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# Crowdsourcing to Support Navigation for the Disabled

## A report on the motivations, design, creation, and assessment of a testbed environment for accessibility

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This report documents research efforts for the design, creation and development of a testbed environment for capturing, evaluating, and utilizing crowdsourced geographic information to support navigation by blind, visually- and mobility-impaired individuals. We describe the planning, design, creation, and assessment of web- and mobile-based data collection tools, the evaluation of the understanding of the system by both the data collectors and the end-users of the crowdsourced information, and an assessment of the interactions among the community of contributors, end-users, developers, and researchers. The findings in this report are part of a larger continuing research project exploring the potential for crowdsourced geographic information to solve a wide range of navigation tasks and other field-based operations.

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# Preface

This report is a deliverable product of Department of the Army Broad Agency Announcement (BAA) #AA10-4733, Contract #W9132V-11-P-0011. The study for this report was conducted jointly by the Engineer Research and Development Center (ERDC) technical lead Douglas R. Caldwell and George Mason University faculty and research staff, in support of the ERDC. Report author Matthew T. Rice wishes to acknowledge the financial support of Dean Vikas Chandhoke, George Mason University College of Science during the preliminary phase of this research project, Fabiana I. Paez, for her editorial support, and Delma Delbosque (ERDC) for support as the Contracting Officer's Representative.

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| Feet | 0.3048 | meters |
| miles (nautical) | 1,852 | meters |
| miles (U.S. statute) | 1,609.347 | meters |
| miles per hour | 0.44704 | meters per second |

# 1 Introduction and Project Overview

Twenty-five years ago, a small city on the California coast had a serious problem. Nestled between the cold Pacific Ocean and the San Gabriel Mountains, producing one of the most pleasant climates in the world, the City of Santa Barbara had become a magnet for mobility-impaired and visually-impaired individuals, who were attracted to the area by a lack of inclement weather, a functional and well-supported public transit system, a vibrant technology- and tourism-based economy, and significant public-assistance housing and support programs.

A growing cohort of students with mobility and vision impairments likewise were attracted to the University of California, Santa Barbara (UCSB) because of the flat terrain, lack of inclement weather, and general support for accessibility. Unfortunately, during this period the university was also the center of considerable controversy as thousands of students, faculty, and staff drove, biked, and walked to work or class every day. Injuries, accidents, and frustration were commonplace, as bike paths and walkways crossed busy roads, and infrastructure was being expanded to accommodate the demands of students, faculty, and staff, who felt that the University should have the best facilities to support their growing ambition and reputation. The chaotic mass of pedestrians, bicycles, skateboards, and motorized vehicles were mixed together in a somewhat inadequate sidewalk and road network.

Campus planning authorities realized that they would need to bring order to the chaos and they embarked on a long-term, multi-faceted effort to partition the incompatible modes of transportation into separate transportation networks, and to provide a buffer for the pedestrians, who counted among themselves hundreds of students, faculty, and staff with vision and mobility impairments.

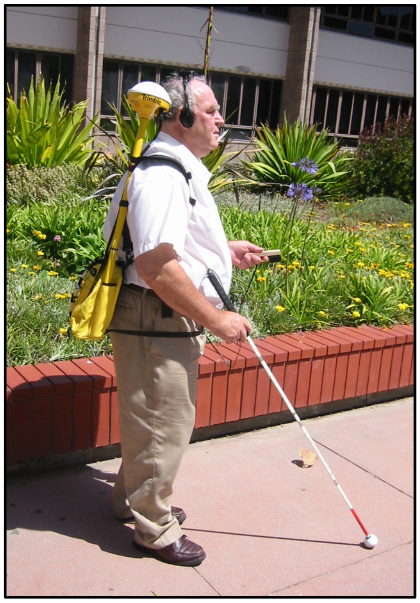

Figure 1. Reginald Golledge using the UCSB Personal Guidance System, circa 2003

An unfortunate yet concurrent event during this time period was the complete loss of vision by a well-known UCSB Geographer and faculty member, Reginald Golledge, who had been an able-bodied and rugged young adult. His sudden and unexplained loss of vision was a devastating blow to what had been a very promising career as a geography faculty member, where vision, and the ability to visually interact with maps and computers was at the very foundation of his identity and the identity of the local department. Fortunately for Dr. Golledge, two faculty members from the UCSB Department of Psychology, Dr. Jack Loomis and Dr. Roberta Klatzky came up with a conceptual design for a system that would allow Dr. Reginald Golledge to use a mobile geographic information system complete with GPS, auditory cues, and directional cues, to regain mobility and navigate across the increasingly busy campus, and therefore regain his ability to move and interact within his workplace.

The development, testing, and refinement of this Personal Guidance System (Figure 1), described first by Loomis in 1985[1] and later in Golledge et al. (1998) and Loomis et al. (2001), became a joint research effort by no fewer than 30 researchers, staff, and post-doctoral researchers and extended from its beginnings in the mid-1980s to the year 2009, coinciding with Dr. Reginald Golledge's death. The significant body of research associated with the system design, testing, refinement, and usability, includes more than 40 peer-reviewed publications, and hundreds of conference presentations and public demonstrations.[2]

1 See "Re: Digital Map and Navigation System for the Visually Impaired," UCSB, November 1, 2012http://www.geog.ucsb.edu/pgs/papers/loomis_1985.pdf

2 The UCSB Personal Guidance System Project research team produced 42 peer-reviewed technical and basic research publications between 1985 and 2008 about system testing, design, and usability. See "Publications," UCSB, November 1, 2012, http://www.geog.ucsb.edu/pgs/publications.htm

The UCSB Personal Guidance System demonstrated the capability of geotechnology to make a significant personal impact in the lives of the visually- and mobility-impaired, and addresses some very significant issues related to spatial behavior, wayfinding, spatial cognition, and human-computer interaction. The system's most notable shortcoming was its inability to accommodate real-time updates and transitory events and obstacles that significantly impact navigation and wayfinding for blind, visually- and mobility-impaired individuals.

Transitory events and obstacles include any object, item, or condition that impacts navigation and wayfinding, causing the blind, visually- or mobility-impaired individuals to alter their planned route. In some cases, these transitory events are inconveniences, requiring slight modification to a route, while in other situations they require significant back-tracking and re-routing. Because transitory events are unplanned and usually unanticipated, they can pose a safety hazard, particularly for the blind and visually-impaired traveler. Transitory events are often temporary, disappearing in a matter of minutes or hours, but they can involve sudden, unanticipated changes that have a much longer presence, lasting months or even years, depending on the type of event and the context for the obstacle or event.

Figure 2. Construction debris and fencing temporarily blocking walkway

Figure 2 shows an example of a transient obstacle on a street adjoining our local campus environment. The construction debris and temporary fencing prohibited everyone (including the disabled) from using the walkway, and for a period of approximately three days caused local residents and campus visitors inconvenience. Avoiding the fencing and debris in this area entailed walking through the roadway, and due to the lack of a nearby crosswalk or curb cuts, presented a safety hazard for all members of the public.

Figure 3 shows a common transient obstacle in the center of the George Mason University (GMU) campus causing particular difficulty to blind, and visually- and mobility-impaired students. The yellow and black electrical conduits covering the electrical cords are placed in the walkway as a means of protecting the cords, as well as to minimize the tripping hazard posed by the cords across the walkway. This type of transient obstacle is not of major importance or concern to non-disabled students, who simply step over it, but it is a significant hazard for blind and visually-impaired individuals, as well as mobility-impaired individuals, whose wheel chairs cannot safely cross over the top.


Figure 3. Electrical cords and conduits across the walkways

The UCSB Personal Guidance System was not designed to – and could not – accommodate transitory events such as those shown in Figure 2 and Figure 3. This limitation forms a major motivation for our research project.

The GMU campus, in striking similarity to the UCSB campus, is rapidly expanding and attracts a large number of students with mobility and visual impairments (estimated by GMU Assistive Technology staff to number between 250 and 300). These students, and existing faculty, staff, and community members also have the misfortune of dealing with the construction, remodeling, expansion, and growth fostered by GMU's rapid expansion. The construction barricades, detours, obstacles, and chaos have become a very regular part of campus life and are simply ignored or sidestepped by able-bodied students, faculty, and staff. For individuals that are blind or mobility impaired, this is simply not possible, and the challenges posed by these temporary inconveniences are very serious and deeply impactful.

GMU, being faced with a very similar set of circumstances and motivations, is using contemporary crowdsourcing techniques and mapping systems to provide a demonstration and testbed environment for collecting, verifying, analyzing, and displaying information about temporary obstacles and transient hazards in the campus environment. The ability to provide real-time georeferenced information about changes in a local environment is seen as a significant benefit of the geospatial crowdsourcing movement addressed in seminal papers by Goodchild (2007, 2009) and the comprehensive technical report from this project last year.[1]

There really is no question that crowdsourcing and related social media technologies are transforming geospatial data production workflows and end-user participation in GIS activities.

Several research efforts and publications have addressed the ability of crowdsourcing to report major natural events, as well as assist those with disabilities. The United States Geologic Survey's efforts to use social media and crowdsourcing to report earthquakes is notable,[2,3] as is Liu and Palen's (2013) summary and evaluation of map mashups and crowdsourcing efforts associated with fires, floods, and disease outbreaks.[4] For the disabled community, Kremer (2013) provides a useful review of some crowdsourcing projects for accessibility,[5] such as Ahn et al. (2006) where crowdsourcing via gaming is used to generate alternate textual descriptions for web images used by screen-reading programs for the blind and visually-impaired.[6] Takagi et al. (2008) present a similar social accessibility framework where crowdsourcing is used to enhance the accessibility of websites.[7] Rice et al. (2012, 2013) discuss crowdsourcing and accessibility

[1] Rice et al. "Crowdsourced Geospatial Data: A report on the emerging phenomena of crowdsourced and user-generated geospatial data". US Army Corps of Engineers, November 2012. http://www.dtic.mil/dtic/tr/fulltext/u2/a576607.pdf

[2] "Did You Feel It?" USGS, September 7, 2013, http://earthquake.usgs.gov/earthquakes/dyfi/

[3] Jason C. Young et al., "Transforming Earthquake Detection and Science Through Citizen Seismology," *The Woodrow Wilson Center, Commons Lab, Science and Technology Innovation Program*, Case Study Series, Volume 2 (2013): 1–64.

[4] S. B Liu and L. Palen, "The New Cartographers: Crisis Map Mashups and the Emergence of Neogeographic Practice," *Cartography and Geographic Information Science* 37, no. 1 (2010): 69–90.

[5] "Facilitating Accessibility Through Crowdsourcing," Karen m Kremer, September 8, 2013, http://www.karenkremer.com/kremercrowdsourcingaccessibility.pdf

[6] Luis von Ahn et al., "Improving Accessibility of the Web with a Computer Game," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Montreal, Quebec, Canada: ACM, 2006), 79–82.

[7] Hironobu Takagi et al., "Social Accessibility: Achieving Accessibility Through Collaborative Metadata Authoring," in *Proceedings of the 10th International ACM SIGACCESS Conference on Computers and*

research, including how crowdsourcing can be an efficient method for incorporating transient obstacles and events into mapping systems. [1,2] These publications and research projects underscore the value of crowdsourcing and its applicability in a variety of settings, including the reporting of transient obstacles as described in this report.

In the context of addressing the issue of navigation for the disabled, our effort addresses three broader research questions: 1) Is crowdsourcing viable for monitoring transitory events throughout their lifecycle? 2) What quality control techniques are required for monitoring transitory events? and 3) Can authoritative and crowdsourced data be integrated for transitory event reporting? The results of this effort will not only be applicable to the university campus, but also to broader concerns regarding crowdsourcing for monitoring any transitory events in micro-environments, such as the military use of crowdsourcing for monitoring obstacles in urban environments.

This funded research project addresses many of these emerging phenomena in a broad manner, and in the current phase, develops a preliminary system to gather, process, and display crowdsourced information about navigation obstacles for a campus environment.

This report will review the development motivations and design decisions, the recruitment of data contributors, the efforts to provide quality assurance, and the future directions of the research effort in the context of current achievements and challenges. The next section of this report addresses the broad development of a geospatial crowdsourcing testbed environment, focusing on the requirements analysis, overall system architecture, field collection application development, quality control, prototype development, recruiting and training activities, and usability considerations.

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*Accessibility* (Halifax, Nova Scotia, Canada: ACM, 2008), 193–200.

[1] Matthew T. Rice et al., "Supporting Accessibility for Blind and Vision-impaired People With a Localized Gazetteer and Open Source Geotechnology," *Transactions in GIS* 16, no. 2 (April 2012): 177–190, doi:10.1111/j.1467-9671.2012.01318.x.

[2] Matthew T. Rice et al., "Crowdsourcing Techniques for Augmenting Traditional Accessibility Maps with Transitory Obstacle Information," *Cartography and Geographic Information Science* 40, no. 3 (June 2013): 210–219, doi:10.1080/15230406.2013.799737.

# 2 Development of a Testbed Environment

In our research proposal from 2010, we outlined the general development of a crowdsourcing testbed environment that would be used to facilitate geospatial data collection by contributors, study the recruitment of contributors and community interactions, and develop methods of quality assurance for crowdsourced geospatial data.

The development of a GMU Crowdsourcing Testbed Environment has been a major priority and center of activity during this phase of research. Beginning with only the most basic conceptual ideas about the testbed and some preliminary demos (consistent and typical for proposed research projects), we proceeded to design and develop a significant set of tools for the testbed environment and have used these prototype tools for data collection and analysis. We have made a significant investment in data modeling, development, and contributor recruitment and training to facilitate the testbed environment and, more generally, the research goals for this project. This chapter discusses some of the motivations and influences for the testbed, the evolution of the testbed design, the development of prototypes and web applications, recruiting and training activities, and modifications to the testbed environment to enhance usability.

## Development and Evolution of General Technical Design

The development and evolution of the general technical design for our system began in early 2010,[1] when the first conceptual system designs were rendered and described by Rice et al. in a publication. The current system includes some of these early ideas, but is based on a much more substantial data model and design, led by a requirements analysis.

### Requirements Analysis and Preliminary User Needs Assessment

During the initial phase of this research, we explored the requirements and general needs of the end-users of our proposed system. As noted in Perkins (2002), accessibility projects that adopt techno-centric engineer-

[1] MatthewT. Rice et al., "Integrating User-contributed Geospatial Data with assistive Geotechnology Using a localized Gazetteer," in *Advances in Cartography and GIScience. Volume 1*, ed. Anne Ruas, Lecture Notes in Geoinformation and Cartography (Springer Berlin Heidelberg, 2011), 279–291, http://dx.doi.org/10.1007/978-3-642-19143-5_16.

ing solutions, without considering the social context and needs of the end-users, generally have poor results and are rejected by the community.[1] With this in mind, we sought out several future end-users of our system, including students, faculty, and community members, who are also members of the disabled community. In discussion with them, a few common issues emerged that guided our data model and system design:

1) The existing campus accessibility map, produced once a year by GMU on paper and in Portable Document Format (PDF), is helpful in designating Americans with Disabilities Act (ADA)-compliant walkways, entrances, and exits, but it does not provide information about any temporary or current changes to the campus accessibility infrastructure. Therefore, the map is less relevant in supporting navigation activities due to the construction-related obstacles that appear on a daily basis.

2) Some campus infrastructure (sidewalks, automated exits/entrances, and elevators) have condition problems that significantly impact accessibility, and the end-users would like to have an efficient way to report and promote the awareness of these items, so that they can be repaired. Elevators that are not working or are taken out of service without warning are a significant problem.

3) Sidewalks with significant cracks, protruding edges, or uplifted sections, as well as pavers or bricks that are loose and protruding upwards can be a serious tripping hazard for blind and visually-impaired students. They can also be an obstruction hazard for students with power chairs that may not have adequate clearance due to wheel size or the presence of an EZ Lock device on the bottom of the power chair.

4) Some campus infrastructure (hydrants, manholes, and curb cuts) have significant design problems which limit accessibility. End-users would like to have a way to report these issues and inform future design, and possibly to fix current design problems through reconstruction.

[1] Chris Perkins, “Cartography: Progress in Tactile Mapping,” *Progress in Human Geography* 26, no. 4 (August 1, 2002): 521–530, doi:10.1191/0309132502ph383pr.

5) Equipment associated with special events placed on the walkways and public areas present an accessibility challenge. This equipment includes tents, concrete anchors and support structures for tents stretching across walkways, and electrical conduits to support public address systems and ad-hoc electrical cabling for special events. These items are a tripping hazard for the blind and visually-impaired, and present many difficult clearance problems for the mobility-impaired.

6) Construction-related detours are frequent, often unannounced, and are marked in an inconsistent fashion, with barrels, cones, and caution tape strung between permanent objects and casually-drawn or non-uniform signage indicating the direction and nature of the detour. There is no consistent method for announcing and indicating the frequent detours related to construction.

7) The surfaces of certain campus walkways, crosswalks, and public areas are difficult with regard to traction, making tripping and slips more likely, and preventing power wheelchairs from maintaining consistent traction. This is a byproduct of weather events (snow, ice, rain, mud) and the inadequate design of some walkways that are consistently flooded or slippery during specific weather events. Snow clearing activities, which often block curb cuts are a related problem. Pavers and bricks that are loose are common in some areas of campus. These items shift underneath the wheels of power chairs and underneath the feet of pedestrians, causing traction problems.

8) Street crossing points are not always well marked. Some crossing areas require a detour through the roadway to travel to the nearest opposite curb-cut or accessible entryway.

9) Crowds are difficult to navigate through, particularly when they are accompanied by bicyclists, skateboarders, and vehicles on the walkways.

10) Several areas of campus and in the local community are common parking areas for construction and maintenance vehicles, and these vehicles often block the right-of-way.

Many members of the local disabled community (our system's end-users) expressed an interest in reporting problems. A flexible, simple interface would be required for facilitating this reporting, particularly for end-users that are visually-impaired or blind. Several end-users wanted to be able to communicate the nature of common obstacles to non-disabled community members, in order to encourage understanding and to improve the prospects for future accessibility.

Based on this general requirements analysis and user needs assessment, we developed a design for our system that would facilitate reporting a variety of transient events related to obstructions, detours, poor surface conditions, crowds and events, entrances, exits, and other items needing repair. The system would be map-based, and would be designed to augment the annual campus accessibility map by providing location and information about transient events and obstacles. The system would facilitate the involvement of end-users in receiving information about transient events and obstacles. Because many of these end-users carry a mobile computing device with them, the system would need to accommodate a variety of display devices and the interface would need to accommodate desktop and mobile screen sizes.

A variety of photographic material and documentation of the most common issues enumerated above has been gathered and continues to be gathered by project personnel to be used in educating and informing non-disabled project contributors. These photographs are periodically viewed and prioritized by some of the same end-users that participated in the requirements analysis, and subsequently used in our project training activities.

### Defining the Initial Pool of Report Contributors

The recruitment process began by identifying who would be the main contributors of obstacle reports. For our testbed on the GMU Fairfax campus, the potential contributors were expected to be individuals who regularly navigate the campus environment, including students, faculty, and staff.

For testing the prototype and performing the initial evaluation of the contribution tools, we focused on recruiting students and faculty members from our close network, such as the students and staff of the Department of Geography and Geoinformation Sciences. We invited professors and instructors, graduate and undergraduate students, Graduate Research Assistants (GRAs) and Graduate Teaching Assistants (GTAs), as well as friends and family that live in the area surrounding the campus to participate in training activities. Furthermore, we asked instructors of geographic information systems (GIS) courses (at both the undergraduate and graduate levels) to allow us to provide a short training session to the students in their courses. We asked the instructors of those courses to provide extra credit to motivate students to complete the training, complete a categorization exercise, and submit reports using the web interface. In total, there were over 90 participants recruited to undergo training.

## Architecture

In order to support the needs of our potential end-users, as determined during the requirements analysis and preliminary needs assessment, a data model was developed, information collection interfaces were developed, and user registration was planned. Each of these components is described below.

### Data Model Development

The term “Data Model” is employed in many different contexts, with a range of meanings. For the work documented here, the Data Model for testbed development consists of a structured diagram with supporting text that shows the actors, elements, and processes that contribute to the application goals, and to the overall research goal of assessing the value of crowdsourced geographic information. Although ideally a data model will eventually be able to serve several purposes, the context of this work suggested that an application goal of identifying obstacles to navigation for disabled persons in a campus environment was appropriate. A simplified version of the overall Data Model for testbed development as of this writing appears in Figure 4.

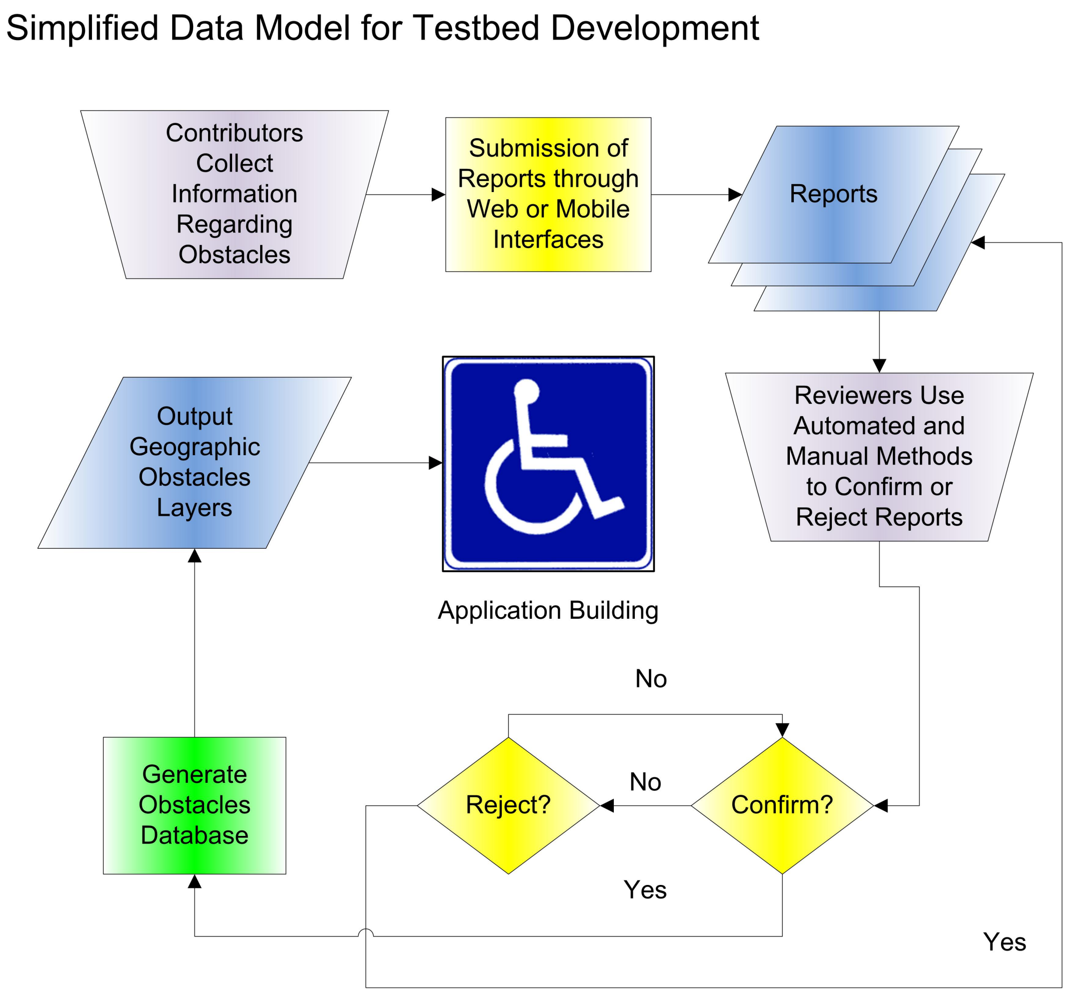


Figure 4. Simplified data model for testbed development

The process of data model development is, usually, an iterative one, and that was the case here. This process began with the identification of actors including Contributors and Reviewers. The primary elements that those actors would generate and review, respectively, were reports of obstacles to routing across campus. Those reports are combined to generate an Obstacles database. In subsequent rounds of data model iteration and refinement the types of reports to be submitted were identified, and the elements to be stored in the obstacles database were identified.

More specifically, the data to be collected by Contributors and the potential uses of those data are summarized in Table 1.

Table 1. Data Collected by Contributors

| Data Element Collected | Potential Uses |
|---|---|
| ContributorID / Username | • Tracking Contributors for measuring productivity or reliability |
| Report Type (New Obstacle, Confirmation of Obstacle, Report Obstacle Removed) | • Used to segregate reports<br>• Potentially used for visualization of different report types<br>• Used in the Reviewing / Quality Assessment Process |
| Location (Text/Address) | • Used to display to Reviewers for confirmation<br>• Potentially used to direct responders for mitigation<br>• Potentially used to direct End Users to avoid obstacles |
| Latitude/Longitude | • Potentially used for confirmation, mitigation, and avoidance |
| Report Date | • Used to define when obstacles are First Reported and Last Reported<br>• Potentially used for spatio-temporal analysis |
| Obstacle Type (Sidewalk obstruction, Construction detour, Entrance exit problem, Poor surface condition, Crowd/event, Other) | • Used for visualization of different types of reports/obstacles<br>• Potentially used for routing variants based on disability type |
| Image | • Potentially used for confirmation, mitigation, and avoidance<br>• Potentially used for manual checking / combination of reports into obstacles |
| Duration (Short, Medium, Long) | • Potentially used to direct response/mitigation activities<br>• Used to compute temporal presence |
| Urgency (Low, Medium, High) | • Potentially used to direct response/mitigation activities<br>• Used by Reviewers to prioritize confirmation activities |
| Comments (location, obstacle) | • Used for a range of confirmation activities<br>• Potentially used to inform other Contributors and Application End Users |
| Status | • Automatically set to “1” or “Unconfirmed” until Review |

Although the review/quality assurance processes are primarily manual in the testbed environment, each of the data elements collected above can contribute to measures of completeness and consistency. That is, if a single report has all of the potential fields completed by the Contributor, then it may receive a higher completeness score, and would generally be considered to be more reliable. With regard to consistency, if multiple reports are received in close proximity, and there is substantial agreement between the data elements the combined reliability of these reports creates greater confidence in the accuracy of the obstacle. These potential measures are discussed in more detail below. Additionally there are data elements such as Report IDs that are automatically added to reports for tracking purposes.

Subsequent to the reporting process, additional data elements are collected during the Review/Confirmation process to be used in generating the Obstacles database from the collected reports (Table 2).

Table 2. Review/Confirmation Elements

| Data Element Collected | Potential Uses |
|---|---|
| ObstacleID | • Unique ID for Obstacles used for tracking |
| ReviewerID(s) | • IDs of all Reviewers who have examined the Obstacle<br>• Potentially used for tracking of reviewer performance and computation of confidence measures |
| ReportID(s) | • The IDs of all Reports that contributed to the generation of the Obstacle used for tracking and obstacle history |
| ObstacleType | • Determined by the Reviewer from the Report(s) or by field examination<br>• Uses as above |
| Estimated Start Time | • From initial report, duration estimate, and Reviewer information gathering<br>• Potentially used for spatio-temporal analysis |
| Estimated End Time | • From Estimated Start time and Duration estimate<br>• Potentially used for spatio-temporal analysis |
| First Reported | • Generated from the collection of Reports that contribute to the obstacle<br>• Potentially used for spatio-temporal analysis |
| Last Reported | • Generated from the collection of Reports that contribute to the obstacle<br>• Potentially used for spatio-temporal analysis |
| Obstacle Status | • Updated by Reviewers from initial setting of “Unconfirmed” in reports<br>• Potentially used to track Obstacles, identify malicious users, prioritize Obstacles for further review |
| Obstacle Urgency | • Determined by the Reviewer from the Report(s) or by field examination<br>• Uses as above |
| Obstacle Image(s) | • One or more Images selected or contributed by Reviewers<br>• Potentially used for dissemination to Contributors (for confirmation reports), Reviewers (for creation of obstacles), and End users for information regarding obstacles and their |

| | |
|---|---|
| | avoidance |
| Obstacle Location | • Determined by the Reviewer from the Report(s) or by field examination<br>• Uses as above |
| Obstacle Latitude/Longitude | • Determined by the Reviewer from the Report(s) or by field examination<br>• Uses as above |
| Comments | • Collection of comments from Reviewers, or from Contributors as approved by Reviewers<br>• Uses as above |

Finally, data elements that are generated by summarizing information from the Reports Database and the Obstacles Database will be developed in future work. These may serve a number of purposes potentially including generating spatial databases of obstacles, reporting on the presence of obstacles over time to decision makers, and reporting to authoritative sources regarding the mitigation of obstacles across the campus environment.

### Event Reporting Information Collecting Requirements

The event reporting application developed in this project was chosen to meet the requirements of the end-users interviewed during the initial requirements analysis phase of the project, as described above. Moreover, the information collected was intended to instantiate the data model that supports the overall project goals.

Toward those ends, contributors submit reports to add, edit, and confirm obstacles. Reviewers examine the reports that are submitted, and use the reports to generate obstacles. The obstacles are periodically reviewed by reviewers and closed or removed from view when they are no longer relevant. The reporting application, while limited to a small geographic area, is similar in some ways to the USGS National Map Corps Structures Application, which is a crowdsourcing program enabling users to add, edit, or remove data from the USGS's National Map Database.[1]

More explicitly, the information content gathered through the event reporting interfaces include location, obstacle type, duration, urgency, and

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[1] "This is the home of The National Map Corps," USGS, September 8, 2013, https://my.usgs.gov/confluence/display/nationalmapcorps/Home

text-based comments. The information content associated with these event-reporting functions is described below.

### Review of Event Reporting Interfaces

In order to make decisions about our own application development and deployment processes, several significant geospatial crowdsourcing applications were reviewed. Applications of this type were previously profiled in chapter 3 of the large phase 1 technical report from 2012 (Rice et al. 2012), and separated into categories based on their primary function (Table 3). The reporting applications profiled in the phase 1 report include Louisiana Bucket Brigade, GasBuddy, Street Bump, Syria Tracker, and Wikipedia. Each application involves the collection of data by contributors, and in some cases, the reporting, display, and confirmation of contributions.

To recognize the applications that have been influential in our work, we profile Waze[1] and SeeClickFix,[2] which are popular tracking and reporting applications. Each of these applications has a growing contributor base and commendable interface design. In the case of Waze, (reviewed in the phase 1 report as a tracking application) the interface is designed for use by a driver or passenger in a vehicle, and efforts have been made to greatly simplify the mode of contribution and the interface.

Table 3. Geospatial crowdsourcing applications

| Tasks | Description | Example |
|---|---|---|
| Imaging | Building collections of imagery. | • Grassroots Mapping |
| Georeferencing | Rectifying maps and imagery. | • Grassroots Mapping<br>• NYPL Map Rectifier |
| Transcribing | Converting text resources to a digital form. | • OldWeather |
| Digitizing | Collecting geospatial feature geometry and attributes from maps or imagery. | • OSM<br>• Google MapMaker<br>• Wikimapia |
| Attributing | Adding descriptive information to known geospatial features or datasets. | • Galaxy Zoo |
| Reporting | Collecting information about a | • Louisiana Bucket |

[1] "Get the best route, every day, with real-time help from other drivers," August 24, 2013, "http://www.waze.com

[2] "Report neighborhood issues and see them get fixed," SeeClickFix, August 22, 2013, http://seeclickfix.com

| | | |
|---|---|---|
| | location, usually through observation or a mobile device. | Brigade<br>• GasBuddy<br>• Street Bump<br>• SyriaTracker<br>• Wikipedia |
| Searching | Searching maps or imagery to identify specific features. | • Field Expedition: Mongolia - Valley of the Khans Project<br>• DARPA Red Balloon |
| Tracking | Collecting paths and traces, usually using GPS. | • Waze |
| Validating | Verifying the quality of existing geospatial information. | • NAVTEQ Map Reporter<br>• Geo-Wiki.org<br>• OSM Inspector |
| Polling/Surveying | Collecting place-based opinions or information from users. | • SurveyMapper |
| Socializing | Contributing geospatially referenced information to social media sites. | • Twitter<br>• Flickr<br>• Foursquare |
| Sharing | Placing content on a hosted site, potentially including data, applications, or finished maps, where users can access and mash-up. | • ArcGIS Online<br>• GeoCommons |

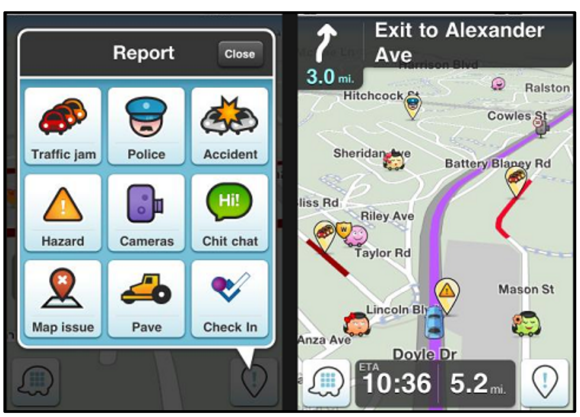


Figure 5. Waze reporting interface and map display (May 2013)

Waze (Figure 5) is an Israeli-founded navigation tool that uses crowdsourcing to establish reports of traffic conditions, police incidents, accidents, hazards, and traffic cameras. The Waze reporting application is significant due to its intuitive interface, design, and ease of use. Our own efforts to reduce the number of categories and selection choices for data contributors while maintaining the quality of information is based on our study and use of Waze. The icon-based data contribution interface is a model for the design of the mobile contribution tools discussed in other sections of this report, and the simplicity of Waze is a general motivating example for us. Finally, the differentiation between the mobile map display in the contribution tools, and the expanded map view in the desktop web interface echoes our own development of our mobile contribution tools and desktop tools with different functionality.


Figure 6. SeeClickFix mobile reporting tool (May 2013)

SeeClickFix (Figure 6) describes itself as a service used to "Report neighborhood issues and see them get fixed." It relies on a combination of contributor reports and connections with local municipal, commercial, and private entities to provide resolution for the reports. The motivations for SeeClickFix (reporting to enable 311 services for municipalities), and Waze (user-engagement to facilitate advertising) inform our attempt to provide a mobile reporting tool. In many ways, we seek to combine the intuitive simplicity of Waze and ease-of-use while walking or traveling with the thoroughness of the reporting system in SeeClickFix.

## Prototype Deployment

Our prototype deployment has been guided by exemplar applications, our requirements analysis, a data model, and the information needs of our end-users. In order to provide a flexible platform to collect reports from contributors working in the field or from a desktop computer in an office, we decided, in Fall 2012, to begin our prototype development and deployment activities with a web application to be used through a browser. This same application could later be modified, resized, and reorganized to run on a mobile device. In many ways, this would save time and effort because code from the desktop application deployment could be re-used in the mobile application deployment. We anticipated that a mobile web application would be used on a variety of different mobile devices (iOS, Android) and would become our primary collection tool. We planned on the desktop web application being both a collection tool and a viewing and management tool, and in subsequent phases of the research would adopt an expanded role as quality assurance methods became more robust and new ways of visualizing content were developed.

We serve our applications using a Microsoft Windows IIS platform running on a Dell PowerEdge server supplied by the GMU GGS and College of Science IT departments. The server uses PostgreSQL v.9.2 (x64), PostGIS 2.0.1 (providing spatial extensions and capabilities to PostgreSQL), PHP 5.3.27 (used to parse PHP files), FastCGI, and Aptana Studio 3, which is a web-programming tool. The code is tested on a local machine and then moved to a server where it is expanded, permissions set, and activated. We are developing additional website tools using the Drupal Content Management System, v.7.22.

The core code for the web interface is available on our project server,[1] with a listing of the base html code, the extensive JavaScript used for interaction and display through the web browser, and PHP, which is used to read and write records to the database. This code will be available for public use and will be documented to highlight functionality.

### Web-based Event Reporting Application Development

The event reporting application was designed and developed from several initial demonstration interfaces and ideas,[2,3] with functionality influences from SeeClickFix and Waze.

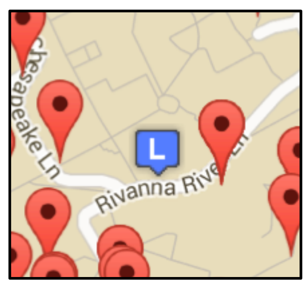

Figure 7. Location icon

In the current web application, there are six main menus, which are numbered and facilitate entry of reports. The menus, along with their functionality, are presented here. Figure 7 shows the map interface and location icon used for georegistering reports. Figure 8 shows the interface menu where a contributor's ID is entered and a date and time selection for the report is made. Figure 9 is our obstacle location menu, with geocoded location, latitude and longitude references, and text-based location description functionality. Figure 10 is

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1 "Testbed Environment Code," September 8, 2013, http://geo.gmu.edu/vgi/codebase/

2 Aburizaiza, Ahmad O., and Matthew T. Rice (2011), "VGI and Geotechnology for Supporting Blind and Vision-Impaired People using a Localized Gazetteer", FOSS4G: Free and Open Source Software for Geospatial, 2011, Sheraton Denver Downtown, Denver, Colorado. Academic Track – Spruce Room, September 16, 2011.

3 Rice et al., "Integrating User-contributed Geospatial Data with assistive Geotechnology Using a localized Gazetteer."

the menu used to select the obstacle type, and Figure 11 shows the menu used for providing duration and urgency estimates for reports. A report contributor can provide a text-based obstacle comment, and general feedback in the final menu (Figure 13) before the contribution is reviewed and submitted (Figure 12). These menus were developed using JavaScript within the Google Maps API, and positioned using the placemark location on the map.

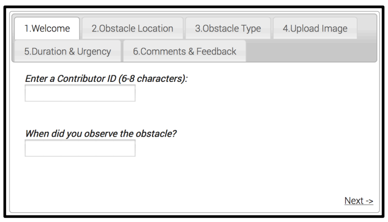


Figure 8. Welcome menu with contributor id and date/time selection

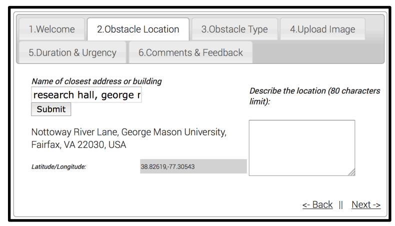


Figure 9. Obstacle location menu

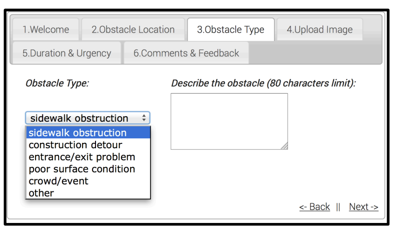


Figure 10. Obstacle type menu

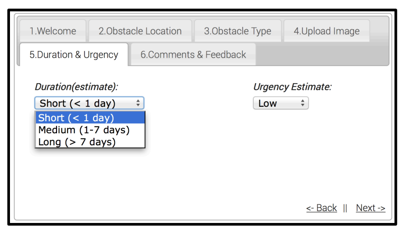


Figure 11. Obstacle duration and urgency menu

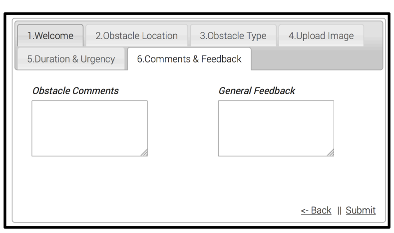


Figure 13. Obstacle comments and feedback menu

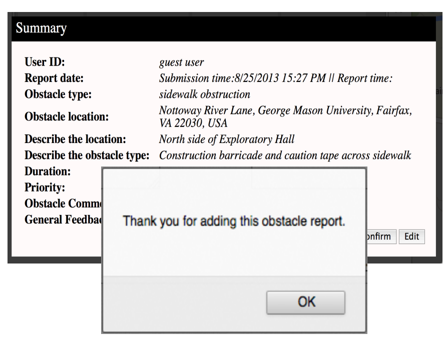


Figure 12. Contributor report summary with confirm and edit, with subsequent submission confirmation

Mobile Application Development

The mobile contribution tools (located at http://geo.gmu.edu/vgi/m/) are visually simpler and do not have the full implementation of quality assurance and analysis tools, but will only have what is necessary for Contributors to submit reports and Reviewers to field-check reports. The layout of the initial screen (Figure 15) is designed to be similar to Waze (profiled in previous sections), and includes icons for the six categories of obstacles contained in the desktop application's obstacle type menu (Figure 10). The mobile application is designed from the same codebase as the desktop tool, but the sizing of the interface is greatly reduced and interface elements are located at the top and bottom of the screens, as typical for mobile web applications used on a small screen. Figure 14 shows how the elements for obstacle location are presented in simplified form and reduced size. The mobile application development environment is Sencha Touch and has been tested for iOS and Android devices.

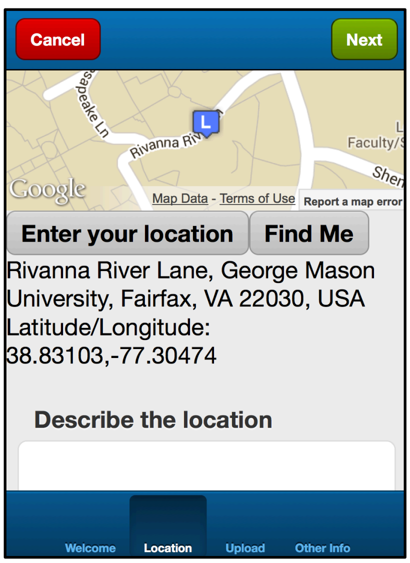


Figure 14. Mobile application, Obstacle Location menu


Figure 15. Initial contribution screen of the mobile web application

User Registration Module

As noted above, the current system (and the directions provided during contributor training) instructs contributors to select an ID, which they use for reporting. This Contributor-ID is stored in the database and used to check consistency between reports, thoroughness of report entry, and the number of reports submitted. The next revision of the web application, to appear in September, will include a direct linkage between the Drupal content management system and the web application, which will allow for more detailed Contributor tracking and reporting, and will facilitate more formal user profiles which can be used for community engagement through the content management system. Experiments with community engagement of this sort were conducted with Blackboard, an internal university content management and curriculum design system. This was done in a closed setting with students enrolled in a GIS course who were also trained through the same online environment as an experiment in online recruiting, training, and engagement.

Although user registration mechanisms in CGD projects are thought to increase quality through accountability, as discussed in chapter 4 of Rice et al. (2012), user registration is generally considered to be a disincentive in many open source communities. We would like to maintain the ability to make anonymous or guest contributions in the future, but we recognize the benefit of registration in terms of quality.

Methods of user motivation and engagement that have found particular success in a variety of other projects include contributor badges, rewards, ratings and peer evaluations. Some recognition systems provide titles to individuals based on their participation or expertise. As an example, the Old Weather site (reviewed in Rice et al. 2012) classifies individuals as Cadets, Lieutenants, or Captains, based on the number of contributions. Future improvements to our system will allow us to better track participants of all kinds, and will allow us to implement ratings or ranking systems to increase engagement.

## General Reporting Statistics, Dynamics, and Feedback

Figure 16 shows that the majority of contributors have only submitted a single report, which was an expected result and not too dissimilar to the dynamics of other crowdsourcing systems such as Wikipedia, where the vast number of contributors make a very small number of reports and a very small proportion of Contributors make the largest number of reports.[1] It is currently uncertain why most contributors only make single reports, though the extension of an extra course credit for undergoing training and

[1] For a graph of Wikipedia edits by the top 10,000 contributors, see: http://upload.wikimedia.org/wikipedia/commons/d/dc/Top_Wikipedians_edit_distribution%2C_November_2012.svg

making a report was a factor in one cohort of approximately 20 students trained in the first week of May 2013. For the other 60-70 trained Contributors, the reason is uncertain.

Wikipedia has a contribution distribution that is even more skewed with very few individuals with multiple contributions and a vast number that have contributed only one or two edits. We anticipate a less skewed distribution, though we now recognize that this dynamic of uneven user contributions is probably common in many crowdsourcing projects.

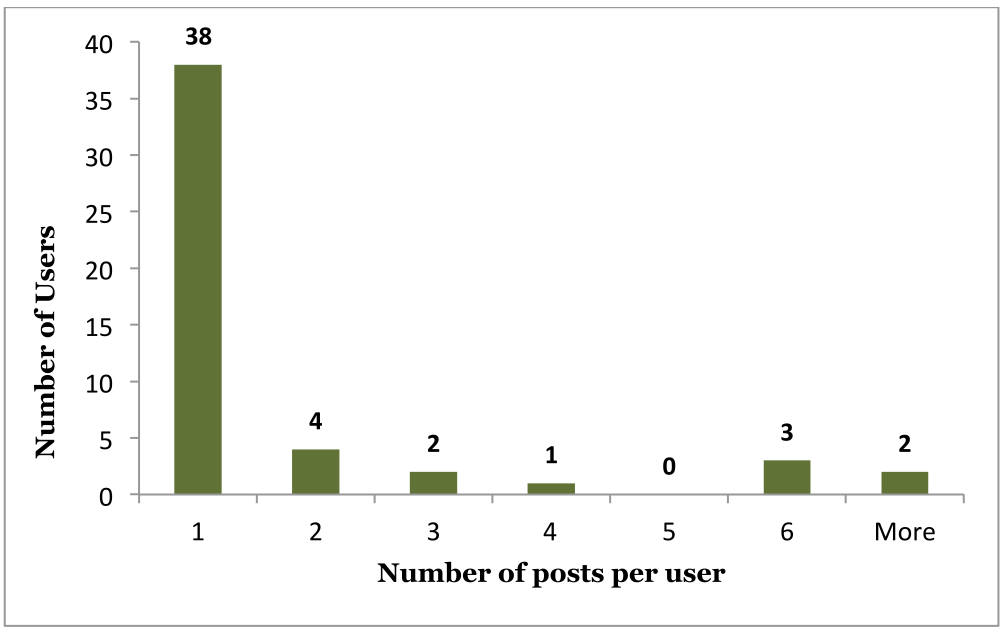


Figure 16. Contributions per user (all users)

Figure 17 shows the frequency of obstacle type within reports we have received. This distribution will change in the future with a revised categorization scheme, but at present appears to be consistent with our initial expectations.

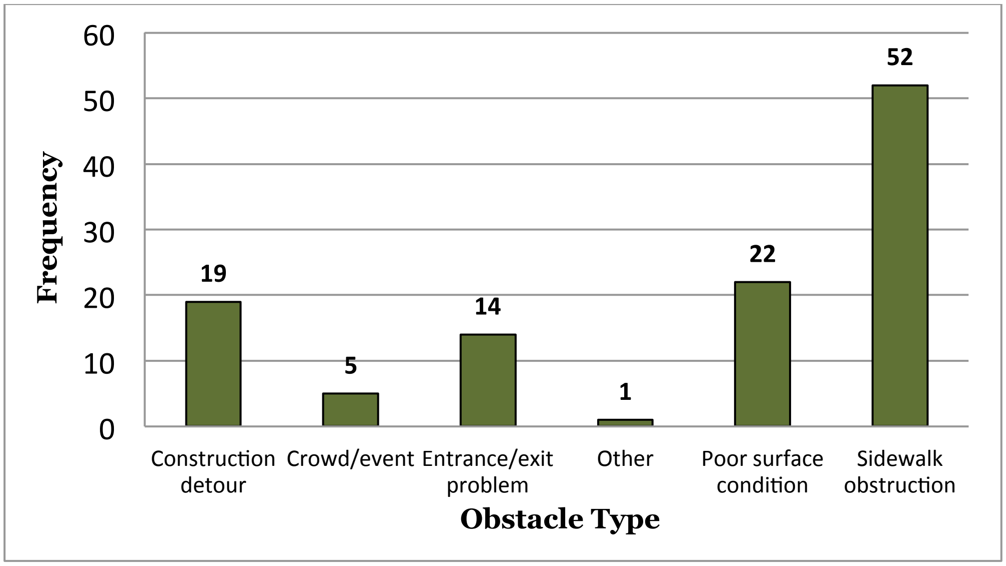


Figure 17. Frequency of reports by obstacle type

We had no preconceived ideas about the distributions for urgency (Figure 18) or duration (Figure 19). We did expect, however, based on our training results, to have few high urgency reports, which are associated with obstacles posing a serious risk to safety. We did initially switch from a larger, more detailed set of duration and urgency categories to a simpler set of categories based on user feedback and we may make additional refinements in the future.

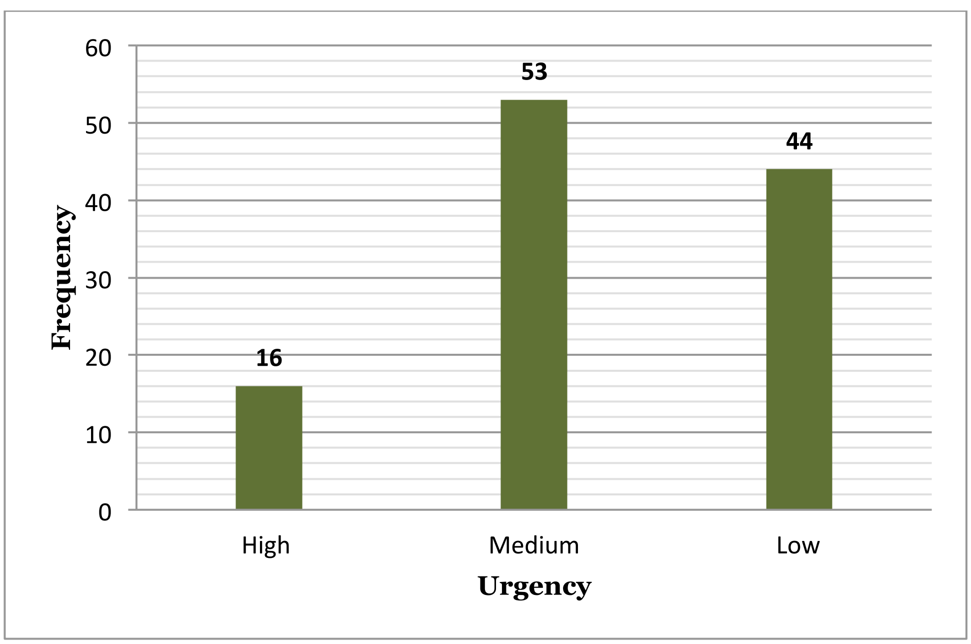


Figure 18. Frequency of report urgency categories

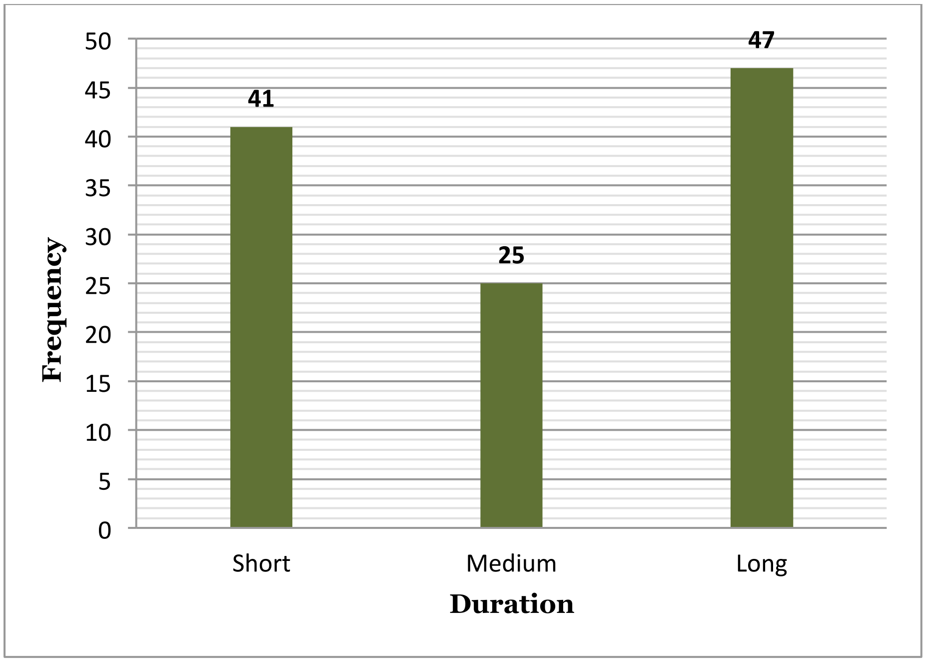


Figure 19. Frequency of report duration categories

## Initial impacts of the event reporting prototype

During several outreach activities with Fairfax City elected officials, transportation personnel, planning and economic development officials, and the GIS manager, the event reporting application was demonstrated and several reports inside the city were noted. One report (shown in Figure 20) notes a closed sidewalk with construction fencing extending to the curb, preventing access except in the roadway. In this area, pedestrians either detour into the actual roadway, cross to the other side of the road through traffic without the benefit of a crosswalk, or backtrack 100 meters to the nearest corner to cross. Subsequently (and likely due to simultaneous reports from residents) a sign was placed both north and south of the detour to provide adequate notice (Figure 21). We are


Figure 20. Sidewalk closed and detour into roadway, reported by contributor application, Obstacle Location menu

collecting anecdotal information related to any actions, such as this, that may be related to authoritative entities using information generated by our reporting application and will report other activity of this type when it is available.


Figure 21. Signage added to facilitate crossing problem associated with detour

# 3 Quality Assessment Techniques for Crowdsourced Geospatial Information

## Background Regarding Quality Measures and Assessment Techniques in CGD

Although the application goals for the current testbed are to develop practical tools for the capture of obstacles to disabled navigation, a fundamental research goal is to determine the value – or some measure of the quality – of the information that is collected. Although the terms "value" and "quality" are – by their nature – subjective, this research can benefit from extant knowledge in the extensive literature regarding quality assessment. The next section reviews some pertinent elements of this large literature. This is followed by a description of a Quality Assessment Sub-data model intended to guide the Review and Assessment processes in this research. This is succeeded by an outline of both currently implemented and future research goals in the assessment of reports and confirmation of obstacles. Finally, discussions of report coverage and malicious content detection are provided, with suggestions for future work.

## Review of Quality Assessment Literature

Broadly speaking, quality assessment is the process of determining if the products of any activity are sufficient to meet the needs of stakeholders in the project. In the context of crowdsourced geographic information, this process can include determining the positional, temporal, and attribute accuracy of the information, the completeness and coverage of the data, and more generally its sufficiency for any particular application.

For geospatial data produced by US Federal agencies, standards for quality assessment have been developed and used, including the National Map Accuracy Standards (NMAS) and the National Standard for Spatial Data Accuracy (NSSDA), which is more relevant and broadly applicable to digital data that is not destined to be used only on a printed map. These two accuracy assessment methods and their applicability to crowdsourced geospatial data are described in Rice et al. (2012). One could argue that these standards are not particularly relevant to the rapidly changing geospatial data collection environment. In particular, these standards are not well suited for modeling the transient events that are the focus of this research.

They do however represent the milieu in which data accuracy is viewed by a large number of professional geographers.

More recent attempts to determine the accuracy of crowdsourced data include Haklay's 2010 study of OpenStreetMap (OSM) data, which demonstrated that the positional accuracy of OSM roads data, when compared to authoritative Ordnance Survey data, was within 6 meters. Hakley's study also concluded that there was non-uniformity in coverage, with a bias toward more affluent areas. Concerns regarding coverage are pertinent to this research, given that the presence of Contributors is not expected to be uniform, nor is the population of end-users uniform in space.

Quality Assessment is about more than just positional accuracy, however. It can include lineage, logical consistency, and completeness, and should include issues such as bias in coverage researched by Haklay. Flanagin and Metzger (2008) were early proponents of the notion that lineage – or credibility – had traditionally been associated with authoritative sources, but that that assumption was set to be continually challenged in the emerging Volunteered Geographic Information (VGI) environment. Goodchild and Glennon demonstrate the value of crowdsourced data supplementing official data in their 2010 discussion of crowdsourced mapping during the recent California wildfires. As discussed in Rice et al. (2012), the issues of consistency and completeness are strongly related to the larger issue of "fitness for use". Does a crowdsourced dataset have errors that are significant enough to pose a risk and create liabilities for the creator? Is there a significant benefit to be gained by using the crowdsourced data in addition to or in the absence of official data?

A number of other significant new publications have emerged addressing the issue of quality assessment, and were not addressed in the previous report (Rice et al. 2012). Of specific interest is the work of De Longueville et al. (2010), which extends fuzzy analysis to this research area by introducing the notion of "Degree of Truth" as a measure of certainty (or conversely vagueness) regarding spatial data. Goodchild and Li (2012) suggest (among other things) that crowdsourcing itself can be used to validate the quality of data. That is, external users can contribute both data and quality estimates of the data of other contributors in the crowd. Koukoletsos et al. (2012) have focused on completeness, employing automated matching methods for both geographic and attribute elements of crowdsourced data. Finally, Ostermann and Spinsanti (2011) have endeavored to outline a conceptual quality assessment workflow for CGD that includes methods for enriching the data collected, assessing quality and credibility, and analyzing the geographic nature of the data that is collected.

While this is not the appropriate forum to continue a thorough literature review of quality assessment in CGD, it is clear that issues of credibility, accuracy, and completeness are important common themes considered by experts in this research area. We considered each of these in our ongoing development of review and quality assessment procedures for the testbed environment presented here.

## Design of Quality Assessment Sub-Data Model

The quality assessment process for the research presented here is encapsulated in the Quality Assessment Sub-Data Model (Figure 22). This sub-data model expands on the elements within the overall Data Model described in Chapter 2 that are specific to the reviewing procedures necessary for building the obstacle database from the raw reports. The primary elements of the Quality Assessment Sub-Data Model are briefly explained below.

Simplified Review / Quality Assessment Sub-Data Model

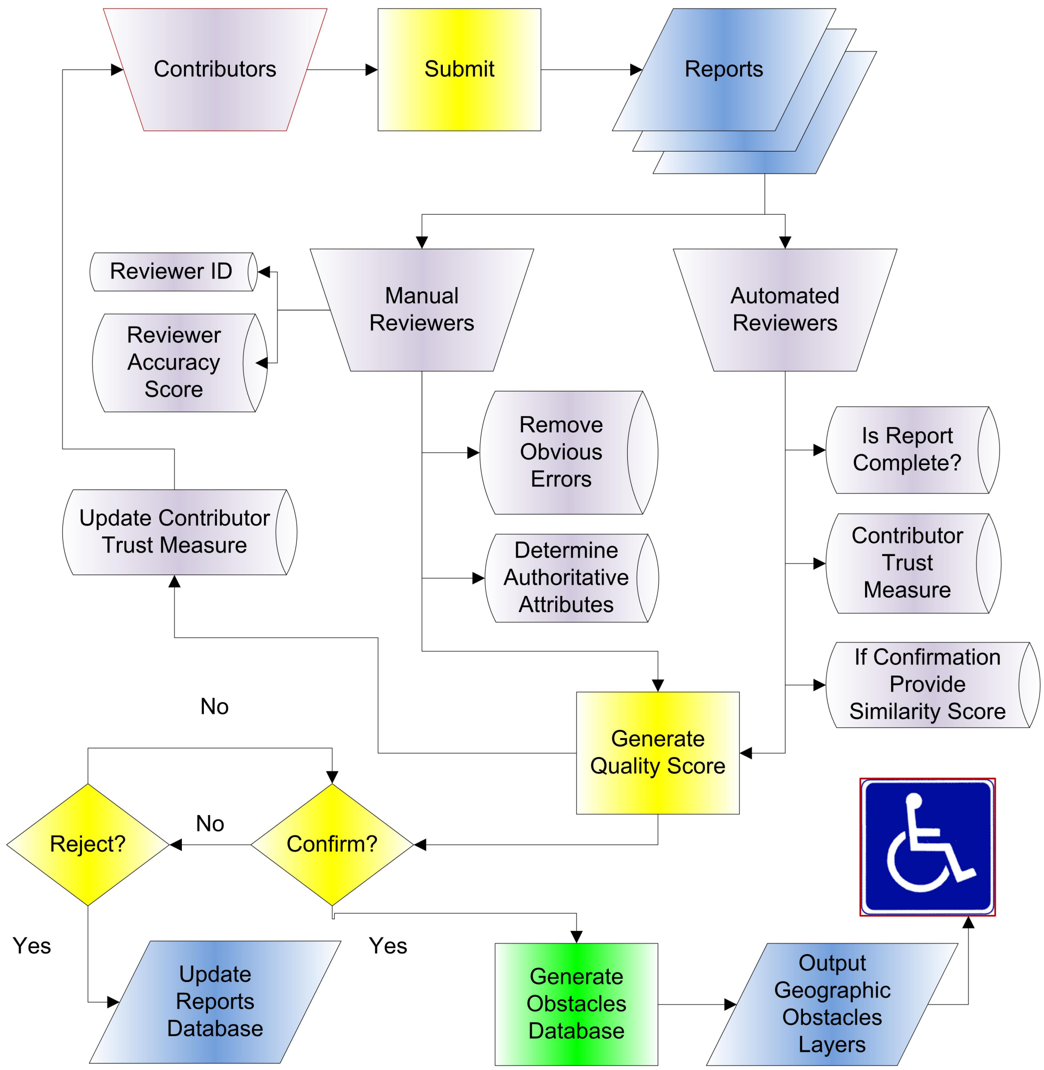


Figure 22. Simplified quality assessment Sub-Data Model

## Automated Report Quality Assessment

It is envisioned that the report confirmation process will consist of two sets of procedures, Automated Review and Manual Review. Every report will be subject to some Automated Review and Manual Review processes. Both processes contribute to the computation of a Quality Score that is associated with the report and which leads to Confirmation or Rejection of the report. This process follows the structure of well-established methods for address-geocoding, where automated methods are used to score candidate locations, and manual review is employed as necessary to supplement or correct errors or omissions.

In the current iteration of the Quality Assessment Sub-data model, there are posited three automated measures that could contribute to the Quality Score for a particular report. They are:

- Report Completeness
- The Contributor Trust Measure, and
- A Similarity Score if the Report is flagged as a confirmation report of an existing obstacle

Report Completeness is simply a measure of how much information is filled out on the Report. The idea behind this measure is that, generally speaking, a complete report with all requested information may reflect the reliability, training, and intentions of a contributor. A presumption is that malicious users are less likely to spend their time completing each of the requested data fields. Similarly, if a Contributor accidentally begins an incorrect report, they will likely abandon it before completely finishing the data entry process.Report Completeness is an imperfect reflection of the nature of crowdsourced data, where the entire process of submitting reports is optional. One can, if they choose, enter a report with very little information present; nearly all of the responses are optional other than a few default selections. The logic behind this measure is that the more of these optional items that are included, the more invested in the process is the Contributor, and therefore the report is more likely to be of high quality.

The Contributor Trust Measure is – as the name strongly suggests – some means of distinguishing the quality of the Contributors of reports. This measure reflects the notion in the literature for credibility or authority among Contributors. Currently, the trust measure is implemented as simply a categorical value assigned to Contributors (1, 2, or 3) and is assigned by reviewers. In future efforts this could be changed to a more refined score through any number of scoring techniques, and that score could, in itself, be influenced in an automated way by the number of reports that are confirmed by Reviewers. Eventually a Contributor with a high Trust Measure may be invited to become a Reviewer of others' reports.

Finally, if a Report is flagged by the Contributor to be a confirmation of an existing report, additional automated quality assessment measures are envisioned in the sub-data model. Although these are still under development, they may include measures of nearness (Location Overlap), and concurrence of obstacle type, duration, and urgency. Essentially, these measures will determine to what extent the confirmation report matches the attributes and location of the existing obstacle. If the report is confirmed, data elements in the obstacle database will be updated to reflect this greater certainty regarding the quality of the obstacle information being reported.

### Manual Report Quality Assessment

In the Quality Assessment Sub-Data Model it is proposed that a manual reviewing process will also be implemented. Depending on the amount of manual reviewing resources available, some subset of reports that have been through the Automated Review may also examined by a trusted Reviewer. At the moment the choice of reports to review is left to the Reviewer, although reports that are short-lived (e.g. moving vehicles on sidewalks, temporary crowds) are currently less likely to be considered for review since they are likely to have been resolved before a Reviewer can examine them. The development of a reviewer report prioritization system in the upcoming weeks will change the way that reports are brought to the attention of reviewers, with high urgency and low duration reports being given a higher priority than others.

In the current testbed environment, Manual Review consists of:

- Selecting a report to review (Reviewer Choice)
- Optionally visiting the reported location in the field to confirm or collect additional data
- Editing reports to correct information
- Changing the status of reports to reflect the level of review or confidence

During this process the Reviewer ID is appended to the Report and the Reviewer's Trust Measure contributes to the overall Quality Score. Currently the trust measure is, again, a categorical measure of Reviewer performance but could be refined in future work. Manual Reviewers are responsible for removing obvious locational errors, obvious vandalism, and other clear errors in reporting. Perhaps most importantly the Reviewer can change the status of the report to indicate if it is under review, confirmed, or rejected as a valid report.

## Creating Obstacles

Creating Obstacles in the obstacle database is the purpose of the automated and manual review processes. Since no report – even the most spurious – is deleted, the outcome of the review process is either to confirm a report or set of reports as an obstacle, or to fail to confirm a report as an obstacle. While ideally the confirmation process would be based solely on the Quality Score generated by a combination of the results of the automated and manual review processes, the reality at the moment is that this is largely up to the discretion of the Reviewers.

There is currently functionality that allows Reviewers to select a subset of reports, and combine them into a confirmed Obstacle. In so doing, the Reviewer can select which of the reports is the most reliable, in order to initially populate the obstacle record. The Reviewer may then edit any elements that need to be corrected. The ReportIDs of the reports that have been combined into an Obstacle are recorded. Similarly, any ReporterIDs and ReviewerIDs associated with those reports are also associated with the resultant Obstacle. A number of fields (discussed in Chapter 2) of the Obstacles database are calculated based on the input reports (e.g. First Reported, Last Reported).

Regardless of whether or not a report is rejected or confirmed, the record of the report is preserved in the Report Database. By retaining rejected reports, subsequent error checking can be done, revisiting of reports can be accomplished if new information is received, and documentation regarding rates of rejected reports can be maintained.

## Report Publication Process

The end goal of developing the Obstacle Database from the Reports is to deliver that database in various forms for the purpose of mitigating obstacles to disabled routing through the campus environment. It is envisioned that report publication could take the form of Summary Documents to be presented to high-level decision makers or summaries of individual obstacles (or subsets of obstacles) to particular agents within the university for the mitigation of those obstacles (such as facilities management).

Perhaps most importantly, the obstacles can be exported as geographic layers for use in applications that inform stakeholders in various ways about the location and nature of obstacles. Subsequent work will include the development of routing applications to be used by disabled persons for the purpose of navigating across campus.

## Accuracy Assessment

Methods of accuracy assessment for the obstacles collected in this research are still under development, but are being based both on well-established methods and novel measures of accuracy.

### Positional Accuracy of Reports

Measurement of positional accuracy requires a locational "truth" from which a measure of variance away from that truth can be captured. Essentially, the most trusted locational representation is the one against which all other locational estimates are judged. This follows the methods employed in Funk et al. (1998) and Church et al. (1998) where positional offsets are represented by vectors, and where the vectors can be converted to error fields. The properties of the vector offsets and error fields can then be analyzed for pattern or systematic error, and the spatial characteristics of the error can be described.

In this research, at the current time, the crowdsourced information is not easily comparable to known and trusted positions from which error measurements can be made. In future research, experiments are envisioned where a set of obstacles are carefully documented by research personnel. Participants will be directed to areas where they are likely to encounter these obstacles, and when reports are made, they will be compared to the known positions, and the nature of the offsets will be described. It is believed that this type of analysis can assist in the refinement of data collection procedures, can lead to improvements in training of Contributors, and can help in the development of more precise reliability scores associated with reports.

### Temporal Accuracy

The challenge of conducting rigorous spatio-temporal analysis has presented a challenge to geographers for decades. Given the natural tendency of geographers to focus on positional accuracy, the measurement of temporal accuracy has received relatively short-shrift. However, recent studies have examined the distributions of incidents in a spatio-temporal solution space (Eckley and Curtin, 2012). Given that the research presented here is focused on transitory events, and given that transitory events have a fundamentally important temporal nature, this is a critical area for future research. While we are not prepared to evaluate temporal accuracy at this time, the comparison of estimated start time, end time, and duration with demonstrably accurate values for those variables is a critical area for future research.

### Attribute Accuracy

Similar – if not more challenging – difficulties exist in determining attribute accuracy. Many of the attributes that Contributors are asked to include regarding obstacles are highly subjective in nature. The determination of the “truth” regarding attributes such as “severity” or “duration” requires expert input; input which varies even among different experts. For this research going forward, there will be the development of consensus beliefs regarding obstacle attributes, with the range of expert opinion captured and retained. Although there is some disagreement regarding their value, measures of inter-rater agreement (such as the kappa coefficient) may be employed in an effort to determine the strength of a consensus view regarding an attribute value (Foody et al. 2013). For cases such as this, it is arguably preferable to build a distribution of probable values. That allows the determination of an expected value for the attribute, based on consensus expert opinion. This further allows a description or computation of a difference – or variance – from that expected value along the distribution of possible attribute values.

Initial research into attribute accuracy has been conducted in order to outline issues in categorization during the event reporting process. As part of the training sessions discussed below, participants were asked to complete a categorization exercise. The exercise was designed to evaluate how well participants, both end-users and potential contributors, understood the predefined obstacle and urgency categories. This allowed us to gain additional insight for improving both the training material overall and the categories used within those materials and the event reporting application itself. The exercise consisted of categorizing 15 pictures that displayed different types of obstacles, as well as assessing the urgency and duration in each event. The pictures used for the categorization exercise were taken from a collection of pictures of obstacles found within and adjacent to the GMU Fairfax campus.

During our requirements analysis and preliminary user needs assessment (discussed in Chapter 2) end-users provided us with additional insight into how the perception of the obstacle types and urgency differ according to specific accessibility needs. Depending on the disability of the end-user, they provided different answers for the urgency options. Also, they suggested modifications to some categories to fit obstacles that we initially had not considered. Considering those differences, we are contemplating including an additional option in the reporting tool, where the contributor can indicate the types of disabilities they believe would be impacted by the obstacle.

## Coverage

As mentioned in the review of the literature above, coverage of the operations area is a particular concern with crowdsourced data, since there is no guarantee that Contributors will report from all parts of the area. The concept of coverage can be approached in a number of ways. Geometric analysis of existing reports or obstacles could identify the largest polygons that are essentially "voids" of information in the study area. Point pattern analytic techniques could describe the extent to which the reports are clustered – or conversely evenly distributed – across the region.

These purely spatial coverage measures do not, however, take into account what is perhaps the more important element of coverage…the coverage of the end-user demand population. Efforts to report obstacles that occur in areas where no disabled persons travel are not of particular value for an application designed to improve routing for disabled persons. This is assuming, of course, that the reason for "voids" of disabled travel is not the presence of obstacles themselves. There is a substantial body of literature regarding ways in which actions can be taken to maximally cover a set of demands in space, the seminal paper being Church and ReVelle (1974). More recent efforts that combine location science techniques with GIS for partitioning areas for patrol have also appeared (Curtin, Hayslett-McCall, and Qiu 2010). Future iterations of the testbed being developed here may well contain computations of coverage, perhaps leading to suggested reporting sub-areas for Contributors.

With regard to the current coverage status in the testbed environment, Figure 23 shows the general distribution of reports for the local area (with one report in Fairfax County ½ mile east of campus not shown). The reports are fairly broadly distributed across campus, which was a surprise, due to our expectation that we would see more redundant reporting in the center of campus near the Johnson Center and quads, where most of the students congregate. Instead, we have most of the areas of campus and the common neighborhood origins for campus visitors well represented in the geographical distribution of reports. We note four areas in black that are considered voids due to no reports being made. These areas, with the exception of West Campus, are busy and filled with the same activities that generate other reports, and we have no clear understanding of why they lack reports. We have not yet made any effort to study the time-space activity patterns of our contributors because of human-subjects reviewing concerns and our concerns about contributor privacy.

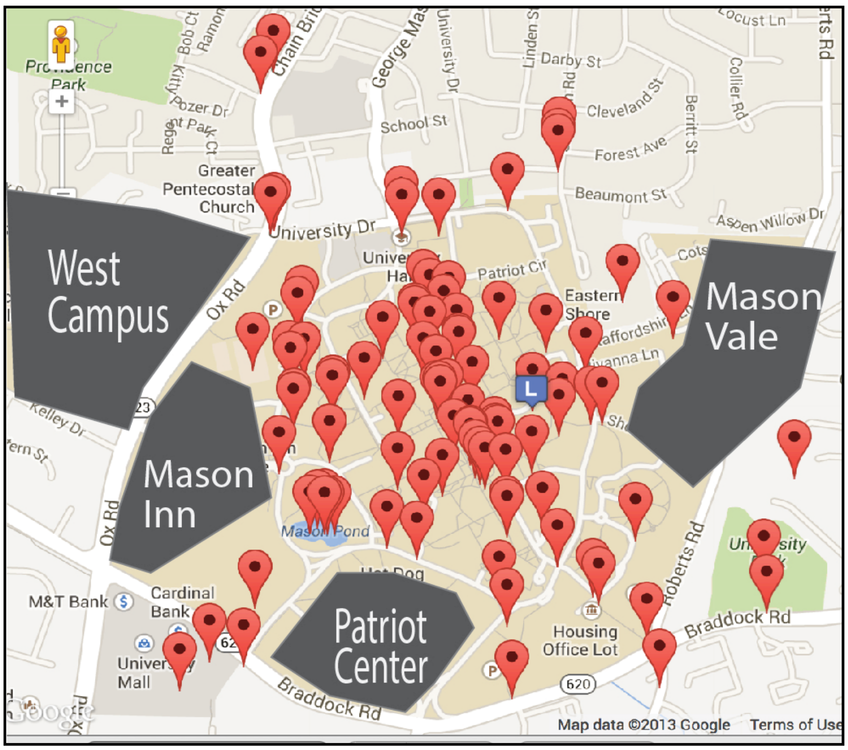


Figure 23. Geographic reporting voids

## Malicious Content Detection

An important consideration in any crowdsourced content system is the potential for malicious and mischievous content, which can damage the reputation and trust placed in the system. The appearance of any malicious or mischievous content can exacerbate existing concerns and fears about quality and undercut efforts in a number of ways. Authoritative data sources even have this concern, as evidenced by the Ordnance Survey's rapid reactions when the public was faced with news of fabricated, intentionally-false content being inserted into data for purposes of detecting copyright infringement (Rice 2001, 2005).

Wikipedia, perhaps the most prominent crowdsourced content archive in existence, has battled malicious content for years and has a sophisticated approach mixing automatic detection of anomalous content and the manual intervention of editors and reviewers, who are trained to identify and fix errors. OpenStreetMap has a similar system, which combines scripts to detect anomalous content and the intervention of editors and reviewers. These systems are based on the ideas embodied in Linus's Law (reviewed in Chapter 4 of Rice et al. 2012), which suggests that with enough individuals inspecting content, errors can be removed. The same dual approach used by Wikipedia and OSM is being developed for our testbed environment.

We are developing scripts to detect anomalous content, and training two reviewers to inspect incoming reports for errors and malicious content. The first element of the automated scripting is a PHP-based tool that quickly searches incoming records and existing database content for matches to a list of Google's 250 banned terms.[1] This list of banned terms, compiled manually by hackers, is now used and modified by a variety of firms to search for objectionable content on their system, and several businesses now sell malicious content detection and bowdlerization[2] functions for use on web pages where end-users have the power to comment or provide input. Our approach does not currently involve bowdlerization, but will instead result in a record being flagged and removed from visibility in the system. The training of moderators and editors has also included knowledge of this list of words that are objectionable to general audiences, and training to detect other forms of inappropriate content related to image content or location-based map graffiti, as noted in Rice et al. (2012).[3]

We have implemented some functions to isolate and restrict report locations to the GMU Fairfax Campus and an approximate ½ mile radius around campus, which reflects the possible areas that have been deter-

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[1] "Google Blacklist – Words That Google Instant Doesn't Like," 2600, September 8, 2013, http://www.2600.com/googleblacklist/

[2] Bowdlerization is the replacement of offensive content with less offensive content, named for Thomas Bowdler, who, in the early 19th century published censored versions of Shakespeare with perceived offensive content removed.

[3] See pages 78-80 of Rice et al. (2012) for examples of text-based map graffiti and other malicious or mischievous content.

mined through the outreach activities to be of interest. In some parts of our contribution tools, the geographic restrictions are implemented while in other areas they are not. We will be implementing a consistent restriction of content to prevent out-of-area contributions, and to identify areas in our study area where contributions are meaningless, such as the Mason Pond, and in the public-restricted forest areas. When contributions are made in these areas, we intend to have them immediately brought to the attention of the moderators, who will manually check to determine whether these contributions are a result of an incorrectly georegistered – yet legitimate – report, or a mischievous report that can be removed.

# 4 Assessment and Examination of User Dynamics, Motivations, and Community Interactions

An underlying premise of crowdsourcing is that a group of contributors exists, and this group has the technical ability and willingness to contribute content. Goodchild (2007, 2009) argues that geographic crowdsourcing (or alternatively, VGI) is unique, in that core subject material being contributed is not highly-specialized, highly-technical, or attained through the process of advanced education or professional licensing. The core subject material of geographic crowdsourcing is geography, of which every living person has some expertise, at least on a local or personal level.

Where our crowdsourcing testbed environment requires anything other than ordinary observational skill, we provide training. The general training and recruitment process detailed in this report has been ongoing for several months both in person and online. We have some knowledge about motivations (some observed, some suggested, some anecdotal), and we have received input from subject matter experts and authoritative participants. This chapter reviews the dynamics of users and community members in our system, with an emphasis on summarizing current and near-term activities.

## Summary of Motivations in Crowdsourcing

Creating a successful method for end-user and contributor engagement may be one of the most important and critical considerations in a crowdsourcing application. The success of these projects depends on the motivations of the crowd and their willingness to participate.

For many of the emergency response scenarios reviewed in Rice et al. (2012), and more thoroughly profiled in Goodchild and Glennon (2010) and in Zook et al. (2010), the motivations of the crowdsourcing contributors are generally ascribed to altruism. For OSM (profiled extensively in Rice et al. 2012), an initial motivation for participation was described by Coast (2006) as a result of resentment over the pricing and licensing practices of the Ordnance Survey.[1] The motivation of contributors is often more complex than altruism or resentment, and may include a desire for self-promotion, a compulsion to fill gaps in areas that lack spatial coverage, and a desire to correct errors, as noted by Goodchild (2007). Jahn (2004) noted the similarities between users sharing navigation data and Abraham Maslow's hierarchy of human needs. Coleman et al. (2009) present an analysis of the complex spectrum of user motivations and user needs, and suggest that some of the differences in user needs are based on the different contexts in which they contribute.

## Outreach to Participants

There are a number of participants in this project. First, there are nearly 100 individuals that have undergone training after being identified or volunteering as potential contributors. Second, there are a large number of disabled end-users. Third, there are many campus organizations that deal with accessibility. Finally, there are several groups off-campus in Fairfax City and Fairfax County that are important and influential participants. The discussion in this section will focus on outreach activities to each of these groups and is a summary of involvement from these participants.

### Outreach to Contributors

We have reached out to a significant number of potential non-disabled contributors to participate in training sessions and provide obstacle reports with our reporting tools. Eighty-eight students, staff, faculty, and local residents participated in single training sessions where they completed an obstacle categorization exercise, provided feedback, and were encouraged to begin contributing reports. Slightly less than half of the training participants contributed reports. One group of twenty-six potential contributors received an online version of our training delivered through the Blackboard educational software environment, and eleven of the twenty-six completed obstacle categorization exercises and feedback. Although this group had a lower general participation rate, the online engagement through an online discussion board was useful in generating detailed comments, suggestions, and interactions. These students noted the importance of having report contributors edit, comment, and close their reports (rather than leaving this function to a moderator); they emphasized the importance of uploading obstacle pictures (a feature that has since

[1] Coast, "OpenStreetMap."

been implemented); and suggested that the report contributors be allowed to view a summary of each report (another feature that has been implemented). Another group of contributors trained in July 2013 encouraged us to use report location icons with colors to indicate status (a feature we have since implemented). They also suggested that we enable the printing of maps showing report locations with accompanying summaries of report attributes.

### Outreach to End-Users

As noted in Chapter 2, a requirements analysis and preliminary needs assessment was conducted to help inform us about the potential system use scenarios. The requirements analysis involved detailed discussions with end-users, who are part of the local blind, visually-impaired, and mobility-impaired community. Three student end-users, one faculty end-user, one community member, and several GMU staff who work with end-users were interviewed for the requirements analysis and user needs assessment. During this assessment, each end-user cited the frustration of encountering obstacles while navigating across campus or nearby neighborhood areas, and while driving their power chairs. The list of important issues noted in Chapter 2 is being updated when new information is presented, as a byproduct of continued outreach and contact with these students, faculty, staff, and community members.

### Outreach to Authoritative Groups

The relationships between authoritative participants in a project like this can be difficult due to conflicting goals and interests. We are cognizant of the difficulties posed by drawing together the groups of authoritative participants described here and we will continue to conduct our outreach activities with them in a careful manner.

#### *Insights from Subject Matter Experts*

Several subject matter experts were interviewed and have offered contributions to our project. Some of them were contracted as consultants, some are members of the disability community, and some are authoritative figures working for campus organizations that deal with accessibility. A common thread through many of their interviews is general frustration dealing with inaccessible environments, and advice to engage with system end-users (members of the disabled community) who will be able to intelligently advise our development decisions.

Dr. James Marston, a long-term resident of Santa Barbara, California and a former employee of the Veteran's Administration Hospital in Atlanta, suggests that frustration with inaccessibility is very common. Citing his experiences on the UC Santa Barbara Campus and in Atlanta, he suggested that if participation in the project led to noticeable accessibility improvements, this would be a significant motivation for end-users to become engaged with the project. As a visually-impaired person, Dr. Marston became frustrated with construction and maintenance vehicles being driven and parked on walkways on the UC Santa Barbara campus. This frustration continued to fester until he was given a position on a campus accessibility board, which allowed him the latitude and authority to request changes. In a recent report for the project, Dr. Marston suggests that we prioritize engaging end-users in contributing reports. As end-users become contributors to the project, they will gain a similar feeling of empowerment that could be useful in building support and acceptance by authoritative groups that work with disabled students.

Dr. Michael Goodchild, echoing a sentiment expressed in Perkins (2002), suggested during early phases of development that the best advice on system development would come from eventual system end-users, and that these individuals should be interviewed and questioned about their potential uses. He suggested that a technology-centered approach, without the input of end-users, would not work well. Goodchild's 2009 paper on the phenomena of VGI notes that the most successful crowdsourcing systems are likely to be hybrid systems that mix the input of subject matter experts and authoritative entities with the expertise of the end-users and contributors to the system. His suggestion to begin by engaging with end-users was advice that we took, undertaking the requirements analysis and preliminary user needs assessment shortly afterward.

*On-Campus Groups*

The GMU Vice-President for Facilities has pledged public support for the project and has given project personnel permission to ask for any resources that are needed. This support was given during a public discussion with Fairfax City officials who were already familiar with the project. The GMU Vice-President for Facilities reviewed the report contribution tools and previewed several reports about blocked sidewalks along Patriot Circle near the Facilities Buildings, and provided some real-time validation of the reports. We envision the GMU Physical Facilities group to be a future contributor of reports to our system and have extended this opportunity to them.

The Assistive Technology Initiative Office (ATI) is partially responsible for producing campus accessibility maps for the GMU Office of Equity and Diversity Services, which handles American with Disabilities Act (ADA) compliance issues on campus. The ATI Office, with a somewhat overlapping mandate with the Facilities GIS and mapping group, has faced difficulty sharing data and working toward common GIS and mapping goals. While both groups have been comfortable for us to work with because of our slightly different focus (academic research and education rather than practical systems implementation), these groups have differing goals and perspectives. We will continue with outreach activities to both groups.

We have offered to begin quarterly meetings as part of a new Accessibility Working Group, involving project personnel, ATI staff, ADA compliance staff, Facilities staff, Office of Disability Services staff (who have been the subject of successful outreach for a long time), and the GMU Kellar Institute for Human Disabilities.

*Off-Campus Groups*

The GMU campus is bordered by Fairfax City and Fairfax County (Figure 24). Fairfax City officials, including the Mayor, several City Council Members, the City Transportation Director, the City Public Works Director, and the GIS Manager, have all been briefed on the project. Fairfax City officials view the project as a positive way to highlight efforts towards ADA-compliance and to strengthen the GMU-City Town/Gown relationship that has been poor in the past. Base data for the parcels, roads, sidewalks, and other infrastructure has been contributed to the project as a show of support. We also envision the City of Fairfax Public Works department and the GIS Manager to be report contributors, and have extended this opportunity to them. We also envision them using our system to view reports and make changes to the accessibility issues in the City of Fairfax.

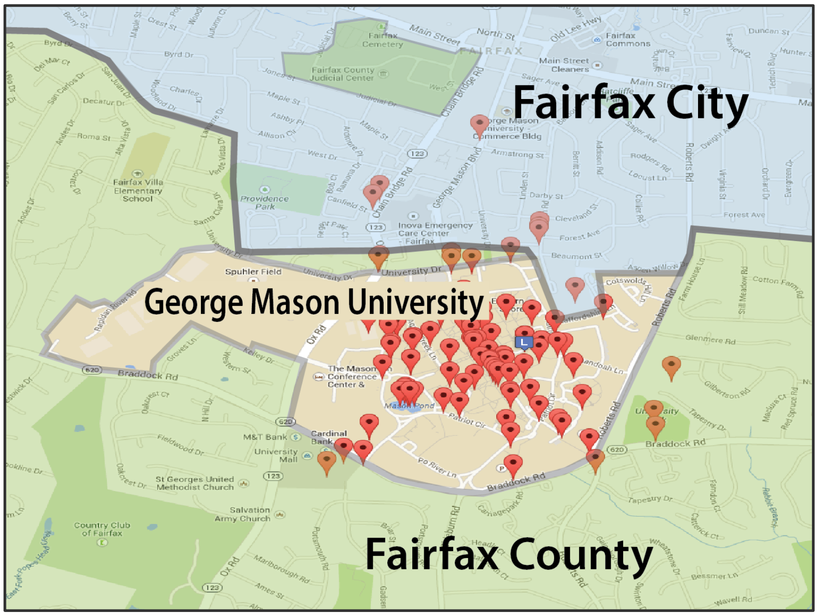


Figure 24. Local political entity boundaries superimposed on reporting interface

Several Fairfax County officials have also been contacted and are supportive, though more difficult to interact with because of the size of the County and the difficulty of addressing local issues in such a large political entity. Assistants to Supervisor for the Braddock District have been contacted through the GMU-City Town/Gown group.

The Virginia State Delegate for the local area has been briefed on the project and is supportive. He is familiar with GIS and hires GIS interns periodically in his capacity as an environmental consultant, so his support is based not only on political factors but also on enthusiasm for the geospatial domain.

The Fairfax County Public Works and Environmental Services Director has also been briefed about the project and is fully supportive. He has been peripherally involved in an ADA-related consent decree process between the US Department of Justice and Fairfax County, and offered an introduction to County staff that has been involved in the remediation activities to satisfy the consent decree. He is also useful as a facilitator with other groups in the County that have a mission related to mapping and accessibility, and has offered introductions to several other groups that use GIS in the County government.

Some members of the Fairfax County Department of Planning and Zoning have expressed interest in the project and have offered help, due to their interest in mapping and GIS as well as their interest in code compliance and ADA issues. Outreach activities to this group are ongoing and being facilitated by a member of the Planning and Zoning Department acquainted with GMU project personnel.

## Recruiting and Training Report Contributors

The recruiting and training process is an essential step for testing and assessing the quality of the reporting tools, and is significant way to increase the quality of the information we collect.

There is very little peer-reviewed literature about training and recruiting best practices within geo-crowdsourcing. As a supplement, we looked at some of the training methods and resources provided by two successful and popular applications that use crowdsourcing to collect data: Waze[1] and OpenStreetMap (OSM).[2]

Waze provides users with short videos to explain the purpose and functionality of their application. [3]. In addition to the videos, Waze provides a user manual. The Waze training material is short, simple, and comprehensive enough to explain the essential functionality of the system.

The OpenStreetMap training material is not as succint and directly engaging as the Waze training material, and this is certainly a reflection of the greater technical complexity and scope of the OSM project. OSM provides introductory emails with information about participation, videos,[4] a wiki,[5] and a questions and answers site.[6] Since there are many different ways to contribute data to OSM, the training methods vary in length and complexity. Some OpenStreetMap training material is technical in nature with a more rigorous scientific theme than the Waze

[1] "Waze - Social Traffic & Navigation App," http://www.waze.com/, accessed September 9, 2013

[2] "OpenStreetMap,", http://www.openstreetmap.org/, accessed September 9, 2013

[3] Waze Gps, "Waze Map Editor Guide Full Clip | Waze," *YouTube*, April 30, 2012, http://www.youtube.com/watch?v=HVksbb1Z4SQ.

[4] [581] steve, "OpenStreetMap," *ShowMeDo*, 2008, http://showmedo.com/videotutorials/series?name=mS2P1ZqS6.

[5] "Beginners' Guide - OpenStreetMap Wiki," July 28, 2013, http://wiki.openstreetmap.org/wiki/Beginners%27_Guide.

[6] "OpenStreetMap Help Forum," accessed August 26, 2013, https://help.openstreetmap.org/.

training material. We want to create material that combines the simplicity and engaging nature of the Waze training material with the detailed explanations and thoroughness of the OSM training material.

Our current set of training material includes an introduction to the project, examples of crowdsourcing applications, a summary of the basic reporting system functionality, and examples of obstacle types, obstacle urgency, and obstacle duration. After conducting training with the first 30-35 participants and receiving feedback, we implemented changes in our training procedures to include obstacle duration and urgency information. During this early training period, we also modified the photographs used for providing obstacle examples, due to confusion expressed by training subjects.

# 5 Summary and Future Directions

For blind, visually-impaired, and mobility-impaired persons, there are two major obstacles to full participation in society: information barriers, and movement barriers. These two barriers, described by Dr. Reginald Golledge during a 2001 commencement address at Simon Fraser University, have become more significant due to the rapid evolution of digital information channels and the extent to which these channels are inaccessible. Systems developed to overcome these barriers, such as the UCSB Personal Guidance System, are a significant advancement, but even these systems lack a crucial feature: the ability to accommodate the unplanned and transient barriers that significantly impact navigation. A sensible way to capture and map information of this type is through crowdsourcing: a rapidly emerging and evolving part of the contemporary information landscape.

This research project seeks to develop methods to crowdsource the location and attributes of navigation obstacles, and to develop methods for validation and quality assurance that will provide some confidence in our system and the information it produces. The two phases of this research have been productive and useful in understanding how crowdsourced geospatial data is evolving and being used in society, and in the development of a testbed environment for continued study of the dynamics and methods for crowdsourcing. We have implemented a training and recruitment program, and have created a map-based reporting tool in desktop and mobile versions that has been tested and used by a number of contributors to report obstacles on the GMU Campus. We have developed a comprehensive data model to guide all of our workflows and activities, and we are implementing practical methods to field check, validate, and quality assess the reports that are being made, and turn those reports into Obstacles.

There are a number of significant lessons we learned in the progress of this research project, and many more that we anticipate learning in the next phase of our work. First, building a community of contributors is difficult. With approximately 12 active contributors from the 88 we have trained, we need to train at least 220 more students, faculty, staff, and other potential contributors to achieve our contributor goals, which are 40-50 consistent, active contributors. A factor that could contribute to a higher retention rate of contributors is a more robust system for engagement, which we will be implementing in Drupal during September, and a way of doing unobtrusive follow-up communication with contributors that have been trained. Creating incentive-based games, rewards, and other similar systems will be discussed during the upcoming months, with input from other faculty colleagues that have researched the efficacy of ratings systems for user engagement.

Crowdsourcing projects such as this involve data collection by non-experts, which can result in problems such as non-standard descriptions, errant placement of information, and the differences in interpreting categories, locations, durations, and estimates for similar events. These problems are a part of the domain and should be anticipated. To the extent possible, we will work to simplify and reduce the complexity of our reporting tools to reduce errors in the contribution process. We will continue developing methods to assess the quality of the information that we collect through the help of our contributors, end-users, and authoritative partners.

In the upcoming months, we will expand our training and recruiting program and capture several hundred more contributors. We will study the spatial patterns of reports, identify and refine our understanding of geographical data voids and attempt to fill them. We will finish the implementation of our content management tools and with their help; we will increase the interaction among users. We hope to see increased engagement and retention of contributors. Finally, we will continue our community-building and outreach activities, and our cooperative work with campus and local authoritative entities.

The next phase of our research project will include methods for visualizing hybrid collections of authoritative and asserted content, and associated quality measurements.

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