quantitative Assessment:* Field experience showed that the crowdsourcing approach was more effective for qualitative assessment of facilities than for quantitative assessment. For example, facility users or student interns were more likely to correctly report a passable/impassable curb ramp or the existence/nonexistence of a truncated dome. They were less capable of assessing whether a curb ramp was ADA compliant, a determination which requires professional knowledge and field measurement. However, a qualitative assessment could serve as a surrogate for the need for quantitative assessment and would help VDOT staff focus on locations where problems are more likely. According to the interview with DDOT, 93% of user-identified locations in the District of Columbia where a truncated dome ramp surface did not exist also had other issues that made them ADA noncompliant.

- *Managing Expectations During Targeted Public Outreach:* While targeted public outreach could significantly improve the relevance and quality of the information collected, it is important for VDOT to clarify and properly manage expectations. Some users may get frustrated if they do not hear any feedback for a few days after reporting an issue. Depending on the purpose of deployment of the app, feedback may be delayed (e.g., if the purpose is to assess the need for new facilities, no action will be taken until a sufficient number of inputs is collected). Therefore, VDOT needs to carefully clarify the purpose of the deployment and in what way the collected data will be used. Users may also be directed to the myVDOT web portal, where customer tickets are logged and timely feedback can be provided through the existing communication channels.

- *Android Versus iOS Versions:* It is a challenge to fully develop a smartphone app, which requires significant time for testing and debugging. Because this study is for proof of concept, the research team developed only an iOS version of InfraHub. A significant number of smartphone users have Android phones. Therefore, to fully deploy the framework, an Android version needs to be developed.

CONCLUSIONS

On the basis of the analysis presented in the previous sections, this study drew the following conclusions:

- *Crowdsourcing approaches and targeted public outreach can potentially help VDOT to improve its bicycle and pedestrian facility inventory and investment by providing additional relevant and quality data in a cost-effective way.* This objective can be achieved through a combination of geoanalysis, inputs from volunteers, and targeted public outreach assisted by a smartphone app and the associated data collection process. The data quality can be

controlled by visually inspecting the photos submitted using student interns, and the long-term costs are small if the data integration is done periodically. This study also concludes that social media data has low relevance to bicycle and pedestrian facility issues and that methods based on it are not effective in addressing VDOT's data needs.

- *Existing VDOT bicycle and pedestrian inventories could benefit from additional enhancement.* VDOT has built multiple comprehensive inventories of bicycle and pedestrian facilities to support different business processes. These facility inventories could be enhanced in different ways. It is important to inform VDOT staff members, such as those responsible for maintenance scheduling, about the data gaps and opportunities for inventory improvement. One good example is noting the differences between the two curb ramp inventories. VDOT staff members responsible for pavement scheduling may need to check both inventories to identify curb ramps that need to be improved while these two inventories are gradually integrated using a process similar to that used by DDOT.

- *Practices of local agencies with respect to bicycle and pedestrian inventory development and retrofit prioritization processes, as well as needs raised by advocacy groups, can inform VDOT about potential opportunities for future improvement.* Targeted public outreach showed that the District Department of Transportation has the most systematic bicycle and pedestrian facility data collection program, built on both advanced technologies and a crowdsourcing approach. DDOT also used the data to support a formal retrofit prioritization process. Although VDOT is facing a much more challenging environment for bicycle and pedestrian asset management (diverse geographic areas versus a single compact urban area for DDOT), it could benefit from the quantitative method DDOT uses, at least for areas with similar geographic characteristics (e.g., Northern Virginia).

- *myVDOT is a good channel for collecting user feedback, but a more targeted tool could complement it in specific areas.* Targeted outreach efforts showed that users usually voice their concerns about bicycle and pedestrian facilities by emailing or calling the offices of county supervisors, filing complaints or grievance forms on agency websites, or submitting requests to the myVDOT web portal. Many people might find a more mobile way to file requests or comments for VDOT anytime and anywhere to be helpful and convenient.

- *InfraHub and the associated data collection process could potentially assist VDOT in targeted public outreach.* This research developed an iPhone app—InfraHub—and the associated data services hosted by AWS to provide a convenient way for users to provide feedback on bicycle and pedestrian facilities. This tool was presented to both local agencies and advocacy groups in the Northern Virginia area, and the feedback has been very positive. The app was tested in the field, and most users, without special training, could correctly identify infrastructure issues they wanted to communicate to VDOT. The app has been promoted by several advocacy groups in the region, and efforts are ongoing. The number of subscribers is small but is growing. Given the small marginal costs for continuous usage, this tool is expected to be supported for the foreseeable future, and the data collected can benefit VDOT's ongoing research on guidelines for curb ramp retrofits.

RECOMMENDATIONS

Drawing on the conclusions, this study makes the following recommendations:

1. *VDOT's Traffic Engineering Division should gradually adopt the framework developed in this study and share information about the InfraHub tool as a means to improve both its bicycle and pedestrian facility inventory and the prioritization process for curb ramp retrofits.* The results of this research showed that the targeted public outreach based on InfraHub and geoanalysis using volunteers and student interns could improve the relevance and quality of data for both inventory enhancement and collecting user feedback compared with traditional crowdsourcing approaches. Using components of DDOT's annual updating process and quantitative methods for retrofit prioritization could complement the framework.

2. *VDOT's Traffic Engineering Division should share information about the differences between the two curb ramp inventories and the strengths of each with appropriate agency staff in the VDOT central office and the districts drawing on findings from this research.* This effort will enable VDOT business divisions to make informed decisions on the best way to use these two inventories to support their different business processes. VDOT staff (e.g., staff responsible for scheduling maintenance improvements to bicycle and pedestrian facilities) need to be aware of the differences between the two inventories and to use them in the best way according to their unique business needs. It would be helpful to disseminate the information through training (including groups involved in existing initiatives, such as audible pedestrian signals), an information flyer, or both while VDOT explores ways to gradually consolidate the two inventories.

3. *VDOT's Transportation and Mobility Planning Division should further evaluate InfraHub's value as a tool for targeted public outreach and geoanalysis for assessing pedestrian accessibility*. VDOT's current initiatives for virtual public involvement may provide one avenue for doing so. Integrating sidewalk, curb ramp, and crosswalk data to assess accessibility supports agency business objectives. The evaluation should include reviewing opportunities to integrate InfraHub features into myVDOT. If VDOT chooses to continue using InfraHub, then a transition plan for VDOT to take ownership of InfraHub and other developments, such as making InfraHub available for Android phones, should be pursued.

IMPLEMENTATION AND BENEFITS

Implementation

With regard to Recommendation 1, by December 31, 2020, the Traffic Engineering Division, with assistance of the Virginia Transportation Research Council, will use the data collected through InfraHub and the findings from the targeted public outreach of this study to support the current VTRC project *Guidelines for Prioritizing Curb Ramp Retrofits under the Americans with Disabilities Act.* That project has been initiated and work is underway.

With regard to Recommendation 2, by July 31, 2020, the Traffic Engineering Division will offer training sessions and/or share an informational flyer on the differences between the two existing VDOT ADA curb ramp inventories. VDOT staff responsible for maintenance activity scheduling may need to understand and leverage both inventories to identify curb ramps that need to be improved. Given the large number of curb ramps for which VDOT is responsible and the complex field conditions, it could take significant time and resources, even with the help of crowdsourcing approaches, to reconcile the two existing VDOT curb ramp inventories developed for different business processes.

With regard to Recommendation 3, by July 31, 2020, the Transportation and Mobility Planning Division and Traffic Engineering Division will share information from this study about InfraHub with VDOT's district bicycle and pedestrian coordinators so they can share it with local stakeholders and advocacy groups as appropriate. This action includes providing internal VDOT access to the InfraHub data from Amazon Cloud and extending the application to an Android platform, thus increasing the potential of participation from local stakeholder and advocacy groups.

Benefits

The benefit of implementing Recommendation 1 is to provide VDOT with more complete and relevant data on its bicycle and pedestrian facilities, using a cost-effective data collection tool for the purpose of developing guidelines for prioritizing curb ramp retrofits under the Americans with Disabilities Act. Lessons learned from this process could also support future applications.

The benefit of implementing Recommendation 2 is to help VDOT personnel make informed decisions on the best ways to use the two curb ramp inventories to support different businesses processes. In the process, VDOT might consider gradually reconciling the two databases to better support future applications.

The benefit of implementing Recommendation 3 is to offer district bicycle and pedestrian coordinators an additional potential tool to collect feedback from local stakeholders, as well as to enhance TMPD initiatives in virtual public involvement processes.

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APPENDIX A
AN EXAMPLE OF EMAILS SENT TO ADVOCACY GROUPS

Dear XXX,

I am an Associate Professor in the Civil Environmental, and Infrastructure Engineering Department, George Mason University. I am working on a VDOT project to develop better outreach methods for collecting feedback on biking and pedestrian facilities. Are you available this week for a phone interview on how your constituents usually voice their facility needs? We developed an iPhone app that allows people to report facility issues quickly and easily (see attached flyer). Do you think this tool is helpful to your constituents? If yes, is there a way we can introduce it to your constituents (email list, Facebook page, or other media)? We greatly appreciate any suggestions.

Thanks!

Shanjiang

APPENDIX B
FLYER FOR RECRUITING INFRAHUB USERS

Figure B1. Flyer Used for Recruiting InfraHub Users

APPENDIX C
INTERVIEW PROTOCOL FOR ADVOCACY GROUPS

Table C1. Interview Protocol for Advocacy Groups

1. How do you feel about the bicycle/pedestrian facilities you/your members use most of the time?	
2. How do you/your members usually voice needs/raise concerns about the bicycle/pedestrian facilities? Can you describe a typical process?	
3. Are you satisfied with the current process? Are there any pros and cons about these channels?	
4. GMU developed a smartphone app, InfraHub, to help users report infrastructure issues/needs (a one-page flyer is attached). Do you have any comments and suggestions? Do you think it would be helpful to your members?	
Yes	Is there a way that you can help us introduce it to more users/stakeholders?
No	How may we improve it to address your needs?

APPENDIX D
INTERVIEW PROTOCOL FOR LOCAL AGENCIES

Table D1. Interview Protocol for Local Agencies

1. Does your agency have a complete inventory of curb ramps, sidewalks, and bicycle lanes?	
Yes	How were they collected and maintained? Are they geo-referenced? What are the main ways of data usage?
No	Do you have a plan to develop an inventory for them in the near future? What are the data collection methods you would consider?
2. How does your agency collect feedback from stakeholders on needs for these facilities? Do you have a phone service/web portal/smartphone app to help voicing needs or reporting issues?	
Yes	What are the pros and cons about these methods? What are the major ways the information collected are used for?
No	Does your agency plan to develop a tool/process for such purposes?
3. Can you describe a typical process on how people voice their needs/report issues through your established process? How often do you receive such requests?	
4. How does your agency prioritize retrofitting needs for those facilities? Do you have a formal process for that?	
5. GMU developed a smartphone app, InfraHub, to help users report infrastructure issues/needs (a one-page flyer is attached). Do you have any comments and suggestions? Do you think it would be helpful to your agency?	
Yes	Is there a way that you can help us introduce it to more users/stakeholders?
No	How may we improve it to address your needs?

APPENDIX E
MAJOR BICYCLE FACILITY ATTRIBUTES INCLUDED IN THE TMPD DATABASE

Table E1. Major Bicycle Facility Attributes Included in the TMPD Database

Attribute Name	Notes
RTE_NM	Route name coded for VDOT business purpose
RTE_COMMON_NM	Common route name
RIM_SIDE_OF_ROAD_NM	Which side of the road it locates
RTE_FROM_MSR	Starting point in the linear reference system
RTE_TO_MSR	Ending point in the linear reference system
RIM_BICYCLE_ACCESS_TYPE_NM	Facility type
RIM_BICYCLE_ACCESS_PAVED_IND	Paved or not (Y/N)
RIM_BICYCLE_PEDESTRIAN_OWNR_NM	Owner of the facility
CURRENCY_DATE	Last updated (many in 2012)
EVENT_SOURCE_CD	Source of the data (many by RIMBP)
EVENT_SOURCE_NM	Source of the data (many by RIMS Bicycle/Pedestrian Access)
RTE_MEASURE_SYSTEM_CD	How it is measured (OSM/OUM)
RTE_CATEGORY_NM	Route category (urban/urban street/county road/state highway primary/interstate frontage road/interstate ramp/non-interstate frontage road/non-interstate ramp/school road/secondary street)
RTE_TYPE_NM	A simplified classification (frontage road/interstate/secondary route/state route/U.S. route/urban road)
LOC_COMP_DIRECTIONALITY_NM	Directionality (bidirectional/master non-prime/master prime/null)
LOC_COMP_DIRECTIONALITY_CD	Directionality code (null/B/N/P)
RIM_BICYCLE_ACCESS_TYPE_CD	Simplified facility type code (DBL/PSH/SBP/SDL/Null)
RIM_SIDE_OF_ROAD_CD	Simplified side of the road code (B/L/R)
BICYCLE_SIDE_OF_ROAD_CD	Bicycle usage side of the road code (B/L/R/Null)
CHANGE_STATUS_CD	Change of status code (null/CL)
CHANGE_STATUS_DT	Change of status date
Bicycles_Restricted	(Null/N/Y)
Surface_Material	Pavement materials (asphalt/asphalt crushed gravel/asphalt stonedust/cement/concrete/crushed gravel)
Imagery_Date	Date the imagery was taken
Mileage	Mileage
Facility_Name	Road or street name
Locality_Facility_Type	Facility types based on different localities (shared lane markings/shared road designation/shared roadway/sharrows/signed bicycle route/signed shared roadway)
Bicycle_Route_Name	Bicycle route name if applicable
Accommodation_Year	When the facility starts to accommodate bicyclists
From_Street	Starting crossing street name
To_Street	Ending crossing street name
Length	Mileage
Lane_Miles	Mileage considers one way or both ways
Locality	Local jurisdictions
Metropolitan_Planning_Organization	MPO in charge
Planning_District_Commission	Planning District Commission
VDOT_District	VDOT District
Divided_Roadway	(-1/null)
Data_Source	Local jurisdictions or MPOs who submitted the data

APPENDIX F
ADDITIONAL ATTRIBUTES INCLUDED IN THE TED CURB RAMP INVENTORY

Table F1. Additional Attributes Included in the TED Curb Ramp Inventory

Attributes	Notes
PED_FACILI	Street level facility (e.g., curb ramp) or non–street-level facility (e.g., driveway)
RAMP_NEEDE	If a ramp is needed to provide access to sidewalk or not
Width	In inches
Surface	Exposed aggregate surface/truncated dome/no detectable warning surface/no curb ramp/TBD/other
Grade	A/B/C/D
Date_Imprv	Date of improvement
Act_Improvm	Replace/Install
Editor	Who recorded the change of conditions
EditDate	Date of record update

APPENDIX G
VDOT SIDEWALK BARRIER INVENTORY BASED ON VIDEO STREAM

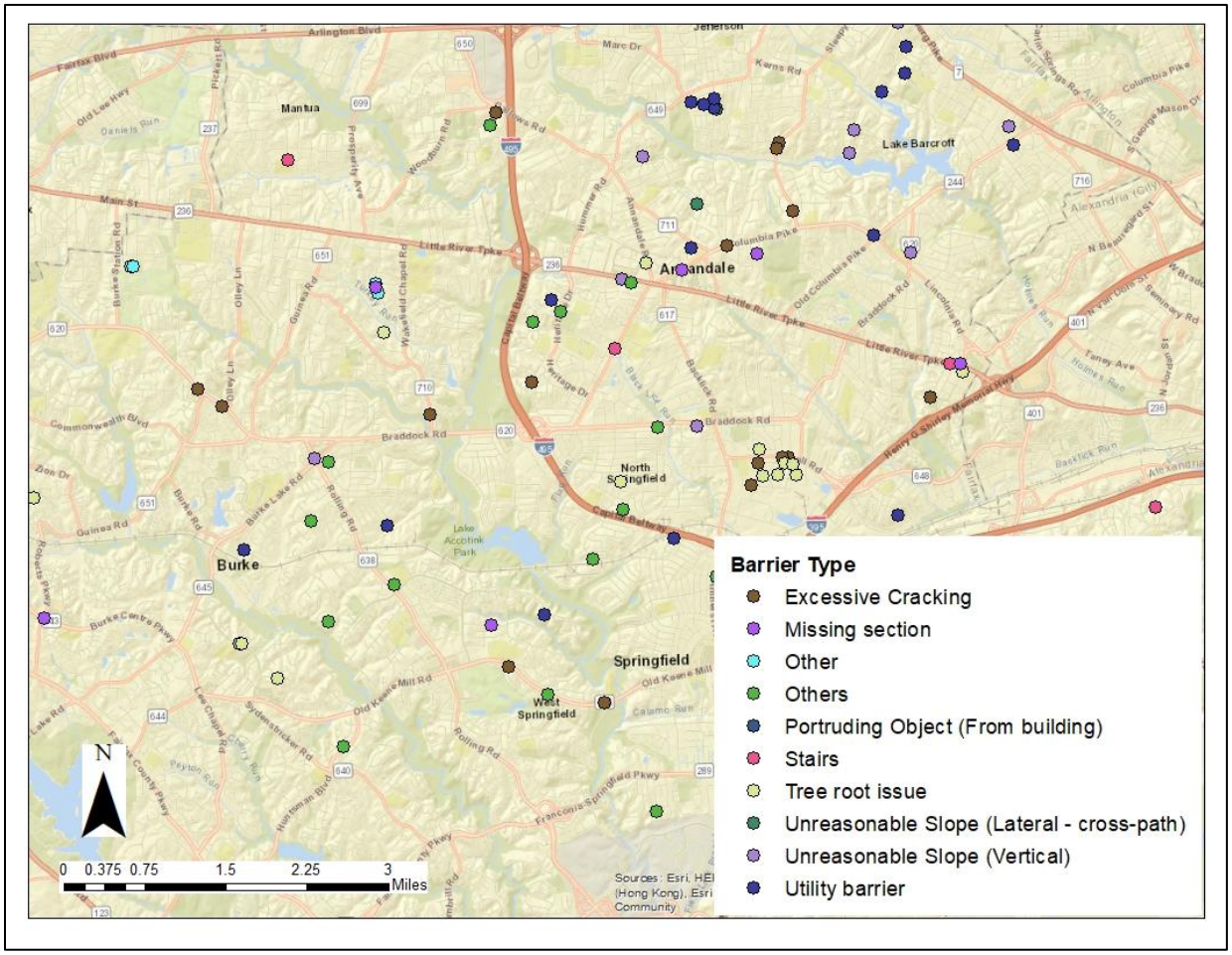

Figure G1. VDOT Sidewalk Barrier Inventory Based on Video Stream

APPENDIX H
AN EXAMPLE OF FALSE REPORTING OF FACILITY ISSUES

Figure H1. An Example of Facility Falsely Reported as Utility Barrier