OneBusAway: Results from Providing Real-Time Arrival Information for Public Transit

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ABSTRACT
Public transit systems play an important role in combating traffic congestion, reducing carbon emissions, and promoting compact, sustainable urban communities. The usability of public transit can be significantly enhanced by providing good traveler information systems. We describe OneBusAway, a set of transit tools focused on providing real-time arrival information for Seattle-area bus riders. We then present results from a survey of OneBusAway users that show a set of important positive outcomes: strongly increased overall satisfaction with public transit, decreased waiting time, increased transit trips per week, increased feelings of safety, and even a health benefit in terms of increased distance walked when using transit. Finally, we discuss the design and policy implications of these results and plans for future research in this area.

Author Keywords
public transit, real-time information, mobile devices, sustainability, safety, walking, health

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces

INTRODUCTION
Public transit systems play an increasingly important role in the way people move around their communities. While there are significant benefits to using transit, many choice riders (that is, riders for whom transit is not the sole option) are reluctant to make the switch. Riders are often confused or intimidated by the complexity of large transit systems. Transit agencies often do themselves no favors by failing to provide information about the systems they maintain in simple, understandable ways. In this paper, we present OneBusAway, a set of transit traveler information tools designed to take some of the uncertainty out of public transit by providing real-time arrival information for Seattle-area bus riders.

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The societal benefits of public transportation are numerous. Public transit provides mobility to those who cannot or prefer not to drive, including access to jobs, education and medical services. Public transit reduces congestion, gasoline consumption and the nation's carbon footprint [1]. In 2007, public transportation saved 646 million hours of travel delay and 398 million gallons of fuel in the U.S., resulting in a savings of $13.7 billion in congestion costs [5]. Use of public transportation reduced U.S. CO_2 emissions by 6.9 million metric tons in 2005 [18]. While hybrid and electric vehicle technologies can reduce the carbon-footprint of single-occupancy vehicles, they cannot compete with public transit in reduction of traffic and promotion of compact, sustainable communities rather than low-density sprawl. By helping travelers move from single-occupancy vehicles to public transit systems, communities can reduce traffic congestion and the environmental impact of transportation.

Towards this goal, there are two principal reasons for providing better transit traveler information: to increase satisfaction among current riders; and to increase ridership, especially among new or infrequent transit users and for non-peak hour trips. These are two key priorities for many transit agencies. It has been shown that transit traveler information can result in a mode-shift to public transportation [14]. This stems from the riders' ability to feel more in control of their trip, including their time spent waiting and their perception of safety. Real-time arrival information can help in both of these areas. Existing studies of permanent real-time arrival signage at transit stations have shown that the ability to determine when the next vehicle is coming brings travelers' perception of wait time in line with the true time spent waiting [6]. Transit users value knowing how long their wait is, or whether they have just missed the last bus. In addition, it has been found that providing real-time information significantly increases passenger feelings of safety [20].

These issues are definitely relevant for users of our regional transit agency, King County Metro. A 2006 survey of King Country Metro riders [7] identified a number of key areas of dissatisfaction for area riders, including the top two: 26% of riders were dissatisfied with their wait time when transferring, while 19% were dissatisfied with personal safety when waiting for the bus after dark. In addition, in a 3-month period prior to the survey, 42% of riders said they had experienced problems with on-time performance of buses.

OneBusAway was created to address some of these issues and out of frustration with existing transit tools. Usage has grown steadily since its launch in summer 2008, despite minimal advertisement and no official backing from the regional transit agency (although this is likely to change). During the month of August 2009, OneBusAway answered some 37,291 phone calls from 2,313 unique callers, responded to 10,567 SMS queries from 1,771 unique users, and handled 89,154 webpage visits from 15,971 unique visitors.

In this paper, we present results from a web-based survey of some 488 OneBusAway users. We also present results from a follow-up survey that focuses specifically on changes in walking behavior when using OneBusAway. The results suggest a number of important positive outcomes for OneBusAway users: increased overall satisfaction with public transit, decreased wait times, increased transit trips per week, increased feelings of safety, and even increased distance walked when using transit. While OneBusAway is not the first system to provide tools for accessing real-time arrival information, we believe that this sort of evaluation of the results of providing real-time transit information is new, and both demonstrates the value of such tools and suggests a number of interesting avenues for future research. Finally, our results make a strong case for transit agencies to provide similar systems for their own riders.

RELATED WORK IN TRANSIT INFORMATION SYSTEMS

Displays that provide real-time arrival information for buses, subways, light rail, and other transit vehicles are now available in a significant number of cities worldwide, at places such as rail stations, transit centers, and major bus stops. However, it is likely prohibitively expensive to provide and maintain such displays at every bus stop in a region. With the increased availability of powerful mobile devices and the public availability of transit schedule data in machine readable formats, a significant number of tools haven been developed to make this information available on a variety of interfaces, including mobile devices. These systems are often cheaper to deploy than fixed real-time arrival displays at a large number of stops. Further, these systems, especially mobile devices, can support additional, personalized functionality, such as customized alerts.

One of the first online bus tracking systems, BusView, was developed by Daniel Dailey and others [13]. More recently, Google Transit, which was started as a Google Labs project in December 2005, is now directly integrated into the Google Maps product on many mobile phones and provides transit trip planning for more than 400 cities around the world [11] (although not real-time information). Interfaces to Google Transit exist on a variety of mobile devices, making use of location sensors such as GPS and WiFi localization on the device to determine a starting location for trip planning.

While Google Transit has been useful to transit riders around the world, it is also significant for establishing a *de facto* standard for exchanging transit schedule data: the Google Transit Feed Specification (GTFS). The upshot is that many of the transit agencies participating in the Google Transit program have also released their transit scheduling data in the GTFS format for third-party developers to work with. Development ecosystems have grown out of the public availability of this data, with many so-called "transit-hackers" working on innovative uses of transit data. The Portland TriMet third-party applications page [19] lists over 20 applications using Portland's transit data, many targeted at providing transit data on mobile devices and many of which use localization capabilities of these devices to return location-relevant results. Similar ecosystems exist in San Francisco and the Bay Area, Chicago, and other major cities.

A number of researchers have looked at how mobile applications might improve the usability of public transit, both for the general rider (e.g., [12]), and for targeted groups such as those with cognitive impairments [3]. As examples of the latter sort of application, both the Travel Assistance Device (TAD) [2] and the Mobility Agents tool [17] use GPS on a mobile device to detect the current location of a bus rider so as to prompt the rider with context specific prompts, such as notification of an upcoming stop. Both tools require assistance of a care-giver in setup and monitoring. The Opportunity Knocks system [16] also provides a mobile, location-aware application to provide cognitive assistance to transit riders. Unlike the TAD and Mobility Agents tools, the Opportunity Knocks system automatically detects the user's current mode of transportation from GPS traces and learns the important places a user travels to, such as home and workplace, without manual labeling. Based on these learned models, the application can automatically predict where a user is headed given only a small amount of tracking data, and can detect when the user does something unexpected, such as forgetting to get off the bus at the regular stop.

The OneBusAway tool suite, by comparison, is not specifically targeted at users with cognitive impairments, but instead aims for general usability by providing a broad set of interface options, with particular focus on pre-trip information as opposed to in-trip guidance.

DESIGN PROCESS

OneBusAway provides a suite of tools to improve the usability of public transit. We primarily discuss the tools that provide real-time arrival information for Seattle-area buses, with details about the design and development of those tools.

Initial Development

Initial work on OneBusAway was started as a personal project of the first author, a frequent bus rider, who was fed up with the usability of existing tools provided by the regional transit agency. The agency has actually had real-time tracking capabilities for its buses since the late 90s and provides web and SMS (through an SMS-to-email gateway) access to arrival information. However, these tools were very difficult to use when riders were actually waiting at a stop, primarily due to providing no way to use posted stop ids to quickly access information for a stop and the resulting complexity of information lookup.

The new set of tools provided by OneBusAway improved on

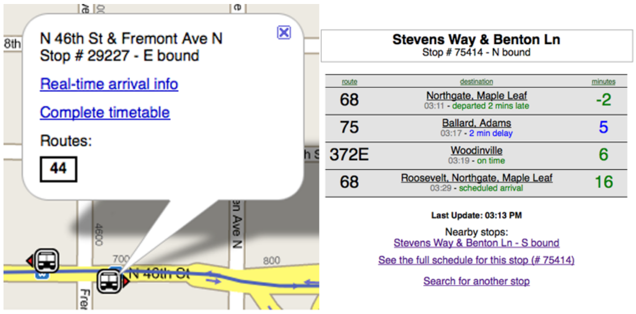

Figure 1. Example of the map-based interface (left) along with real-time arrival information for a single stop (right).

these original tools in a number of ways. First, the proper mapping between stop id and real-time arrival was constructed so that users could quickly access information using a stop's posted id. Second, multiple interfaces were developed to promote greater access to information. In addition to a standard web interface (`www.onebusaway.org`), an interactive-voice-response (IVR) phone interface, an SMS interface, an iPhone-optimized web interface, and a very basic text-only web interface were added so that a user could easily access information using a variety of devices. For a range of mobile devices, from a basic cellphone to a powerful smart phone or something in between, there was an appropriate interface available. Additionally, in September 2009 we released a native iPhone application that includes automatic localization of the information presented using the phone's GPS capabilities. (This was in beta test at the time of the survey.)

We'll briefly describe some of the specific features of the various interfaces as they exist today. The standard web interface allows a user to search for stops by route, street address or map area. Results are visualized on a standard map, as shown in Figure 1. Note that details like indication of direction of travel at a particular stop make it easier for a user to distinguish between multiple nearby stops, such as when two stops are directly across the street from each other. Real-time arrival information includes details about the route, destination, and time remaining until departure. In addition to the real-time arrival information, a full schedule in stem-and-leaf format is provided for each stop.

The iPhone-optimized and text-only-optimized web interfaces offer similar functionality with formatting appropriate for the target device. Both interfaces allow a user to enter a stop id to quickly receive arrival information, or to search for a stop using a search tree that narrows results based on the route, destination of travel, and street location of the target stop, allowing stop lookup when the posted stop id is missing or the user is not physically at the stop.

The IVR phone system offers similar functionality to the iPhone and text-only web interfaces, except via a touch-tone phone interface with text-to-speech. Again, a user can quickly receive arrival information using a stop id or search for stops through a tree-like menu system. Users can also bookmark frequently accessed stops for quicker access in the future. The SMS interface is the simplest, only allowing the user to find real-time arrival information by stop id.

In all of the interfaces listed so far, the user can also easily filter arrivals at a stop by route number, which is an important feature at busy stops where many transit vehicles can be arriving in a short time interval.

Iterative Design

These interfaces were informally evaluated in the summer of 2008 with a number of students and heavy transit users. After integrating feedback from these users, the OneBusAway website was launched with pointers to the various tools for accessing information.

The design of the various tools, along with development of new features, has been further shaped by feedback from users over the past year. OneBusAway provides a number of feedback mechanisms (email, Twitter, blog, bug tracker) that allow a user to make comments or suggestions about the tools. Because OneBusAway is open-source software, users have also submitted improvements of their own. For example, one user wanted the ability to see real-time arrival data for multiple nearby stops integrated in a common view. That user coded up the improvement, submitted a patch, and the feature is now available to all users of OneBusAway.

Of course, not all feedback concerns interface usability issues. The bulk of user feedback is a result of data and reliability issues: real-time arrival information is occasionally wrong, underlying schedule data has errors, neighborhood labels are incorrect, or a server is down. These are typical issues inherent to running a service used regularly by a large group of users.

In addition to the feedback from users with regards to the design and functionality of OneBusAway over the past year, we have also performed an initial survey of 25 OneBusAway users about their usage of OneBusAway on the iPhone platform, along with a follow-up survey of 16 users who participated in the beta-test of the native iPhone application. Additionally, we did a small user study of 12 users comparing how long various search operations took using our native iPhone application versus our existing tools. The results from these surveys and study, focusing on location-aware aspects of OneBusAway, are reported elsewhere [9].

Implementation

OneBusAway provides users with a variety of interface options, and the underlying implementation and technology stack is quite diverse as a result. The OneBusAway server back-end is written in Java and uses a variety of standard open source development libraries and frameworks in its implementation. The system is composed of a number of service modules, each providing specific functionality, which are coupled together using the Spring inversion-of-control framework. Java object persistence to a relational database is handled by the Hibernate framework. The Tomcat servlet container combined with the Apache Struts MVC web framework does the bulk of the heavy lifting for web-based publishing. Client-side AJAX applications are written primarily using Google Web Toolkit, which compiles Java source code into optimized Javascript.

For our telephony system, we use the Asterisk PBX server to pass incoming calls to handling code using the FastAGI interface. The only piece of non-open-source software in the entire system is our text-to-speech engine, which we license from Cepstral. Our native iPhone app is written in Objective-C using standard Apple SDK frameworks and is connected to the OneBusAway server back-end through a JSON-serialized REST-ful web service.

As mentioned, OneBusAway is open source software licensed under the Apache 2.0 license. The source code for the project, along with further implementation details, APIs, and documentation, can be found at our project site on the web: `http://code.google.com/p/onebusaway/`.

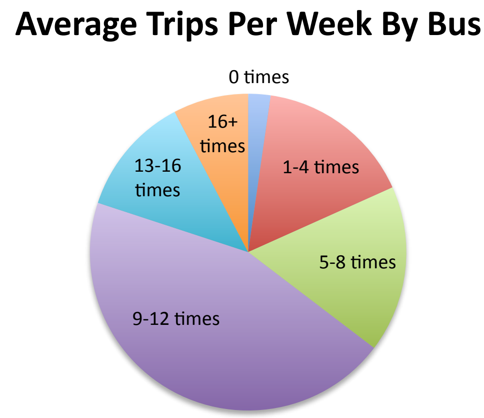

Figure 2. Average number of trips per week by bus from survey respondents. More than 60% of respondents could be classified as daily riders (9 or more trips a week).

METHOD

To evaluate the effects of using the OneBusAway system, we developed two user surveys. (The full survey artifacts are available at `http://onebusaway.org/research/`.) The first, primary survey was engineered to query users about their usage of OneBusAway and how OneBusAway had changed their overall perception of public transit, including issues of satisfaction, utility, perceived wait time, frequency of travel, safety, and other factors, through a standard online survey.

Survey participants were recruited through notices on the OneBusAway website, the OneBusAway Twitter feed, and a number of Seattle-area blogs where OneBusAway had been mentioned in the past. Our advertisements stated "Help us understand how you use OneBusAway" and as an incentive, survey participants were optionally entered in a drawing for two $25 gift certificates. Our goal was to reach regular users of OneBusAway, along with users who had tried OneBusAway before, but were not necessarily regular users. The survey was anonymous, but users were invited to email a special OneBusAway email address on completion of the survey to be entered in the gift certificate drawing.

A total of 488 respondents took the survey during five days in August of 2009. We gathered basic demographic information about survey respondents, including gender, age, annual income, and number of children in household. Overall, respondents were 70% male. Age ranges of respondents included 18-24 (18%), 25-34 (55%), 35-44 (17%), 45-54 (7%) and 55 or older (3%). Annual household incomes were under $20k (8%), $20-40k (16%), $40-60k (18%), $60-80k (16%), $80-100k (18%), and over $100k (24%). A total of 13% of respondents reported having children in their household.

We can compare the demographic ranges from survey respondents with the demographics of typical transit users in the region. A 2006 survey of King County Metro riders [7] shows that our survey respondents are more predominantly male and younger, while income levels are comparable. Of riders in the 2006 survey, 46% were male, with age ranges of 16-24 (15%), 25-34 (20%), 35-44 (19%), 45-54 (23%) and 55 or older (24%); household incomes were under $25k (16%), $25-35k (7%), $35-55k (19%), $55-75k (18%), $75-100k (17%) and over $100k (24%).

Our survey sample population is likely skewed toward OneBusAway users enthusiastic enough to take a survey. Even so, it is worth noting that the 488 respondents who took the survey are nearly 10% of the daily OneBusAway user base.

One interesting finding from the initial survey was that users reported walking more as a result. Given significant national concerns with health and obesity, and the value of walking for health, we wanted to pursue this issue in more depth. To do so, we developed a shorter second survey that asked for specific details about connections between OneBusAway and changes in walking behavior. Of the 488 respondents from the initial survey, 193 entered the gift certificate drawing, providing us with their email contact information. We advertised the follow-up survey to those respondents. Survey participants were optionally entered in a second drawing for two more $25 gift certificates. A total of 139 respondents took the follow-up walking survey during five days in August of 2009, a response rate of 72%.

For both surveys, free-form responses were summarized using a coding table for each question, which provide the response statistics for comments in the results section.

RESULTS

With the exception of walking results, which are discussed later in specific detail, all results are from the first, primary survey with 488 respondents.

Usage of Transit and OneBusAway

We asked survey respondents how often they rode the bus on a weekly basis. The results, presented in Figure 2, show that

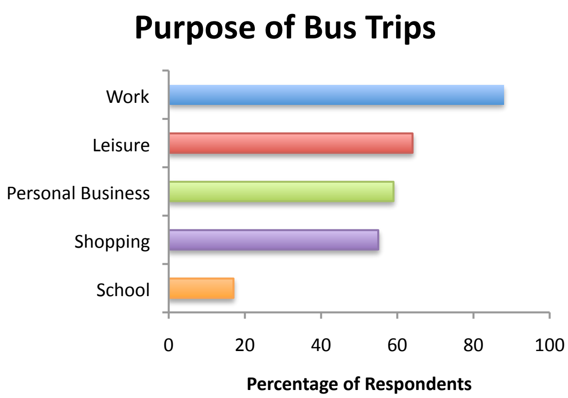

Figure 3. Purpose of bus trips as percentage of total respondents. Commuting to work was the most frequent response.

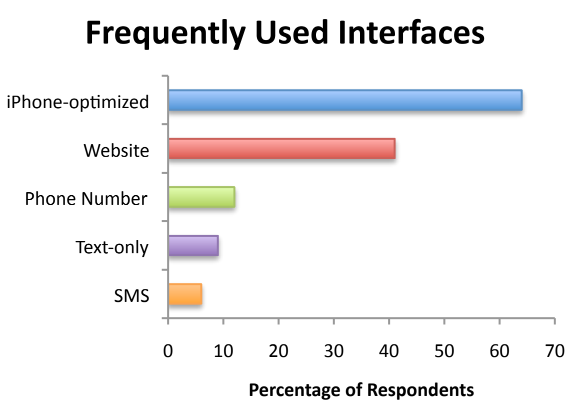

Figure 4. Percentage of respondents who frequently use the specified OneBusAway tool.

the majority of respondents (more than 60%) could be classified as daily riders, making 9 or more bus trips each week. Additionally, we asked respondents for what purpose they rode the bus. Results are presented in Figure 3 and show that commuting to work is the most frequent response, though non-commute trips such as leisure, personal business, and shopping are frequent as well.

The survey also asked respondents which OneBusAway tools they used, if any. We show the relative percentage of total respondents for each individual interface in Figure 4, with the iPhone-optimized and standard web interfaces dominating the usage. We can compare the relative ratios of users of the various tools in the survey results with actual usage statistics from our server logs to assess how closely the distribution of users in the survey matches real-world-usage. The ratio of web users to phone users in the survey is 7.0 while the ratio in actual usage is 6.8. The ratio of web vs. SMS for the survey is 8.4 and 9.0 in actual usage. These ratios show a reasonably close match in usage ratios between the survey and actual OneBusAway usage.

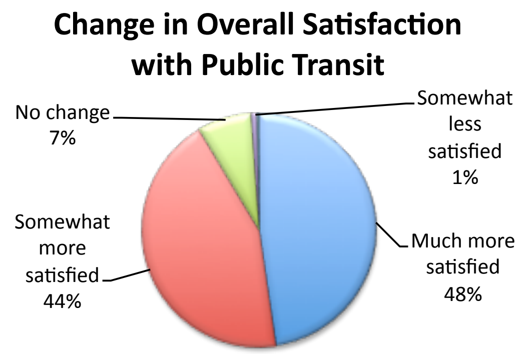

Figure 5. Change in overall satisfaction with public transit as a result of using OneBusAway. The change, as reported by respondents, is overwhelmingly positive.

OneBusAway and Changing Behavior

Satisfaction With Public Transit

We asked survey respondents whether their overall satisfaction with public transit had changed as a result of using OneBusAway. The results, summarized in Figure 5, show an overwhelmingly positive change in overall satisfaction as a result of using OneBusAway, with 92% of respondents stating that they were either somewhat more satisfied or much more satisfied with public transit as a result of using OneBusAway. This is a remarkably strong effect from adding a relatively inexpensive technology to public transit.

To get a better picture of user satisfaction with public transit with regards to OneBusAway, we asked respondents to describe how their satisfaction had changed in a free-form comment. We had 418 responses, which fell into a small number of key categories. The most common response, mentioned by 38% of respondents, concerned how OneBusAway alleviated the uncertainty and frustration of not knowing when a bus is really going to arrive. A typical comment:

> The biggest frustration with taking busses is the inconsistency with being able to adhere to schedules because of road traffic. Onebusaway solves all of that frustration.

and

> I no longer sit with pitted stomach wondering where is the bus. It's less stressful simply knowing it's nine minutes away, or whatever the case.

The next most common response, mentioned by 35% of respondents, concerned how OneBusAway increased the ease and flexibility of planning travel using public transit, whether it be a question of which bus to take or when to catch it. A typical comment:

> I can make decisions about which bus stop to go to and which bus to catch as I have options for the trip home after work.

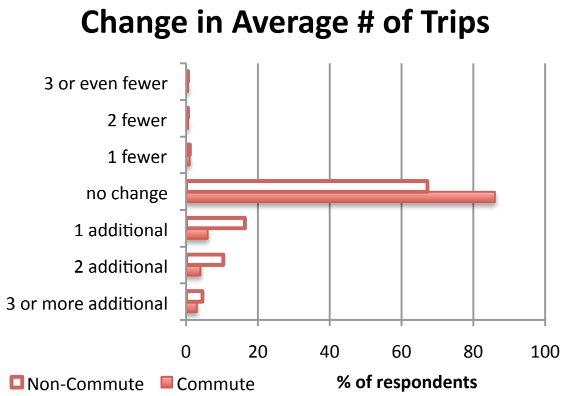

Figure 6. Change in the average number of trips per week among users of OneBusAway. Note the larger reported increase in non-commute (choice) trips.

and

> It helps plan my schedule a little better to know if I can take a little extra time or if I have to hurry faster so I don't miss my bus.

Other responses included saving time (25%) and the general convenience of OneBusAway tools (10%), especially in comparison to existing tools.

In addition to the comments describing changes in satisfaction with public transit, we also found that satisfaction was significantly negatively correlated with age among respondents ($X^2 = 24.615$, $p = 0.017$). That is to say, the younger the rider, the more satisfaction they have with public transit from using OneBusAway.

Time Spent Waiting

We asked survey respondents if there had been a change in the amount of time they spent waiting for the bus as a result of using OneBusAway. Among respondents, 91% reported spending less time waiting, 8% reported no change, and less than 1% reported an increase in wait times. Regarding the relationship between satisfaction and wait time, we found that overall satisfaction with public transport is highly correlated with decreased wait time amongst survey respondents ($X^2 = 40.467$, $p < 10^{-5}$). These results are further confirmed by the user comments, noted in the previous section, that list time savings as a major reason for increases in overall satisfaction.

Number of Transit Trips Per Week

In addition to changes in satisfaction and wait time, we asked users how the average number of trips that the user takes each week has changed as result of using OneBusAway. We asked users specifically about the number of commute and non-commute trips they make. The results, presented in Figure 6, show an increase in the number of trips taken by OneBusAway users, with more gains in non-commute trips.

Access to Schedule Information

We also asked respondents how they typically find bus departure time information. While some 16% of respondents reported using the published schedule provided by the transit agency in either paper or online form, a full 73% of respondents indicated that they used OneBusAway to find out when the next bus will actually arrive, without consideration of the published schedule. The remaining 10% used some combination of the two, or else existing trip planning tools. This shift away from traditional static schedules has some important policy implications, presented in a later section.

Perception of Personal Safety

We asked users how their perception of personal safety had changed as result of using OneBusAway. While 79% of respondents reported no change, 18% reported feeling somewhat safer and 3% reported feeling much safer. This increase in the perception of safety when using OneBusAway is significant overall ($X^2 = 98.05$, $p < 10^{-15}$). We also found that safety was correlated with gender ($X^2 = 19.458$, $p = 0.001$), with greater increases for women.

We additionally asked respondents whose feeling of safety had changed to describe how in a free-form comment. Of such respondents, 60% reported spending less time waiting at the bus stop as their reason, while 25% mentioned that OneBusAway removed some of their uncertainty. Respondents specifically mentioned waiting at night (25%) or at unsavory stops (11%) as potential reasons they might feel unsafe in the first place. Respondents also described using OneBusAway to plan alternate routes (14%) or to help decide on walking to a different stop (7%) in order to increase feelings of safety.

A representative comment:

> Having the ability to know when my bus will arrive helps me decide whether or not to stay at a bus stop that I may feel a little sketchy about or move on to a different one. Or even, stay inside of a building until the bus does arrive.

and:

> Onebusaway makes riding the bus seem more accessible and safe. I can plan when to leave the house better and spend less time waiting at dark or remote stops.

These results are consistent with a 2006 King County Metro rider survey which found that 19% of riders were dissatisfied with personal safety while waiting for the bus after dark [7].

Walking to a Different Stop

We asked survey respondents how likely they are to walk to a different bus stop based on information from OneBusAway. While some 19% of respondents reported no change in their walking habits and 3% reported they were less likely to walk to a different stop, a full 78% reported they were more likely to walk to a different stop. We had not expected such a significant response regarding increased walking in

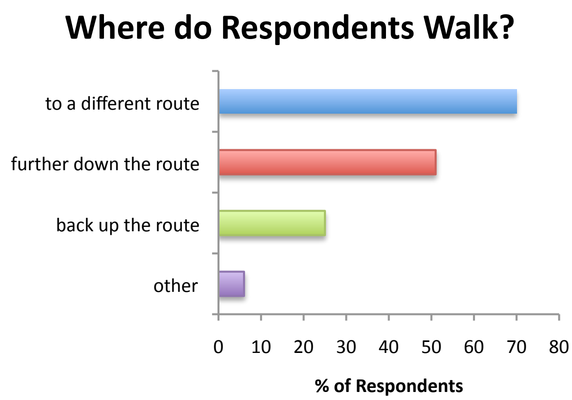

Figure 7. Where do respondents walk when they choose to walk to a different stop? Walking to a stop on a different route was the most frequent response.

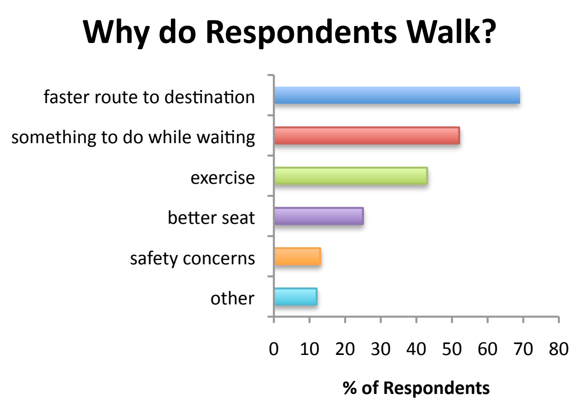

Figure 8. Why do respondents walk to a different stop? A faster route to their destination was the most frequent response.

the original survey, which is why we undertook the second survey to provide more detail about how and why walking habits had changed.

In the followup survey, we asked again how likely respondents are to walk to a different bus stop based on information from OneBusAway, and had an almost identical response (79% as more, 19% as no change, and 2% as less). We next asked respondents where they walk when they walk to a different bus stop. The results, shown in Figure 7, show that the most popular choice was to a stop on a different route, while stops further along or further ahead on the current route were picked less frequently.

We also asked respondents to classify why they walked to a different stop. Responses, shown in Figure 8, indicate that finding a faster route to their destination is the most popular reason. On average, OneBusAway users surveyed estimate that they walk 6.9 more blocks per week than before using OneBusAway (SD=8.2), with a median value of 5 blocks. The high standard deviation and multiple reasons given for walking suggests that our survey may capture multiple walking populations with different motivations to walk.

Several respondents commented about OneBusAway not only increasing their walking, but decreasing the stress involved with the walk, especially the threat of being passed by the bus while in between stops. As one explained, "Before OneBusAway, I played what I like to call Metro Roulette: start walking to the next stop for exercise, and hope my bus didn't pass me by. Now, though I miss out on the adrenaline rush elicited by Metro Roulette, I can make an informed decision about whether or not to walk to the next stop..." Respondents also explained that OneBusAway lets them know the speed at which they must walk. "(It) helps me decide whether I need to run or walk to the stop."

Multiple respondents also commented about their decision to walk the entire distance to their destination based on OneBusAway information. "If I know a bus is a long time away from arriving, I'll just walk to my destination if walking would be faster than waiting." This was particularly true in the case of transfers.

In the first survey, there were a tiny number of respondents who indicated they actually walked less due to OneBusAway than they otherwise would. This result struck us as strange initially, but we subsequently realized that users might be taking advantage of the real-time arrival information from OneBusAway to hop on a bus arriving shortly to save a trip of a few blocks that they would have otherwise walked. Some 26% of respondents in the follow up survey indicated that they do in fact take the bus for short trips for which they previously would have walked based on information from OneBusAway, but overall the balance is more walking.

Additional Feedback

The survey included an additional free-form response question asking users if they'd had any specific problems with OneBusAway or if they had suggestions for improving OneBusAway. The biggest complaint by far concerned data reliability issues (25% of respondents). Respondents noted that real-time arrival information had not been accurate at one time or another, or that schedule data for a particular stop was incorrect. Beyond data issues, users had a laundry list of usability complaints and feature requests, including requests for native apps tailored to specific mobile devices, location-aware search, real-time trip planning, better management of frequently accessed stop information, and easier search all recurrent suggestions. We address some of this feedback in our future work section.

DISCUSSION

Before we discuss the results from our surveys, we must note a few important caveats. First, the survey results are self-report, which can call into question the reliability of responses and limits the potential strength of claims we can make using response data. Second, we do not have a control group of users who have not heard of or used OneBusAway or other real-time arrival information tools, which limits the strength of claims we can make regarding changes in behavior resulting from the OneBusAway tool. Despite these limitations, we believe the results from the survey, bolstered by qualitative comments from survey respondents, make a strong case for the value of systems such as OneBusAway.

Specifically, survey respondents indicated a number of positive outcomes as a result of their usage of OneBusAway: increases in overall satisfaction with public transit, decreases in wait time, increases in the average number of weekly transit trips (non-commute especially), increases in feelings of personal safety, and increases in likelihood of walking. Of these outcomes, only satisfaction and feelings of personal safety are subjective measures. The remaining outcomes concerning wait time, number of transit trips, and distance walked come with the caveat that they are self-report statistics rather than being direct measurements of behavior.

The reduction in wait time is especially interesting in this regard. We believe this reduction is a combination of actual reductions in wait time, along with reductions in perceived wait time. Previous studies have shown that fixed real-time arrival signage induces reductions in perceived wait time for transit riders [6], and it is likely that a similar effect holds for users of our system. We outline plans for a follow-up study to measure the difference between actual and perceived wait time in our future work section. But regardless of how much of the reduction in wait time is perceived and how much is actual, survey results show a strong correlation between reported reductions in wait time and an increase in overall satisfaction with public transit.

The increase in number of trips per week is a potentially important finding for policy makers looking to boost usage of public transit. Again, the exact increase is hard to quantify with only our survey results due to potential self-report bias, but the larger increase in non-commute trips makes intuitive sense as riders have more flexibility in this area to make gains in weekly ridership. Comments support the notion of more non-commute trips as well: "While my work usage was pretty much on a fixed schedule, OneBusAway has made impromptu trips much more convenient," "The OneBusAway app makes me feel more comfortable with spontaneously changing trip plans," and "Better able to fit in quick purchasing trips."

Our survey results also indicated that for some of our users, feelings of personal safety play an important role in using public transit, and that OneBusAway can help address concerns in this area. Despite the improvements brought by OneBusAway, we feel there are some real opportunities for addressing this issue further in a value sensitive way [10] to provide riders with additional tools and resources.

The reported increase in walking is notable, because there are health benefits from increased walking, independent of whether the users are walking for exercise or just to get to their destinations faster. As we've noted before, the self-reported number of additional blocks walked by respondents is probably not an accurate measure of actual walking. However, quantitative and qualitative results from the survey paint a strong picture that users of OneBusAway have the additional flexibility and confidence they need to walk to a different stop when they so choose.

Just as the increase in walking by OneBusAway users was unexpected, people are using OneBusAway in other unexpected ways. One user comments:

> OBA makes [it] much *much* easier to avoid standing room only busses by letting me know there's a follow up bus right behind the current full bus.

Other users commented as well that they were using OneBusAway to decide whether it was worth getting on a crowded, standing room-only bus or if they should wait for the next bus in a few minutes that will be mostly empty. Like predicted arrival time, the number of available seats on a bus is another important piece of information which we'd like to make more visible in transit systems. We have already talked with agencies about allowing drivers to note when their vehicles are full in an automated way so that riders can avoid a packed bus.

Some design principles that have served OneBusAway well include: quick access to information when and where it is needed, service across a variety of interfaces (primarily on mobile devices), and methods for accessing arrival information when away from the actual stop. These principles are also relevant for other real-time traveler information tools.

A significant number of survey respondents reported issues arising from the reliability of the underlying data feed, pointing to an area in which design improvements are needed for both OneBusAway and other applications for this domain. The underlying real-time arrival information used by OneBusAway is definitely not 100% accurate, as tracking vehicles and predicting arrival times in dynamic urban environments with changing traffic conditions is an on-going area of work for both academic researchers and commercial vendors. Specific opportunities exist for presenting the inherent uncertainty of arrival information in an appropriate way to users. Routing information, timetables, and other machine-readable schedule data sets provided by transit agencies are not without flaws either. Options for addressing these occasional errors might include providing users with targeted feedback tools, so that transit agencies can in part crowdsource the correction of their transit data.

Policy Implications

Real-time arrival information using fixed signage is relatively accepted as a means to increase ridership by reducing rider anxiety, increasing the perception of reliability and presenting an image of a modern transit system [15]. In addition, the results above suggest that providing transit traveler information using tools such as OneBusAway yields other positive outcomes as well. If these results hold on wider-scale evaluation, this would confirm that providing real-time arrival information on mobile platforms is a worthwhile investment for transit agencies, because the benefits to riders and the agency can far outweigh the costs.

In the transit service planning industry, 10 minutes has long been considered the barrier between schedule-based and headway-based service. A recent study found that at 11 minutes, passengers begin to coordinate their arrivals rather than arriving randomly [15]. This is consistent with earlier studies documenting random versus coordinated arrivals. Therefore, at a time between buses greater than 10 minutes, passengers want a schedule to coordinate their arrival times. However, with the introduction of real time information such as OneBusAway, we have shown that users more frequently refer to real time information than to schedules to determine when to wait at the bus stop. This is important for transit service operations because a significant amount of time is lost in attempting to maintain reliability for scheduled service — planners must build a certain amount of slack time into the schedule. One study found the slack ratio to be 25% in Los Angeles [8]. With headway-based service, supervisors use real time transit data to maintain a certain amount of time between buses, rather than attempting to maintain a schedule, thereby allowing free running time and saving slack time [21]. This savings in running time can reduce agency costs to provide the same level of service on a transit route.

In addition, the investment in website and phone-based real time transit information can also save an agency substantially in deployment costs. As an example, Portland deployed their Transit Tracker program in 2001 with information displays at transit stops, a webpage and more recently a phone system. The transit tracker signs at light rail stations and 13 bus stops in Portland cost $950,000 including message signs and conduit. The cost for computer servers and web page development was much cheaper at $125,000 [4]. Given the widespread availability of cell phones and web access, providing real time transit information via a service such as OneBusAway could yield a substantial savings for an agency over constructing real-time arrival display signs. At the same time, we don't want to unfairly disadvantage people who do not have access to such technology.

Finally, our application joins a growing list of innovative transit applications running on a variety of mobile platforms, made possible by forward-thinking transit agencies that have made their routes, schedules, and real-time arrival information available via public APIs. For these reasons, we encourage other transit agencies to include real-time arrival information in their transit systems and to publish this data, along with static schedule data, through public APIs so applications like our OneBusAway toolset can help make public transit work better for the riders who use it every day.

Future Work

We are encouraged by the results of our initial evaluation, but we are also cognizant of the limitations of self-report-bias and lack-of-control-population. We initially hypothesized that changes in user behavior from using OneBusAway would be minor at best and that a very large study of OneBusAway users and non-users would be required to establish statistical significance. However, our initial findings lead us to believe that we can obtain meaningful results from a long-term mobility study with a smaller number of participants, which can at the same time allow us to gather much richer and more interesting data. We thus plan to undertake a new study, in which we recruit a set of users who have not heard of OneBusAway and give them instrumented programs to run on their cell phones that perform activity recognition, so that we can track their actual transit usage, walking and other travel behavior over time. At the midpoint of the study, we will give half of the user base access to OneBusAway, and assess how their usage changes with respect to that of the control group. This measured data would be supplemented with before-and-after surveys to paint a more concrete picture of changes in behavior from using OneBusAway.

We would also like to explore the issue of perceived wait time by performing a user study comparing the perceived passage of time spent waiting for a bus both with and without OneBusAway. We hypothesize that the addition of OneBusAway will reduce the inflated wait time normally perceived by waiting transit riders back towards the actual wait time.

We have a number of additional future goals for the OneBusAway project. First and foremost, we are working on wider deployment of OneBusAway, including support for more local transit agencies in the region.

One commonly requested feature from users has been a location-aware tool that makes finding nearby stops and routes easier, especially if the tool is tailored to native environments on mobile devices like the iPhone and the Android platform. We have been making progress in this area, as we have developed a native iPhone application for OneBusAway that focuses on location-aware capabilities of the phone, now available via the Apple iTunes App store.

While a native application can be carefully tailored to its specific platform, the number of different kinds of mobile devices grows larger by the day and we do not have the resources to develop native applications for all of them. For that reason, we are also pursuing the development of a common Javascript-enabled AJAX-style application that can make use of increasingly powerful mobile web-browser, some of which offer geolocation capabilities. The portability of such an application would allow us to reach a wider range of potential OneBusAway users.

In Autumn 2009, we began to systematically apply the Value Sensitive Design theory and methodology [10] to OneBusAway, initially working toward a principled prioritization of potential projects to help ensure that our limited resources are best spent meeting the actual needs of the larger public-transit-using community, and at the same time giving special weight to the needs of riders who depend on transit for their basic mobility needs (as an issue of fairness and justice). As an example of one such project, we are actively exploring mobile applications and interface specifically tailored to blind and deaf-blind users. The same technologies that allow us to pursue advanced location-aware mobile applications can help us build applications tailored to specifically address the usability issues faced by this group of transit users.

CONCLUSION

In this paper, we have presented the results from a survey evaluation of OneBusAway, a set of tools specifically providing access to real-time arrival information for public transit and improving the usability of public transit in general. The results of this survey are that respondents have an overall increase in satisfaction with public transit, make more transit trips on a weekly basis, spend less time waiting for transit, have increased feelings of personal safety when using transit, and often walk further when using transit. These outcomes are all positive in terms of increasing the use of transit to reduce traffic congestion, reducing the environmental impact of transportation, and encouraging the development of compact, livable communities. There may even be additional health benefits from the increased amount of walking amongst OneBusAway users. Qualitative and quantitative survey results aside, thousands of users are using OneBusAway every day to make their transit system work better for them.

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