Where's My Bus Stop? Supporting Independence of Blind Transit Riders with StopInfo

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ABSTRACT

Locating bus stops, particularly in unfamiliar areas, can present challenges to people who are blind or low vision. At the same time, new information technology such as smart phones and mobile devices have enabled them to undertake a much greater range of activities with increased independence. We focus on the intersection of these issues. We developed and deployed StopInfo, a system for public transit riders that provides very detailed information about bus stops with the goal of helping riders find and verify bus stop locations. We augmented internal information from a major transit agency in the Seattle area with information entered by the community, primarily as they waited at these stops. Additionally, we conducted a five week field study with six blind and low vision participants to gauge usage patterns and determine values related to independent travel. We found that StopInfo was received positively and is generally usable. Furthermore, the system supports tenets of independence; participants took public transit trips that they might not have attempted otherwise. Lastly, an audit of bus stops in three Seattle neighborhoods found that information from both the transit agency and the community was accurate.

Categories and Subject Descriptors

H.5 [**Information Interfaces and Presentation**]: User Interfaces; K.4.2 [**Computers and Society**]: Social Issues—*Assistive technologies for persons with disabilities*

General Terms

Design, Experimentation, Human Factors

Keywords

Public transit, tools for blind and low vision riders, accessible transit stops, community-sourcing, crowdsourcing

1. INTRODUCTION

Public transit plays a key role in the lives of many blind and low vision people by providing access to employment, education, shopping, medical services, friends and family, and recreation. However, significant barriers to its use still abound [1]. Consequently, blind and low vision people often resort to other means of travel such as taxis, paratransit, or rides from others, particularly for unfamiliar routes and destinations [14]. This can be more expensive, less convenient, involve imposing on others, and result in less independence.

One specific challenge for blind and low vision bus riders is locating and verifying bus stop locations, particularly in new or unfamiliar areas [1]. They often search for physical landmarks such as the bus shelter, benches, or transit sign as a cue that they have reached the stop, but the design and location of the stop relative to the intersection are frequently quite variable.

We present StopInfo, which builds upon a widely-used transit application called OneBusAway[1] to provide very detailed information about transit stops, tailored to the needs of blind and low vision riders. We collaborated with King County Metro, a local transit agency in the Puget Sound region, to seed StopInfo's information with their internal data on bus stops. We then constructed an interface that allows the community to verify this data, or add additional information not found in Metro's database.

We present results from a five week deployment of StopInfo to six blind and low vision participants. We also demonstrate how collaborating with a local transit agency and the community produces accurate information through a StopInfo information audit of three Seattle neighborhoods' bus stops.

We investigated the following research questions:

1. Was StopInfo usable, and was the information helpful to blind and low vision transit riders?

2. Did our participants attempt public transit trips with StopInfo that they would not have otherwise?

3. Did our participants feel confident traveling to unfamiliar destinations with StopInfo?

4. Did StopInfo use contribute to our participants' feeling of safety while traveling?

5. Was the aggregate of information from the transit agency and the community accurate?

[1]http://onebusaway.org

Our key findings include a successful deployment where StopInfo was usable and helpful. We determined that independence was an important value for blind and low vision transit riders, confirming prior work [1]. StopInfo supported independence by providing information helpful to attempting previously unattainable and unfamiliar trips. However, StopInfo did not affect feelings of confidence traveling and safety in public. This could indicate that blind and low vision people similar to our sample employ tools and strategies to maintain active lifestyles, but are encouraged by new tools like StopInfo, which fill current wayfinding information gaps. Overall, we found that the information disseminated by StopInfo was highly accurate (97.3%) for key fields such as the stop position relative to the intersection, with lower accuracy for more ambiguous fields.

2. RELATED WORK

Prior Work. This work builds upon prior work performed by our group, in which *independence* and *safety* were identified as two key values for visually impaired transit riders [1]. Azenkot et al. investigated the efficacy of providing information about bus stops through a system they developed called GoBraille, which allows blind and deaf-blind riders to access information about bus stops through a wireless Braille display connected to a smartphone. Our work differs in that we utilize the built-in accessibility features on the iPhone such as VoiceOver, and integrate it in to a mainstream transit application used by the general population of public transit riders. By doing so, we enable collection of bus stop information from transit riders already at bus stops, and allow for the dynamic creation of new information categories that can be filled in by the public. Another important difference is that we have deployed a working system that is actually used by blind riders for day-to-day transportation needs. We report the experiences of a small number of participants from our field study, but the system is ready for widespread use. Prasain [19] describes a prototype version of the StopInfo system, called StopFinder, consisting of a standalone iPhone app and sample data for a stop for user testing. The system was well received by the blind community, encouraging us to pursue the work reported here. In 2013, Hara et al. developed a way for crowd workers like those on Mechanical Turk to use pictures of stops on Google Street View to label features of bus stops with 82.5% accuracy [14]. However, accuracy was reliant on the quality of the picture on Google Street View; stops were occasionally obscured by a moving car or pedestrians. StopInfo differs in that it collects stop information within an application that riders often check while waiting at the stop.

Navigation and wayfinding. Research on navigation and wayfinding for blind travelers is extensive. Some of the research has been translated into practice by orientation and mobility professionals, commonly referred to as O&M instructors. O&M instructors teach blind travelers skills including how to use a white cane or dog guide, how to find their way from one point to another, how to cross streets safely, and how to use public transportation. More recently, interest in technology-based wayfinding solutions, such as using GPS services for location and mapping services for finding directions, has increased substantially. It is clear that technology is a lucrative navigation tool for blind people and has room for expansion. Within the HCI and accessibility literature, Quiñones et al. [21] present the results of a needs-finding study for navigation by visually impaired people, emphasizing issues arising from changes in the environment and other breakdowns. Guentert [11] describes a train station navigation assistant for blind travelers that provides detailed information on navigating complex stations. Banovic et al. [2] examine how visually impaired people learn about and navigate their environments, noting that they not only satisfy their immediate needs but also learn information that may enable future opportunities. Yang et al. [29] describe Talking Points 3, a mobile location-aware system that seeks to make the environment more legible to blind and visually impaired users by representing important features such as paths, landmarks, and functional elements, to support spatial awareness beyond procedural wayfinding. The StopInfo research contributes to the work on supporting wayfinding in two respects: first, by investigating the role of very detailed information about transit stops themselves; and second, by deploying a practical system that can be used on a daily basis by blind and low vision riders, allowing us to investigate use under real conditions.

Geowikis. A system that provides detailed transit stop information can be viewed as a specialized geowiki. Literature on geowikis includes OpenStreetMap[2], which is certainly the largest geowiki. Haklay [13] provides an assessment of the success of OpenStreetMap, both in terms of accuracy and coverage, in comparison with Ordnance Survey datasets in the United Kingdom. Another notable geowiki is Cyclopath for bicyclists [18, 20, 24], which also includes route-finding capabilities. Other research projects have utilized crowdsourcing of geographical data to improve pedestrian route-finding, such as Guy and Truong's work on intersection geometry using Google Street View [12], and Völkel and Weber's work on pedestrian path ratings for different mobility impairments that are derived from user-driven annotations within their system, RouteCheckr [25]. The commercial application BlindSquare[3] also harnesses crowdsourced information from FourSquare[4] and OpenStreetMap to provide information about nearby businesses and other locations for blind travelers. In this work, we concentrate on providing a free system with geographical information optimized for blind and low vision riders.

3. A VALUE SENSITIVE APPROACH

Much of our research is ultimately motivated by attempting to better support certain human values such as independence, safety, equity, participation, respect, and community. To approach these value questions, we employ value sensitive design [10], a principled, systematic approach to the consideration of human values in the design of information technology. The primary features of value sensitive design are: consideration of both direct and indirect stakeholders (that is, the users of technology and those affected by the technology even though they do not use it); a tripartite methodology, consisting of conceptual, empirical, and technical investigations, iteratively and integratively applied; and an interactional theory to the value implications of technology.

In the work reported here, we focus on one key set of direct stakeholders: the blind and low vision users of the tools. An investigation of the full range of stakeholders and their val-

[2]http://openstreetmap.org
[3]http://www.blindsquare.com
[4]http://www.foursquare.com

ues is planned for future work. (The other direct stakeholders are the riders who enter or verify information. Key indirect stakeholders include bus and train drivers, other passengers, family and friends of the users of the tools, passersby at the transit stop, and orientation & mobility trainers.) In prior work on transit traveler information systems for blind and low vision riders [1], we found through interviews that *independence* was a central value for these riders, and to a lesser extent *safety.* In our interviews and field work, one of our goals has thus been to investigate whether this is still the case in this project, and also what other values might be important. In other prior value sensitive design work [3, 4], the researchers found it valuable to draw a distinction among stakeholder values, explicitly supported values, and designer values — an important designer value for us is avoiding paternalism toward people with disabilities.

4. SYSTEM DESCRIPTION

Front-end application. We chose to build StopInfo on an existing transit traveler information system called OneBusAway [6, 7, 8, 9, 26, 27], which is a set of tools that provide real-time arrival predictions and other transit information, such as where bus stops are located on a map and which stops are traversed by a particular route. OneBusAway builds on the work of Dan Dailey and others on real-time transit information systems, such as MyBus and BusView [16], and has been widely adopted in the Puget Sound region, used by over 100,000 unique transit riders each week. The system is freely available as an application on the iOS, Android, and Windows Phone platforms, and also via SMS, interactive voice response, and the Web. Research on OneBusAway has found a number of significant benefits, including increased or greatly increased satisfaction with public transit for 92% of survey respondents, increased feelings of safety for some (particularly while waiting at night), and decreased wait time at the stop [27]. One of the goals of our research group is to make these benefits available to as wide a range of people as possible, and we have devoted significant attention to ensuring that the apps, in particular the iOS app, provide adequate accessibility.

We decided to integrate StopInfo with OneBusAway on iOS for a number of reasons. First, OneBusAway is already used by a large number of people, and many check the application from their smartphones while waiting at bus stops. This enables us to leverage a large existing userbase by directly allowing the community to enter information for the stop as they wait. Secondly, the OneBusAway iOS application is already heavily used by members of the blind, low vision, and deaf-blind communities in the greater Seattle region who use and rely on public transit, and has been developed and tested to remain accessible to this community. Finally, StopInfo is a natural extension of OneBusAway, and can also be useful to the general population of transit riders. It includes relevant information such as how well-lit a stop is at night, which has safety implications, and whether a stop may be closed.

We integrated StopInfo with OneBusAway iOS by placing an info button with the accessibility label "About This Stop" next to the name of the stop on the details view for that stop (Figure 1). We also inserted a table cell underneath that stop's arrival times with the text label "About This Stop" in case the button was not discovered. Tapping or double tapping on the button or table cell brings up StopInfo as an integrated web view within the application, and is also accessible through Apple's VoiceOver screen reader. When a user accesses StopInfo, they are presented with a text list of the stop features. An asterisk indicates that the information still needs verification. Below the list of stop information there are links to add or verify information, report a stop closure, learn what each field means, learn more about the study, and to optionally log in with an existing Facebook or Google account.

Information categories and collection. To seed StopInfo with basic information, King County Metro provided our research team with the database used to record bus stop details for its 8,000 stops in the Seattle area. Based on feedback from interviews with blind and low vision transit riders in prior work[14], we prioritized information about stop location, bus sign type, presence of a schedule holder, and the number of shelters at a stop. Interviews also suggested that the number of benches and the presence of trash cans were helpful for identifying the stop, which was information that Metro did not collect. Our research group additionally chose to collect information about the bus sign placement, orientation and position of bus shelters, and the overall stop lighting. These latter two groups were provided only by community-sourced information.

StopInfo uses a voting system to determine verification of a field. Each information submission, including the original information from the Metro database, counts as one vote. A feature is verified when two requirements were met: it has at least three votes, and the votes have a supermajority of 75% for one value. This means that information is considered verified only when at least two users have submitted agreement with the original Metro value, or three users reach a supermajority consensus on a field not provided by Metro. A disagreeing vote cast after a field has reached verification status will cause it to be marked as unverified again if it takes the voting percentage below the 75% threshold. Users can submit information for any field except the distance (in feet) of the stop from the intersection. Finally, we allow users to submit free-form comments when logged into the system with their Facebook or Google account.

5. METHODS

Our principal evaluation of the StopInfo prototype consisted of a five week field study with blind and low vision participants. Additionally, we measured the rate of user participation in verifying and adding stop information, and assessed the accuracy of the information provided.

5.1 Field Study

Participants. We recruited six participants, four female, from King County through email lists of local blindness organizations. Their ages ranged from 31 to 62, with a median of 45.5 years. Three participants were totally blind; the remainder had varying degrees of usable vision. Four participants reported living in suburbs of Seattle and two live in urban centers. Four participants use public transportation at least once a day and two participants reported traveling on the bus a few times each week. Reasons for using public transportation included traveling to work, appointments, errands, and recreational activities.

We required that participants use their own iPhones for the study and that they use public transportation often enough to report on at least ten such experiences during

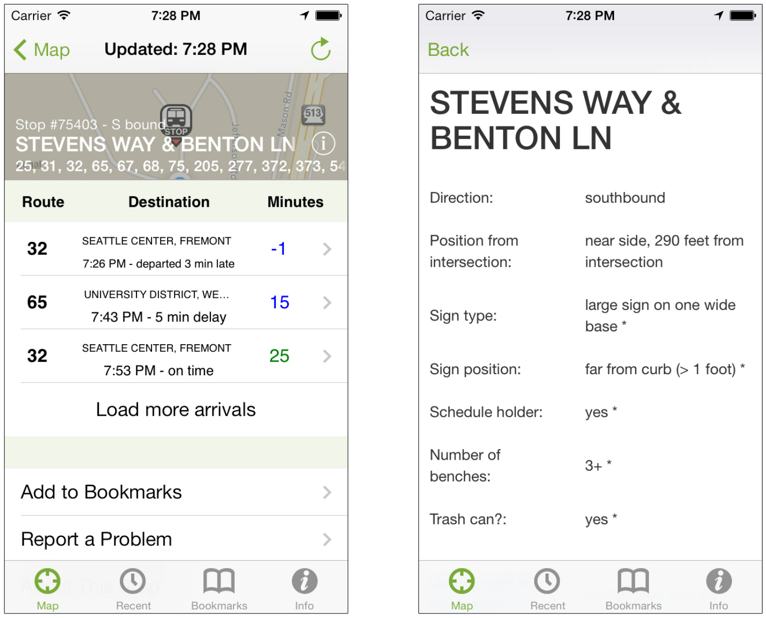

Figure 1: (left) The stop details screen in OneBusAway. StopInfo can be accessed through the info button next to the title. (right) The StopInfo view and associated information for the specified stop. An asterisk next to a field means that information has not yet been verified by three or more people. If no information exists for a particular field, we do not display it. Both screens were also tested extensively for accessibility using VoiceOver.

the study period. We verified (median of 4 out of 5) that participants were comfortable using their iPhones.

Procedure. Participants met for an introductory interview at the University of Washington. They answered questions about demographics and their public transportation use. We then asked about important underlying values to traveling as a blind person, such as independence and safety, using a value-oriented semi-structured interview [15]. We also asked how they find unfamiliar and familiar bus stops. We trained them to use OneBusAway and StopInfo, and oriented them to the web form on which they would report their travel experiences during the field period.

The web form was a quick questionnaire, accessible at any time. The questions asked about the trip, the buses they rode, and included items gauging the familiarity with the trip and their confidence. We also inquired what features of StopInfo they used. We checked in with each participant once a week to answer questions and to update them on their progress. We asked participants to submit 10 forms but incentivized up to 20 forms.

After five weeks, participants met us for an exit interview where we asked for feedback about StopInfo and gauged their overall usage of each StopInfo feature. Participants were compensated for their time and activities, with a maximum compensation of $100.

During all phases of the study, participants rated several values on a 5 point Likert scale. For example, to assess independence, we asked "How important is it to you to travel independently?" with the choices of "not at all important" (1), "somewhat unimportant" (2), "neither important nor unimportant" (3), "somewhat important" (4), and "very important" (5).

Web Forms. Our participants submitted a total of 76 forms during the field study. Participant submissions ranged from six to 20 forms with a median of 12 forms. Participants used StopInfo during 42 (55.26%) of the travel experiences. StopInfo use by individual participants ranged from 0 uses to 13 uses with a median of 6.5 uses. The percent of trips during which participants used StopInfo varied from 0% to 100% with a median of use during 67.5% of total trips submitted.

We recruited a sample that was already savvy at traveling independently and using their smartphones. We recognize that this may not reflect the general population of people who are blind or low vision, but we wanted to evaluate StopInfo and incorporate use patterns into future work that concentrates on how StopInfo can encourage people who do not use public transportation often. We evaluated StopInfo usage patterns according to three themes: usability, independence, and safety. We computed how important certain values were to participants on 5-point Likert scales during the introductory and exit interviews. From the web forms, we computed frequencies of StopInfo use, trip familiarity, and confidence during trips. Qualitative comments extracted from the interviews and web forms reinforce our findings.

5.2 Rider-Contributed Stop Information

User Participation. We obtained the number of user submissions to the system from the app database. One form submission corresponds to one row of data, containing at least 1 and up to 11 fields. From queries, we determined the total number of information submissions, the number of distinct users as indicated by the ID of the device they used to access the service, and the number of bus stops for which information was provided.

Stop Audits. In addition to computing the amount of information submitted, we assessed its accuracy by performing an audit of a sample of bus stops. The primary goal of this audit was to evaluate user submissions, but the data from the transit agency was also considered. We selected three areas in Seattle to audit, focusing on locations with a range of population densities, a high demand for public transit, and a relatively high amount of user feedback from StopInfo. For each survey area we determined which stops users had provided at least one piece of information for. We then walked each survey area on foot, carrying a smartphone with GPS to navigate between bus stops and to ensure that no bus stops with user-submitted data were missed. At each stop we recorded values for every major field for which StopInfo allows information submission: stop position, sign type, sign position, number of benches, number of shelters, orientation and placement of shelters, and presence of trashcans. Because we performed these surveys during the day, and because it was not as relevant to our study, stop lighting was not recorded. Shelter orientation and placement were omitted because these fields received very few information submissions (6 in total, only 1 within survey areas). In total, 38 stops were surveyed. These audit values were later compared with the original Metro data provided, the user-submitted information, and the combined amalgamate data to determine the overall accuracy.

6. RESULTS

In this section, we first present the results from our field study according to the themes of usability, independence, and safety. We follow with results of participation rates for adding or verifying stop information.

6.1 Field Study

StopInfo Usability. StopInfo was usable and the information presented was helpful to our participants. P4 noted that *"StopInfo is great because you know exactly where the stop is."* All participants said they would continue using StopInfo after the study.

The most helpful information categories had median ratings of 5; these included the position of the stop relative to intersection, name of bus stop (e.g., "3rd Ave. and Pine St."), and the position of the sign relative to the curb. Interestingly, P2 described how she appropriated this information to assist her in wayfinding *after* a bus ride: "When I got off the bus, it was helpful to know the bus stop was at the far side of the intersection."

One source of confusion was our use of terms for stop position relative to the nearest intersection. These terms are standard in the transit industry, but not among the general public, such as "near side" (i.e., a stop before an intersection). P1 didn't understand the concept until a researcher *"explained it better."* P4 said we should *"put [the definition] in Help."* Further confusion arose from bus stops at transit centers since our information fields were biased toward bus stops along streets. The relative position and distance from the intersection were not applicable in this case, but these fields remained on the information view, and did not provide any information specific to the transit center, such as the position of each bay. P3 felt this was the only "inaccurate" information in StopInfo.

Independence. Consistent with prior work [1, 14], all participants were very interested in being independent, and rated it a 5 in terms of how important it is to them while traveling. However, their interest in whether others perceived them as independent varied ($Mdn = 4$). This can be explained by some participants citing disinterest in others' opinions. Participants were also very interested in knowing way finding information ahead of time ($Mdn = 5$).

Data from the web forms indicates that StopInfo supports tenets of independence. On 29 (38.16%) of the web forms, participants indicated the trip was one in which they would not normally attempt on public transportation. StopInfo was consulted during 26 (89.66%) of those trips.

We also computed StopInfo use based on each participant's level of familiarity with each trip. An odds ratio shows that during the 12 trips rated at the 1 and 2 familiarity levels, participants were twice (2.04 times) as likely to consult StopInfo when compared to StopInfo use during the 60 trips rated at the 4 and 5 familiarity levels. We omitted the trips rated as neutral (3). These usage patterns answer affirmatively our research question as to whether participants would attempt more unfamiliar trips on public transportation with the given information about bus stops through StopInfo. An unexpected finding was that StopInfo is consulted a high percentage (80% to 100%) of the time until the highest familiarity level (5), where usage drops to 28.57%.

We further broke down StopInfo use compared to the total number of trips taken by participant, shown in Figure 2. Half of the participants found StopInfo useful during all trips. P5 appreciated the option to confirm information, saying, *"I mainly used StopInfo to verify what I already knew."* P3 and P5 found StopInfo especially useful during unfamiliar travel, while P6 liked the system but did not find instances in her daily life that warranted its use.

StopInfo supports independence by providing information previously inaccessible on the go. Furthermore, it could make the difference between a user attempting a trip and staying home, and for confident travelers, can provide confirming information during unfamiliar trips.

During the interviews, we inquired about confidence during trips without access to travel tools. This resulted in a neutral response ($Mdn = 3$), contrasting with a higher ($Mdn = 4$) confidence level given attempting unfamiliar travel with tools. P1 explained, *"I would be very uncomfortable, I wouldn't go"* in response to traveling unfamiliar routes without tools, while P2 mentioned, *"I wouldn't feel confident at all."* However, we found no relationship between trip familiarity level ($R^2 = .34$) and confidence during submitted trips, and no relationship between StopInfo use and confidence during submitted trips ($R^2 = .17$). Many factors can influence confidence, but our sample had problem solving skills and knew about a variety of travel tools prior to the study. Consistent with prior work [14], the most popular strategies (with the number of of the participants who employ them) include consulting OneBusAway (6), searching for characteristic bus stop landmarks (6), using other navigation apps (5), consulting transit agency's online trip planners (4), and asking passersby for assistance (3). For example, P5 said, *"I know how to use my resources,"* and P6 commented that, *"The things that hold me back tend to be information."* Our sample had great skills, but needed more information, which StopInfo provided for the unfamiliar trips attempted during the study.

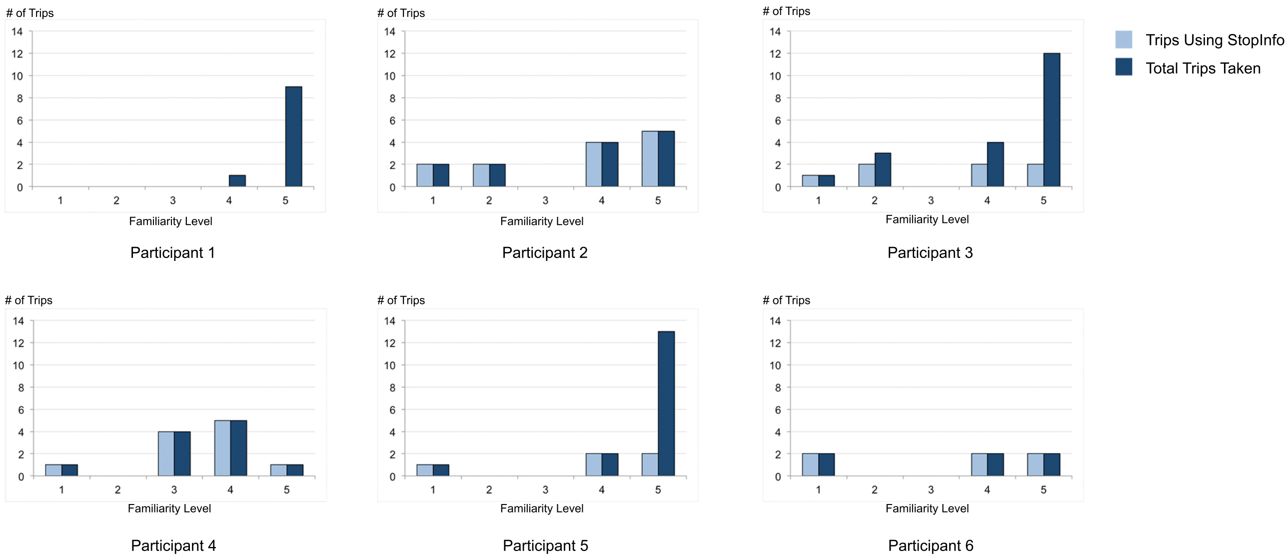

Figure 2: The number of trips (y-axis) taken per familiarity level (x-axis, where 1="very unfamiliar," 5="very familiar") for each participant. The light blue bar (left) indicates transit trips taken while using StopInfo. The dark blue bar (right) indicates the total number of transit trips taken for that familiarity level.

We also noticed that participants considered using their tools and asking for assistance as tenets of independence. P1 stated, *"I'm not afraid to talk to people,"* and P2 defined independence as *"having a balance"* between doing things on her own and asking for help. However, themes of wayfinding information gaps abounded with comments such as P3's: *"I just hope that I'm on the right street and at the right stop."* This sheds light on future research questions to explore designs that fill information gaps and become part of the standard repertoire of tools available.

Safety. Participants felt fairly safe traveling ($Mdn = 4$). Similarly, most participants were unconcerned about using a smartphone in public ($Mdn = 4$). We wanted to make sure StopInfo did not negatively impact feelings of safety, and all participants reported no change in safety traveling or security using a smartphone after the study. In fact, P5 believed the added information presented benefits that outweighed the potential risk of using his smartphone more often in public. *"There was more to take advantage of with the added app and information."* Consistent with prior work [11], safety seemed to have minimal importance to our sample.

In summary, StopInfo is a usable system that provides very detailed information about bus stops on the go. It promotes tenets of independence by positively influencing unfamiliar travel using public transportation. Future work can concentrate on fixing usability issues such as inaccurate transit center information and incorporating StopInfo to work seamlessly with other wayfinding solutions.

6.2 Bus Stop Information Submissions

For the StopInfo system to be optimally useful, the information should be reliable. We were primarily interested in two things: the information accuracy in aggregate, which combined both Metro data and user-submitted data, and the accuracy of users alone, which will influence future work in improving the interface and determining thresholds for information verification.

Quantity of information. StopInfo received a high number of information submissions immediately after launch, diminishing after the first two weeks to a slower but steady rate of typically 5-10 submissions per day. In the three months following public deployment, 467 users made 870 information submissions for 576 unique bus stops out of a total 8481 stops covered by StopInfo. User-provided information covers less than 7% of stops, concentrated heavily in high-traffic areas.

Quality of information. We evaluated information accuracy by comparing the audit data to the data provided by Metro and submitted by users, as well as to the aggregate data actually displayed on StopInfo. Because the fields were categoric measures, percentage agreement was used with an exact match qualifying as agreement, similar to Rundle et al. [22].

For each stop, StopInfo displays a minimum of four fields: stop position, sign type, schedule holder, and the number of shelters. This data was provided by Metro and is present for all stops. All additional fields are user-submitted data only. For the information in aggregate, we found that stop position and number of shelters were both highly accurate, correct more than 90% of the time in both cases. Sign type, schedule holder presence, and sign position were the three least accurate fields.

Participants in the field study identified stop position (relative to intersection) and sign position (relative to curb) as two of the most important pieces of information. Though stop position is very accurate, sign position was the least accurate field in aggregate, possibly due to ambiguity. The sign position field in StopInfo presents two options, "close to curb (<1 foot)" and "far from curb (> 1 foot)". The distance may be difficult for users to gauge, or users interpreted "close" more loosely, despite the measurement given.

Landmark Type	Percent of Data Assessed as Accurate			
	Metro	User	Aggregate	Verified (N)
Stop position	97.4%	77.9%	97.3%	100.0% (9)
Sign type	68.4%	71.2%	65.8%	87.5% (8)
Sign position	N/A	56.5%	55.2%	100.0% (2)
Schedule holder	73.7%	46.0%	57.9%	37.5% (8)
Number of shelters	92.1%	92.9%	94.7%	100.0% (13)
Number of benches	N/A	91.1%	93.3%	100.0% (7)
Trash can?	N/A	78.6%	75.0%	100.0% (6)

Table 1: Data Accuracy. "Metro" is data from the transit agency, "User" is data contributed by a single user, "Aggregate" is the aggregate rating displayed by the system, and "Verified" includes only those ratings marked as verified ("N" is the number of such ratings).

The sign type and schedule holder fields have relatively lower accuracy, 65.8% and 57.9% respectively. We identified three likely sources of this error from this audit. Firstly, Metro is in the process of replacing old signs. During the audit, 4 bus signs in the audit area were replaced with signs of different type. While the ultimate goal of StopInfo is for users to provide updated information on such changes, it is unknown yet how quickly they will do so. Secondly, both sign and schedule holder fields map poorly from the original Metro database into StopInfo. The Metro definitions of signs do not perfectly fit into the categories chosen by the research team, and we may need to consider revising categories. Thirdly, there is ambiguity in the intent of the information. We originally intended the schedule holder field to indicate an extra or protruding attachment to a bus stop pole that could be physically felt; based on submissions to StopInfo, users seemed to instead be using the schedule holder field to indicate any bus schedule at the stop, even those otherwise integrated into the pole or sign.

While only about a quarter of bus stops in the audit area had verified information, we found that information marked as verified was highly accurate, 100% in nearly every category except the schedule holder category, due to the ambiguity already explained. The one error in a verified sign type arose from a sign installed after the information submissions were made.

7. CONCLUSIONS AND FUTURE WORK

Our initial deployment saw a good number of entries for bus stops in the Puget Sound area. However, our goals for this work are not only to deploy and field test a research prototype, but also to work in cooperation with the transit agency to transition it to long-term operational use so that it can become a valuable resource for all transit riders in their daily commutes. This will require encouraging continuing participation over time to keep information up to date. In addition, we would like to collect information for as many stops as possible in the region, not just a cluster of stops in the same area (such as downtown). In future work, we plan to investigate this as a question of incentivizing participation [17, 23].

Another application for this work involves the incorporation of the data collected through StopInfo into a trip planner or navigational aid such as BlindSquare or CrossingGuard [12]. Since the most important information to our participants included the stop's position relative to the intersection and the sign's position from the curb, a natural extension would be to utilize a traveler's GPS location to help determine proximity to the bus stop sign or other stop features. Furthermore, since position relative to intersection was confusing to participants, finding better ways to explain and present that field is crucial since that information is so helpful. Community-sourced information could expand to include geotags of these features in order to gain precise location data if the navigator is using a GPS-enabled tool. Incorporation of other geowiki data, such as that in OpenStreetMap, can help with planning routes from the traveler's starting point all the way to their destination. Ideally, the presentation of this route-finding information will be integrated with the app itself.

Earlier results from investigating the impacts of OneBusAway [8] included the unexpected finding that 78% of OneBusAway users reported that they were more likely to walk to a different stop as a result of having the application, estimating that they walked an average of 6.9 more blocks/week than before using OneBusAway ($\sigma = 8.2$). The most common reason for doing so was to find a faster route to their destinations, but exercise was also a frequently given reason. We want to investigate whether we can provide similar benefits for blind and low vision riders (both to allow them to find faster routes, and for exercise — the latter being particularly relevant given reported problems this group faces in getting enough exercise [5, 28]). We anticipate two components to this: first, providing good wayfinding information for users to walk between stops, again conveniently presented in context using the app; and second, perhaps providing self-tracking and social incentive tools that allow users to track their progress toward goals, either individually or as part of a self-selected group.

There are multiple possibilities for expanding the system. One is to include information relevant to additional groups of users. We have already collected some additional information on stop closures (of interest to all riders), and whether the stop is well lit at night (relevant to safety). Investigating the results of providing this information is left for future research. Another direction will be to include information tailored for riders with mobility impairments, beyond the current simple "wheelchair accessible" indication in the transit agency database. Finally, OneBusAway is now operational in other regions beyond Puget Sound, including Atlanta, New York City, and Tampa, with experimental deployments elsewhere. A number of other agencies have expressed keen interest in deploying StopInfo in their regions as well, which should both be of practical benefit to riders there, as well as provide research opportunities for cross-region comparison.

In conclusion, we deployed StopInfo as a response to an information gap identified in prior work. The field study showed that the system is generally usable and helpful. Furthermore, we learned that the information can influence spontaneous and unfamiliar travel. This supports independence which is of paramount importance to our sample. The study itself encouraged our participants; for example, P5 concluded that *"[StopInfo] has made me want to do more independent cane travel,"* and P4 echoed with *"This [field study] gets me out of the house."*

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